RCA Engineer

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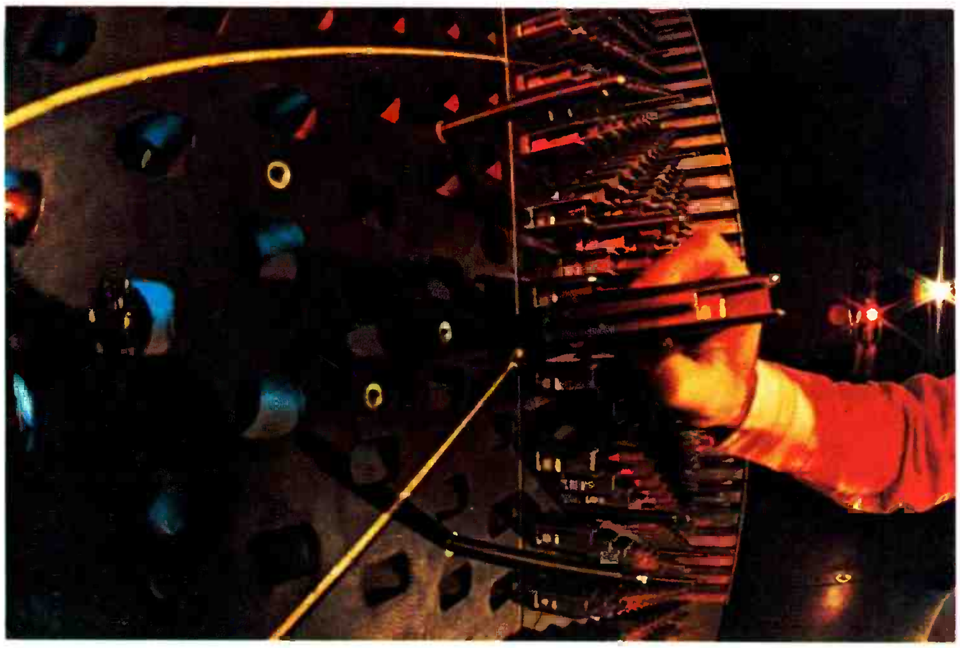
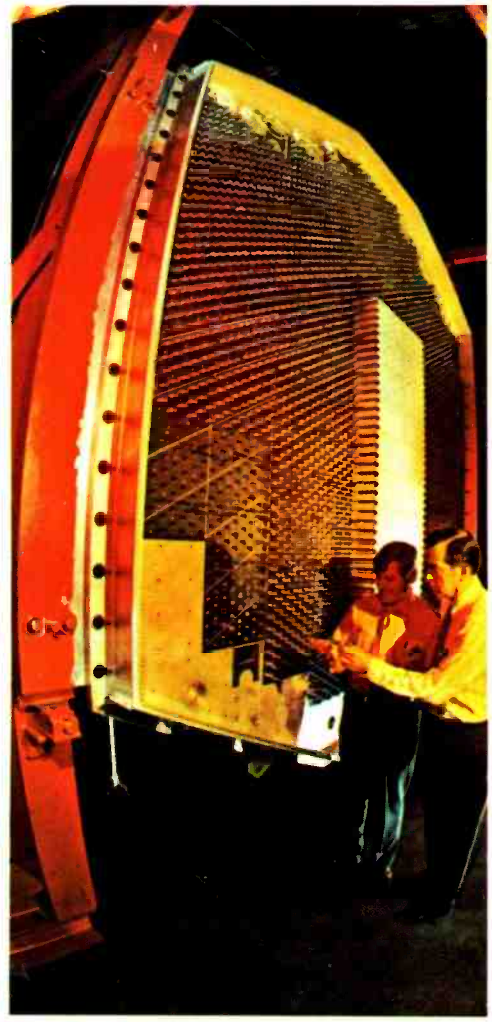
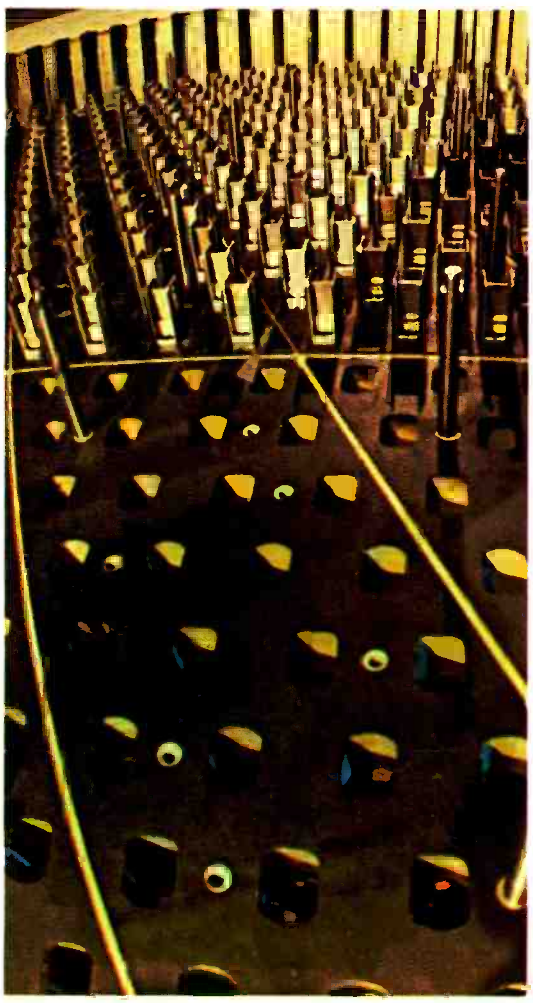
17th Anniversary Issue







AEGIS—unprecedented technical challenge

When RCA was awarded the AEGIS Weapons System contract we were faced with an unprecedented technical challenge—that of designing and building the Navy's most complex, automated defensive surface missile system. I am proud of our dedicated AEGIS team. Their accomplishments have met or exceeded every major challenge in the two and a half years of the program's life.

Just recently, AEGIS passed its second contractual milestone. This included completion of the critical design review, plus the initial testing of the AN/SPY-1 computer program.

Through this achievement, the way is now open for fabrication of the first engineering model leading to land-based testing this year. Additionally, as the AEGIS team worked toward this goal, system simplification studies and feasibility demonstrations showed that the system could be reduced significantly in weight, power requirements and costs, while maintaining overall performance and reliability. This design simplification and added flexibility may enable the AEGIS system to be installed economically in a larger number of warships than originally had been anticipated.

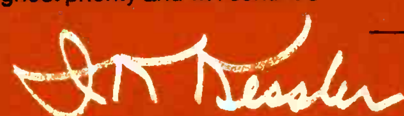
Further evidence of our success has been the initial integration of hardware and software and the successful demonstration of such critical system functions as automatic search, detection and track, and combat system control.

This accomplishment is a major step toward the total integration of radars, computers, missiles, manned aircraft and other naval weapons that will provide the quick reaction and concentrated fire power needed to counter the air and missile threats facing the fleet in the next decade. This on-schedule demonstration engenders confidence in the future total success of the program.

This attainment also confirms dramatically our approach to computer programming for AEGIS. From the beginning, the implementation of a systematic and comprehensive development plan plus the design of an advanced tactical executive computer program were tailored to respond to the quick-reaction requirements of AEGIS.

Thus, our commitment to reliability achievement through the establishing of new standards of performance excellence is being accomplished . . . and it is being accomplished through the professionalism on the part of every individual associated with the AEGIS program.

Our commitment to AEGIS will continue to be of the highest priority and will continue to receive our maximum attention



I. K. Kessler, Executive Vice President
Government and Commercial Systems,
Moorestown, N.J.

Our cover

The AEGIS program brought a major government contract to RCA, and with it came unparalled technical and management challenges. Five papers in this anniversary issue (Goodwin, Nessmith, Weinstock, Kruger and Jurkiewicz, and Phillips) describe some of these challenges. The cover features the AEGIS phased-array antenna, showing the phase shifters (upper left), antenna structure (upper right), and array module (center). In the photo at lower right are Robert M. Scudder of Array Antenna Systems; John Drenik of Mechanical and Structural Engineering; Charles T. Pennacchio of Manufacturing; William H. Sheppard of Project Management Staff; and Nicholas F. Artuso of Antenna/Receiver Engineering. **Photo credits:** Ken Kleindienst and Ron McNally of Missile and Surface Radar Division, Moorestown, N.J.

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RCA Engineer

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• To disseminate to RCA engineers technical information of professional value • To publish in an appropriate manner important technical developments at RCA, and the role of the engineer • To serve as a medium of interchange of technical information between various groups at RCA • To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions • To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field • To provide a convenient means by which the RCA engineer may review his professional work before associates and engineering management • To announce outstanding and unusual achievements of RCA engineers in a manner most likely to enhance their prestige and professional status

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Shaping the future at RCA
Keynote address

Anthony L. Conrad

Editor's Note: Because of its special relevance (not only to the 150 attendees at the RCA Engineering Conference, Buckhill Falls, Pa) but to every RCA engineer and scientist, Mr. Conrad's keynote address is presented in this issue in its entirety.

BECAUSE OF MY BACKGROUND, I look upon this conference as something of a homecoming. Robert Frost defined home as "a place where if you have to go there, they have to let you in." I didn't have to come here, but I still thank you for letting me in.

This conference takes place at a significant time in our corporate life. We are making decisions today concerning new technological opportunities that will profoundly affect RCA's future.

I want to discuss some of these opportunities with you. But before I do, let me comment briefly on RCA's current situation.

We all know that the past year has been a particularly trying one, not just for RCA, but for the economy in general. But the important thing to remember is that we have come through it and we're moving ahead. Our withdrawal from the general purpose computer business is behind us. The economic outlook is brightening. Our first quarter showed substantial progress, and it is continuing. In certain key areas—such as color TV and solid state—our performance has exceeded expectations. Other good news:

Just last week two important new contracts were awarded to elements of RCA. The Service Company captured the operation and maintenance of BMEWS and DEWline—a contract expected to yield sales of $102 million over the next three years.

The second new one is another contract with the Peoples Republic of China—for $6.0 million. It calls for installation of an earth station at Peking as well as conversion of the temporary station at Shanghai to a permanent facility.

Our non-electronic subsidiaries have broadened RCA's participation in the consumer market and in the service-related sector that represents one of the fastest-growing segments of the economy. Together, they have added more than $1 billion annually to our sales volume and they are growing vigorously.

But let it be clearly understood that these newer activities have never been intended to replace our traditional businesses or to change the basic character of RCA. We are, and intend to remain, primarily an electronics company whose principal activities relate to communications and information handling. Now that we have withdrawn from the general purpose computer business, we can focus our attention even more effectively upon the great range of opportunities that are developing in these areas of principal interest.

I can recall no period in the short history of electronics when we've had so much advanced technology at our disposal. Moreover, the need and the opportunities for new applications of that technology have never been more apparent.

Our society is moving under forced draft through an information revolution. We are replacing the communications systems of the past with new ones for a more demanding social and economic environment.

The success of RCA in this era of change will require more than a simple, straight-line projection of our traditional products and services. It will hinge on a clear understanding of what our markets require of us. It will demand an equally clear application of our corporation's special capabilities and resources. And in our highly competitive industry, it will call for increasingly rapid translation of results from research to the marketplace.

Three current projects symbolize to me how we are responding to this challenge. They are SelectaVision, data communications, and broadband information systems.

Each illustrates the way we are seeking to win the race to the market with the best products or services at the earliest possible time. Each engages our laboratories, our engineering organizations, our production facilities, and our marketing staffs. Each has been mobilized on a task force basis, without regard to divisional lines.

In SelectaVision, this strategy has made it possible for RCA to demonstrate a practical new magnetic tape color-video player-recorder and to announce that it will be on the market by late 1973. Judging by industry reaction, we are not alone in believing that our product is the best yet shown, as well as the least costly to the consumer. Our consumer electronics distributors responded with great enthusiasm when shown the MagTape system at Las Vegas last week.

It may be asked why we have chosen to push forward with a magnetic tape system rather than one using our own HoloTape systems or video discs. The answer, quite simply, is that magnetic tape technology is already well in hand. It offers us the immediate advantage of earlier entry into the market with a quality product competitively priced. And unlike HoloTape systems or video

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discs, our Selecta Vision Magtape is more than a playback system. It also records off the air or from a home TV camera.

We're continuing work on playback-only systems, which promise much lower cost to the consumer for both machine and software. We've made considerable progress, and it is possible that these products will in time supplement the magnetic tape systems. But for the immediate future, we are counting on MagTape to establish a strong position for RCA in this new business.

The SelectaVision story contains a lesson that can be applied generally to the quest for profitable new products and services. We recognized that the product represented a major business opportunity if we could reach the market rapidly and at the right price. We also knew that we had on hand most of the engineering and manufacturing skills to do the job. But we found that in one area, it might take us years to develop in full measure a particular skill that was needed. This was the technique for quantity production of a mechanically precise tape transport. We sought out a quality house, Bell & Howell, to produce the component for us, and were therefore able to achieve a marketable product in the shortest possible time.

I recognize that most of you need no urging, but let me cite this as a precedent to be followed in similar cases. There is no need to feel frustrated when we find ourselves deficient in some aspect of technology vital to a project in which time is a critical factor. You know as well as I that we can develop almost any technical competence that relates to our business if we put our minds and resources to it. But it may often be more to RCA's advantage, as it was in this case, to wed our technology to that of another company that is already able to provide what we lack.

The flexible and coordinated approach that marks our SelectaVision effort can help immensely in developing RCA's opportunities in the other two projects I've cited—data communications and broadband information systems.

We see these as major growth businesses in the years ahead. Market projections indicate that data communications are growing faster than any other aspect of electronics. They should account for more than $5 billion of business annually by 1975. Over a longer stretch, the broadband information systems business looks at least as promising. Today's cable TV may well form the basis for a diversified home information industry that could generate a yearly volume exceeding $15 billion in the 1980's.

Consider RCA's stake in these developments.

We're equipped to move into the data communications market from a position of strength that few if any of our competitors can match. We already design, manage, and service systems for large corporate users. We have unsurpassed competence in communications and information processing. We have a highly competent nationwide service organization. We are as well positioned as anyone to produce selected forms of advanced hardware.

The Service Company's teleprinter leasing and reservation system terminal servicing activities have established us firmly in one aspect of data communications. RCA Globcom is engaged in other phases. It has recently embarked on formation of a joint users group which would provide its corporate members with common "end points" for data transmission. This service entails utilization of multiplexed broadband lines each with a capacity of 75 circuits to replace the single circuit dedicated lines these companies now lease individually. We can look forward

Mr. Conrad, during his presentation, emphasized the importance of an increasingly rapid translation of the results of research to the marketplace.

Anthony L. Conrad
President and Chief Operating Officer, RCA
New York, N.Y.
is the eighth President in the history of RCA. As Chief Operating Officer he directs and supervises the daily operations of the Corporation In this capacity he is responsible for all divisions and subsidiaries of the Corporation, except the National Broadcasting Company, Inc., which reports to the Chairman of the Board. In addition, Mr. Conrad has responsibility for the RCA Staff International activity and the Manufacturing Services and Materials activity

Previously, Mr Conrad had been Executive Vice President, Services, since April, 1969. He was elected to the RCA Board of Directors at the company's 1970 annual meeting.

He is a member of the Board of Directors of The Hertz Corporation Random House, Inc., RCA Global Communications, Inc., Banquet Foods Corporation, and Coronet Industries, Inc, all subsidiaries of RCA. Mr. Conrad also is a member of the Board of Directors of Atlas Chemical Industries, Inc and Chesebrough-Pond's, Inc.

Mr. Conrad served as President of the RCA Service Company for eight years prior to his appointment as Vice President, Education Systems, on Corporate Staff, in August 1968 He joined the RCA Service Company in 1946 following his discharge from the U.S. Army Signal Corps. He then held various managerial and engineering assignments with that RCA subsidiary.

Mr Conrad was named Manager, Missile Test Project, at Cape Kennedy, Florida, in 1953, and was responsible for establishment of the large RCA missile and space vehicle tracking operations there. He received the RCA Victor Award of Merit for his work in this field. He was elected a Vice President of the Service Company in 1956 and its President on January 1, 1960

Mr Conrad was graduated from Lafayette College in 1943, with a BA in Physics, and was commissioned a Second Lieutenant in the U.S Army Signal Corps shortly thereafter During his military career, he was Commanding Officer, 220th Signal Radar Maintenance Unit and also served in various Signal Schools.

Mr. Conrad is a Trustee of Lafayette College and is past President of its Alumni Association

May 22, 1972, Buckhill Falls, Pa: About 150 participants at the RCA Corporate Engineering Management Conference enjoyed dinner and the subsequent keynote address: "Shaping the future at RCA" presented by A. L. Conrad, President and Chief Operating Officer, RCA.

soon to profiting from the operation. It will also profit the users by providing reliable data transmission at reduced cost.

Our business strategy in data communications involves progressive expansion of our service base, to be followed by entry into hardware manufacture on a selective basis. In broadband information systems, we're moving in the opposite direction.

As a start, we've acquired a manufacturing company—Electronic Industrial Engineering—that can produce advanced hardware for cable TV operators. As our commitment to this field grows, we expect to use our experience and skills to develop new services as well as new types of equipment.

Apart from entertainment, broadband networks will be able to provide a wide spectrum of two-way home and business communications, from data transmission to personal banking and shopping services. It's likely that new housing will eventually be wired at the outset for broadband interior communications of all kinds. And if you can devise an inexpensive way to equip existing homes, you'll help to speed the introduction of these services and strengthen RCA's position in the business.

The projects I've described are important elements of the integrated approach we're taking toward the development of useful new products and services. There are many others. Among them are some that could be even larger and more profitable than SelectaVision or data communications or broadband information systems. One possibility is the domestic communications satellite business, in which RCA is prepared to play a prominent part as a common carrier either alone or in consort with others.

The tactical communications systems of the U.S. military services are now clearly ready for major modernization and upgrading through application of digital and satellite technology. This opens another vast area of opportunity to RCA's Government and Commercial Systems.

In every new field I can envision, your performance as engineering managers will be critically important. You'll deal in concepts on the frontiers of knowledge in advanced communications. You will have to see that your engineers are kept up to date through effective programs of orientation and training. You and they will have to work together in teams that transcend boundaries among disciplines and between divisions.

Our goal must be a balanced and harmonious combination of scientific, engineering, product planning, and marketing efforts throughout RCA. In no other way can we be assured of the smooth two-way flow of ideas and information so essential for rapid progress from laboratory to product line.

You have an added obligation that may be less obvious but is no less important. Never forget that you are part of management. As such, you have and must exercise influence to make certain that advanced development and engineering programs receive their full share of our divisional and corporate resources. There will always be a strong temptation on the part of non-technical management to economize on research and engineering when P&L pressures rise. You must induce them to resist that temptation whenever such action could weaken RCA's ability to remain competitive in any important area of technology.

Let me conclude with comment on another growing challenge. All of industry today faces a rising demand to do more about the quality, safety, and reliability of its products. This is not a passing phenomenon. It will persist, and we must accept it as a further incentive to improve everything that we make and sell. Our foreign competitors have already started to respond. They are prodded by the greater difficulty of providing adequate service in distant markets. But American business can afford to do no less.

Let me add that RCA has not been idle. I recently spent a day in Indianapolis reviewing the many plans and programs we've initiated to meet this challenge. With your help, we are well on the way. I am confident that you and your engineering teams will continue to dedicate yourselves to the achievement of products whose quality and reliability will enhance RCA's stature and its profitability.

During the next several days, you'll learn more about our strategies and specific plans and prospects. At the same time, you will share in the opportunity to renew our commitments to RCA's progress in electronic communications and information technology.

In working toward the goals we have established in these fields, you can take satisfaction in knowing that there is a direct relationship between your efforts and RCA's success in its principal businesses of today and tomorrow.

Speaking as one who has enjoyed more than 25 years of close association with RCA's engineers, I know that our future could not be entrusted to more competent hands and minds.

The Engineer and the Corporation

Shaping the future at RCA

Description and summaries

W. O. Hadlock, Editor

The information in this article has been compiled from random notes, information provided by the speakers, and recordings made during the Corporate Engineering Management Conference. Since many of the presentations included company-private information, the summaries and abstracts of talks are limited in scope and content. Additional information may be available from the conference speakers whose summaries appear at the end of this article.

Credit is given to M. Korsen, Mgr., Product Design, Missle & Surface Radar Division, Moorestown, N. J., and Hans K. Jenny, Staff Engineer, Industrial Tube Operations Department, EC, Lancaster, Pa., who supplied reference material. Information concerning the section on "feedback" was provided by Frank W. Widmann, Mgr., Engineering Professional Development, Corporate Engineering Services. Special thanks also to all of the Conference speakers for their cooperation and help.

Conferees (above and below) shown during the business and technical sessions. G. B. DiGirolamo (top photo), Administrator, Engineering Education Programs, served as projectionist during the lectures.

At the Corporate Engineering Conference, convened at Buck Hill Falls, Pennsylvania, May 21-24, the underlying theme was *shaping the future at RCA* through the effective utilization of the combined talents of engineering and corporate staff business activities. More than 150 participated, including key members of top corporate and division managements, market planners, chief engineers, and other engineering managers involved with the utilization of technical resources at RCA. The three-day conference was sponsored by Dr. James Hillier, Executive Vice President, Research and Engineering.

A unique opportunity

The conference provided a unique opportunity for attendees from more than 20 divisions of RCA to exchange ideas concerning their roles in accomplishing related business plans. Such plans not only include the existing products in a particular division but involve the effective utilization of associated products, capabilities, and services of all RCA activities. The conference also provided an additional opportunity to assess the challenges in selecting appropriate technology and bringing that technology to the marketplace. The major roles to be played by data communications and information handling services were points of concentration during the conference.

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Idea exchanges invited

In opening the meeting, Dr. Hillier welcomed the 150 representatives from nearly all divisions and subsidiaries of RCA, and solicited an exchange of their ideas and an active participation in helping to *shape the future at RCA*. Dr. Hillier stated: "I happen to think that RCA is going to play a very important role in the electronics of 1985 . . . and that most of the people who are going to play an important planning and engineering role are in this room this morning. Thus, we have selected *shaping the future at RCA*, as the theme for our meeting. Perhaps, the most useful purpose of this meeting is to take you out of your day-to-day routines and give you a chance to meet associates from other divisions and discuss mutual and prominent problems. Therefore, we decided the best backdrop for this meeting would be to give each of you a picture of all parts of RCA. I hope, when you leave, you will have been convinced that RCA is determined to grow in the electronics business."






Dr. J. Hillier (below), Executive Vice President, Research and Engineering served as moderator of the three-day engineering conference, assisted by (from top) A. R. Trudel, Director, Corporate Engineering Services; E. W. Herold, Director, Technology; H. Rosenthal, Director, Engineering; F. Edelman, Director Operations Research, Corporate Planning; and D. J. Parker, Chief Engineer, Government and Communications Systems.

A challenge for management

Highlight of the first-day's session was the keynote dinner presentation made by RCA President, Anthony L. Conrad. Mr. Conrad challenged RCA's engineering and management groups to review their warehouse of technological skills and to determine how such resources can be marshalled to contribute toward RCA's steady business progress; emphasis was given to the existence of a great opportunity for growth in electronics as part of long-range business plans. Noteworthy products and systems cited as having promise were SelectaVision, discrete 4-channel sound, data communications, broadband information systems, cable TV support products, and the specialized systems and devices produced by Government and Commercial System's applied research and engineering groups. Mr. Conrad cited the steady market progress of color TV, and mentioned major government contracts received by RCA Service Company and by Government and Commercial Communications Systems activities. (*Mr. Conrad's complete talk immediately precedes this article.*)

A 3-day program of business and product plans

Dr. Hillier introduced speakers from corporate finance, planning, manufacturing, industrial relations, and other activities concerned with shaping the future of RCA. The speakers described such vital considerations as the need to look beyond the financial statement in evaluating RCA's net worth and assessing RCA's business planning processes; the constant demand to develop and more fully utilize RCA's personnel on a broad scale; the necessity of maintaining a close interface between engineering and manufacturing services–and–materials; and, the continuous need for the RCA technical staff to join with marketing in assuring RCA's successful future. Attention was given not only to the role of RCA as a leader in electronics in USA but also to its role as a multi-national company in garnering its share of the rapidly growing overseas business.

Special program features that attracted attention were presentations by executives from RCA subsidiaries such as The Hertz Corporation, Banquet

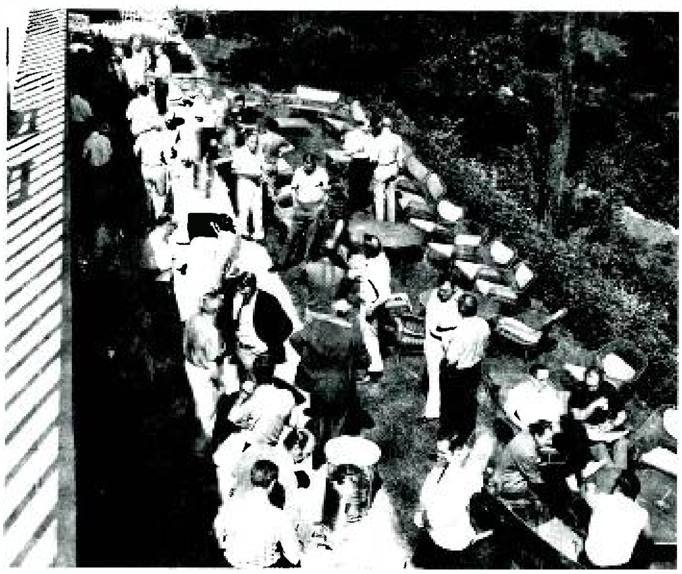
Foods Corporation, Coronet Industries, Inc., and Cushman and Wakefield, Inc. Particularly interesting to all the members of RCA's traditional communications and electronics activities were the historical descriptions of the formation of the subsidiaries and of the early challenges overcome by these non-electronics businesses. The subsidiaries revealed business approaches that kindled interest among members of RCA's traditional electronics businesses.

On the second and third days, the conference examined the role of research and engineering in helping to shape the major business areas—current and future. Continuing activities—Electronic Components, Consumer Electronics, and RCA Records—were described as contributing significantly to RCA's business success by providing a substantial base of resources to support new developments. Some new product advances were described by representatives of the Solid State Division and Government and Communications Systems.

The 4-channel sound and the SelectaVision systems planned for introduction during 1973 were demonstrated at the conference. NBC and RCA Global Communications revealed new products such as VideoVoice. Advances in solid-state devices, integrated circuits, and hybrid technology—and the approach to the marketing and development of broadband information systems—were described. RCA Laboratories representatives emphasized their key role in the transfer of valuable scientific information—and as a pivotal element in furthering innovation and entrepreneurship in the new business cycle.

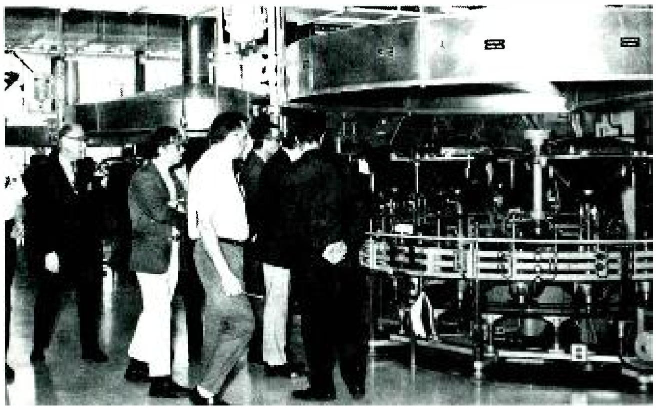
Entrepreneurship and task forces

During the presentations there was increased evidence of the successful use of streamlined task forces to concentrate on the development of major new business opportunities. Task force groups have been organized by top management in the Corporate Staff to address new ventures such as SelectaVision, data communications, and consumer information systems. A task force draws together individuals from several cognizant operating and staff groups to focus the needed variety of talents (engineering, research, marketing, manufacturing and finance) upon



Conference attendees continue discussions during luncheons and between technical and business sessions.

Demonstrations of the 4-channel stereo sound system and of SelectaVision systems were provided. Top center photo, Rex Isom, Chief Engineer, Record Engineering, holds RCA's Q-8 tape cartridge during his demonstration of RCA 4-channel sound systems. Above, H. Ball and W. Hannan describe MagTape and SelectaVision systems.



Participants are shown boarding a bus for an inspection trip to the Electronic Components facility in Scranton, Pa. Visitors to Scranton observe the production of tubes, and are briefed on the cutoff, sealing, and annealing processes in manufacturing color TV tubes. Another group made an inspection trip to the Solid-State Division facility at Mountaintop, Pa.

a single business opportunity. Such task groups are given responsibility for starting the new businesses and products.

Exhibits and plant tours

Exhibits depicted some of the functions provided by Corporate Engineering Services including Technical Publications, Engineering Education Programs, Corporate Standards Engineering, and the RCA-MIT Industrial Liaison Program.

Conference attendees made inspection trips to the Solid State Division facility in Mountaintop, Pa., where a variety of solid-state devices and hybrid circuits are being manufactured, and to the Electronic Components facility at Scranton, Pa., where matrix color television tubes are being produced in mass quantities.

Workshops

On the final day, workshops and individually organized activities were led by A.R. Trudel, F. Edelman, and D.J. Parker. Several groups were formed in which participants discussed ways to: 1) stimulate interdivisional cooperation and 2) capitalize on the strengths of such a diversified company as RCA. The workshop groups were invited to submit what they considered to be important suggestions to Dr. Hillier for his consideration. It was understood that some of the good suggestions and ideas could be implemented directly by the participants.

The themes for discussion proved to be interlocking topics that are both important to RCA's success. To capitalize fully on RCA's strengths requires a high degree of interdivisional cooperation. Some of the major actions recommended (by all groups) to further such cooperation were as follows:

1) Increased interaction between divisions in which joint goals are developed.
2) Develop a general manager joint council to accomplish 1) above, and take advantage of the diverse capabilities of a large corporation such as RCA.
3) Develop mechanisms that provide reward systems and recognition for cooperative interdivisional efforts and successes, on a personal performance basis.
4) Assign budgets, specifically tagged for interdivisional use, to pull together new ventures.
5) Avoid interdivisional "hangups" by stepping up communications between divisions, using every means available, including video tape.
6) Encourage and support highly motivated, qualified technical task-forces and entrepreneur groups.
7) Strengthen the organizational position and leverage of engineering activities in many major operating units.

Conference summation

Dr. Hillier's concluding remarks (following speaker's summaries) on the final day of the conference epitomized the enthusiasm of the technical staff concerning the many opportunities available in electronics and communications; in new entertainment products; in information handling services; and in broadband information systems that promise to increase future businesses and profits for RCA.

Emphasis was given in several presentations to the fact that the future cannot be based on technology alone; rather, it must be based on a viable combination of marketing, engineering, distribution, and low-cost manufacturing plans. Relevance and selectivity are also keys to "shaping the future at RCA."

Conference feedback

As this article is being written, most of those attending the conference have responded to a comprehensive questionnaire. Nearly all respondents evaluated the conference as above average, excellent, or much better than previous conferences of the series. Some respondents went so far as to classify the conference as "wonderful", "outstanding", or "best ever attended".

Nearly all of the delegates who responded expressed high or very high interest in the talks, demonstrations, and exhibits. Especially high interest was shown in the addresses by Mr. Conrad and Dr. Hillier and in those presentations focusing on corporate objectives, future businesses, technological opportunities, and new products and services.

The majority of the workshop participants who responded said they obtained ideas that will help them at work and contributed ideas that should help others at work. Most participants agreed that the workshops were a worthwhile investment of time; also, the majority of respondents who toured the Scranton and Mountaintop Plants found the tours interesting, informative, and worthwhile.

Comments of the responding attendees show that a major objective of the meeting was met: to increase understanding and cooperation in the total engineering community of RCA by providing an opportunity, not possible in the normal course of business, for chief engineers and other engineering managers from all parts of the company to meet and know each other better . . . and to meet and know key members of top corporate and division managements. In summary it may be said that the conference was a distinct success.

Sessions and summaries

The business and technical sessions during the three-day conference were divided into six categories as follows:

Session I—A Corporate Overview
Session II—RCA Subsidiaries
Sessions III and IV—Programs and Role of Engineering in our Major Business Areas—Current and Future
Session V—Plant Tours and Product Demonstrations
Session VI—Workshops

Dr. Hillier served as moderator for the sessions, assisted by: A.R. Trudel, Director, Corporate Engineering Services; E.W. Herold, Director Technology; H. Rosenthal, Director, Engineering; F. Edelman, Director, Operations Research, Corporate Planning; and D.J. Parker, Chief Engineer, Government Communications Systems,Communications Systems Division. The conference was organized and arranged by F.W. Widmann, Corporate Engineering Services, assisted by Doris Hutchison, Conference Registrar.

The summaries reported in the following pages are intended to provide a general overview of the business and technical presentations; additional information may be available from the individual speakers.

Session 1—
A Corporate Overview

"Looking Beyond the Financial Statement" ... by C. C. Ellis
"Corporate Goals (1972-1977)" ... by G. C. Evanoff
"The Second Resource" ... by R. F. Maddocks
"The Face and Interface of Manufacturing Services and Materials" ... by G. A. Fadler
"Follow RCA to the Future" ... by J. J. Johnson
"RCA as a Multi-National Company" ... by E. J. Dailey

Session 2—
RCA Subsidiaries

"The Hertz Corporation" ... by R. J. Perman
"History and Philosophy of Banquet Foods Corporation" ... by H. A. Stamper
"The Coronet Story" ... by R. L. Morrow
"Cushman and Wakefield—Its Role in Housing American Business" ... by H. A. Semler
"Keynote Address" ... by A. L. Conrad

Session 3—
Programs and Roles of Engineering in our Major Business Areas—Current and Future

"Electronic Components in RCA—An Ever-Challenging Business" ... by C. H. Lane
"Solid State Division—Business and Engineering" ... by W. C. Hittinger
"Consumer Electronics" ... by M. H. Glauberman
"Government and Commercial Systems" ... by Dr. H. J. Woll
"RCA Records and Engineering Management" ... by W. R. Isom

Session 4—
Plant Tours

Solid State Division at Mountaintop, Pa.
Electronic Components at Scranton, Pa.

Session 5—
Programs and Roles of Engineering in our Major Business Areas—Current and Future (Cont'd)

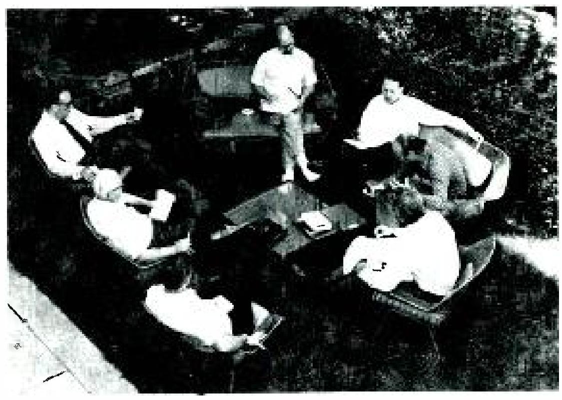
"The National Broadcasting Company—Operations and Engineering Department" ... by W. H. Trevarthen
"The Global Point of View" ... by S. N. Friedman
"SelectaVision Progress Report" ... by H. Ball
"Hybrid Technology" ... by R. S. Engelbrecht
"Systems Marketing and Development" ... by R. W. Sonnenfeldt
"Report from the Laboratories" ... by T. O. Stanley
"Conference Summary" ... by Dr. J. Hillier

Session 6—
Workshops and Individually Organized Activities (Led by A. R. Trudel with D. J. Parker and F. Edelman)

- **Ways to Stimulate Interdivisional Cooperation**
- **Capitalizing on the Strengths of a Diversified Company**

Product Demonstrations

- **4-Channel Sound ... by W. R. Isom**
- **SelectaVision ... by H. Ball**

Photos above: Conference attendees exchange ideas during workshop sessions which concentrated on 1) ways to stimulate Interdivisional cooperation and 2) capitalize on the strengths of a diversified company.

Description and summaries (cont'd)

A Corporate Overview

The first session of the Corporate Engineering Conference consisted of presentations by executives representing six major corporate functions. Each of these presentations spanned the entire range of RCA Corporate activities. Summaries of five of these presentations follow. One presentation—"Follow RCA to the Future" by J. J. Johnson—is omitted: Mr. Johnson is preparing a complete paper for a future issue.

Looking beyond the financial statement

C. C. Ellis
Senior Vice President, Finance,
RCA Corporate Staff, N.Y.

The world sees a company through the window of its published financial statements. But this view is not the whole story; one must look beyond the three basic financial statements; the balance sheet, the earnings statement, and the funds statement. These statements included in our annual report are the only "official" documents available for the public, and provide the following:

a) *Balance sheet*—contains the assets, liabilities, and net worth. The assets show what you own (valued at what was paid for them) less depreciation; this is balanced against liabilities, or what is owed. The net worth, basically is the difference between what you own and what you owe. Banks traditionally look at net worth before loaning money. Now, is this really a true picture of you as an individual, or your company? Nothing is attributed to your ability to earn money which is a key factor.
b) *The earnings statement*—represents more nearly what you have been able to do with what you have (goods sold less expenses). This determines a profit or loss after income tax consideration. After dividends are paid out, the balance of the money is available for use in the business. Until very recently, this and the balance sheet were the only statements required. Now, the SEC requires a third, the funds statement.
c) *The funds statement*—is basically a report on where you got your cash and how you used your cash. This is needed since the profit and loss statements include many figures that are not cash such as depreciation and consignment sales. So, the fund statement gives an idea of cash flow, also called sources-and-uses of funds, or working capital.

Missing values

But now that we have reviewed these three exhibits, many important things are not included which have a great bearing on the reputation and future of the company. All of these parameters can be assets or liabilities. Some of these are:

1) Company name and reputation
2) Product distribution and franchise
3) Company's competitive position with respect to all competition
4) Technical know-how, employee skills, and proprietary processes
5) Age of management and type of organization
6) Patents
7) Labor environment and goodwill
8) Industry characteristics (up or down).

These are all important, although they cannot be touched, seen, or kicked. These factors are difficult to price and evaluate since there are no rules for appreciation or depreciation.

The earnings statement is more indicative yet it doesn't tell what profits will be earned in the future and the risks of not reaching projected profits. And we don't know what dividends will be paid in the future. The earning statement looks at the past, not the future.

Real value

So, none of these statements reflect real value which is what we strive to determine. Stock advisors and consultants look at real value which is a matter of individual judgment. Such decisions bear upon answering the following questions:

a) What happens to environments in which a company operates? .
b) What should the company be capable of earning in the future?
c) How much earnings will be passed on to shareholders?
d) What are values of "missing" assets?

To illustrate the effect of real value, look at IBM's balance sheet showing 6.642 billion dollars, yet the market value of IBM's stock shares (owned by the public) is 44.583 billion dollars. Thus, the public says that IBM is worth 37.941 billion dollars *more* than that of the balance sheet, accountable only through the missing intangibles. RCA is worth 1.820 billion dollars *more* than the balance sheet, again a very sizable miss. U.S. Steel shows 1.75 billion dollars *less* than the balance sheet.

Because development costs are paid immediately (rather than taken as a liability) there is a tendency to *underprice* products sold. A move is afoot to estimate future earnings by evaluating (in terms of dollars) performance, technical know-how and management values.

I sincerely believe we are very capable, that our technical know-how, our processes, and our name and reputation are achieving far in excess of the goals we have set for ourselves.

Corporate goals: 1972-1977

G. C. Evanoff
Vice President
Corporate Planning, Finance & Planning Staff
RCA, N.Y.

Edior's note: Major portions of Mr. Evanoff's talk contained company-private information which cannot be published. Therefore we are publishing a few selected highlights from his presentation.

The Corporations's primary goal is to maintain a steady and substantial earnings-per-share growth. To achieve this goal it is believed that annual revenue and profit improvements will be required at a rate in excess of GNP growth for the period of 1973-77

Sustained performance in this range requires that the company double in size and profiability in approximately 5 years. The Corporation's long-term performance trend line over the past 35 years indicates an average capability, historically, for doubling about every 7 years. Obviously, there has been some cyclicality in the pattern and for some shorter periods actual performance was either above or below the trend. Although the past is not a predictor of future performance, it does provide perspective for RCA's basically good long-term performance.

Corporate performance goals

The Corporation now is in the midst of a recovery from a depressed base following the decline from its 1966-1969 peak. Therefore, it appears appropriate to establish accelerated growth as an objective for the intermediate term.

Whether the goals tentatively set for 1973-77 are realistic remains to be determined, since the specific performance targets will be firmed up as the planning process unfolds in the weeks ahead leading to Business Plan approvals at year-end. In any event, it is clear we are in a period which requires special emphasis on investment in additional revenue and building long-term profitability.

Sources of RCA's pretax profit—1971 vs 1966

The Corporation's electronic operations (CE, EC, G&CS, and SSD) experienced a multi-million dollar pretax profit decline from 1966 to 1971. The balance of RCA increased its profitability over the same period, thus partially offsetting the corporate decline.

As a percent of total profits, the electronic operations were more than two-thirds of the Corporation total in 1966, and less than half in 1971. This performance was neither unexpected nor disappointing. The pattern of growth in the electronics industries is largely cyclical. RCA as a leader in key segments of the electronics industry achieved a peak plateau in 1966 from which it declined into the valley of the 1970 recession and a moderate 1971 recovery.

Recent diversification actions and performance of the inherently more stable service operations helped cushion the impact of the electronics downturn on total Corporate earnings. As we look ahead to the future, it is fully expected that the growth potential of electronics operations will be supported properly and their contribution to the Corporation will increase. In fact, our expectation is that electronics profits should more than double 1971's level by 1977.

Growth possibilities

Since earnings performance is now in an improving trend, RCA has a unique opportunity to invest in development of new business while at the same time avoiding a profit downturn. New business accounts for 4% of 1976 projected revenue included in the 1972-76 Long-Range Plan. Although other opportunities were under consideration by many Divisions, the level indicated by firm programs included in the LRP must be viewed as too low to support Corporate goals.

Some major growth opportunities being pursued are:

Consumer Electronics
- SelectaVision.
- Home entertainment cable TV.

Electronics Components
- Entertainment components, primarily overseas OEM.
- Communications components for business and government markets.

Solid State
- Integrated Circuits, primarily RCA and some OEM with major applications in home entertainment, instrumentation and controls, telecommunications, and automotive industries.

Government and Commercial Systems
- New and broader generations of mobile, aviation and studio communications equipment and systems.
- Data Communications and signal distribution equipment for both cable and satellite communications systems.

Glōbcom
- Alascom and White Alice communications systems.
- Communication services via satellite systems.
- Other communications services, including VideoVoice.

Summary of 1972-1977 strategies

The primary strategy is to concentrate on building the strengths of the basic RCA businesses, and invest now for the future through both re-direction of cash generated by improved earnings and the use of added debt capacity made possible by the improved earnings. And finally, develop new revenue sources from added investments in consumer, communications electronics and services fields; through selective expansion of RCA participation in overseas markets, and new business development.

The second resource

Dr. Robert F. Maddocks
Staff Vice President
Organization Development and
Compensation Planning
RCA Industrial Relations, N.Y.

RCA's financial and material assets represent one critical Corporate resource; however, a second resource is the human skills within the Corporation. In numbers alone, the totals are impressive: approximately 120,000 employees.

The prime question is how to direct these human resources and skills to achieve Corporate objectives, and improve upon RCA's business position while creating a high degree of job satisfaction. Every manager is probably aware of these needs and believes he is concentrating on optimum performance. The management of these resources may very well be the determining issue in whether or not the corporation meets its objectives as outlined.

Role of Industrial Realtions

Industrial Relations has an important role to play in helping management with this task. The role of Industrial Relations is to understand existing and projected business plans, respond to unique differences in RCA activities and support and influence management people involved in solving business problems.

The Industrial Relations philosophy calls for general guidelines for all major operating units while allowing maximum freedom for the development of innovative, creative, and unique programs required to meet specific business goals. However, it is essential that RCA Industrial Relations be assured that each activity has established a program that is responsive to its own requirements. Therefore, while Corporate programs will exist, specific programs can and should be developed in each unit.

The joint task we see is how to have an organization that continues to be viable and healthy.

Forces to deal with

The type of activity should take into account the forces which exist today. Individuals have more alternatives available to them today and loyalty and fear appear to have lost much force in getting people to perform. At the same time, employees of all age groups seem to have a great desire and willingness to deal more openly with problems affecting them and question traditional ways of operating.

A significant trend is the growing desire by individuals to contribute to their organizations—by striving to gain worthwhile goals. Thus, the more a group can generate this involvement, the more likely the members of the group will be dedicated, involved employees with high investment in their work.

Our history, precedent, and traditional ways of operating tend to become fixed and are difficult to modify even though conditions have changed. We must examine our traditional methods against changing conditions and modify our activity accordingly.

Conclusion

The goal of Industrial Relations is to help the organization achieve objectives while providing conditions for the growth and development of employees. Managers, leaders, and all employees have somewhat similar desires to make meaningful contributions. Working with what managers must achieve, Industrial Relations can provide help with the following activities:

1) Helping to set standards for management selection and practices.
2) Measuring organization climate.
3) Influencing the involvement and commitment of people to work.
4) Implementing a talent inventory system to identify and assess management talent in the Corporation.
5) Planning manpower requirements in advance.
6) Appraising performance (how are we impacting on people?)

7) Upgrading productivity—job enrichment, give greater responsibilities, build effective organization climate.

In closing, the second resource, the human resource, and the manner in which it is utilized and managed may very well be the determining issue in our future.

The face and interface of manufacturing services and materials

G. A. Fadler
Vice President
Manufacturing Services and Materials
RCA Corporate Staff,
Cherry Hill, N.J.

The fundamental objectives of the four functional areas of Manufacturing Services and Materials Staff are:

1) Reduce the cost of acquisition, use, and handling of materials,
2) Enhance and maintain the fixed assets of RCA,
3) Improve quality and reliability at minimum costs, and
4) Increase the productivity of our manufacturing divisions.

These objectives are satisfied by services provided to the major operating units by four major activities as follows.

Materials

Materials activities coordinate the centralized negotiation for commonly purchased materials through the consolidation of requirements; a reduction of $3 million was achieved in 1971. Similarly, transportation and packaging effected savings of $1.2 million, and foreign-sourced purchases accounted for $3 million savings.

Facilities and real estate

Facilities and real estate provides direct technical assistance in the maintenance of facilities, professional management of construction projects, and coordination and control of owned and leased facilities. Particular attention is given to obtaining effective control of pollutants at nominal facility costs and also monitoring to ensure compliance with legislation.

Reliability and quality

Reliability and quality activities develop programs directed at managing quality losses through measurement of actual cost of quality and implementation of quality cost corrective action systems. Continued indoctrination in the concept of quality-loss prevention through closer management of the design and production phases of operations is a major current Staff effort.

Manufacturing

Corporate Staff Manufacturing assures improvement of manufacturing proficiency and helps solve manufacturing problems. In 1971, Manufacturing systems and technology capitalized on its experience in computer-controlled automatic test, data collection, process control and field diagnostics to contribute to successful implementation of several major cost-saving projects in the divisions of RCA. Through these experiences, a total concept of manufacturing measurement and control has evolved. Projects involving automatic test and data collection of solid state TV sets, process control and color measurement techniques at Coronet Industries, quality related data collection in many major operating units, coupled with an educational program for plant personnel, constitute the principal plans for 1972.

The Industrial and Manufacturing Engineering Staff has objectives in three main areas: 1) assist in the design and installation of integrated manufacturing systems, 2) reduce manufacturing costs, and 3) improve in product quality and reliability.

Interface with the technical community

Although engineering and manufacturing understand individual charters, more can be done to understand mutual responsibilities. To achieve an effective engineering-manufacturing interface, the complexities arising from the types of businesses we're in and the variety of organization structures must be understood. Because engineering and manufacturing functions are separately identified with great clarity and efficiency, communication problems can sometimes arise, with each function tending to "do its own thing." What can happen is that one function may lag with respect to the other and so hold back possible progress. Communications problems must be even more thorough when we engage in multi-national manufacturing. To communicate technology and maintain a close interface, particularly during state-of-the art design and manufacturing, is essential for better manufacturing involvement.

The need for effective engineering–manufacturing collaboration has been made greater by the world-wide nature of today's competition. We have some basic disadvantages relative to foreign competition such as higher wage costs of all kinds. Although we still have the highest absolute productivity, the rate of improvement has slowed significantly compared with other countries. Our government does not support industries' needs as other governments do, and we are encountering high costs to protect our environment, a policy not significantly supported by the rest of the world. Lower profit margins result in a lower rate of new capital addition compared with many international competitor countries.

These are some of the disadvantages, but the situation is not all gloomy. You are effectively countering with efforts like the adoption of modular construction in the solid state color television chassis, permitting low-cost assembly. Other RCA groups are designing high-technology products to reduce costs: you are specifically designing for automation in manufacture as, for example, in the phototubes operation. You are employing technological innovation which has produced the dynaflex record. We must keep these kinds of efforts going.

The task ahead

Addressing the task ahead, we must continue to improve our separate competences. Manufacturing, for instance, must upgrade its skills to support and contribute to your advancing technical invention. Together, engineering and manufacturing need to reinforce some fundamentals; quality performance, for example, continues to see demands for improvement. Consumerism demands continue to increase. Customer awareness of quality is sharpened by our communications media; governmental requirements for high quality are on the increase. Performance requirements now take on a new dimension.

Another fundamental consideration is standardization. The tendency to support public taste for variety leads to proliferation of product types. Where such variety supports profitable returns is one thing, but we must continue to examine such action to avoid this pitfall where no purpose is served. Standardization of products, processes, and materials needs to be a constant effort.

Our international involvement presents us with new competition about which we must learn more. We need to continually appraise our competition's products and manufacturing efficiencies.

Conclusion

Engineering and manufacturing must look ahead for survival. Major mutual effort must be devoted to the identification of the *greatest* opportunities or losses in the manufacturing cycle. Large material and assembly costs, for example, are opportunities for action. Low-throughput yields present an opportunity for loss reduction.

Survival can be defined in the ultimate as the attainment of customer satisfaction. Optimization of design for manufacture through effective teamwork during design and production phases must be aimed toward obtaining that satisfaction profitably.

RCA as a multi-national company

E. J. Dailey,
Staff Vice President,
International Planning
RCA Corporate Planning, N.Y.

First, the word *multi-national*. I don't know who first coined the phrase as descriptive of large corporations that have investments and operating units in a number of different countries. Interestingly, dictionaries don't list it. So far, there is no consensus on any type of formal definition.

Multi-nationalism

There are a number of different aspects of "multi-nationalism" including for example, nationality of ownership, nationality of board membership and nationality of management in addition to geographical widespread operations. Most so-called "multi-national" corporations are not multi-national at all in ownership, Board of Directors or management even though they do have many operations outside their home country. In this sense, they might better be called "international" rather than multi-national and RCA falls in this category. A company that can claim to be "multi-national" seems to have a certain status image or higher pecking order, than only an "international" corporation.

Geographic spread of foreign subsidiary operations—1971

	Consumer Electronics	*Commercial Systems*	*Coronet*	*Electronic Components*	*Government Systems*	*Hertz**	*National Broadcasting Company*	*RCA Institutes*	*RCA Service Company*	*Random House*	*Records*	*Solid State Division*
Argentina											•	
Australia						•	•				•	
Belgium						•					•	
Bermuda						•	•					
Brazil				•		•					•	
Canada	•	•	•	•	•	•	•	•	•	•	•	•
Chile	•			•							•	
France				•		•					•	
Germany						•					•	•
Italy				•		•					•	
Mexico	•			•		•	•				•	
Spain						•					•	
Taiwan	•			•								•
United Kingdom		•		•		•	•		•		•	•

*In addition to the above, during 1971, Hertz maintained subsidiary operations in the following:

Austria, Bahamas, Barbados, Columbia, Denmark, Greece, Israel, Jamaica, Luxemburg, Malaysia, Monaco, Netherlands, Neth. Antilles, New Zealand, Norway, Panama, Portugal, Philippines, Singapore, Sweden, Switzerland, Venezuela

Competitive aspects

On the other side of the coin, however, and in particular from the viewpoints of foreign host countries, the name and concept of multinationalism is becoming more and more anathema. This can be easily understood when it is realized that breaching or overriding national boundaries to become multi-national is a direct challenge to national sovereignty or the host government's presumption of control over all activities, people and entities within its national boundary. This confrontation between national sovereignty and multi-nationalism is heating up worldwide and is certainly one of the root causes for the negative shift in receptivity toward private foreign investments explained later.

Starting in 1967, responsibility for exports and foreign subsidiaries was shifted from the International Division to the Operating Divisions each of which now has worldwide cognizance for its products and services.

Annual real GNP growth rates for major developed countries—1958/59-1975

Country	*1958/59-1968/69*	*1971*	*1972*	*1971-1975*
Japan	11.2	6.10	6.0	9.0
Spain	6.0	4.50	6.0	7.0
Portugal	4.4	7.00	5.0	5.7
Canada	4.8	6.00	6.0	5.0
France	5.7	5.60	4.5	5.0
Italy	5.7	0.75	2.5	5.0
Belgium	4.7	3.75	3.0	4.5
Finland	3.8	4.00	3.5	4.5
Norway	4.8	5.25	4.0	4.5
Netherlands	5.3	5.00	3.0	4.5
West Germany	5.1	3.25	1.5	4.5
Sweden	4.4	0.25	3.0	4.4
United States	4.5	2.75	5.5	4.2
United Kingdom	3.1	1.75	3.0	3.3
	*Weighted Averages**			
Europe (West)	4.9	3.4	3.2	5.4
United States, Japan & Canada	5.2	3.7	5.1	6.4
Total	5.1	3.6	4.4	6.1

*Weighted by GNP's
Sources: OECD and Arthur D. Little, Inc., forecasts.

Why foreign business for RCA

What is the attraction in international business? Why go abroad? There is a complex of reasons:

- Partly because like the reasons for climbing the mountain, the foreign market "is there".
- Many of our competitors and peer companies have gone abroad more strongly with overall beneficial results.
- Overall growth in many countries is higher than in the US.
- Many products that have matured in the US, are still on strong growth curves elsewhere.
- For marketing oriented companies, there is as much potential outside the US as within; operations confined to the US embrace only half or less of the free world demand.
- There are added profits to be earned abroad.

On balance, the 1967 shift in International operating pattern to the division's responsibility was certainly in the right direction as demonstrated by the fact that RCA's international revenues more than *doubled* in the five years 1966-1971. Foreign activities fall into three categories:

- Exports
- License
- Subsidiaries
  - Manufacturing only (Feeders)
  - Marketing only (e.g. Hertz or Neye)
  - Manufacturing and Marketing for host markets.

By end 1971 we had 100 foreign subsidiaries operating in 37 countries under the management of 12 operating divisions. At the same time, seven divisions are exporting to 138 countires. Foreign licensing continues to show strong growth and outstanding results. The combined revenues from the three channels of international activity accounted for about 14% of total corporate revenues in 1971 and a larger share of the net income.

Business climate

Before touching on our firm international plans for the future, what is the business climate like outside the US today for RCA as an aspiring multi-national company?

During the twenty-five year period following World War II up to about 1969-70, the demand for goods and services and the wherewithal to acquire them was nearly universal. The result was that almost any company and particularly any American company, could expect to be received with open arms almost any place in the world for almost any product or service that company proposed to sell or manufacture.

This is no longer true. The ready receptivity toward foreign commercial ventures has peaked-out and protectionist barriers are going up or not coming down, almost every place outside the US. There are different reasons for this. In the *developed* areas such as the larger EEC countries, the UK and Japan, American investment is not now so readily welcomed because these economies generally have caught up engineering-wise, distribution-wise, product-innovation-wise; they are now generating adequate investment capital internally and there is a rising wave of "nationalism" or protectionism.

The practical consequences of this adverse shift in attitude toward American private foreign investment is a growing list of restrictions and investment ground rules. As if increased hostility toward American private enterprise abroad weren't enough, rising nationalism *here at home* is also questioning the very concepts and right to exist of US multi-national corporations. The Hartke-Burke Bill sponsored by organized labor and a number of congressmen, if enacted would effectively close down most existing US industrial operations abroad and would prevent the establishment of new ones.

Commercial opportunities

From a combined analysis of the environments in world blocs, the individual countries within each bloc and RCA's spectrum of products and services, commercial opportunities for RCA during the next ten years will be concentrated geographically in:

European Economic Communities (EEC)
- Belgium-Luxemburg
- Denmark
- France
- Italy
- Norway
- UK
- W. Germany
- Selected associate member countries

Latin America
- Argentina
- Brazil
- Mexico

Japan

Australia

In the non-electronic businesses of RCA, there will be major opportunities in the enlarged EEC and Japan for Service Company, Banquet, Coronet and Hertz. With regard to the future, presently identified plans will *double* total RCA international revenues by 1976.

Technical interface

What of the interface between our international activities and the technical community? I mentioned earlier that one of the reasons that investments by American private companies are no longer so readily welcomed abroad is the fact that in many *developed* countries (as distinguished from poorer *developing* areas) native technologies have caught up with ours in several major industries and are rapidly catching up in others.

In a few cases such as Germany and Japan, a greater portion of their respective GNP's is being devoted to R&D than is now true in the US. However, in absolute amounts of money or in technical man-hours they have not yet caught up with us, since our GNP is much larger. Another measure of success of foreign technical efforts is the sheer number of patents being issued in the EEC and Japan, for instance. Still another aspect is the large number of US patents presently being issued to foreigners, something like 40% last year, I believe.

As a consequence, we will be able to sell or utilize abroad only our best technologies. Not our second-best, as many American companies did in the 1950's when they gained their first foreign footholds. There is still both a place for and a desire for our technology off shore, but increasingly it will be only for the very latest state-of-the-art. As a practical matter, the primary interface between RCA's technical community and the world outside US will continue to be our foreign licensing activities which channel our technology to both our own foreign subsidiary operations as well as licensing our patents and technology to others.

In conclusion, if we achieve our 1976 plans for foreign revenues—and I think we have a good chance—RCA by almost any measure will have caught up and will be in fact a true international corporation.

RCA Subsidiaries

The second session concentrated on four of RCA's newly acquired subsidiary companies. Top operating executives from Hertz, Banquet Foods, Coronet, and Cushman and Wakefield presented the background, ongoing programs, and business outlook for their companies. Summaries of these four presentations follow.

The Hertz Corporation

Ronald J. Perman
Chairman and Chief Executive Officer
The Hertz Corporation, N.Y.

Let me put Hertz in the perspective of the national economy. As many of you are well aware, the division in our society between manufacturing and service industries has been changing over the years. The service sector—in which Hertz plays a vanguard role—has been growing at a rapid rate in the past half century, and particularly since World War II. Today more than half of every consumer dollar is spent on services.

Rapid growth

No service industry has enjoyed greater growth than renting-and-leasing because more and more people want the temporary use of all kinds of equipment—without the costs and responsibilities of ownership.

Turning to the physical aspect of our business we operate approximately 135,000 vehicles from corporate-owned car and truck locations around the world. Net profit for 1972 is expected to reach a record high for The Hertz Corporation.

Rent-a-car operation

At the moment, we operate approximately 50,000 vehicles in this part of our business, available for short-term rentals through corporate-owned locations throughout the United States.

Hertz Corporation succeeded in establishing its service on a broad geographic basis via owned and franchised operations in large cities and suburban locations.

The period of the 1960's was primarily one of consolidation for Hertz. The coming-of-age of air travel gave a tremendous boost to Hertz revenue, as did its expansion beyond the continental confines of the United States.

From an early letter of credit, circa 1925, Hertz has now extended charge privileges to 1.8 million motorists who currently hold its charge cards. We also recognize other generally accepted cards for car rental purposes and estimate that some 20 million motorists hold these other cards.

Truck renting and leasing

Truck renting-and-leasing is a division of Hertz operating vehicles from a variety or types of locations throughout the United States.

Truck renting and leasing is our second most senior business. This division of Hertz got its biggest forward momentum when The Hertz Corporation purchased the business of one of the largest and oldest truck leasing firms in the East—Metropolitan Distributors, Inc. The business grew steadily along two lines, leasing and short-term rental. It was not until 1958 that the truck business was surpassed by the Rent-A-Car business.

Car leasing

Our next most significant domestic activity is car leasing; this operating unit concentrates on the long-term leasing of cars—generally 2 years. It leases thousands of vehicles through locations in the United States.

Hertz entered this extremely stable and growing part of the industry in the year 1955, with the acquisition of the Robinson Auto Rental interests, a major East Coast lessor. Two types of service are provided, or any combination of features between the two. Under the full maintenance lease, for example, Hertz provides all services except fuel and lubrication, even including registration and insurance. Under the finance lease, Hertz buys the vehicle and, at the end of the lease, disposes of it. The lessor handles all other matters himself and absorbs the gain or loss on disposition of the car.

International

Our most rapidly growing unit is International; this we define as any area outside the US. Hertz owns and operates a fleet of vehicles, essentially cars, through a network of corporate-owned locations. We have corporate operations and licensee operations in over 100 countries and territories. In 1957 a joint venture with American Express was established to enter and expand the international renting and leasing market. In 1966, Hertz acquired full ownership of International by giving Hertz stock for American Express interest in International. Hertz primarily rents locally manufactured cars and employs local citizens of the countries it serves.

Like the domestic rent-a-car business, Hertz International finds most of its rentals take place at airports—again the fly-drive characteristic of the United States. As International's car rental broadens in scope and size, it finds that most of its business comes not so much from Americans traveling abroad as from nationals of other countries in their own and other lands. Thus, this part of Hertz service can be said to be a truly international business.

Other businesses

In 1965, Hertz entered the business of renting construction-type equipment to contractors and industrial firms. Hertz Equipment Rental provides a variety of equipment through some three dozen locations in the U.S. and, on a limited scope in the Far East.

The *equipment-rental activity* has broadened over the years by acquisition of concerns that included sales distributorships. In 1970, the business became international in scope with the acquisition of Air Mac International operating in the Philippines, Singapore and Malaysia. To give you an idea of this Hertz service, the kind of equipment available ranges from small tools to small earth moving equipment, hydraulic cranes and even immense crawler cranes.

In 1965 Hertz entered the *car-parking industry* through acquisition of Meyers Bros. The subsidiary operates locations in the US and Puerto Rico.

Similarly, the *trade-show and exposition industry* was another segment of the service industry that we moved into in 1966. That year we acquired United Exposition Service Company, which uses locations in selected major US cities. United Exposition provides drayage, furniture and display equipment and warehousing for trade shows and expositions.

Still expanding along automotive lines, Hertz in 1969 bought the British concern of Silcock & Colling, one of the largest *transporters of new autos* through Great Britain. At time of acquisition, Ford was the only customer and Silcock moved the bulk of their production each year. Now Silcock serves Chrysler to some extent and also handles imports from other manufacturers.

The company uses three methods of vehicle delivery—by road, driven individually; by rail on two-tiered "cartics" to a distribution point and then by road; and by road transporter, carrying 6 or 8 cars. It's planned to develop the business on the continent and between England and the continent as the European Economic Community's market is broadened.

It was a natural extension of Hertz interests of serving air travelers to enter the *airport hotel-motel industry*. This occurred in 1968 with the opening of a new city-within-a-city concept of airport terminal, the Hertz Skycenter at Huntsville, Alabama. Here, under one roof, was hotel, convention, ticketing, baggage and all other terminal services, as well as office space for exhibitors and a recreation area adjacent to the center. Hertz will be opening the second of its Skycenters the end of this summer, at the new Jacksonville, Florida, airport.

Innovations

The Hertz "Number-One Club" uses RCA-6 Computers to improve service to the customers. This system keeps on file all pertinent information regarding "Number-One Club" members and permits Hertz to have a car ready and the Rental Agreement 95% prepared in advance. The "Number-One Club" kicked off in April and customer reaction has been positive. We believe this is a major forward step in customer service and gives us a decided edge over the competition.

The second innovation is an automated system initiated in a phased approach beginning in the New York City area some three years ago. This innovative method concerns automated car control and rental calculation and we are now ready to expand to a nationwide system.

Upon customer arrival at the counter, the vehicle is assigned and the rental agreement information completed. In our New York area, this process is expedited by use of a terminal on the counter. The terminal allows input of vehicle number, vehicle mileage and the rate plan selected. This information is printed on the rental agreement.

The New York Zone on-line computer, located in the Manhattan East Side Airlines Terminal, stores the transaction and maintains an updated status of every vehicle in the New York pool. Reports are periodically generated showing number of vehicles at each location, maintenance history, and various business statistics. The computer system improves fleet utilization, minimizes rental calculation errors, and also proves useful in tracing stolen vehicles and identifying customers responsible for traffic tickets. Upon customer return, the check-in mileage is entered through the terminal, and the amount due calculated by the computer for printing on the rental agreement. Completed rental agreement forms are then sent to our Oklahoma City Data Center for customer billing, collection, follow-up and receivable processing.

We feel we have made major progress in using computer and communications techniques in providing better customer service and business controls. However, the growth in volume and complexity of our business will require more sophisticated approaches in the future. In designing this system we were well aware of similar actions by our competition. The automated system will initially be implemented in our high-volume locations. It will later be expanded to additional stations and integrated with our Reservation and Data Center operations.

Future

Let me conclude this overview now by switching to a view of what lies ahead for Hertz. As the largest and most diversified company in its field with the greatest experience, market penetration and spread — Hertz has been the chief beneficiary of the trend toward increased use of its industry's services. The same forces in society that have shaped the expansion of renting and leasing remain strongly in effect for the foreseeable future. At Hertz, we believe the outlook is bright for the company, and that the next five years will witness an increase in its revenues and profits.

The history and philosophy of Banquet Foods Corporation

H. A. Stamper
Chairman and Chief Executive Officer
Banquet Foods Corporation,
St. Louis, Mo.

The predecessor of Banquet Foods Corporation, the F. M. Stamper Company, was founded in 1898 in the town of Clifton Hill, Missouri, which had a population of 600 then, and has a population of 600 today. F. M. Stamper was a teacher in a rural one-room school and began his business career moonlighting, buying poultry and eggs from nearby farmers and consigning the product to dealers in St. Louis, Kansas City and Chicago. He prospered modestly, moved the business 14 miles east to Moberly, Missouri, and in 1904 sold it to Swift and Company. One year later he purchased it from Swift for half of what he had sold it for a year earlier.

In 1915, two developments changed the character of the industry. Refrigeration reached a stage of efficiency which made it practical to slaughter poultry at origin, hold it at a temperature of 38° F. and ship it to any point in the country. There was, however, still a demand for live poultry, slaughtered at the point of consumption, particularly from persons of eastern European origin. To satisfy this, the live poultry railroad car was developed, making it possible to feed and water live poultry enroute. These innovations required capital and stimulated a trend toward larger and fewer organizations dealing in poultry and poultry products.

Processes, products and shipping methods remained static for the next 25 years. By 1940, before the United States had entered World War II, it had committed itself to the support of Britain and Russia in the form of arms and food. The most effective form in which high-protein food could be delivered was that of dehydrated eggs. Dehydrating facilities were meager, and to stimulate their construction, the government issued certificates of necessity, which permitted a three-year writeoff. The government's demand for this product was virtually insatiable, since in the early war years, two-thirds of the shipments did not reach destination, but were sent to the bottom by Hitler's submarines. By 1943, the F. M. Stamper Company was the nation's largest producer of dehydrated eggs, operating 5 plants with a daily capacity of 2½ million eggs.

In 1942, with the nation actively in the war, it was found that the most acceptable field ration was canned, deboned chicken. Again the government offered a fast writeoff on facilities to produce the ration, and canning became a logical extension of the company's basic business. By war's end the company's balance sheet looked little different from the beginning, because of the 91% excess profits tax, but the physical plants in a dozen cities were excellent by the standards of the middle 40's. Here fortune smiled. President Truman kept meat under rationing and price control for 18 months after the war ended. It was logical for the company to divert its canning facilities to the domestic market, and in the 18 months Banquet developed a solid consumer franchise on canned chicken, a marketing organization and a knowledge of the retail food field. When red meat was decontrolled, the poultry industry died for a year until the public's pent-up appetite for meat was satiated. Finally, however, appetities came back into balance and canned chicken became an important and profitable staple of the company's operations.

In the early 1950's, developments in metallurgy made possible the stamping of inexpensive aluminum pans and trays, and the frozen prepared foods industry was born. At least 20 major food companies rushed to enter and competition was acute. By the early 1960's, dropouts had reduced the field to three major contenders—Swanson, which in 1955 became part of Campbell Soup Company; Morton, which in 1956 became part of Continental Baking Company (later merged into IT&T) and Stamper. Together the three organizations enjoyed a combined market share of about 85%.

Banquet's business was built on a three-pronged philosophy:

1) We concern ourselves less with competition than with the maximum exploitation of the opportunities a product affords.
2) We are selling food, not a convenience specialty. There comes a point in volume when you can deliver the consumer convenience at no added cost. When you've done that, you've gotten basic.
3) It is possible to convert any sound food product from a low-volume, high-cost specialty to a high-volume, low cost staple by intelligent pricing and merchandising. The leverage lies in the fact that the retailer must mark a specialty up by 40% or more, but a high-volume staple by 20%, or as low as 10% on an advertised feature, because it builds store traffic.

Currently Banquet's fastest growth is in fried chicken products, and that trend seems certain to continue. Frying chicken, which is an 8 billion pound annual industry, is an attractive target and we believe it will make Banquet one of the largest and most profitable units of RCA.

The Coronet story

R. L. Morrow
President,
Decorative Furnishings &
International Division
Coronet Industries Inc.
Dalton, Georgia

Coronet Industries is one of the newest members of the RCA family having been acquired in February, 1971. The firm began in August 1956 at Dalton, Georgia, a small town in the northwest part of the state. Three men—Bud Seretean with education, background and experience in marketing, Jack Bandy in finance and administration, and Guy Henley in manufacturing were the three principals who founded the Company. Tufted carpet was in its embryonic stages in 1956 representing only 20 percent of the industry's volume. The principals recognized that the tufted process had major pluses over the traditional woven process—namely, higher speeds and greater product versatility. Tufting could utilize synthetic fibers which were soon to become available for floor covering use. With these advantages Coronet began to offer lower prices, better values and styles with better performance thereby building its market share.

Rapid growth

These factors helped Coronet to grow rapidly and in 1964 the Company went public, showing a volume of approximately $30,000,000. A year later the stock was listed on the American Stock Exchange and management embarked upon an acquisition program aimed at making Coronet Industries a broad based home furnishings manufacturer. The company's stock was listed on the New York Stock Exchange in 1966.

Three divisions

At the present time our company is made up of three divisions. *Carpet Division* accounts for about 60% of our present annual sales volume. We are the fourth largest carpet manufacturer.

Furniture Division comprises 12 plants and 8 divisions doing about 30% of our annual sales volume. We are major suppliers of seating for hotels, restaurants and public areas. We are manufacturers of beds for nursing homes and hospitals, and manufacturers of flexible polyurethene foam for our own plants as well as other manufacturers. We manufacture wood furniture for laboratories, schools, and dormitories and also have several divisions manufacturing residential upholstered furniture.

Decorative Home Furnishings Division is involved primarily in the vinyl wall covering business.

International effort

Our international efforts involve a 50/50 joint venture in Canada—Coronet Carpets Limited which has worked well. We are currently proposing our own manufacturing facility in Europe. In addition to the equity involvements we also maintain licensing agreements with major carpet manufacturers in the United Kingdom and in Australia.

Engineering

How does engineering fit into our short and long term plans? We currently have a small but highly qualified corporate engineering staff. These are specialists in mechanical engineering, chemical engineering and industrial engineering. Through this staff we can meet the demands for physical facilities—process innovations and improvements as well as the evaluation of new equipment and technologies. We are continuously working to automate operations to combat labor shortages and to decrease labor costs. We are currently involved in a major program of installing an engineered standard cost system into our operations. The major changes in machinery and equipment will continue to be made by suppliers; therefore, our engineers have to evaluate the work of these suppliers.

Major advances in dyeing have always been, and we are convinced will continue to be, made in Europe; therefore, our people keep updated on European processes and equipment. In the area of Research and Development our main efforts are in new and improved products. In line with this, the R&D group is market oriented so that its activities satisfy market needs.

Conclusion

I appreciate the opportunity of sharing with you the concepts and products of Coronet. I will be glad to answer any specific questions you may have. In closing, let me remind you to make sure that you have Coronet carpet under your RCA television set.

Cushman and Wakefield—its role in housing American business

H. A. Semler
Senior Vice President
Finance and Administration
Cushman and Wakefield, N.Y.

A 35-mm slide synopsis was given of the firm's sales, leasing, project consulting and building management activity in 13 cities across the United States and in Puerto Rico. Following this, the nature and scope of Cushman & Wakefield's activities were outlined in relation to its 1972 Business Plan objectives, the firm's growth in sales were traced from 1966.

Business activity

The expansion of business that has taken place in the past five years has enabled Cushman & Wakefield to become a leading national commercial real estate organization. Today, over 60% of the Company's sales are derived from its four offices in the New York Metropolitan area. Cushman & Wakefield has established regional offices in major cities where they are engaged in consulting contracts for the development of major commercial office buildings and plazas.

Approximately 69% of the firm's income is derived from its sales and leasing brokerage activity performed by a staff of approximately 140 brokers and salesmen. The second major source of income for Cushman & Wakefield is fees earned in the operation and management of commercial office and apartment structures. Cushman & Wakefield manages approximately 250 buildings throughout its various offices. This management includes all phases of building operation such as maintenance, collection of rents, safety, elevator operation, etc. This activity accounts for nearly 14% of the firm's total gross sales.

Special services

Based on its heavy experience in the operation and maintenance of high-rise commercial buildings, Cushman & Wakefield, in the past few years, has developed a *project consulting activity*. This group is engaged by investors and property developers to advise and assist in the arrangement, design and construction of high rise commercial buildings. Cushman & Wakefield is presently assisting, as consultants, in the design and construction of the Sears Tower in Chicago. This will be a 110-story structure—the tallest in the world. It will house the Sears Home Office and be the headquarters for other major corporations.

Cushman & Wakefield conducts a *real-estate appraisal function*. This activity is staffed with expert professional appraisers and serves corporate clients and City, State and Federal Governmental Agencies in the appraisal of properties and serving as "experts" in court proceedings.

Cushman & Wakefield operates an *insurance brokerage activity*. This function conducts sale of commercial insurance and assists Cushman & Wakefield clients on their insurance requirements as a part of our project consulting and building management operations.

Objectives

In listing the Company's objectives for 1972, it was indicated that Cushman & Wakefield intends to:

1) Continue its expansion in the national commercial realty market,
2) Enhance its capabilities in those markets in which it is already established,
3) Explore new fields of profit in real estate and related activities, and,
4) Support RCA Corporation in the sale, acquisition, lease and management of appropriate properties.

RCA properties

The status was reviewed of major RCA Corporation properties for which Cushman & Wakefield is acting as agent. Some of the RCA properties the National Real Estate Corporation has listed for sale include plants in Memphis, Tennessee; Marlborough, Massachusetts; Lancaster, Pennsylvania; and Dayton, New Jersey. Cushman & Wakefield has sold RCA facilities in Cincinnati, Ohio; Lewiston, Maine; as well as acreage in Parsippany, New Jersey.

Business plan

It was indicated that Cushman & Wakefield based its 1972 Business Plan on an expected improvement in the office space leasing market during the latter part of 1972. This, combined with the improving American business economy and increase in other business areas such as building management and project consultation, should make 1972 a profitable year for Cushman & Wakefield.

Programs and Roles of Engineering in our Major Business Areas—Current and Future

RCA's "traditional" businesses were highlighted in the third session. Spanning the range from today's products and services to the application of advanced technology for new programs, key management from eleven major operating units provided insight into their ongoing and future businesses. Summaries of ten of these presentations follow. One presentation—"Systems Marketing and Development" by R. W. Sonnenfeldt—is omitted because of the company-private information it contained. Mr. Sonnenfeldt is planning to submit articles relating to this topic for future issues of the *RCA Engineer*.

Electronic Components in RCA—an ever challenging business

C. H. Lane
Division Vice President
Technical Planning
Electronic Components
RCA, Harrison, NJ

Our business is characterized by change—nothing ever remains status quo for very long. For example, in the past 12 months we have reorganized our management structure; consolidated some operations; closed some plants; opened other plants; dropped marginal product lines; and dramatically expanded our international business.

Worldwide business

EC conducts a worldwide business engaged in the design, development, production and marketing of a broad line of active electronic components for the consumer, industrial, aerospace and military markets. This includes vacuum tubes, solid-state devices mostly employing gallium arsenide material, and a growing number of subsystems.

About a year ago we consolidated our TV Picture-Tube Division and Receiving-Tube Division and our glass operations into a new organization known as the Entertainment Tube Division with Joe Colgrove as Division Vice President and General Manager. The Industrial Tube Division has its headquarters at Lancaster under the direction of Tex Burnett as Division Vice President and General Manager. In addition to these two operating divisions, we have two sales and marketing organizations: the distributor organization headed up by Joe Haimes; and an equipment marketing and distribution organization under the direction of Gene Duckworth, as Division Vice President. A number of strong staff functions support these organizations.

Receiving tubes

To give you an idea of receiving tube volume, five years ago the industry produced over 400 million units; last year it was 220 million; this year 200 million; and, it is expected to drop to around 120 million by 1976. To sum up our receiving tube strategy, it is simply to maximize our profits.

Picture tubes

The picture tube business is quite important to EC. Let me say a few words about our glass plant at Circleville, Ohio; the glass envelope represents almost 35% of the final picture tube cost. The supply of glass items has been under the control of 2 or 3 domestic glass suppliers since the advent of the television industry. A few years ago RCA made a bold decision to go into this business itself with the objective of eventually supplying a majority of its own requirements. This meant a move into a whole new technology where the designs of equipment and facilities were foreign to us. Now, 3 years later, we are successfully operating a 20-million dollar facility at Circleville. This impressive project is on-stream producing face plates and funnels in the 19 and 25" sizes and should pay off handsomely for RCA in reduced glass costs. RCA Laboratories has played a significant role in determining the glass compositions required, and the melting and annealing parameters.

In the picture tube business, RCA is a leading producer. We are the prime supplier of tubes to RCA's Consumer Electronics Division; in addition, we furnish products to many other OEM accounts whose names are well known to you. We offer about 150 different color types which are available in 9 different sizes ranging from 14" to 25". Marion, Ind. and Scranton, Pa., are the major manufacturing plants, with engineering located at Lancaster. To continue growth, we launched foreign ventures in Canada, and joint ventures in the UK, France, and Italy where color markets are emerging.

Last year we discontinued domestic manufacture of black-and-white picture tubes as it was becoming increasingly unprofitable due to declining volume and price competition. We have underway a joint venture with Chunghwa Electronics, in Taiwan, to build a black-and-white tube plant comprising about 80,000 square feet.

Industrial tubes

The other operating part of EC's organization is the Industrial Tube Division. ITD's sales spread over a large list of diversified products. ITD has its headquarters at Lancaster, Pa., a facility of over 1,000,000 sq. ft. In addition it maintains facilities devoted to microwave business in Harrison.

Even though the ITD has suffered through cutbacks in defense spending and the vagaries of the economic situation, our present 5-year forecast indicates a good sales growth by 1976.

EC's Distributor Products activity merchandises and sells all of the products manufactured by EC plus certain purchased items such as audio magnetic tape, batteries and test equipment through a network of 1100 independent electronic distributors across the country.

Receiving-tube engineering

Our engineering manpower has been considerably reduced. Essentially, receiving tube engineering is a holding action wherein we continue to introduce a few new types each year primarily for the replacement market, and to provide timely evaluation of our competitors products and work on new product ideas.

Harrison, New Jersey	Receiving Tubes Home Office Industrial Tubes
Lancaster, Pa.	Industrial Tubes Picture Tube Engineering
Scranton, Pa.	Picture Tubes
Marion, Ind.	Picture Tubes
Circleville, Ohio	Glass Operations
Los Angeles, Calif.	Picture Tubes
Woodbridge, New Jersey	Receiving Tubes
Midlands, Ontario	Picture Tubes
Juncos, Puerto Rico	Picture Tubes -- Mounts
Barceloneta, Puerto Rico	Picture Tubes -- Masks
• Taiwan	Monochrome Picture Tubes
• Skelmersdale, U.K.	Picture Tubes
• Romilly, France	Picture Tubes
• Anagni, Italy	Picture Tubes
Princeton, New Jersey	Affiliated Labs
Mexico City	Picture Tubes Receiving Tubes
Belo Horizonte, Brazil	Monochrome Picture Tubes
Cowansville, Canada	Receiving Tubes

• JOINT VENTURE

←EC locations and activities.

Device	Sub - System
Gas Laser	Construction Transit
MIC Transistor Oscillator	Radiosonde Transmitter
Charge Coupled Imaging Device	TV Camera
Silicon Storage Tube	TV Frame Storage Unit
TWT	ECM Recirculating Storage Unit
Varactor Diodes	UHF TV Tuner
TEO	Automotive Speed Sensor
Power Tubes } Solid State Devices }	Power Modules
Bismuth - Telluride	Thermoelectric Generators

ITD subsystem market opportunities.

PRODUCTS	MARKETS
Electro Optics	Broadcast
Camera Tubes Photo Tubes Image Tubes Display & Storage Tubes Optoelectronic Devices	Communications
	Navigation
Power Regular and Large Power Tubes Lasers	Instrumentation
	Information Handling
Microwave - SEC Tubes Solid State Thermoelectrics	Surveillance
	DoD
	Scientific

Industrial tubes: products and markets.

Picture-tube engineering

This is by far our largest engineering activity. Our new system surrounding smaller tubes is an exciting new development. It is a simplified, high-performance, lower cost system which is uniquely suited to small, portable TV sets. Features involved are automatic convergence, low-cost deflection yoke, precision static toroidal yoke, and a cost-reduced picture tube. These advances will save several dollars in convergence circuitry, and lessen the setup-and-adjust time for the set manufacturer. This new concept utilizes a slit-mask, line-screen structure to provide improved transmission and competitive brightness.

The subject of matrix color tubes is very complicated, involving considerations such as cost, availability and merchandising efforts. An important question is whether the viewer can see the difference between a matrix tube and a non-matrix tube; and, if so will he pay the additional premium for the matrix tube?

In the non-matrix (traditional tube) a large portion of the phosphor dots are not energized by the electron beam—a fact which definitely impairs the contrast of the resulting picture. The fundamental idea of a matrix tube is to have the face of the tube covered with a light-absorbing black compound except where the dots are situated. In the most efficient system there would be no phosphor present that is not emitting light.

The most efficient system is called a negative-matrix tube wherein maximum brightness is obtained without sacrificing contrast or black-picture level. Years ago we developed a positive matrix tube which contains phosphor dots larger than the electron beams (the negative matrix has a beam larger than the dot). The positive matrix has a significantly lower manufacturing cost than the negative matrix. We are proceeding with an aggressive engineering program in the negative matrix area and the challenge is substantial.

ITD engineering

The Industrial Tube Division engineering is widely diversified, has numerous products and markets, and many design and development programs underway.

In the standard camera tube area, one of our principal projects is the further development of the "vistacon" tube. This is a continuation of a program of several years duration to recapture the profitable camera tube business lost to Philips when they introduced their lead-oxide tube, the Plumbicon. With about 1000 active TV stations in the U.S alone, each utilizing from 3 to 20 cameras and with 3 or 4 tubes in each camera you can readily see the importance of this market to us.

An area of major emphasis within ITD is semiconductor devices for microwave applications and opto-electronics. Another area of much interest to us is the continuation of our developmental work on silicon target camera tubes—i.e. adopting silicon solid-state technology and materials in camera tubes.

Finally, as mentioned earlier, we see subsystems built around EC's devices as the most promising way to increase sales and margins for ITD's products.

Conclusion

We are deeply conscious of the continued need to adquately measure and effect improvements in engineering productivity. We are concerning ourselves with the professional development of our engineers —with making job assignments challenging rather than mundane—with effective communications—with having our engineering leaders and managers play a greater role in the making of business decisions—and with maintaining proper ratios of professional to support personnel.

Solid State Division—business and engineering

W. C. Hittinger
Vice President and General Manager
Solid State Division
RCA Somerville, NJ

RCA Solid State is perhaps somewhat of an enigma in the electronics industry. Our image is fragmented. We are recognized as technological leaders in some disciplines, yet our total image may be contra-synergistic. In other words, we seem to be less than the sum of our individual product line images.

We hold a significant share of the microwave market, yet our profile in the entire RF market is low. We are the largest single supplier of triacs, yet our image in the thyristor field often fails to reflect that fact. According to 1971 EIA statistics, we supplied 55% of all linear IC's used by American manufacturers of consumer electronic products, yet our visibility is quite low as a supplier of linears for the combined industrial-commercial market place.

We have been steadily striving to strengthen our market image and to achieve position during the past two years. We have done so through concentration on product lines that match our technical and marketing strengths—and through a product line organization aimed toward profitable operation in each major product line. Some results have been most gratifying.

COS/MOS technology

COS/MOS integrated circuits have come into their own as a major product line. In 1971 the total COS/MOS market was only $7 million, with that figure more than doubling in 1972. By 1976, however, world-wide COS/MOS sales for the entire semiconductor industry are expected to reach $100 million.

As the developers of COS/MOS technology, we have been in a unique position to capitalize on the original work performed by the RCA Laboratories in the early 1960's. We have indeed capitalized on that work—to such an extent that our standard commercial line now contains more than 180 types of digital circuits in DIP, DIC, flatpack and chip configurations. And this at a time when much of the competition is still introducing its first types.

Furthermore, we are working toward qualification of our COS/MOS products and production facility under MIL-M-38510. We expect to have the first IC product line in the semiconductor industry to qualify under this stringent high-reliability specification.

Other solid state technologies

We have introduced more than 100 types of linear IC's for industrial use, many of them nothing more than our standard types proven through several years of use in consumer electronics, but types that are particularly appropriate for industrial applications.

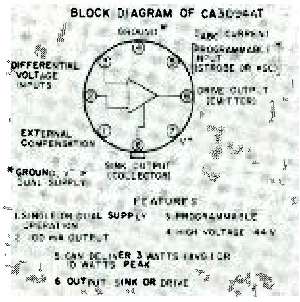
We have broadened our activities in the RF area, particularly through a marketing challenge in the mobile communications field.

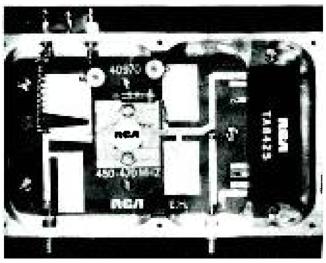
We have established a *packaged circuit functions* activity wherein we are developing true hybrids containing both discrete devices and integrated circuits to meet customer needs for more complex functions.

We have continued to strengthen our position in power transistors, with new types and new technologies. Our findings on thermal fatigue certainly impacted the industry.

Similarly, our recent disclosure of test data on hermeticity problems in aluminum TO-3 packages provides vital information to OEM's. The aluminum package can have an inherent weakness in the solder bond between the eyelets and the aluminum header. Under temperature cycling, fractures develop at this interface, destroying the device's hermeticity. Our steel package, with its glass-to-stem high compression seal, welded cap, and controlled solder process, offers at least an order of magnitude improvement over aluminum in terms of hermeticity, reliability and long-term, trouble-free performance.

Our progress has been due, in part, to concentration on selected product lines that offer us greater opportunities for success. By judiciously combining our effort in areas of acknowledged strength—such as power devices and linear IC's—with emerging technologies—such as COS/MOS—we optimize our future.





Programmable power integrated circuit: the CA3094 (left) is a differential-input, power-control switch/amplifier with auxiliary circuit features for ease of programmability; an error or unbalance signal can be amplified to provide an on-off signal up to 100 mA. **The simple UHF high-power amplifier** (right) consists of a TA8425 hybrid power driver and a TA8172 transistor (the main building blocks for a mobile transmitter). The TA 8425 (right), with 100 mW input, provides 15-W output over a passband of 440 to 470 MHz: the TA8172 (center) delivers a minimum output of 30 W, with minimum collector efficiency of 60%.

Product profit centers

But our growth will also evolve from our business operations. We no longer operate with the traditional organizational structure.

We have structured ourselves as a series of profit centers, according to six major product lines: power transistors, thyristors and rectifiers, RF and microwave devices, packaged circuit functions, linear integrated circuits, and COS/MOS integrated circuits and liquid crystals. The first four are grouped under Ben A. Jacoby, Division Vice President, Power. The latter two groups report to Bernard V. Vonderschmitt, Division Vice President, Integrated Circuits.

The key to our organization is to focus on achieving profitability. Each product line manager has complete control over his business. His organization includes marketing, design engineering, applications engineering and production control functions. He reaches directly into our production plants in Mountaintop, Pennsylvania, Findlay, Ohio, and Taiwan to program and control his production requirements.

When problems develop, we can isolate them by product line and by function within that product line. The focus is immediate and intense. And the reaction can be equally immediate and intense.

We support the product line organizations with central activities that include marketing, engineering services, and quality assurance. Our central marketing organization, under Daniel P. Del Frate, directs the field sales force, distributor marketing, major contract administration, market research and planning, distribution services, and communications.

Competitive position

If we rank US solid state suppliers on the basis of domestic and export sales, RCA ranks fourth, behind Motorola, Texas Instruments and Fairchild. On the other hand, if we rank suppliers according to world-wide sales, we find the ranking is TI, Motorola, Philips, Fairchild, ITT, Hitachi and RCA.

We cannot be satisfied with our position in either ranking. We feel that our product line selectivity and organizational concept will strengthen us domestically. But we have also reorganized our approach to international markets.

International sales

Dr. D. Joseph Donahue, Vice President, Solid State—Europe, administers our operations that include the production facility in Liege, Belgium, where we now produce power devices. He also directs applications engineering and marketing groups in Liege and Sunbury-on-Thames, England.

We recognize that success in Europe is contingent upon on-site production and customer support. We must think like Europeans and act like them; that is, we must be European. Dr. Donahue's current organization reflects that philosophy. Manning by US personnel is minimal and will continue so.

We have also restructured our marketing approach to other parts of the free world, particularly Japan.

Conclusion

In conclusion, we plan to shape our business operations to offer us the greatest opportunities for success. That success will be reflected most dramatically by our movement up the ladder in the rankings of domestic and world-wide solid state suppliers.

Consumer Electronics

M. H. Glauberman
Director,
Engineering
Consumer Electronics
RCA, Indianapolis, Ind.

Before looking at the engineering and design phases of Consumer Electronics, lets look at the market trends for our products: radios, tape recorders, phonographs, black-and-white television, and color television receivers. Listed below is the total US market (in millions of units) for each product line.

RCA Product	*Tot US Market (Millions of Units)*
Color TV	6.8
Black-and-white TV	7.5
Radio	34.0
Phonograph	6.0
Tape	10.0

There is a definite trend toward imports (non-EIA) dominating the total US consumer electronics market. This is particularly true for radios and tape recorders (practically all foreign made), and to some degree for all product lines. US is better positioned for console phonographs since they are too bulky for shipping long distances economically. Most imports in this category are stereo module systems and AM/FM tuners. The audio market (radio, tape, and phonos) has about 75 companies competing (Motorola, Westinghouse, Sylvania, Admiral and Ampex have withdrawn during the last 12 months).

In black-and-white TV, there is a leveling off of the market share between domestic and foreign brands. Zenith and RCA are the top two domestic producers. In color TV, RCA leads in the production of US made receivers, and Zenith is second.

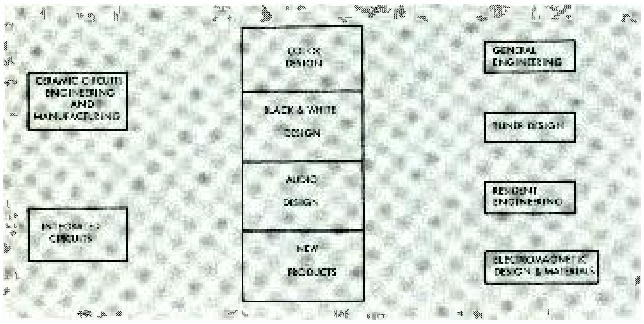
The growth trend favors portables over consoles. Prices, generally, are on a constant move downward due to the large number of competitors (all with plenty of plant capacity). An ominous reverse twist is that some Japanese companies are setting up assembly plants in US to obtain sales of TV consoles; this is a market in which the Japanese have been a minor factor due to high shipping costs.

Engineering

As shown in the functional diagram, Engineering has four main design groups (center) supported by related activities. General Engineering provides assistance in component testing, reliability and safety analysis, Underwriter's Laboratory servicing, and engineering standards. Resident engineering functions are located at

Indianapolis, Bloomington, Juarez, Taiwan and the Tokyo Corporate Purchasing Office.

The Electromagnetic group designs power transformers, flyback transformers, yokes, and forty or fifty other inductive devices. The Materials function (with metallurgists, chemists and ceramicists) serves all engineering groups and industrial designers. Ceramic Circuits Engineering and Manufacturing produces over 15,000 circuits/day for color TV. The Integrated Circuit design group is located at RCA's Somerville plant and their primary thrust is color TV.



Engineering Department: Consumer Electronics

Forces impacting on engineering

During projected planning processes, engineering must be alert to the trends in changing screen sizes; the proper selection of hybrid, solid state, or hybrid/solid state chassis; the choices of negative and positive-matrix kinescopes; and the need for compatibility of design with changing trends in industrial styling.

There are many other important forces impacting on engineers and engineering management such as the effect of offshore manufacturing, the ever-present demand for low cost, the severity of product safety requirements, and the demand for high-reliability and long-period warranties.

Offshore manufacture

The building of receivers and components in foreign countries requires that RCA engineers train foreign engineers concerning the design of our products, assure the compatibility of RCA designs with production conditions existing in the foreign country, and devote more time to "factory-follow-up".

Warranties

Since warranties cover service labor and parts for either 3 months or one year, this cost element must be factored into the total cost of the receiver. So, both long-life requirements and low-cost needs place challenges on the engineer. He must think and design for lowest total cost.

Safety

Every component and circuit is carefully analyzed to identify potential safety hazards. By observing and studying a component failure, the designer can redesign to overcome a fault. Following are typical questions to be answered:

- What happens if a resistor opens?
- What happens if a capacitor shorts?
- What happens if a circuit breaker doesn't open?
- What happens if a transistor fails?

After determining the answers to these design and safety questions, an analysis is made by engineers who had nothing to do with the design; finally, at a safety review meeting, the most experienced engineers review the previous analyses. A formal procedure exists which imposes a recipe for product safety involving both "start production" and "finish production" checks before a product-safety release is given.

Engineering programs

One major engineering program covers cable-ready TV receivers, and is aimed at the fast growing number of cable TV subscribers and expanding cable TV services. A ghost-free, interference-free, TV set has just been introduced that employs a super-shielded tuner. The performance, in the face of strong interfering signals, is remarkable.

Another significant program will lead to the introduction of the SelectaVision magnetic-tape player-recorder in 1973.

The present high-reliability program has a goal of radically improving the reliability beyond anything presently available. This program involves a reliability prediction of the TV set before production. RCA government engineering data, construction of mathematical models, and studies of component failure rates have resulted in "close fits" between theoretical predictions and what happens in the field.

Some outputs of the reliability program result in the transfer of valuable information to the RCA Service Company and to Parts and Accessories, and aid in the formation of effective engineering design guides. For example, such guides now permit the calculation of transistor warranty costs.

Engineering with other divisions

We have a close working relationship with the Record Division on phonograph products and on important advanced development projects. The Solid State Division is our largest source for integrated circuits, silicon controlled rectifiers, and other solid state devices for consumer products. A group of our engineers is permanently located in Somerville, N.J. to work on integrated circuits. The Entertainment Tube Division is our source of kinescopes and receiving tubes for domestic production. Parts and Accessories is responsible for provisioning in the field. The RCA Laboratories scientists are our partners in improving present products and in coming up with new products. Last on the list, but certainly not least in our esteem, is the RCA Service Company. We design and manufacture the Service Company's line of institutional TV receivers.

Government and Commercial Systems

Dr. H. J. Woll
Division Vice President
Government Engineering
Government and Commercial Systems
RCA, Moorestown, N.J.

In Government and Commercial Systems, as in all of RCA, we must make maximum use of our engineering capabilities. Our broad-based IR&D program, the generation of new technology in government contracts, and the wide diversity of our product lines necessitate a strong emphasis on planning, management and team work.

Coordination and planning

Achieving technical coordination among all our activities demands that planning, marketing and engineering be closely related. In G&CS, the heads of these three functions, referred to as the "Troika," work so closely together that we often consider them as one. Through this almost monolithic approach to planning, marketing and engineering, we achieve a very close relation between business performance and investment.

Planning is a continuing activity in each of our divisions. Requirements are analyzed, customers are visited, technical capabilities are considered and our image is developed. As a result, business areas and specific targets are chosen. Individual target-capture plans or business-development plans are made in each division, which include strategy, schedules and required investments. These plans are reviewed periodically by the Troika, emphasizing the integration of the planning, marketing and engineering functions. As a result, the nature of our IR&D and engineering programs is a consequence rather than a determinant of our plans.

Evolution of technology

An important fact in the government business that is considered in our strategy is that our RCA sponsored development programs, and our IR&D, are only a small percentage of our total engineering effort. The remaining engineering effort comes from contracts that we have elected to pursue. The final investment decision, thus, is in the hands of the government, rather than under our direct control. Currently, we have 78 target-capture plans, each with a strategy—part of which is the required technology.

Our capture plans have led to our 134 IR&D projects, each with objectives, technical approach and assistance needed from other divisions.

With this pump priming effort we seek further sponsorship from the government in the form of technique contracts. We have booked 99 technique contracts in the past year. They are planned for in our target-capture plans but are awarded at the discretion of the government rather than funded through an RCA investment decision. With this background we seek the major systems and equipment business.

Since major systems require 5 to 8 years to mature and important technology requires 3 to 5 years to develop, both reasoning and experience indicate the need for stability and continuity. We stay with a promising technology and devote the necessary effort year after year. Customer recognition of established competence in technology must be achieved.

Continuity does not mean that we forecast the future by extrapolating the past. We seek new and emerging technology. But, our progress is evolutionary, with about 20 to 30% change from one year to the next. A breakthrough or the lack of one may affect a segment of our technology but not the broad thrust of the effort.

Major multi-year IR&D projects such as the AEGIS radar, the R100, R215 and LSI Computers have led to or are leading to important systems contracts. Our strategy is to place additional emphasis on such projects by making them an explicit part of our Five Year Technology Plan. We are identifying and developing plans for such projects in every division.

Our planning process in Government Systems is well defined and time tested, and similar disciplines tailored to commercial needs are being applied in Commercial Systems. Through our emphasis on a close relationship between planning, marketing and engineering, we continually plan for and develop technology of the future.

Major government and commercial areas

A brief description was given of each of the Divisions and activities in G&CS. Their product lines and specific illustrations of new systems and products were briefly described. A summary is:

Astro-Electronics Division
Chief Engineer: W. P. Manger

Systems and Satellites
- Meteorological
- Navigational
- Communications
- Earth Resources
- Planetary
- Ground Data Handling

Subsystems
- TV, Sensors, Power

Aerospace Systems Division
Chief Engineer: N. L. Laschever

- Command and Control
- Automatic Test Systems
- Air Traffic Control
- Military Computers
- IR, TV and Lasers
- Navigation and Guidance
- Airborne Radar
- Space Rendezvous
- Airborne Weapon Delivery

Electromagnetic and Aviation Systems Division
Chief Engineer, Government Engineering: F. C. Corey

- Electronic Warfare
- Drum Memories
- Collision Avoidance
- Special Purpose Computers
- Info Storage/Retrieval
- Displays
- Intelligent Terminals

Aviation Equipment
Manager, Engineering: G. A. Lucchi

- Radar
- Transponders
- Navigation
- Communication
- Flight Control
- DME

Broadcast Systems
Manager, Broadcast Engineering: A. C. Luther

- Systems Engineering
- Studio Systems
- Color Cameras
- Video Recorders
- Transmitters
- Antennas

Commercial Communications Systems

Manager, Communications Engineering: K. L. Neumann

- Mobile
- Portable
- Base Stations
- Control Consoles
- Digital Systems
- Vehicular Data Systems

G&CS Division/RCA Ltd., Canada
Manager, Engineering: J. R. G. Cox
Director, Research: M. P. Bachynski

Commercial
- Communications Systems
- Broadcast
- Displays

Government
- Communications Systems
- Satellites
- Research

Government Communications Systems
Chief Engineer: D. J. Parker

- Radio Products
- Transmission Systems
- Data Communications
- Message/Circuit Switching
- Magnetic Recording
- Laser Recording
- EW/Intelligence Systems

Missile and Surface Radar Division
Chief Engineer: D. M. Cottler

- Air Defense Systems
- Antennas
- Command and Control
- Ballistic Missile Defense
- AEGIS Department
- Air Traffic Control
- Instrumentation Radar
- Signature Analysis
- OTH Radar

Advanced Technology Laboratories
Director: P. E. Wright

- Microsonics
- Lasers
- Holography
- Sensors
- Thermal Management
- Pattern Recognition
- Signal Processing
- Electro-Optics
- Computer Technology

Systems Development
Manager: K. K. Miller

- Requirements Analysis
- Systems Synthesis
- Systems Evaluation
- Systems Selection
- Life Cycle Cost
- Human Factors

Central Engineering
Manager: S. K. Magee

- Standards
- Parts
- Materials
- Packaging
- Documentation

The newly created Palm Beach Division reports to I. K. Kessler; and, J. Vollmer has just been named the General Manager. It is planned that in addition to continuing to supply present products and to provide power supplies and similar commercial equipment for internal RCA use, that this Division will be a source and testing ground for new products and systems.

RCA Records and engineering management

W. R. Isom,
Chief Engineer
Engineering, Record Operations
Indianapolis, Ind.

The RCA Record division involves a different approach from that of the other communication and electronics operations. Here, we are concerned with a business supported by a rather small engineering and manufacturing force. We have an efficient new million-dollar engineering building that provides 30,000 square feet of space.

Nature of record business

We have a fast-turnover business which requires the monthly issuance of about 100 new releases including records, tapes, and cassettes. That means essentially, we have that many new products each month, from start to finish. The usual life of one of our products is about six months; so, the complexion of the business is rather unique at RCA.

Mr. Laginestra heads up the operation which has about 2500 people and the productivity rate is high. There is another important part of the operation—unseen employees, the recording artists. Their costs, together with copyright expenses represent between 30% and 50% of our total costs.

The ratio of stereo-eight cartridge over cassettes is about 8-to-1. The continuance of the cassette business is advantageous since we can benefit from the record recordings, using the same music and much of the same production costs. Sales of 30,000 or more per product release is required for profitability. Some releases make it big, others don't; the Elvis Presley recordings, after 15 years, sell more records than the recordings of any other single artist. The dominance of RCA and Columbia seems to occur in cycles; six years ago RCA was leader; then Columbia; now RCA appears on the way back.

Engineering

One of the challenges for engineering is to prevent the aforementioned dominance from cycling in the wrong direction. The "discretionary dollar" in development and engineering must go into new products.

However, innovating new technical methods and reducing manufacturing costs depend upon our maintaining a high rate of sales to provide budgets for engineering and manufacturing the records, tapes, and SelectaVision. There are approximately 50 engineers and managers in our operation; the managers in engineering are: A. Stancel, SelectaVision; Joe Wells, Recording Electronics; Charles Harlow, Equipment Development; and George Humfeld, Plating, Plastics and Compounds.

The nature of engineering and the relationship of engineering-to-record profitability is rather interesting. The better-engineered, high-quality records return to RCA good sales and profit. Records can be sold internationally under private brands and create greater demands overseas for high-quality products.

Engineering is concerned with plastics, chemistry, mechanisms, thermodynamics, electronics, and acoustics, to name a few involved fields. Because of the mass production aspects, our engineers are alert to getting new automatic presses, better compounds, better performance, and better signal-to-noise ratios. In our development of 4-channel sound, we have learned much that will help us attain better record quality and performances of 60 dB or better.

The tape business will not replace the record business but will be an adjunct to it. The high-quality stereo-eight and cassette businesses will grow but so will the record business (at a rate of about 15% per year).

Automatic presses

The first automatic presses made in Indianapolis 25 years ago for 7-inch records have turned out 2-billion records. Both RCA and competition have come out with 12-inch automatic presses. In 1968, RCA developed a 12-inch automatic press which is now in full production in England (but is not used up to theoretical capacity). Today there is lively competition in the sophistication of automatic press design; some are computer operated. When we build our new plant in about 2 years, it will have the most advanced and best American made press available.

NBC Operations and Engineering

W. H. Trevarthen
Vice President
Operations and Engineering
NBC, New York

As everyone knows, NBC is a broadcasting company. The television network consists of 202 television stations (5 NBC owned), and the radio network has 233 AM stations (4 AM/FM owned stations).

The broadcasting division of the Company, which generates most of the business and income, consists of many departments, all related to putting programs on the air. For example: the Radio Division, the Owned Television Stations Division, the News Division, the Television Network Division, and other supporting departments.

Operations and engineering

The Operations and Engineering department is headquartered in New York; there are approximately 1,800 people in the department. The total staff at the National Broadcasting Company is approximately 5,500, so 33% is represented by Operations and Engineering. It constitutes the following subdivisions:

TV Network Operations
- Studio/Field (TD's, Audio Eng, Video, Cameramen & Lighting Eng)
- Technical Facilities and Maintenance
- Broadcast Operations and Communications

Engineering
- Technical Development
- Broadcast Systems
- Architectural Design and Construction
- Air Conditioning
- Building Maintenance

Production Services
- Design, Art and Scenic Services
- Studio and Staging Operations
- Security

Radio Division Engineering
Burbank
- In addition to the same elements for New York which I have mentioned, it also has Unit Managers and Business Affairs.

Everything this side of the microphone or camera as differentiated from talent on the other side of the microphone or camera is the responsibility and function of the Operations and Engineering Department. In all of NBC, there are 164 separate union contracts; and the Operations and Engineering Department must work with a substantial number of these contracts.

Broadcasting is an "instant" business to put programs "on-air" at a certain time and end them on time. Scheduling is a very complicated process, as all elements must fit properly if we are to maintain a creditable operation. This requires considerable advance planning and constant updating to achieve the desired result. More complicated operations like the Sapporo Olympics, the Nixon China and Moscow trips, political conventions, etc., are planned far in advance.

New facilities planned

Our staff engineering department lays out new studios and new facilities for the production and playing of television and radio programs. At this time, NBC has adequate studio facilities, although two or three of them still require modernization which is planned for 1973.

In New York, we have a master-plan rebuilding program of the central plant which dates back to 1932. The plan slated for completion in 1974 consists of installation of a master grid (signal routing apparatus) and a computer system and associated hardware to perform all functions much more readily than we are capable of doing today.

The global point of view

S. N. Friedman
Manager
Video and Data Systems
RCA Global Communications, Inc.
New York

The entire globe can aptly be called "The World of RCA Global Communications"—for RCA Glōbcom communications links do, indeed, encompass the entire sphere.

RCA Glōbcom's primary obligation within this global framework is concisely defined in the RCA Policy Manual, which states, "RCA Glōbcom is charged with the responsibility of serving the public interest as a regulated common carrier." As an international common carrier, RCA Glōbcom leases circuits to subscribers with terminal points throughout the United States connected to their correspondent terminals in almost every major country throughout the world. RCA Glōbcom assumes end-to-end responsibility for all of its Telex and Telegram Services, and leased circuits, including terminal equipment and the reliability of the overall service. This requires that we provide and operate central facilities in key cities in the U.S. and branch offices around the world.

Effects of automation

Automation has become the byword and each of our major services is marked by the latest in computer technology.

Computer Telex Exchange (CTE)—we consider this tridundant computer system to be among the best in the world, with its minicodes, telextra, camp-on, and immediate access system as special features.

Computer Telegram System (CTS)—this is the last word in modernization of the old torn paper tape era. Associated computerized services are provided by the Automatic Retrieval Computer, the Domestic Automatic Telegram System and the Automatic Dial-Out Service.

Aircon (Automated Information and Reservations Computer Oriented Network)—provides computerized message switching service for firms with international private communications networks. There are 4 Aircon terminals—2 in New York, 1 in San Francisco and 1 in Manila.

Leased Channel Service—shows promise of becoming the largest revenue producer of all international services. Subdivided into Teletype and Voice/Data bandwidth circuits, their tariffed lease costs challenge Engineering to devise new techniques and technology to insure optimum circuit utilization.

Hot Line Service—this is a shared trunk leased service where the subscriber pays for lease of the terminal equipment and also pays an established toll charge for individual calls. The initial Hot Line was to Puerto Rico; Hawaii and Brazil have been added; European terminals are in the offing.

International systems

Other new horizons currently being forged outside the continental United States include:

RCA Alascom—this is the long lines telephone system in Alaska. It has added a new dimension to RCA's role as a common carrier.

Earth Stations—an important "first" was the earth station in Guam which RCA Glōbcom constructed and operates. Following this pattern, the first permanent earth station in the People's Republic of China was built in Shanghai by an RCA team early this year. And as you have heard from Mr. Conrad, negotiations are being concluded for another earth station to be built in Peking. Still another is being proposed in Adak, Alaska by RCA Alascom.

New developments

Among the new developments which are about to be introduced into the marketplace are:

Mini-Computer Message Switching Systems—for lease to industry for use in private communications networks.

VideoVoice—we have high hopes for this, the world's first all-electronic system for transmitting single frame TV pictures over standard voice grade circuits. This is the result of the truly professional-level team effort in the development and design by RCA Glōbcom Engineering and the Princeton Labs Communications Research Laboratory.

Many noteworthy developments are also in the offing in the near future:

Domestic Satellite Communication System

White Alice—a troposcatter system carrying telephone circuits for Alaska, which is being considered for purchase from the Air Force by RCA Alascom.

Alyeska Pipeline—RCA Alascom has submitted a proposal to design, install and operate a microwave system for the 800 mile long, ultra-high reliability Trans-Alaska Pipeline.

TAT-6 Cable—we will share in the ownership of this latest and largest transatlantic cable.

Joint User Group—RCA plans to utilize domestic circuits with other entities on a shared user basis with responsibility for overall management.

Executive Conference Service—which will provide centralized conference rooms and facilities in key cities for remote conferencing aimed at providing the benefits of the conference without the usual travel requirements.

Hinterland Expansion—plans for the establishment of central facilities in numerous cities around the country outside of the major gateway cities.

Aeronautical/Navigation Satellite System—investigating opportunities to provide ship-shore-satellite navigation facilities.

Effect of new technology

That's the look at RCA Glōbcom. And how has Engineering performed in all of this? The growth of revenues and fixed assets over the years has been accompanied by a substantial reduction in the ratio of cost-of-staff to sales. This is a direct result of the new technology and it provides a measure of the significant contribution which Engineering has made to RCA Glōbcom.

SelectaVision progress report

Henry Ball
Director, SelectaVision
Systems Development
Indianapolis, Ind.

On the previous evening, two systems, MagTape (a magnetic recorder-player) and HoloTape (a holographic tape player) were demonstrated. These systems represent development results of the Corporate SelectaVision program.

The organizational makeup of the SelectaVision effort may be of interest. Because of its broad technical range requiring the facilities and know-how of skill centers in several geographically different and organizationally divided locations, a Program Management Group under the leadership of R. C. Bitting, Division Vice President in Consumer Electronics was formed.

Entrepreneurial group

This group has a Director of Marketing (recently transferred into the CE Marketing organization), a Manager of Administration and Financial Controls and a Director of Systems Development. Closely coupled with this group is Tom McDermott, Staff Vice President, Special Programs, located in New York, whose concern is the software for SelectaVision player systems. A breakdown of distribution of the technical effort within RCA's organizations shows the following percentages:

RCA Laboratories	52%
Consumer Electronics	31%
RCA Records	12%
Electronic Components	5%

Funding relating to this program has been handled through this Program Management Group. In each case (unlike the conventional task force concept) the normal line organizations have remained unaltered, with the Program Management acting in a staff capacity.

SelectaVision

SelectaVision is a contraction for "Selective Viewing" or "Selective Television". Three technologies have been actively pursued toward this goal: Holography, Magnetic Tape, Electron Beam Recording.

SelectaVision HoloTape technology has virtually reached commercial performance level. At this point in time no product decision regarding implementation in the consumer market has been made. However, a number of applications for its capabilities are currently being pursued.

SelectaVision VideoDisc is well on its way toward system and product definition. Its promise of low player and low software cost make it currently a highly promising technology for the broad video player field.

SelectaVision MagTape, a magnetic tape recorder-player, came into being during the last year and a half. The unit demonstrated the previous evening had been shown to over 40 companies and product announcements regarding its planned availability in late 1973 have been made.

The unit (which is expected to sell at approximately $700) can record and play; a small black-and-white camera, and later a color camera, can be added. Bell and Howell and Magnavox have joined RCA in the manufacture and sale of the MagTape recorder-player. The competitive situation was summarized by identifying and relating to other systems being announced or introduced into the market.

The goals of the SelectaVision Program most appropriately fit the needs for creative engineering and focus upon developments which will enable RCA to open new markets and to enlarge those already served.

Solid state hybrid technology

R. S. Engelbrecht
Staff Engineer, Engineering
Research and Engineering
David Sarnoff Research Center
Princeton, N.J.

The continuing trend toward more complex electronic systems in the Seventies will place ever increasing demands on all phases of solid state technology. Thus, we may expect large scale integration of semiconductor devices, as presently applied to information processing, to expand into other areas of electronics—communications, entertainment, automotive, and industrial. In some cases, the complete "system on a single chip" may even become a reality. However, all but the simplest applications will probably require the assembly of several semiconductor IC's, along with many other active and passive components, into larger building blocks.

Solid state *hybrid* technology may thus be defined as an integrated set of diverse, but compatible, solid state devices, materials, and processes for producing reliable and cost-effective functional circuits or subsystems. Of the many processes in use today, one that is becoming increasingly important to RCA consists of a thin ceramic substrate, about one inch on a side, on which conductors, resistors and small capacitors are deposited by thin or thick film metallization techniques. Unencapsulated semiconductor chips, both IC's and discrete devices, are directly connected to the substrate conductors, using the beam-lead or flip-chip process. Bulky passive components, such as large capacitors or transformers, are similarly attached. The overall assembly is suitably protected by a plastic or metal encapsulation, and provided with pluggable or permanent connections to the larger system which it serves.

RCA's needs

Considering RCA's diverse needs, and the modest cost of a basic ceramic-circuit facility, it is not surprising that virtually each of our major electronic divisions has established its own solid state hybrid fabrication capability. Although the general process is similar for all, each division has added its own specialized engineering effort to match the hybrid circuits to its particular products and markets. These range from the highly customized, few-of-one-kind and quick-turn-around activities in G&CS meeting extreme reliability and performance requirements for government and space applications, to the highly automated facility in CE, producing millions of identical circuits at very low cost for RCA solid state television receivers. Between these extremes, straddling both the technology and volume requirements of other divisions, we find SSD's hybrid manufacturing facility at Mountaintop, which presently directs its main effort toward specialized high-power (up to 1 kilowatt) solid state subsystems for the rapidly growing industrial and automotive markets. Because of the specialized skills and fabrication methods employed by all of these activities, direct interdivisional utilization of our corporate engineering and manufacturing resources has thus far been limited to a few specific areas of overlapping needs and capabilities.

Research and advanced development

To maintain RCA leadership in this rapidly evolving and expanding field, a small but well focused research and advanced development program has been established at RCA Laboratories, Princeton, and in the Solid State Technology Center (SSTC) in Somerville. In addition to assisting operating divisions in the solution of their immediate engineering and production problems, they have established programs aimed at better basic understanding and systematic long-range improvements in hybrid technology. Thus, the beam-lead interconnect technology pursued by SSTC is expected to substantially advance our capability for producing highly reliable, low cost, and densely packaged multichip assemblies. Similarly, recent studies at Princeton have provided much better insight into the adhesion properties of thick conductor films to their ceramic substrates, leading to more reliable and better controlled thick-film fabrication methods. Beyond their own purely technological programs, these activities also provide for the exchange of know-how among the operating divisions, and for the necessary interdivisional standardization which will be required if we are to take maximum advantage of our corporate resources.

Conclusion

Hybrid solid state technology appears particularly well suited to serve RCA's diversified needs. Developing a long-range and flexible set of materials and processes, and assuring its timely adaptation to the operating divisions' specific needs, will help maintain RCA's leadership in electronics.

Report from the Laboratories

T. O. Stanley
Staff Vice President
Research Programs
RCA Laboratories
Princeton, N.J.

I'll report to you today on our progress in planning the allocation of our research resources for 1973. To that end, we have conducted a series of meetings this spring, in which many of you took part. In these day-long meetings, we reviewed our research program and your research needs. We chose the spring—a less busy time than the fall—in order to insure your participation, and, more importantly, so that much of our research program could be included as an integral part of your five-year business plans.

Additional factors that this year required substantial explicit attention to the allocation of research resources were:

1) The shifting spectrum of RCA businesses—the growing role of services and acquisitions,
2) RCA's departure from computer main frame business relative to research content, and
3) The reorganization and reorientation of the Laboratories that was effected consequent to our reduced assessment base.

After our meetings with you and an additional meeting with our Corporate Staff colleagues, the Laboratories' management holed up for four days in Point Pleasant. We emerged with a tentative allocation plan which we are now refining and iterating through our group heads.

The selection criteria that we used—which projects and what level of effort—warrant some discussion. First, we looked at:

1) Payoff—profit and growth
2) Business risk—does it fit potential market and does it fit RCA?
3) Technical risk—technical capabilities available
4) Total cost (time)

This gave us a first list of research tasks. Next we considered what sort of portfolio balance we had in this list with respect to:

5) Long term health of RCA—3rd generation products and services
6) Putting out fires/compensating for under threshold division projects
7) Maintain (or develop) important expertise
8) Balance in payoff, risk, and timing

It is important to note that at any given moment in time our portfolio balance with respect to "beneficiaries" may be distorted since our major projects are best undertaken in sequence.

(Mr. Stanley next showed three charts indicating the distribution of projects with respect to risk, payoff and timing. A fourth chart depicted the correlations in these factors among projects. It was noted, for example, that the largest projects were in the high-payoff, short- and medium-risk categories, and that there were many small projects in the medium-payoff, low-risk short-time categories.)

We will be back to all of you individually with a more complete story on allocation after our next iteration, which should be completed in the near future.

The Engineer and the Corporation

Shaping the future at RCA Concluding remarks

Dr. James Hillier

Editor's note: Reproduced herein are Dr. Hillier's concluding remarks upon completion of the recent RCA Engineering Conference at Buckhill Falls, Pa. His thoughts symbolize the general high level of interest exhibited by participants during the 3-day business and technical sessions. We believe every engineer and manager will relate to the general thesis that the appropriate application of the combined forces of technology and marketing will be one of the keys to future success.

In the first three days you have had the unique experience of hearing an exposition of the major part of the activities of RCA—electronic manufacturing, subsidiaries and corporate staff. In spite of the wide diversity of the activities described, a sense of unity of thinking and of purpose has pervaded the picture leading to the conclusion that RCA is a most remarkable corporation.

The theme of the conference —"Shaping the Future at RCA"—has proved to be very appropriate. The shape of the future has been revealed and confirmed in many ways. Of particular interest to the engineering managers are the obvious conclusions that electronics is going to continue as RCA's major business—and that long range plans ensuring its future growth are being developed and implemented.

You heard plans to make sure that the investment funds needed for future growth will be available. You heard reports on programs that are already in being for RCA's participation in several major electronic services that we see developing in the future. You were presented with the specific challenge of increasing your participation in the management of the future of your divisions and subsidiaries—not just on technical matters but on the business impact, present and future, of your engineering programs or lack of them.

I personally believe that in the communications and information handling business, which is RCA's main involvement in electronics, our optimism is based on some very fundamental premises:

1) We live in a finite world with finite resources.
2) People have reasonably uniform fixed, physical and mental capabilities.
3) Communications requirements compound with the number of people communicating.

It is in the inevitable collision between the compounding communication requirements and the fixed resources and fixed capabilities of human beings that RCA's future opportunities reside. The only apparent solution to the dilemma this collision presents, is through technology. Note that both communications systems and the related technology are RCA's business.

We have a number of limited resources of significance to RCA. An obvious example is spectrum space. It is technology that is going to solve some of this problem—by signal compression, by higher frequencies and transference to cable. Another example of a finite resource is energy. Transfer of intelligence requires little energy and will become a substitute for energy-consuming travel. Still another is numbers of people. As populations grow and communications requirements grow accordingly, the numbers of people required for the intermediate operations invariably outrun the supply in the

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population. This forces the automation of the intermediate operations and places the burden of entry to the system on the originator of the communications or transactions. The direct distance dial system of our telephone service is an advanced example of this.

These few examples make the point that in RCA's communications and information handling businesses there are inevitable trends that provide our future opportunities, and that technology will be one of our keys to success. But the door to success has several locks of which technology is only one. Moreover, the keys to the locks are changed with time.

Technology is no longer a scarce commodity and will not be the limiting factor in the implementation of new services. Marketing and economic strategies will become the controlling factors in the successful entrepreneuring of such services. Technology will become, more and more, the necessary but not sufficient factor.

Earlier speakers pointed out that new consumer services must be entrepreneured by a corporate task force. Specialization in our divisions will enable them to participate in the implementation of a service and in its continuing business. However, that same specialization prevents any division from having the competence, resources or motivation to entrepreneur a completely new service on its own, particularly when more than one division or subsidiary must be involved. This is the reason behind initiation of the SelectaVision, Data Communications and Broadband Information System projects.

One or more of these can be the answer to the famous question of "What, after color television?" The markets are there; the technological, engineering and manufacturing capabilities are in place in RCA. Couple these through the dedication of RCA people and we will put renewed growth into our "mature" electronics businesses.

Incidentally, let's take the negative connotation out of the word "mature." Mature businesses are not dead. Properly managed they are not even sick. Mature businesses must be the most productive of the profits that will provide the funds needed for investment in the future.

When you add up all the words of the past three days, they say that there *is* a future for electronics. The challenge is for all of us to maximize RCA's role in that future. You, the engineering managers of the company, are essential to that process. In addition to managing your engineering activities you have the much tougher job of putting engineering into management—making engineering a significant factor in controlling the destiny of your own divisions.

That, gentlemen, is the challenge I leave with you. The opportunity is there, the resources are there and you have the understanding and support of the top management. The rest is up to you.

Dr. James Hillier
Executive Vice President
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studied at the University of Toronto, where he received a BA in Mathematics and Physics in 1937, MA in Physics in 1938, and PhD in Physics in 1941 Between 1937 and 1940, while Dr Hillier was a research assistant at the University of Toronto, he and a colleague, Albert Prebus, designed and built the first successful high-resolution electron microscope in the Western Hemisphere Following this achievement, Dr. Hillier joined RCA in 1940 as a research physicist at Camden, N.J. Working with a group under the direction of Dr. V. K. Zworykin, Dr. Hillier designed the first commercial electron microscope to be made available in the United States In 1953, he was appointed Director of the Research Department of Melpar, Inc., returning to RCA a year later to become Administrative Engineer, Research and Engineering In 1955, he was appointed Chief Engineer, RCA Industrial Electronic Products. In 1957, he returned to RCA Laboratories as General Manager and a year later was elected Vice President. He was named Vice President, RCA Research and Engineering, in 1968, and in January 1969 he was appointed to his present position. Dr Hillier has written more than 100 technical papers and has been issued 40 U.S. patents. He is a Fellow of the American Physical Society, the AAAS, the IEEE, and Eminent Member of Eta Kappa Nu, a past president of the Electron Microscope Society of America, and a member of Sigma Xi. He served on the Governing Board of the American Institute of Physics during 1964, 65. He has served on the New Jersey Higher Education Committee and as Chairman of the Advisory Council of the Department of Electrical Engineering of Princeton University. Dr. Hillier was a member of the Commerce Technical Advisory Board of the U S. Department of Commerce for five years He was elected a member of the National Academy of Engineering in 1967 and is presently a member of its Council.

The AEGIS weapon system acquisition

W. V. Goodwin

Missile and Surface Radar Division has been involved with the AEGIS weapon system program since its onset more than ten years ago. In this period, changes in national policy, which—in turn—affected Navy procurement practices and specific needs, have translated into considerable challenge to both RCA management and engineering. The resulting dynamic ten-year evolution of the early Advanced Surface Missile System (ASMS) to the present AEGIS weapon system has required that RCA develop the total weapon system management skills needed to handle the broad spectrum of management activities and decision processes. Correspondingly, the RCA engineering community has had to respond to technical challenges that did not exist a decade ago.

SIGNIFICANT AND VALUABLE LESSONS have been learned with regard to the dynamics of the modern major weapon system acquisition process. These lessons can and should be applied to other system-oriented programs within RCA. This article is devoted to examining these lessons.

Early decisions

. . . need for a plan and plan for a need

Let us begin our analysis with the familiar term—initial conditions. From an industrial and military viewpoint, a weapon system begins with recognizing a need to meet an existing or potential threat. The system operational requirements for AEGIS have been known for some time in terms of the expected fleet air warfare threat. Indeed, at the time of our first association with ASMS, the Navy was carrying out a fleet-wide program to upgrade its existing air-defense systems. These would have to operate reliably in a threat environment characterized by hostile electronic countermeasures and in all weather conditions.

RCA, whose technical and management credentials had been established with the Navy as early as the 1950's with the land-based Terrier and Talos programs, was asked to participate in this "get well" program. We were given the assignment of studying the Terrier weapon system from the standpoint of operational reliability, design deficiencies, and possible performance improvements. RCA accomplished two objectives in this effort over a period of several years.

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The first involved significant contributions to missile fire control system operational availability and performance. An on-line automatic-fault-detection and isolation system for the AN/SPG-55B radar was designed and service tested in the *USS Biddle* (DLG-34). Also, a digital ranging and automatic electronic counter-countermeasures system was designed for the Talos fire-control system and installed in several of the Talos cruisers beginning with *USS Albany* (CG-10).

The second major contribution made during the Navy program was the creation of a dedicated and skilled team of system engineers and project management personnel who understood the "real world" of the Navy's air defense needs. This set the stage for a series of key government and RCA decisions independently leading to the award of the AEGIS weapon system to RCA.

In the mid-1960's the Department of Defense process for procurement of major systems was based on a series of efforts aimed at achieving an almost perfect definition of the system prior to the development and production contract. This approach, it was then theorized, provided a basis for a total package procurement in which cost, schedule, and technical performance could be determined in detail at the outset of the contract.

Cornerstones of the AEGIS system

AEGIS was born in this environment and began with the Pre-Contract-Definition phase for ASMS in 1964. The cornerstones of the system were then, as now,

- Fast reaction time,
- Environmental immunity,
- Fire power,
- Extended coverage, and
- Availability

to meet the threat of highly coordinated multiple attacks in a severe electronic countermeasure environment and adverse weather conditions.

RCA recognized that the first four cornerstones dictated the need for a wideband phased-array radar capable of furnishing multiple-target fire-control-track data for extended-range missile

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received the BEE from the Rensselaer Polytechnic Institute in 1949 and the MSEE from the University of Pennsylvania in 1955. Mr. Goodwin has 19 years of experience in technical and management assignments associated with Navy air defense guided missile programs, as well as other major missile systems. Between 1949 and 1954, he was part of the RCA Radar Engineering Group. In 1954, Mr. Goodwin joined the Bendix Missile Division as the Manager responsible for the Talos autopilot. He rejoined RCA in 1959 as Manager of Advanced Projects. Later, as Manager of Advanced Range Instrumentation, he had complete management responsibility for the development of advanced tracking radars under various government contracts. During the period between 1963 and 1967, Mr. Goodwin attained Technical Directorship of the Terrier Weapons System study program and the AN/SPG-55B evaluation program. This effort led to follow-up programs through 1967 during which time Mr. Goodwin became Terrier Program Manager, responsible for the AN/SPG-55 improvement program and the Terrier Weapon System evaluation. Mr. Goodwin was appointed Marketing Manager for the Missile and Surface Radar Division in 1967. In this capacity, he placed particular emphasis on the formative ASMS efforts by directing RCA investment and planning in anticipation of ASMS Program approval. Presently, he has full executive authority and responsibility for the direction and control of the AEGIS program.

guidance. A weapon in the form of a high performance interceptor missile capable of an extremely high launch rate was also needed. By combining the "real world" lessons learned about at-sea availability with innovative systems engineering and technology, RCA participated successfully in this Pre-CDP phase. The Navy, however, was confronted with the obstacle of program costs and could not achieve the complete elimination of technical risk prior to program approval. Thus the basic ground rules for weapon system acquisition at that time slowed progress toward AEGIS.

The author and Capt. Wayne E. Meyer, AEGIS Weapon System Manager, examining one of several of the newly designed AEGIS command and control consoles.

Key program decisions

RCA, however, was making other program and technical decisions while AEGIS was being delayed. We were vigorously pursuing the corresponding Army Air Defense Program—SAM-D. Many of the system design problems of SAM-D and AEGIS are quite similar and these similarities between each service's requirements led to an AEGIS/SAM-D commonality study in which RCA established a basis for common phased-array-radar technology.

The first key management decision by RCA was to establish prudent and timely technology advances in constrained-feed array design through a system-requirement-oriented marketing investment plan.

The Navy, participating in the final evaluation for the SAM-D award, singled out RCA's phased-array-radar approach as highly desirable for AEGIS albeit not considered optimum for SAM-D. This appraisal provided impetus for further AEGIS-oriented effort on the part of RCA engineering management. Consequently, we had established a key technology base when the ASMS program was approved to proceed independently of SAM-D.

A second far-reaching management decision by RCA was to apply the experienced cadre of air defense system engineers to ASMS, including those associated with the SAM-D Contract Definition program.

AEGIS contract definition

. . . the end game as the game changes

The prelude discussed above set the stage for the next series of management decisions and innovative engineering effort that culminated in the award of the AEGIS prime contract to RCA. Hewing to the DOD policy of complete contract definition and detailed cost estimating for both development and production prior to major government investment, the Navy prepared a voluminous bid package for response from industry.

This bid package set forth the requirement for a "total system prime contractor" and included the development and production of not only the shipboard elements of the weapon system but also the new missile, shore-based training facilities, logistic facilities, and the supporting documentation for acquisition and ownership. Preliminary estimates by both contractors and the government set the total development cost close to one-half billion dollars. The contemplated production was tied to a proposed shipbuilding program that ran as high as one ship a month for upwards of three years—a tremendously large program.

Considering that the investment to date had not been insignificant, RCA management found itself faced with the following questions:

- Would the program really be approved by the Secretary of Defense?
- Would a lesser, but acceptable program be approved?
- Who was the real competition?
- Should we attempt to be prime or subcontractor?
- What other new business programs must be pursued simultaneously?
- What other new business programs might be dropped because of commitment of ASMS?
- What chance did RCA have of successfully participating if some form of ASMS were to proceed?

RCA also recognized that a subtle change in DOD policy in weapon system acquisition had been occurring. This policy was not readily evident in the bid package. This DOD policy was embodied in the so-called "Packard Principles", established by then Deputy Secretary of Defense David Packard:

1) Trade-off operating requirements against cost on a continuing basis.
2) Establish the program schedule and funding profile with sufficient time and funding to accommodate inevitable development problems.
3) Maximize simplicity and austerity of design.
4) Treat *cost* as a *principal* design parameter.
5) Use proven technology except when essential realistic need or potential cost benefits demand new technology.
6) Always consider existing equipment or modification of existing equipment as alternatives to development of new equipment.
7) Base progressive commitments of resources upon accomplishment (demonstration and tests) rather than calendar dates.
8) Rely on equipment testing in preference to paper studies.
9) Assess risk continuously and plan accordingly.
10) Invest development dollars to save production and operating costs.
11) Minimize development/production concurrency.
12) Make engineering changes only to correct deficiencies, increase effectiveness, prevent production slippage, or reduce costs.

Careful analysis of these principles coupled with our experience in the real world of fleet air defense indicated most

Captain Wayne E. Meyer, AEGIS Weapon System Manager, smashes a bottle of champagne against the AEGIS AN/SPY-1 shipboard antenna before it was lifted from truck and fitted into antenna pedestal. The 17,000-pound antenna will be utilized for running test patterns in an important development in the AEGIS program.

probably a program of lesser scope would finally be approved. Further analysis and assessment of available weapons indicated that the AEGIS missile would most likely be an augmented Standard Missile rather than a new development.

These two conclusions, if correct, would yield an AEGIS development program of roughly half the relative cost. This cost consideration, it is noted, is a common thread throughout the "Packard Principles."

The serious competition for prime contractor appeared to be two aerospace corporations both of whom would have to subcontract most of the AEGIS system except for the missile. Preliminary discussions with one of these aspirants disclosed a system approach geared to an extremely advanced missile design with correspondingly less emphasis on the phased-array radar. Our assessment was that RCA's best interest was not to join with this particular prime contractor. Other considerations left us the choice of either not participating or becoming the prime contractor. With the expected approved program to not include a new missile development, the technological pivot became the phased-array radar. Our prior investment payoff was readily apparent.

The next level of technological strength needed to round out the total system lay in tactical computer programs and command-and-control capability as well as shipboard fire-control background. The command-and-control problems associated with advanced air defense were understood from our SAM-D experience. Technical strength and experience in naval tactical computer programming was obtained from Computer Sciences Corporation who had established a reputation in this area.

We enlisted the Raytheon Company as a potential subcontractor because of their experience in the design of fire-control radars and high power cw illuminators. In order to be fully responsive to the Navy bid package, we employed the services of the Bendix Corporation for missile design along the lines of modifying the Standard Missile technology for AEGIS application.

Thus, an objective assessment of our combined technological base indicated a high probability of success if our basic premise of cost-versus-requirement tradeoff was correct. RCA top management made the final decision to pursue AEGIS at some expense to other potential new business programs.

The AEGIS Contract Definition phase began. The basic strategy had been formed and was followed. *This strategic adherence to plan, combined with the early investment in phased array radar technology, was undoubtedly the key to RCA's becoming AEGIS prime contractor.* Needless to say, the technical approach in terms of detailed system design varied as we learned and responded to Navy review and guidance. Preconceived ideas were at times difficult to change, particularly in a pressing environment of less than complete technical risk assessment. However, we continuously treated cost and risk as principal design parameters.

We addressed, for the first time, the concept of milestone contracting; *i.e.*, specific points in the contract at which progress could be measured and one of the "Packard Points" explicitly invoked in the Navy requirements. Using this concept as a base, we were able to develop an AEGIS development program management plan meeting the program objectives and capable of being measured by both RCA and Navy management. This management plan was structured to accommodate changes and stretch-outs in fiscal funding without losing its fundamental integrity. We entered the AEGIS development contract with this background.

The AEGIS program

. . . two and a half years of milestone achievement and still going

At this point in time, with the completion of Milestone A on schedule, Milestone B ahead of schedule, and looking forward to Milestone C, we can look at the past and contemplate the future with respect to the lessons we have learned:

- We have learned that the weapon system acquisition principles set forth in Mr. Packard's guidelines are indeed a way of life.
- We have learned that the successful development of a major weapon system requires total and dedicated involvement by technical and management personnel in industry and government.
- We have learned that what we believe to be the best interests of the user, in this case the United States Navy, is also in the best interests of RCA.
- We have learned that we *must* operate within cost constraints for a program to continue to be supported.
- We have learned in the past several years that *all* technical problems cannot be foreseen but can be solved or accounted for through a total system approach.

The technological results are evident in the hardware and software developing at the Missile and Surface Radar, Aerospace Systems, and Electromagnetic and Aviation Systems Divisions of RCA . . . at Computer Sciences and at Raytheon.

We have established an engineering team unsurpassed in the field. The RCA engineering community can be justifiably proud of their accomplishments on and for AEGIS.

AEGIS weapon system engineering management tools

Dr. J. T. Nessmith, Jr.

The AEGIS weapon system, MK 7, is a U. S. Navy surface-missile system with capabilities that far surpass any existing system. Now in engineering development, having been through the conceptual and contract definition phases, the equipment and computer programs are in the test cycle. In the near future, the integrated weapon system will be installed and tested in a shipboard environment.

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received the BEE from the Georgia School of Technology in 1947, the MSEE and the Ph D from the University of Pennsylvania in 1957 and 1965, respectively. Prior to joining RCA, Dr Nessmith was employed by the Civil Aeronautics Administration in field engineering and maintenance of various electronic airways navigation aids and later, at the CAA Aeronautical Center, as radar instructor. In 1952, Dr Nessmith joined RCA where he directed work on the acquisition radar for the Terrier Guided Missile Fire Control System. He then became project engineer on the T-44 Fire Control System followed by the AN/FPS-16 Instrumentation Radar series and the UPS-1 Search Radar. He was the TRADEX Radar Systems Project Manager and became TRADEX-PRESS Program Manager in 1963. In 1965, he became Manager, Systems Projects and, in 1966, Manager of Systems Engineering. In 1971, he was assigned to his present position. Dr. Nessmith is a Registered Professional Engineer in N J, a Senior Member of the IEEE and a member of the Engineering Management and the Aerospace & Electronics groups, an Associate Fellow of AIAA, and a Member of the Franklin Institute.

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The basic driving parameters in the design for performance of the AEGIS weapon system are:

- High availability
- High fire power
- Fast reaction time
- Large-area defense
- Operation in adverse environments

Further factors in the design are:

Modularity of design, in equipment and computer programs, so the weapon system may be adapted to the needs of the various classes of ships;
Minimum total life cycle costs;
Simplicity of design; and
Safety in operation.

These performance objectives, coupled with the other detailed specifications, demanded an approach to the weapon system engineering that would assure delivery of a total weapon system rather than separate radar, fire-control, and command-and-control systems.

Responsibilities

The AEGIS weapon system is a group of compatible major systems as shown in Fig. 1. The Missile and Surface Radar Division is responsible for the Weapon System engineering effort to assure that these major systems operate as a unified weapon system that will provide the Navy with an anti-aircraft warfare capability to meet the threats of 1975 and beyond.

Added to the total weapon system engineering effort, RCA is responsible for the design of equipments and computer programs for the Radar, AN/SPY-1; the Command and Control System, MK 130; the Operational Readiness Test System, MK 545; and the common computer programs in the system, including the executive, utility, and test programs.

Computer Sciences Corporation, as a major subcontractor, furnishes RCA with computer programming design and coding support for these equipments. Raytheon, another major subcontractor, is responsible for providing to RCA the equipments and computer programs that comprise the Weapon Direction System, MK 12, and the Fire Control System, MK 99. The Launching System, MK 26, will be provided directly to the Navy by Northern Ordnance—as will the Guided Missile, RIM66C-1, by General Dynamics. The Housing, MK 20, which encloses the electronic equipment and supports the phased-array antenna and the illuminator director, will be provided by the Long Beach Naval Shipyard.

RCA is also responsible for furnishing design criteria and, in some cases, supplying the auxiliary equipment such as prime power sources, converters, and air and water cooling systems.

Operational overview

The operation of the weapon system is shown in Fig. 2. It begins with a search-

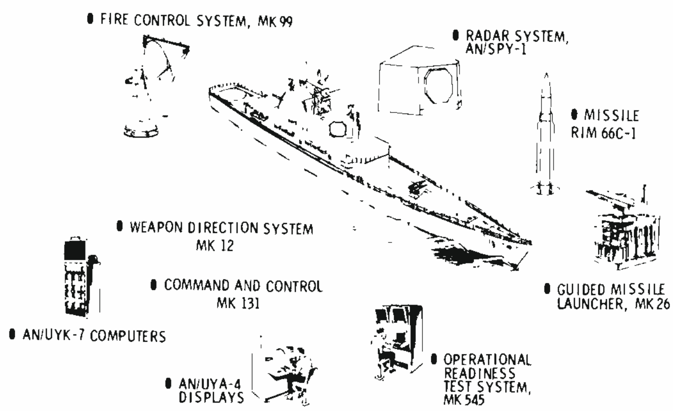

Fig. 1—Major systems of the AEGIS weapon system, Mk 7.

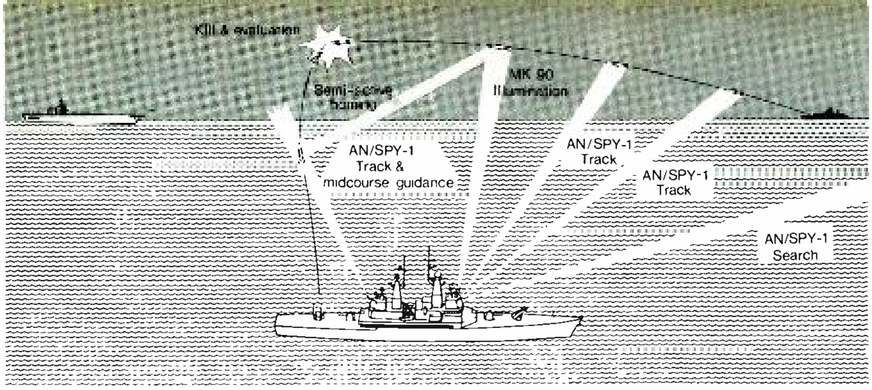

Fig. 2—Weapons system operation.

and-detect operation by the phased-array radar. A detected target is placed into track by the radar and passed to the command-and-control system for evaluation. Once a target is determined to be a threat by the command-and-control system, orders are furnished to the weapon-direction system to develop a fire-control solution. Missiles are loaded on the launcher by commands furnished by the weapon-direction system. The phased-array radar furnishes target-track data to the fire-control system, which designates the launcher firing position through the weapon-direction system.

After launch, the missile is guided by the phased-array radar until the homing phase of the flight, at which time the fire-control system illuminator is slaved to target coordinates supplied by the radar, thereby furnishing the illumination on which the missile can home. Following intercept, the illuminator is available for the next threat. In the meantime, the multifunction phased-array radar, coupled with the multicomputer control system, continually searches for new targets and simultaneously tracks targets already detected or engaged. The result is virtually instantaneous response to any new single or multiple threat that appears. These features add up to a firepower capability adequate to meet the threats of 1975 and beyond.

While the other major systems are looking outward to fulfill tactical objectives, the Operational Readiness Test System turns its attention inward to assure the continuing operation of the weapon system. The Operational Readiness Test System continually updates combat-capability status for the ship's Commanding Officer. In addition, if a fault occurs, the system locates and defines repair procedures to the maintenance crews. This built-in automatic-test capability, coupled with the design for high reliability, provides very high weapon system availability.

Weapon system engineering purpose

Though each system has a clearly specified function, these functions interact strongly in a fully operational weapon system and cannot be treated independently. (However, there is required a degree of independence within systems and between systems for casualty-mode operation.) It is the purpose of weapon system engineering to assure that interdependence of system to system and weapon system to ship, as well as the interdependence within the operational environment, is fully considered in the design of the systems and the interfaces, such that the weapon system will operate as an entity to meet the functional and performance requirements.

In their classic text, "System Engineering," Goode and Machol[1] refer to the "tools of system design." They single out 13 tools for special attention; i.e., probability, mathematical statistics, simulation, game theory, system logic, computing, cybernetics, linear programming, group dynamics, information theory, servomechanism theory, and human engineering. Many of these analysis tools are being applied continuously on the AEGIS program. Moreover, they are subsets of the system engineering management tools developed and utilized on AEGIS, for the technical management of the program. Management tools used by weapon-system engineers are the subject of this paper.

Weapon system engineering management tools

The weapon system specification matches the functions and the performance levels of the weapon system against a set of threats and the total environment in which the system performs. This document is the basic weapon-system engineering tool. Its development, during the Contract Definition Phase of the program, was an iterative system-engineering process of synthesis and analysis that was bounded by the user needs, the state of technology in a specified time frame, and cost.

Lower levels of specifications define the functions and performance of each major system. These documents are the domains of the radar, command-and control, fire-control, and missile-systems engineers. These specifications allocate functions between computer programs and equipment. This allocation provides, in the next level, separate specifications for equipment and computer-program performance and defines the tasks facing the equipment system designer and the computer program system engineer. At the next lower level, drawings for the equipment and specifications for the computer programs allow the designer to take over.

The requirement for an engineering development program, in itself, recognizes that it is not feasible to fully specify every detail, down to the least computer-program bit and equipment part. Iterative design is still required at all levels of the weapon system, and system engineering management tools in the form of specific documentation are required for that design. It would be expected, in a production phase, that some of these tools, not in the original

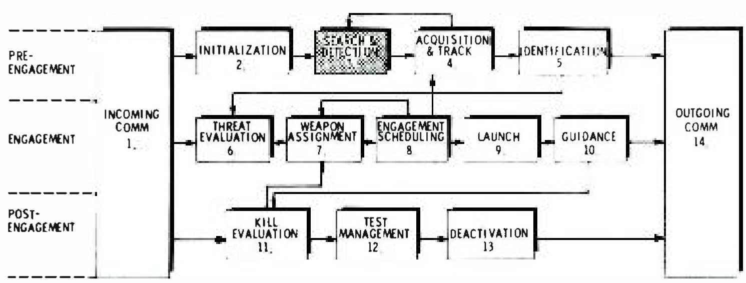

Fig. 3—Allocation of functional requirements for the search-and-detect operation.

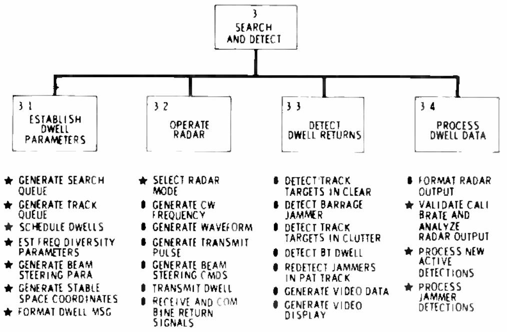

Fig. 4—Functional allocations to computer programs and equipment

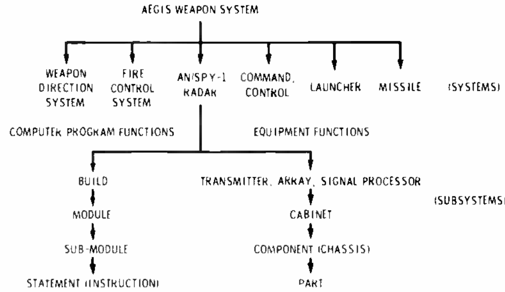

Fig. 5—Allocation of Computer programs and equipment within the AN/SPY-1 Radar.

specification, might be incorporated into the production specifications once the system is proven out in the test program.

During the learning process that takes place during the design, the designer learns more about the system through design iterations and through fleet experience on existing weapon systems. This latter is an important element of the AEGIS program. Fleet reports are continuously brought to the attention of the weapon system designer as to the degree of effectiveness of systems, equipments, components, and materials in fleet operational use. Consequently, field reports form one of the weapon system designer's most valuable tools. On the AEGIS program, the system designer is encouraged to verify his findings in the design and the fleet reports by visits to operational ships. If the design process or these reports identify problems and the need for change in the engineering development model or for production, the specification is changed, via contractually established routes.

In addition to the weapon-system specification, the fleet reports, and the verification visits, the following tools have been developed to assure that the interdependent relationships are designed into the systems:

Functional and interface tools,
Performance tools, and
Discipline tools.

These tools support the weapons system design and provide the vehicle for technical audits. The audits may be either down through a specific system or across the system or systems at a specified level.

The functional and interface tools will be described in some depth in this paper. These tools are:

- Functional flow diagrams and descriptions,
- AEGIS intersystem interface document,
- Facility interface development specifications,
- Computer program interface document, and
- Augmented operator procedures.

The performance tools to be discussed are:

- AEGIS error budget, and
- AEGIS operational performance assessment.

The discipline tools—which are basically plans of action for assuring availability, electromagnetic compatibility, standardization, and safety—will be covered in subsequent papers.

Functional tool

Functional flow diagrams and descriptions

The functional-flow diagrams and descriptions (F^2D^2) are vehicles for identifying and allocating functional requirements, established by the basic weapon system specification, to each level within the system. As an example, the target-engagement can be divided into three phases: pre-engagement, engagement, and post-engagement. These phases can be allocated further into fourteen functions, as shown in Fig. 3. Fig. 4 is a breakdown of the search-and-detect function showing the allocation[2] of functions between equipment and computer programs. There is a flow relationship associated with these functions also which is found in the F^2 D^2 documentation at the Tier "1" level. In this particular function (3.0), both the equipment and computer programs are totally contained in the AN/SPY-1 Radar. An overview of these functional allocations and subsequent allocations in the AN/SPY-1Radar is given in Fig. 5, which shows the break in the AN/SPY-1 hierarchical structure between computer programs and equipment. [Note that in the overall hierarchical structure, the top level is referred to as the *weapon system;* the radar, command and control, etc. are referred to as *systems;* groups of cabinets, such as the signal processor, as *major sybsystems;* and groups of computer-program modules as *builds*.]

As a means of visualizing the interrelationships between the computer programs and equipments, we take a computer program statement on the one hand and a part on the other; integration of each gives a *submodule* in the computer program and *chassis* in the equipment. [Groups of parts on a single board are often called modules at this level. However, in this paper, modules will refer to grouping of computer programs that perform a set of functions.] Further integration of submodules provides a *module* in the computer programs, and the integration of chassis provides an *equipment cabinet*.

The computer programs and equipment interact primarily at the module/cabinet level, though interaction does occur at other levels. (It is at this level the man-machine interaction also takes place.) The integration of modules into computer program builds, and the cabinets into major subsystems, is followed by integration of the computer program builds and the major subsystems into systems such as the AN/SPY-1 Radar. Interaction between systems is primarily through the digital messages, as described in the computer program interface document.

The functions performed by each element in each tier of the heirarchal structure—down through the computer-program-module/equipment-cabinet level—are tied together by functional flow diagrams and descriptions. To assure that the functional allocations to the system are clearly understood and controlled, a working group with members from each of the major system designated, and chaired by the leader of the System Engineering Functional Analysis group, periodically audits the implementation of the system against the F^2 D^2 documentation at all levels. In doing so, the working group formally approves the functional aspects of the design and recommends changes or real-locations.

Interface tools

Facility interface development specification

Installation of the AEGIS system in the combatant ship imposes definite requirements and constraints on the ship and the system. These requirements and constraints are prescribed in the facility interface development specification, by the need to support adequately and reliably, the operational missions of the ship.

The AEGIS system interfaces the combatant ship by way of the ship's structure; electrical power systems; heating, ventillating and air conditioning systems; electronics-cooling systems; compressed-air systems; signal switchboards; and signal-distribution systems.

The physical interface requirements thus impose restrictions on :

Weight;
Space and arrangement;
Foundations;
Electrical power;
Heat, ventillation, and air conditioning;
Electronic-cooling water;
Compressed air;
Steam and condensate; and
Ship flexure.

And the signal interfaces impose requirements on:

AEGIS-combatant ship intercommunications.
Characteristics of the signals transmitted between AEGIS and ship equipment.
Ship equipment characteristics that cannot be changed without impacting AEGIS design.
Ship equipment performance parameters that are critical for specified AEGIS performance.

Each requirement imposed by the AEGIS system or by the combatant ship must have acceptance by both parties. Unilateral changes cannot be made to an approved agreement. Working groups meet as required to discuss and recommend changes required as a result of design changes in the AEGIS weapon system or the ship. Thus, under control, the facility interface development specification represents a continuously updated assessment of the current design approach. For example, this document provides a readily-available status report on the power needs weight, space, and power requirements at the AEGIS weapon system level and at the individual equipment levels. It rapidly identifies problems for effective corrective action and identifies possible reductions in weight, space, and power—three parameters critical in fitting the equipment to smaller combatant ships.

AEGIS intersystem interface document

The AEGIS intersystem interface document contains the interface diagrams and the functional interface definitions of the electrical and electronic interfaces between any two of the AEGIS systems and between the AEGIS systems and the ship. Since the input requirements of one system affect the output design of a second system and the systems are designed by different organizations, it was necessary to reach a set of definitions that met the needs of each system within the constraints of total weapon system requirements. A working group, chaired by a weapon-system engineer, and composed of representatives from each system, was established to resolve the input/output requirements. Since the physical paths between systems could be of considerable length, a knowledge of the ship and the physical and electromagnetic environment was important in determing the interfaces, and the basic design of the interfaces must take such factors into account. Consequently, members of the working group included skills that were knowledgeable of such requirements. The output of the group is the set of definitions contained in the AEGIS intersystem interface document.

Once defined, the interfaces must be controlled. There are more than 2,000 specific interfaces between systems. Some of these are simple (*e.g.*, a single power line of 120 V, 60 Hz, 1 kW, Type 1); others are of multiple functions that require ten pages to describe.

The development and control of this tool also requires that the responsible individuals, in both cases, sign an agreement that they have agreed to each function and its definition. These individuals then assume the responsibility for providing the necessary input/output equipment and computer programs. After approval, no unilateral changes are made. The document then serves to establish the requirements for system interface design—including the cables, input/output equipment and computer program interface development, as shown in Fig. 6.

Computer program interface document

The AEGIS weapon system is controlled by three multipurpose computer groups in the radar, the weapon-direction, and the command and control systems. The seven to nine computers used—depending on the weapon system variant—are AN/UYK-7 Multiprocessors, designed for use throughout the Navy. The digital messages between systems, which tie the systems together to perform a specified weapon system function, are actually links between the operational programs that exist in each computer. The many weapon system functions require inter-and intra-system communications between computers and within each computer between the operational programs and the executive.[3] Therefore, the needs and requirements must be clearly defined down to the bit level. The AEGIS intersystem interface document provides the information at the performance level. Augmenting this document is the computer program interface document which has been developed for the definition, coordination, control, and documentation down to the bit level.

The responsibility for developing and maintaining the computer program interface document is vested in a working group, chaired by the leader of the Computer Program Interface group with representation from each system design team. This group is responsible for system design of the baseline digital interface, for periodical reviews of design implementation, and for recommending necessary changes to the cognizant systems project managers.

Augmented operator procedures

The short-reaction-time requirement of the AEGIS weapon system in responding to a threat leads to the philosophy that many essential functions be computerized. The requirement for low life-cycle costs leads also to use of the computer to do routine tasks to reduce manpower requirements.

In the decision-making process, however, the officers and crew must be in control of the system from detection through an engagement, while receiving the support from the computers. Augmented operator procedures have been developed to aid in the design of the interface between the man and the weapon system.

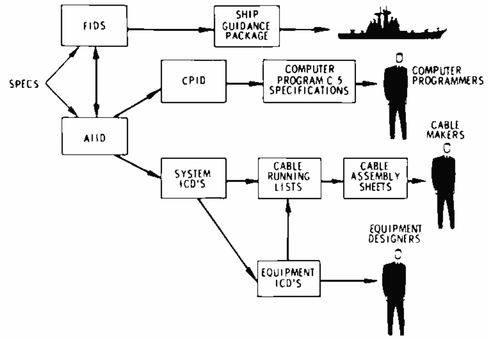

Fig. 6—Electrical and physical interface document interrelationships.

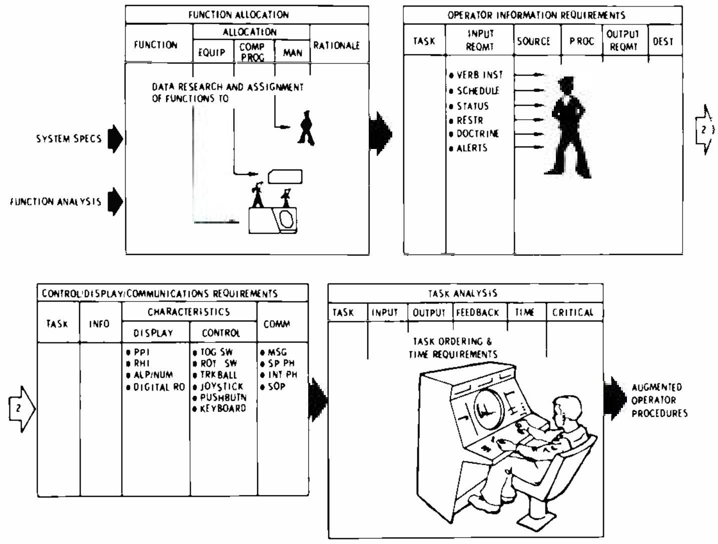

Fig. 7—Derivation of augmented operator procedures.

The process of development is outlined in Fig. 7. Initially, there is a functional allocation to equipment, to computer programs, or to a man. Once the operator functions have been defined, the following operational criteria are established:

Information needs of the operator,
Mode by which the operator will receive that information
Action to be taken by the operator in response to the information, and
Method by which the operator will take action.

Once these input-output relationships of the operator are established, ordering of these is accomplished through a task analysis.

The task analysis is then translated, by operator position, to operator procedures. A major difference, however, between the augmented operator procedures and normal operator procedures is the description of the equipments with which the operator interacts. This description has proved highly successful in review of operator positions by fleet users. This was accomplished during the design and fabrication stages of the engineering development, through the tests of the procedures by Navy personnel. The approach was validated using mockups of consoles, Navy operators at the consoles, and specific scenarios.

The lead responsibility for developing the procedures was vested in a working group led by the human factors activity in weapon system engineering, with each of the systems represented on the working group. Continuous liaison was established with the Naval Training Unit through the Navy Program Office representatives. The cooperation between all of the groups involved was a major factor in the early development of the procedures.

These procedures will be further verified during the test and evaluation phases. If changes are necessary, the procedures can be revised easily. However, changes in equipment and/or computer programs would require approval by the cognizant system project manager.

System locks

Up to this point, we have treated the tools more or less independently. Each tool has a hierarchical structure—getting into greater detail as one proceeds from the weapon system level to the system level, to the subsystem level. However, each tool is also locked into the specification tree through the common functions or parameters specified therein. Locks between functional and interface tools are established also through a commonality of functions or parameters. The locks between tools and specifications at three different levels are shown in Fig. 8.

Names of individuals are furnished at the third level (Fig. 8c). These individuals are directly responsible for a particular tool which must lock in every respect to the other tools and to the specification. The locks between computer programs and equipments in particular systems occur through the B-1 specifications (Fig. 8a), whereas the lock between computer programs in different systems is through the computer program interface document. One lock not shown, but which occurs at all three levels, is between the facility interface development specification and the ship specifications. In general, all weapon system engineering management tools are taken through the third level, to provide detailed traceability of a particular function which involves equipment, computer programs, and operators and the signals, cabling, and controls that link them.

Performance tools

AEGIS error budget

The AEGIS error budget is a system engineering management tool used to allocate, audit, and control the AEGIS system and subsystem errors in such a way that the total performance objective is met. To accomplish this purpose, it:

- Identifies, by system and subsystem, the error source and its impact at the weapon-system level;
- Furnishes a means to control major changes as they impact the total weapon system;
- Establishes and assures traceability from the weapon-system level through the subsystem level of error allocations, to equipment and computer programs; and
- Communicates quantitative descriptions of error sources, and error models, to aid in predicting and verifying weapon system performance, as discussed in the next section.

The top-level error budget itself is functionally oriented. These functions include radar tracking, target illumination by slaved illuminator, target engageability, launcher pointing, and target acquisition by missiles. From these are derived the allocations to lower-level component errors such as: MK19 Gyrocompass coordinate-conversion errors, CWI RF collimation

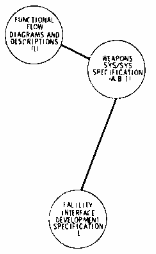

Fig. 8a—Systems locks—first level.

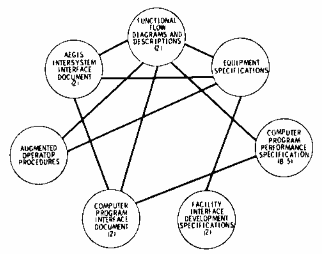

Fig. 8b—Systems locks—second level.

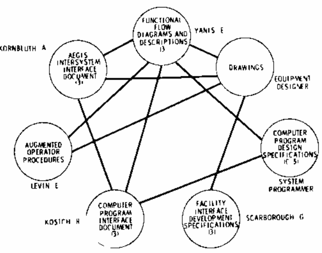

Fig. 8c—Systems locks—third level.

error, target-prediction velocity error, contribution of high frequency noise to radar tracking data, and seeker pointing error.

The AEGIS operational performance assessment discussed in the next section is predicated upon an accurate error model of the individual system functions. Control of the error model at all levels is exercised through a working group which is made up of representatives of each of the systems, with chairmanship by Weapon System Engineering. This group is responsible for having, as part of the error budget:

- Functional diagrams for each system showing error sources, types, and values.
- A hierarchical error budget showing traceability from the weapon-system level down through the lower-level tiers for each system.

In the performance of its tasks, the working group identifies problems, provides plans for resolution, and evaluates change proposals at the subsystem and system level for impact at the weapon-system level. The chairman of the error-budget working group is responsible for providing the assurance that when the subsystems and systems are assembled, the combination will not compromise weapon-system performance.

AEGIS operational performance assessment

The AEGIS operational performance assessment furnishes, on a continuous basis, the current estimate of weapon system performance capability in operational situations—using the anticipated performance of each system as a base. Examples of typical weapon-system performance measurements are:

1) Range of first intercept, considering reaction times, target profiles, and velocities;
2) Fire power as a function of the number of launchers and illuminators available; and
3) Probability of intercept.

Examples of the weapon-system parameters critical to weapon-system performance are:

Detection range as a function of radar mode, scan interval, propagation factor, and electronic countermeasures.
Reaction time, including launcher cycling times, in environmental conditions appropriate to the operational situation.
Missile performance, such as flight profile, time of flight, and elevation angles at launch.
Probability of providing adequate illumination of the target.
Probability of initiating and maintaining radar track.

Presently, total weapon-system performance is estimated through the use of computer simulations. A dynamic weapon-system simulation provides for detailed analysis of system response to a single target from detection to intercept.

The simulation represents the weapon system in sufficient detail to reflect the effects of radar-detection and tracking operation, closed-loop control-system dynamics, threat and missile dynamics, and major system errors. The simulation has been, is being, and will be used:

To evaluate alternative control loop configurations;
To assist in the evaluation of error allocations;
To identify problem areas requiring design attention;
To validate the key performance parameters by analysis of weapon-system performance for a wide variety of scenarios;
To predict performance to be expected under test conditions (such as multipath and clutter) in order to assist the development of test scenarios and data collection requirements; and
To assist in the test and evaluation process, both at the land-based test site and in a ship, by providing a model against which test results can be correlated so that actual weapon system and systems performance can be compared with established performance requirements.

A working group—chaired by the weapon system engineering activity, with participation from each of the systems activities—has been established to define, audit, and control operational performance. This group is responsible for continuously updating the estimated performance of the weapon system. At the initiation of the program, the estimates of performance were based to a large extent upon anticipated values of performance within the lower-level systems. As these system elements go through the process of design, fabrication, and test, these estimates are updated to reflect measured data. Over this period, necessary changes can be tested for their effect on total operational performance. Once established that changes are necessary, the change is recommended for approval by the cognizant systems project manager. If the change involves two or more systems, the recommendation is made to the program manager as well as to the affected systems project managers.

This operational performance assessment also provides a tool for effective tradeoffs during the follow-on to the engineering development, whereby the sensitivity of changes having potential cost savings can be estimated with respect to total weapon-system performance.

Conclusion

The basic concepts of each tool described in this paper had been known prior to its use in the AEGIS program. Each was further developed and refined to fit the specific needs of the program. The application of each tool is changed as necessary to fit specific needs as the program enters new phases. Unique, however, is the integrated use of these tools to form a multidimensional yet independent approach to system engineering management. Mature weapon-system engineering judgment, supplemented by these tools, ensures that the complex major systems that comprise AEGIS will perform as a total weapon system in an operational environment.

Acknowledgments

The author acknowledges the contributions by members of the AEGIS system engineering group, particularly those responsible for the effective use of these tools: R. J. Renfrow, E. M. Yanis, A. E. Kornbluth, R. Kosich, E. Levin, F. G. Scarborough, and R. A. Wilsher.

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Computer control of a multifunction radar

Dr. W. Weinstock

Today's multifunction radar systems combine phased array radar hardware with modern computer systems. In the radar world, the process of going from systems requirements to hardware parameters is fairly well understood and documented; the companion process in the computer world is not. Furthermore, little exists in the literature about the process of going from overall systems requirements to a balanced allocation of radar and computer requirements. Consequently, hardware and software tradeoffs tend to be driven by the problems that are readily understood—the hardware problems. Unbalanced system designs and a disproportionate burden on software development can result if the problem is not approached on a system basis. The purpose of this paper is to disclose the methodology of designing a software system for a multifunction radar. By doing this, it should become clear what the critical concerns are, what the trade-off parameters are, and how the overall systems design process flows into a radar system analvsis and a computer software/hardware system analysis.

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received the BSEE, MSEE and PhD from the University of Pennsylvania in 1946, 1954, and 1964 respectively. From 1946 to 1949, he worked in the design of airborne radar at Philco. In 1949, he joined RCA and, from 1949 to 1953, was involved in the design of various radar and signal processing equipment. Since 1953, he has been engaged in systems engineering with primary emphasis on radar. Recently, he served as technical director of the RCA/Martin pre-CDP study of the Advanced Surface Missile System (ASMS) for the Navy. During the contract definition phase of ASMS (later AEGIS), he was Technical Director of the RCA/Raytheon/Bendix team. Since the engineering development job was awarded to RCA in 1969, he has been involved in various aspects of the AEGIS engineering effort, with particular emphasis on the phased-array radar and its control computer. Dr. Weinstock received a citation from the Air Force for his systems engineering contribution relative to establishing the joint U.S./U.K. requirements for the BMEWS station in England. He has been a consultant to the Navy, having served as a member of the ASMS Assessment Group and the AN/SPG-39 (TYPHON) Advisory Group. Dr. Weinstock was a lecturer at the 1960 and 1961 special summer sessions on Radar Systems Engineering at the University of Pennsylvania, and is a contributing author to tne book *Modern Radar*. He holds three patents. In 1972, he received the David Sarnoff Outstanding Achievement Award in Engineering. Dr. Weinstock is a member of the Tau Beta Pi, Pi Mu Epsilon, Eta Kappa Nu and Sigma Tau

THIS PAPER STARTS with the radar systems engineer's point of view—the system is a radar with a computer "box" tied into it. No computer background is assumed on the part of the reader. As we start to probe what this box has to do, we end up going through the process of software architecture—the program systems engineering aspect of the problem.

In the interest of highlighting principles, a generic system has been chosen for the sample design analysis. While its characteristics are consistent with the state-of-the-art, its parameters are not intended to reflect any particular system.

Functional description of system

The basic jobs of a multifunction radar are the detection and tracking of targets. In the case of detection, this can involve establishing that a target is present in a background of noise, environmental clutter, and interference. Tracking involves the measurement of target parameters on a periodic basis. The parameters which are measured and the sampling rate are determined by the end use of the data. In general, the minimum that is measured are the target coordinates. From periodic measurements of these, target rates can be established and flight path estimated. In addition, future position can be extrapolated. For applications where high accuracy is required, it is generally necessary to have high data rates.

While the complete set of tasks performed by a multifunction radar is application oriented, the set of critical functions is not. An examination of phased arrays for satellite surveillance[1] and ballistic missile defense[2] shows that they require the same basic operations that one encounters in other system applications—such as air defence and air traffic control. Fig. 1 presents a top-level block diagram which is representative of these systems.

Note that the radar system has been divided into two parts, the radar and the controller. This is a standard and somewhat arbitrary division which separates the general purpose control computer and its programs from the rest of the radar system. In general, the radar involves all of the hardware associated with the execution of a single dwell. It includes the transmitter, the receiver, the signal processor, and the means for transferring data. The radar controller relates single-dwell information from the radar with other information. By doing this, it develops track histories and eliminates redundant detections in adjacent beam positions. In essence, the radar is a single-dwell device (even when more than one pulse

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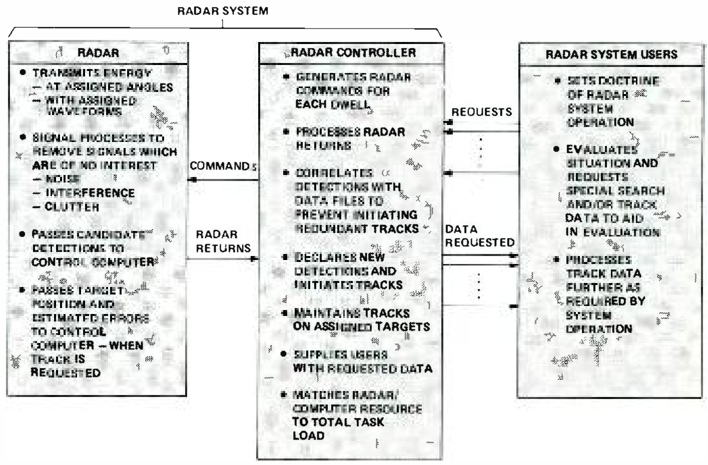

Fig. 1—Representative system block diagram.

is required at that beam position to accomplish its purpose—as in the case of MTI or integration) and the controller makes all decisions where data beyond the current dwell is used.

The radar system users are, in general, other data processing systems and operators. The division between the radar and the user functions may not always be clearly definable on a hardware basis. Thus, a single computer may house both the radar control functions and some user processing functions (as in the case of the AN/FPS-85[1]). Regardless of where the interfaces occur, the radar controller must be able to service a multiplicity of users. It is this requirement, together with the support of a multifunction radar, that demand a "time sharing terminal" type of control computer operation. As we will see, the necessity of being able to handle a number of processing tasks at the same time—by multiplexing computer resources—has a fundamental impact on the computer system requirements. This, coupled with the necessity to do high-priority real-time tasks, drives the computer program design.

Radar system operation

Before developing the control computer requirements, let us take a second look at the system block diagram. This time we will do it from the viewpoint of the radar hardware engineer. Since the primary purpose of this paper is to develop the computer control process for a hardware-oriented individual, we will start with a description of the system as he might see it. This is given in Fig. 2. A variety of ways exist for feeding power to the multiplicity of elements in the antenna, and generating the phase shift commands to the drivers which set the phase shifters.[3] These are

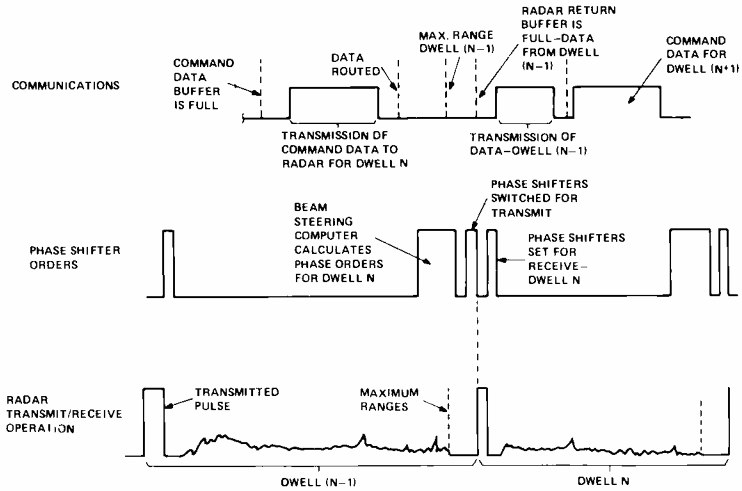

Fig. 3—Representative command/respond sequence.

contained within the concept shown in the block diagram, although they can lead to considerably different hardware.

The control computer determines all the conditions for the next radar dwell. It determines the angular position of the beam, the time of transmission, the frequency, the waveform and pulse period to be used, the appropriate detection threshold, and the appropriate support information—such as dwell identity assignment. Since the computer operation is asynchronous with the radar, some form of buffering is required. The number of dwell commands accumulated in the buffer is a function of many factors. Among these is efficiency with which the computer can generate batches of sequential commands as compared to generating one command at a time. This topic will be treated in some detail later in this paper. The accumulating buffers can be in one of three places: they can be part of the control computer's main memory; they can exist as a separate interface entity (as in Ref. 1); or they can be part of the radar hardware. This choice is a subject for sub-system trade-off. The radar synchronizes its transmission to the time commanded by the controller. A common time base is required to effect this operation.

In this way, radar timing synchronization is initiated. The commanded waveform and carrier frequency are generated in the waveform generator and exciter, amplified in the transmitter, and fed to the array antenna.

The phase shifters in the array antenna are set so that the transmitted beam will be in the commanded direction. The controller commands the angular coordinates of the beam and the carrier frequency of the transmission. This information is sufficient to determine the phase shifter settings required at every antenna element. This computation is a natural one for a special purpose computer—the beam steering computer. It is desirable to have this as an integral part of the radar hardware to minimize the problem of communicating the large number of phase-shifter orders involved. Thus, the general-purpose computer gives the three pieces of overall command information—two angles and frequency; the special purpose computer translates these into hundreds, or possibly thousands, of individual phase-shifter commands.

The received signals are processed in the way commanded by the controller. In general, search data is processed differently than track data. In search, we are just trying to establish the presence of a target; tracking requires special processing to allow for the estimation of target parameters. Thus, different paths exist through the signal processing. The routing for any dwell is determined by the purpose of the dwell as stated by the control computer.

The signal processor extracts all the

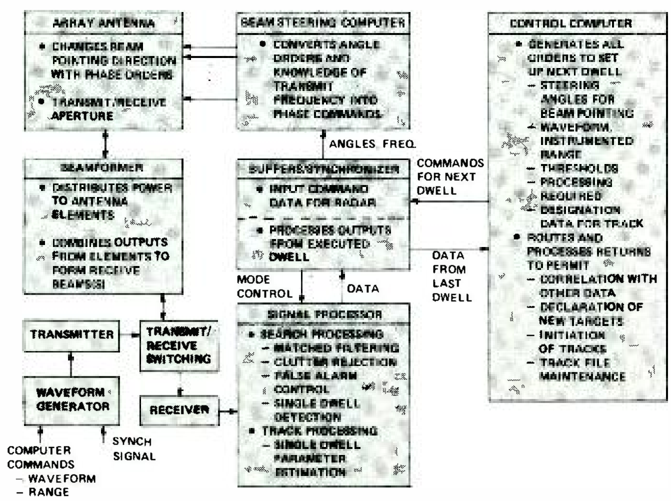

Fig. 2—Radar system block diagram—hardware overview.

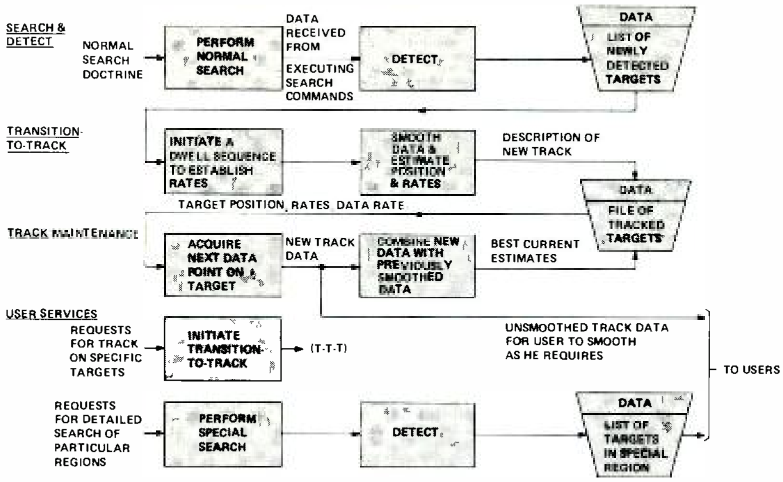

Fig. 4—The basic radar processes.

information obtainable from the dwell itself. In the case of search, all of the dwell returns are processed to exclude noise and, in some cases, clutter and interference. Such processing may involve more than one pulse return during the time of the dwell. However, it does not involve information obtained outside of the dwell period. The radar has no memory of past dwells—that is the job of the control computer.

Since search processing can involve hundreds to thousands of resolution elements and since these must be handled during the time of a dwell (typically milliseconds), an extremely high data rate exists. Clearly, this type of problem calls for analog bulk processing or its special-purpose digital equivalent. The signal processor has the task of destroying information which is of no interest. Thus, all of the resolution cells are examined leading—in general—to only a limited number of detections/dwell. The signal processor can reduce the number of candidate target cells by several orders of magnitude. (This is the ratio of all range, angle, doppler cells to those containing target-like returns). The resultant output is something that can be communicated to, and handled by, state-of-the-art general purpose computers. One of the basic problems of effective signal processing is to minimize the flow of undesired signals, thereby minimizing the possibility of saturating the general-purpose computer. It will become clear, in this paper, that the control of the saturation problem is one of the most significant factors in determining the computer program design.

To gain some perspective as to how the radar and its controller interface on a timing basis, consider Fig. 3. This shows the sequence of events that must occur in parallel with radar transmission/reception in order to effect two-way communications. Basically, a block of command words is communicated to the radar. After these are received, the beam-steering computer calculates the phase-shifter orders for the next transmission. This can be done while the radar is still receiving returns from the last transmission. Once the time of the maximum range return has elapsed, the phase shifters can be switched for the next transmission. At this time, the signal processor is set up to accommodate the next dwell. At the time commanded, the next transmission is executed. When the transmission is completed, reception can begin. Since many systems employ non-reciprocal phase shifters, the array has to have a complementary phase distribution on its aperture to receive at the angle where it transmitted.

While the system is being set up for the next transmission, the data received from the last transmission can be loaded into the buffer for transfer to the control computer. At this point, the information gathered on the last dwell can be transmitted to the computer in the appropriate format. For the scheme just described, which illustrates dwell-by-dwell operation, two-way transfer occurs within the inter-dwell period. The ability to do this puts constraints on the communication rate and the tolerable delays in initiating the communication processes.

Parallel processes and their interrelationships

The method for establishing the data processing requirements is as follows. First, the functional requirements are identified. Then, these are defined in terms of processes. After this, the constraints imposed by the real-time operation, the computer hardware environment, and the performance requirements at peak load are applied to define the software in detail.

Functional requirements

Let us examine Fig. 1 again to identify the basic system functions. As we can see, these are:

- Search and detect,
- Transition-to-track after a new detection has been established,
- Continuing track maintenance by acquiring new data and consolidating it with past data, and
- Supporting the various users of the radar by handling their data requests.

There are many ways of categorizing the various radar functions. The preceding list is one way of presenting these as separable functions. Note that functions that make further use of the radar data are considered as part of the user function—rather than the basic radar data. Thus, from the viewpoint of this definition, the processing of tracking data to compute, say, satellite ephemeris or the solution to a fire-control problem, are considered "user" functions.

In general, a data user will process data over a longer span than that required for the target tracking function. The radar's tracking function is optimized for holding the target and extracting data. The radar's output data is smoothed only to the extent required for track maintenance. Subsequent processing to compute quantities like satellite ephemeris will involve a longer memory span and more smoothing. Thus, a hierarchy of memory spans exists within the system. The radar hardware's memory covers only the present dwell. The radar controller's memory covers the number of dwells necessary for track maintenance. The user's memory will, in general, cover a number of these track data intervals, as is exemplified in trajectory calculations and the displays of flight path history.

Basic processes

Note that each process shown in Fig. 4 starts with an input data list or file, and ends producing another. Thus, search and detect has a list of positions in space to investigate, and as a consequence of doing this, generates a file of new detections. This process can continue running indefinitely, with new members being added to the list.

The transition-to-track sequence starts with the list of new detections and generates the data required to describe the new detection in the same way as targets that are undergoing track. This requires that rates be established, given that our initial knowledge of the target is limited to the positional information associated with the detection. Since, at this point of time, there is considerable uncertainty as to where the target will be in the future (we don't know rates yet), data must be acquired quickly. Since quality rate data can be obtained by operating with a large number of samples, over a long time base, the transition-to-track problem is a demanding one. Good rate information must be obtained before the target moves appreciably from its detected position. Thus, suitable rate data is obtained by taking a significant number of samples over a modest time interval. On this basis, the transition-to-track problem is critical because of its demands on systems resources.

Since a single detection dwell can require a sequence of transition dwells —which are critical on a timing basis—care must be exercised to limit transitions to new targets alone. Thus, an extremely important aspect of the detection process involves the correlation of any detection by the radar with previous detections. Such detections can occur for two reasons. First, a previously detected target can be redetected during subsequent scans. Second, if a target is of more than marginal strength, it can be detected in a number of adjacent beam positions. Note that a scan pattern will, in general, not yield these redundant detections in any particular sequence. This is highly dependent on the detailed way that the volume is scanned, and where the target is located. The correlation process is probably one of the most demanding that has to be performed by the controller. Failure to achieve a high degree of success can cause a proliferation of targets and an expanding load on the system.

The transition-to-track function continuously processes the list of new detections, creating adequate estimates of position and rates so that the targets can be entered into the track file. The process continues to run in this way: processing one data list and entering another.

The track maintenance function is the one that updates the entries in the track file. It continuously generates best estimated position and rates. Its primary job is to guarnatee that quality data will be maintained. The data rate will generally be determined by the end use of the data. To a first approximation, one can consider that the data rate is set by end use requirements and *a priori* knowledge of the target situation. Thus, track maintenance has the job of establishing when the next data point must be obtained, and taking the steps required to obtain it. The minimum rate is that required to hold the target.

Obviously, the track-maintenance problem has some of the time-critical aspects of the transition-to-track problem. The difference is that maintenance only requires the resource commitment on a dwell-by-dwell basis to do its job; transition requires that resource be committed to a number of dwells in sequence to do its present job. The major difference is that if something is wrong during maintenance, a single dwell can be lost; whereas in transition, a sequence of dwells can be lost. As we will see, it is the allocation of critical resources which is the driving force in the computer program design.

The processes described up to this point imply some form of *a priori* tasking of the system. Implicitly, a search doctrine determines what will be searched on a continuing basis, and some form of tactical doctrine will determine data rates on targets in track. Since these processes are in support of an overall mission, with identifiable users, this situation is subject to change. Such change can arise for any one of a number of reasons. One of these is the possibility that the targets seen will exhibit unexpected behaviour. Another reason is that the ultimate user can have other sources of data, and might want to task the radar system on this basis. Thus, the users can call for special search or track requirements which are outside of the currently employed operating doctrine. Functionally, this expands the scope of the search-and-detect and transition-and-track maintenance functions. It also leads to a multi-user operation of the system and the need to establish priorities to resolve conflicts over resource allocations.

Bulk data handling and multiprogramming

The radar system represents a resource which must be allocated on a priority basis. The resource can be described in many ways. One way is to consider the radar power and dwell time associated with the radar hardware, and the processing time and computer memory associated with the radar controller.

Each dwell commits the radar to a transmission of energy, and to staying in the dwell position long enough to process targets out to maximum range. The radar time resource is tied to the second factor, and thus to target range. The energy required in the transmission can be a function both of target maximum range, function of the dwell, and, possibly, past behavior of the target. In general, the energy transmitted is related to dwell function and tactical conditions. It is not directly determined by target range. Thus, the radar resource of time becomes more tied up with long-range targets, while power becomes more tied up with tactical functions. Localized interference may require an increase in power to maintain track data quality. In summary, long range targets in a difficult environmental situation are most demanding of radar resource.

The data processing limitations arise on an entirely different basis. The amount of processing time per target dwell will, in general, be independent of its range. The amount of computer memory needed to support a target is also independent of target range and signal-to-noise ratio. Thus, the way to approach the saturation limit of the computer is to input many data points/units time. This ties up the processor and the memory of the controller.

Note that this limiting condition may not necessarily tax the radar. For example, if we had to track a large number of short-range (large-signal-return) targets, this would imply modest power and minimal radar time. This represents a relatively undemanding problem for the radar. From the viewpoint of the computer, it represents a saturation situation—especially if the large number of returns are associated with many targets. Thus, radar system saturation can come about in many ways. It is extremely important that system performance stay at maximum level when saturation occurs—both in the radar and in its controller. This implies some form of priority system which is self-protective.

The reason for our concern about saturation is that one can only design reasonably for likely peak conditions. This is done while recognizing that extreme peaks can occur and, when they do, some means must be provided for averaging out the impact of the extreme demand. In general, this will be done by deferring tasks which are not as time critical. There is no inherent problem as far as the radar is concerned. Radar power demands can be constrained by separating the exeuction of

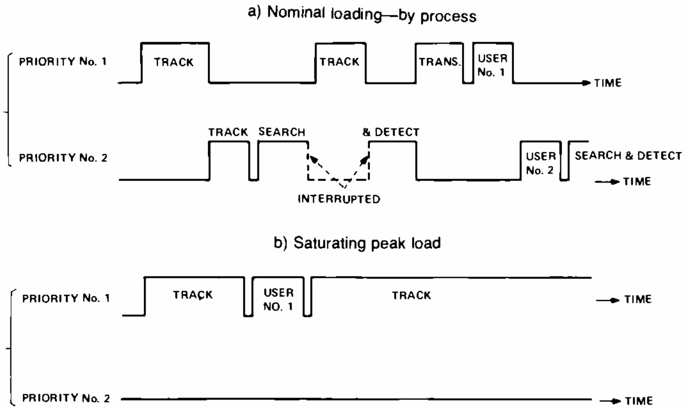

Fig. 5—Sample processing sequences.

high-power-demand dwells. Radar time is self constraining—there is no way to use up more than we have. The computer resources of processing time and memory represent somewhat different problems.

The problem of memory is basically tied to the number of targets that can be handled. For a given system, a ceiling exists on target capacity, based on a given memory resource. In the case of an extreme load, where the memory is inadequate to support the task, low priority targets must be dropped until file space becomes available. This requires a priority scheme for file management.

The problem of processing time management is, conceptually, more difficult. Again, if an extreme peak occurs, low priority processing tasks must be dropped temporarily to accommodate the critical tasks. In a real-time system, we must be sure that the highest priority jobs can be accomplished on a timely basis. In general, this type of situation comes about when a number of high priority targets enter the system in a short period of time. The entry of a number of targets into high-data-rate tracking in a short interval, for example, can produce this situation. Likewise, the detection of a number of new targets, which demand time-ciritical transition-to-track, can produce this peak situation.

The processing concept must allow the various processes to progress in the machine in parallel and, when peak conditions arise, the less critical processes are held in abeyance until the critical ones are done. Thus, if the processing alternates between search-and-detect and track maintenance during a period of moderate load, the machine may switch over to tracking only if a priority loading arises.

The processing must be capable of switching from doing a number of tasks to doing only high priority ones. It must be capable of responding to these transient peak loads in a timely manner, without throwing away the results of partially-completed lower-priority jobs. Furthermore, it must be capable of handling these problems efficiently relative to the amount of processing effected per unit time. These are the problems that drive the system design of the computer program.

The way that the system handles a mix of functional priorities and target priorities is illustrated in Figure 5. Normally, top priority functions occupy only a limited amount of the processing time. Normally lower priority targets can also be handled. The approach for handling lower priority functions is to do them as time permits. Furthermore, to minimize delays, some of the lower priority processes can be segmented so that they can be stopped at a convenient point and then resumed when the high priority task is completed. For the case of the saturating load, operation on low priority tasks can be suspended until the peak load has tapered.

The preceding discussion has shown that the requirement to handle different processes, with different priority levels, can lead to a processor being multiplexed between different jobs. *Multiprogramming* is the name given to the technique by which two or more separable computer programs may be allowed to execute within a processor before any one program is complete. In Fig. 5 the search-and-detect function was interrupted by a higher priority track function. When this was completed, the search-and-detection process continued to completion. It is clear that some means is required to recognize the presence of a high priority processing requirement, terminate the present effort, initiate the higher priority action, etc. This is done by an *executive* or supervisory program. It must handle the task of multiplexing control of the machine among various processing elements—on a priority basis. It must be capable of interrupting on-going processing when a higher priority event occurs. In general, it must be able to handle a heirarchy of different priority levels. Some of the basic features that characterize the so-called "third generation" computer systems are: the multiplexing of resources as exemplified by multiprogramming, the requirement to handle multi-level priority interrupts with automatic allocation of resources, and the ability to multiplex efficiently among a number of users.[4,5,6]

If the executive program is required to handle calling up different processes, on a priority basis, then the system must pay a price to do this. The price involves the time required to bring one process to an orderly stop, and then to start the higher priority process. The time required by the executive program to do these operations is overhead. The processing involved relates to computer resource handling, rather than getting any particular task done. Since the time for executive actions is, in general, not insignificant compared to the time required to get a single data point processed, steps must be taken to minimize the overhead.

The problem of efficiently handling data can be seen readily in the saturating peak load case, depicted in Fig. 5b. Here we have a sequence of high priority processing requirements. We also have a real-time constraint on the system operation. To illustrate the problem, let us consider two ways of handling these high priority requests. The first will be to process requests as they arise. The other way will be to accumulate requests and batch process. The number of requests that can be accumulated must be limited so that the resultant commands are available at the required time. This is acceptable since the real-time constraints can be satisfied, using lower executive overhead. This is illustrated in Fig. 6.

As we can see from Fig. 6, the basis for bulk handling of data is that the time to process and execute a track request is less than the time between data samples. Thus, data can be processed in a timely manner with a reduced amount of executive action. The basic reason for this is that there is inherently no difference in processing a list of requests or a single request (a list of one). In both cases, the processing must start by referring to data that must be handled.

The way that the processing requirements are converted into a structure of program segments (or modules) is very much dependent on how we handle the time-critical, peak-load problem just mentioned. The events requiring the most rapid response must be identified. Since, in general, this response time to a request will be longer than the processing time, bulk handling will be possible. The number of targets/requests that can be handled as a group depends on the minimum response time.

Although Fig. 6 illustrates the executive overhead problem, it does not show how to make full use of either the radar's execution time or the radar controller's processing time. In the case of the radar, its time should be spent in a continuous series of transmission/reception dwells. In the case of the controller, processing should be occurring continuously in a high load situation. The way to achieve this full utilization of resources is depicted in Fig. 7.

A group of commands must be available before the radar gets done executing its present sequence of dwells, if continuous radar operation is to be obtained. Thus, generating future commands must occur in the period that the radar is executing the present set of dwells. In addition, the data from the last sequence of dwells must be processed at this time. As Fig. 7 shows, during the interval of the $(N-1)_{st}$ sequence of dwell executions, we must process the returns from the N^{th} sequence and then generate the commands for the $(N+2)_{nd}$ sequence. If this sequence is not followed, the system will be unable to handle its real-time problem.

The system must process the last batch of received data, the N^{th}, prior to generating the next set of commands, the $(N+2)^{nd}$. In the case of tracking, the data from the N^{th} set is merged with past data so that a best estimate can be made of where to command the beam for dwell $(N+2)$. The length of time the radar spends executing any dwell sequence must exceed the time it takes to process the returns from a sequence and generate the next set of commands. Thus, the processing time for commanding the radar and processing its returns cannot exceed the radar execution time. If it does, then commands may be delayed and critical events will be delayed.

Thus, there are three packets of time associated with the process. These are the times for command generation, radar execution, and return processing.

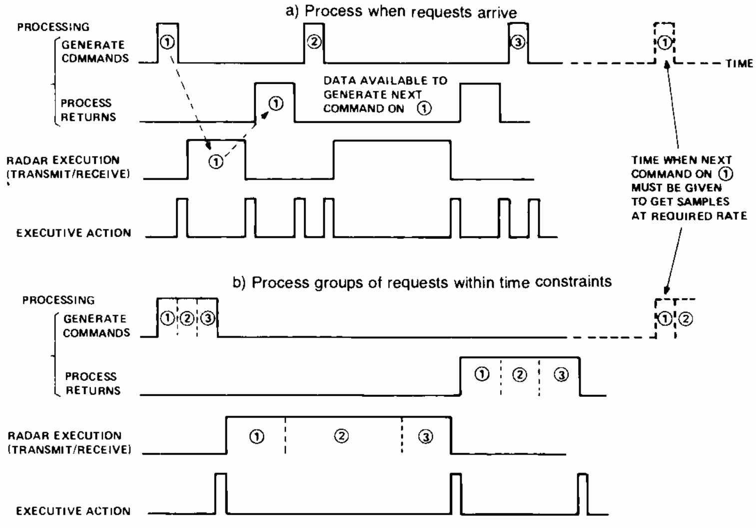

Fig. 6—Alternate ways of handling high priority requests.

Since radar execution times are set, as are the number of executions required per packet, the question that arises is—can the processing for command generation and return processing be done, in the remaining time. Implicit in the way this question has been stated is the assumption of a computer hardware configuration. Actually, the basic question is how to trade off between hardware and software in effecting a solution, if there is a processing-overload problem.

The hardware aspect of a solution to the problem, in the limit, could call for another machine with more processing capability. Lesser hardware solutions could call for replacing certain processing, done by the general-purpose computer, with special hardware. The hardware/software trade-offs must result in a system that can handle the peak real-time problem. This can be done by suitably taking into account the fact that tasks which are not time critical can be deferred in a peak situation.

The handling of past returns and future commands must be done on a priority basis to avoid delays on critical targets. This is the method for operating when the system tasking exceeds its capability. In general, this type of situation represents an extreme case. In normal operation, one would expect to handle all of the lower priority tasks as well. These can be initiated when they become the highest priority tasks remaining. This is illustrated in Fig. 7, for tasks A and B. Such tasks might involve routine search or communicating with a noncritical data user.

Lower priority tasks must be done when time permits. However, they cannot run so long that high priority tasks are unduly delayed. Thus, some method must be provided for segmenting this processing. Two methods are possible. The first involves pre-emption of control by a higher priority task as soon as it arises. This requires that the present task be put aside in such a way that it can be resumed when time permits. An alternate method, time slicing, breaks all lower priority jobs into non-preemptable segments, or modules. Stringent bounds must be put on the

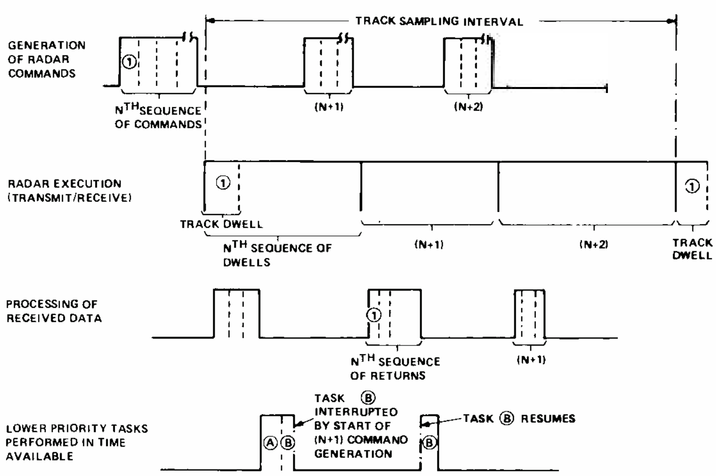

Fig. 7—Multiprogramming for full processor utilization and continuous radar operation.

execution times of these modules to avoid excessive delays in the transfer of control to the time-critical tasks. The lower priority tasks could be sliced into too many pieces, resulting in short delays, but high executive overhead. The choice of preemption, or time slicing, is a basic problem which will be answered as the software system design is developed.

A number of questions have been raised as to how the processing will have to be segmented to handle real time operation in a varying load situation. To answer these questions, we must allocate the processing requirements (of Fig. 4) to processing modules. This is the task of the software architect.

The next two sections will show how the functional processing requirements flow into requirements on blocks of data processing. Following this, these blocks will be consolidated into a multiprogram structure. This will define the software architecture, the basic requirements of executive control, and the type of data base structure needed to make it work.

Further definition of the parallel processes

The four functional processes that we have considered—search and detect, transition-to-track, track maintenance, and user services—have a number of processing requirements in common. To define the data processing system, we must first break down each functional process into its own processing flow. Following this, we will consolidate common requirements. Thus, the task of commanding a dwell execution can be done by one processing module, regardless of the function of the dwell. We shall now consider each process with the view of identifying common processing elements.

Search-and-detect processes

The search-and-detect processes are shown in Fig. 8a. The search part of the process requires that a sequence of radar com nands be generated that will allow a specified volume of space to be searched at a specified rate. The extent of this volume and the search rate are, in general, doctrinal inputs. Conceptually, there is a list of beam coordinates which must be transferred as radar orders, at the required rate. Practically, it may be more desirable to generate the list as required.

To further define each search dwell, it is necessary to specify the transmitted waveform and the length of the dwell period. In general, the amount of transmitted energy in a dwell depends on the maximum range required. However, it may vary with tactical factors as well. Thus, the transmitted waveform, as well as the maximum range, must be established on a doctrinal basis for the various parts of the radar coverage. Once the angular coordinates of a dwell have been generated, doctrine ties in waveform and dwell interval. Other parameters, such as transmitted frequency, detection thresholds, receiver gain-control settings, etc., can also be tied to the dwell at this point. In effect, a completely described dwell sequence is available—ready for scheduling. It must be recognized that the term "completely described dwell sequence" means that all of the command information necessary to set up and control the radar hardware has been identified.

The scheduling of the event requires that a time be assigned for the execution of the dwell by the radar. The time assignments should allow the desired volumetric search rate to be realized. Ideally, the system will generate the beam list at the same rate that we wish to scan, and the execution times will be assigned directly. As the search generator adds a new beam to the list, a time would be assigned. Unfortunately, this approach could only be used in a system dedicated to do search. Since other functions, such as track and transit-to-track, must also be handled, scheduling conflicts can arise. Because these other functions are more timeciritical than search, they would have higher priority in the case of a scheduling conflict.

It is clear that events which want to be executed at approximately the same time must be examined on a priority basis, and execution times must be assigned accordingly. Because of this, the short term average search rate may fluctuate about the desired value. To a first approximation, the scheduling of radar time is done on a task priority basis. There are, however, other resources whose management has a direct impact on the scheduling process. These are computer processing time and the management of radar power. Clearly, one would not shcedule an event, regardless of its priority, if the resultant processing requirement or power demand pushes the system beyond its capability. Conceptually, the event scheduling recognizes all these constraints and schedules accordingly.

In practice, there are many ways of achieving these scheduling goals. These are, of course, problem dependent. The type of solution depends on the degree to which the various resource constraints occur simultaneously. In the case where radar time and power dominate, one can assign time and power on a priority basis.[7] In the case where both radar time and processing time are simultaneously constrictive, it may be necessary to allocate the scheduling task to a higher authority—the executive program itself.[8] For the purpose of this paper, we will assume that the radar constraints and processing are handled separately. In this intermediate situation, event scheduling is radar-resource oriented. Processing-resource limitations are handled in an equivalent manner. The data resulting from a priority command may have to be separated on a priority basis, so that processing load can be limited; this is treated in the next section.

Having managed event scheduling to handle the event-priority problem and the radar-power-management problem, a list of events is available for commanding the radar. The process of commanding the radar involves the formatting of the data in a form suitable for communications, and then initiating of these communications. Suitable identification must be tied to the commands so that when the results of command execution are sent back, the appropriate actions can be taken. The radar commands are executed at the time designated in the transmitted message. Afterwards, any detections that have resulted are communicated to the controller for subsequent processing.

Since the processes of initiating and maintaining track are very demanding of system resources, it is extremely important to exclude detections which are of no interest to the system. A large part of this problem is handled in the signal processor where signals due to noise, interference, clutter, etc., are excluded by single dwell processing. In addition, areas where spurious signal continuously arise can be blanked out by operator/user actions which inhibit automatic detections in troublesome regions. Thus, detections which are communicated to the computer are likely to be targets of interest. However, even these can present a problem. It is possible to redetect a target which has already been acted on. This can lead to initiating a costly sequence of actions which can result in more than one track file being set up

Cabling designs for phased arrays

I. D. Kruger | L. F. Jurkiewicz

The ribbon-cabling system used for the AEGIS phased array provides minimum cable bulk, complete EMI shielding, rugged mechanical design, repeatable electrical characteristics, and ease of assembly and maintenance. The ribbon cables are 0.040-inch thick and come in widths up to 2½ inches. Their terminations are molded connectors that can be grouped in a three-tier arrangement, with cable branching accomplished by a unique matrix-welding technique.

For the AEGIS program, the Missile and Surface Radar Division has produced a phased-array antenna representing the latest state of the production art.

For the array cabling system to keep pace with the required production techniques being advanced in other component areas (*e.g.*, ferrite phase shifters, multilayer distribution boards, strip-line RF power dividers, and dip-brazed horn element clusters) new cabling technology application was necessary. Each array module requires cabling for 32 phase shifters, 38 twisted-pair inputs and 5 DC voltage leads. When the compliment of 140 array modules are considered and phase shifters, monitoring circuits, and shielding circuits are added—some 23,000 individual wires are being distributed throughout the array.

The first attempts were to stay with conventional, individually shielded, twisted-pair leads as a distribution method—the approach used for the experimental subarrays. This technique had the advantage of economy in cable harness manufacture. However, the sheer bulk of the wire and connecting devices and the necessity for completing the thousands of connections reliably during the final assembly operations forced the examination of other techniques.

The bulk of harnesses and connectors, in itself, would not be a valid reason for departing from established approaches, if it were not for the space and access problems associated with production phased arrays. Rear access to all line-replaceable components from within the ship's deckhouse is mandatory for maintenance of the array. The phased array principle causes phase shifters and elements to be spaced on a precise repeated configuration within the confines of a rigid aluminum welded structure. Furthermore, the array modules are individually fed by waveguide, self-duplexing directional couplers that consume a considerable portion of the available space, particularly when disconnect flanges are considered. Yet, driver-board nests and receiver phase shifters must be accessible from within the array, so a clear access space must be left which further reduces the available volume.

Thus, it becomes mandatory to limit cabling harness size to the very minimum and to reduce or eliminate connecting devices and junction boxes.

The requirements for the cable harness system are then reduced to an approach providing:

Minimum cable bulk;
Few or no connectors;
Completely shielded cables and connectors for electromagnetic-interference protection; and
Rugged mechanical design to withstand assembly handling stresses and meet shipboard conditions.

Fortunately, developments in cabling techniques had been going forward during the 1960's, not necessarily for application to phased arrays, but motivated by the requirements listed above for other electronic applications. In military as well as commercial applications, packaging constraints were forcing an increase in the wire-to-harness-volume ratio.

AEGIS cabling approach

The ribbon-cable and integral connector-as-a-junction-box technique selected for the AEGIS phased array provided a cable system meeting the required needs. This approach features

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conductors of silver-plated-copper strips, 0.003×0.020-inch cross-section on 0.050-inch centers, laminated into a dielectric base and shielded with 0.0015 inch copper foil. The ribbons are machine laminated to close tolerances, are 0.040-inch thick, and come in any desired widths up to 2½ inches. The Army had initiated connector specifications (MIL-E-55544), providing 0.100-inch-thick and 2⅝-inch-wide connector inserts that terminate the ribbons by a special welding process to a unique bend-proof pin-and-socket combination. The molded connector inserts can be grouped into a three-tier arrangement, as further described herein. By this approach, analog signals from one cabling harness source can be combined with digital-logic signals from another harness grouping and DC power from another group at the three-tier shielded receptacle.

The ribbon cable approach also offered an additional unique connecting feature: main-harness to individual-array-module branching could be accomplished using a matrix-welding technique. This process elminated the need for exposing connecting points for wire wrap or solder connections. The matrix welding is performed by a patented "flex weld" process perfected by the Ansley Corporation and licensed for general use to a number of ribbon cable manufactures. The method employs a controlled-energy release to the weld when the applied pressure reaches a prescribed level. The weld tips are preheated and penetrate the dielectric laminate containing the conductor strips so that welding is actually accomplished in an oxidation free environment under the dielectric melt. When completed, the ribbon-cable matrix connections are still protected by the dielectric and outer shield, and an additional potting compound is applied for strain relief. The joint is only four times greater in volume than the original ribbon-cable matrix section.

Electrical characteristics

The ribbon-cable configuration allows closely controlled electrical-transmission-line characteristics to be established and maintained. Conductor spacing can be accurately maintained relative to the shield and adjoining conductors, and the dielectric can be chosen for proper capacitance. Analog and digital signal attenuation in the array must be controlled to insure proper phasing of the drivers.

Table I—Critical signal and cable characteristics.

Analog signal characteristics	
Risetime:	0.75μs
Falltime:	0.75μs
Pulse width:	10μs
Pulse amplitude:	30 levels from 0 to 15 V
Frequency:	5 kHz
Digital signal characteristics	
Risetime:	10 ns
Pulse duration:	3 μs
Pulse amplitude:	0 to 0.25 volts
Electrical characteristics of ribbon cable for analog/digital-signal distribution	
Impedance:	110 ± 15 ohms
Capacitance:	17 ± 3 pF/ft
Propagation delay (analog signals):	1.8 ± 0.1 ns/ft per foot
resistance:	0.1 ohms/ft (± 15%) at 20°C (equivalent #30 wire)
Crosstalk (analog):	15 mV (max.) settled to adjacent pairs
Crosstalk (digital):	15 mV (max.) settled
Shielding:	70 dB attenuation to electric fields and plane waves between 14 kHz and 10 GHz
Branching (analog):	Up to 10 loads, at 10 kilohm/loads
Branching (digital):	Up to 5 loads, at 18 kilohm and 15 pF/load

H. Inacker and L. Henderson of the Signal Processing group at M&SR were able to analyze the system to determine the required ribbon-cable impedance and delay characteristics and prescribe testing procedures. Table I summarizes these signal requirements and lists the electrical characteristics of the cable. Early tests on experimental lengths of the ribbon cable proved that the signals could be properly distributed to the array modules, and the final testing of production cables has also confirmed the design.

Electrical distribtuion

The input and output connections to the phased-array antenna are as shown in Fig. 1. Except for coaxial and waveguide interfaces, signal inputs come through high-density connectors and multiple-pair shielded cables. The discussion that follows mainly concerns the use of ribbon cables with welded junctions for branching of signals from main trunk lines to 140 array modules and 68 receive phaser units. The DC bus distribution throughout the array also imposed several challenges, leading to development of a unique laminated bus which is also described.

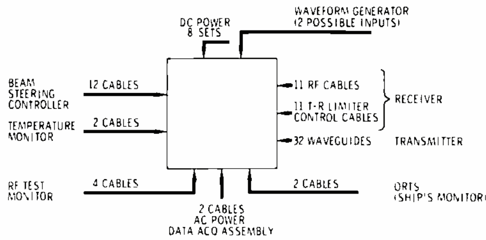

Fig. 1—AEGIS multifunction-array-radar antenna inputs and outputs.

Array modules and receive phaser assemblies

The major electrical distribution problem within the antenna involves routing signals and power through the 141-pin connectors (3 layers) to each of the 140 array modules and through the 51-pin connectors (3 layers) to each of the corresponding receive-phaser assemblies. Fig. 2 shows the relative locations of the array (face) modules within the antenna structure, and Fig. 3 shows the configuration of a basic array module. There is one receive-phaser assembly required for every two array modules. These receive phasers are located behind their respective array modules on the antenna structure. Fig. 4 shows the functional grouping of the array modules, receive phasers, and associated components that make up a single typical subarray.

RF subarray

The array module can be thought of as the basic distribution unit for control signals. However, for RF purposes, the array module is part of a subarray: two array modules are combined for receive-only operation and four array modules are combined for transmit-only. One receive phaser assembly is associated with each two array modules as shown in Fig. 4.

Array-module inputs

Phasers (coarse phase shifters) at the array-module face shift the phase of incoming or outgoing RF energy. This phase shift determines the antenna directivity (coarse steering). The inputs to the array module needed to achieve coarse steering are defined in Table II.

Since the array modules are identical, a problem arose when the modules had to be installed in normal and inverted positions. If all modules shared the same signals, phaser signal locations

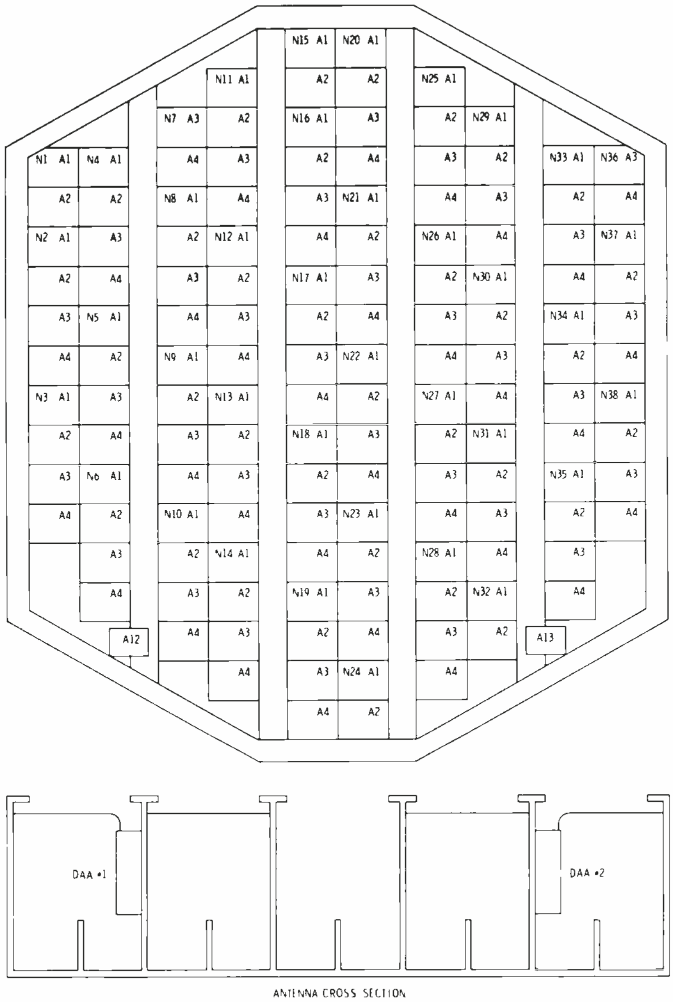

Fig. 2—Layout of array modules on AEGIS phased-array antenna (view from inside the ship's deckhouse).

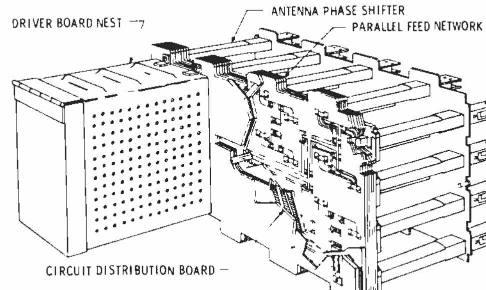

Fig. 3—Typical element array module.

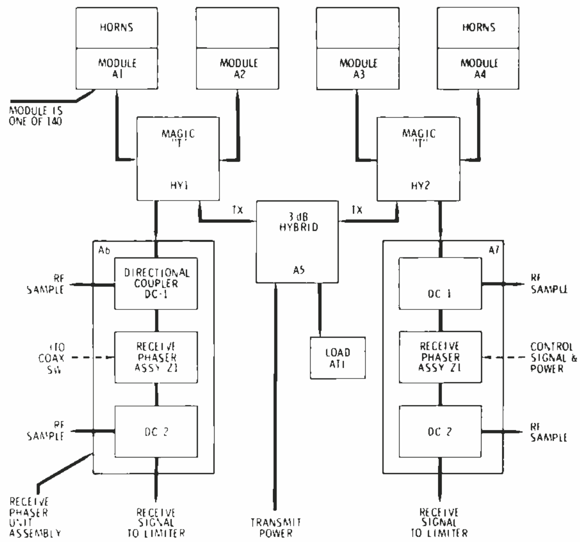

Fig. 4—Typical grouping of RF subarray modules.

would thus be transposed in an inverted module. This problem was overcome by reversing ribbon inputs and pairs to P1A and P1B of each inverted module (see Fig. 5). A staggered (or jagged) weld-takeoff pattern was required, and care had to be exerted that signal and signal-return lines were not reversed.

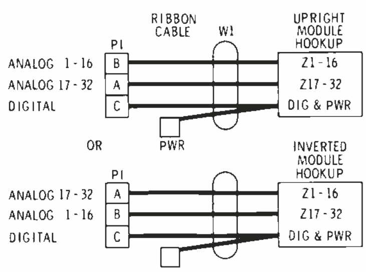

Fig. 5—Array module inputs.

by reversing the gates A and B in the ribbon cabling distribution (see Fig. 6)

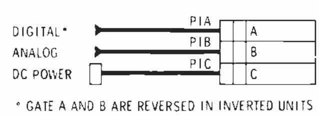

Fig. 6—Receive phaser inputs.

Table II—Array module inputs.

Quantity	Type
32	Analog (pair)
5	Digital (pair)
	• Start gate A
	• Start gate B
	• Clamp gate
	• Reset
	• Driver test strobe
1	Monitor, status (pair)
1	Spare (pair)
5	DC power lines
	± 12 VDC and returns
	± 38 VDC and returns

Notes
1) No more than ten modules get branched analog signals from any one pair of main trunk lines.
2) No more than five modules get branched digital signals from any one pair of main trunk lines.

Receive phaser inputs

For every two array modules, one receive phaser assembly is used, as shown in Fig. 4. One phase shifter and one circuit board are the main components of the receive phaser.

The receive phasers provide fine steering; Table III shows the required inputs. A problem arose when it was desired to use the same part number in various locations where the direction of RF was reversed. This was solved

Table III—Receive phaser inputs.

Quantity	Type
1	Analog (pair)
5	Digital (pair)
	• Start gate A
	• Start gate B
	• Clamp gate
	• Reset
	• Driver test strobe
1	Monitor, status (pair)
1	Spare (pair)
5	DC power lines
	± 12 VDC and returns
	± 38 VDC and returns

Notes
Analog signals are not shared between units, but Digital signals are shared by as many as five units.

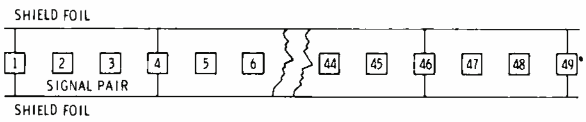

Fig. 7—Analog ribbon cable cross-section.

Analog signals cable

A cross-section of the analog signal ribbon cable (Fig. 7) shows the 49 rectangular conductors and the 0.0015-inch copper foil shield above and below the wires. The shield is tied to the end wires, feeding a 47-pin array module connector wafer.

The conductors are divided into signal pairs, each separated from its neighboring pair by a conductor grounded to the shield system. In general, the grounding is done only at the antenna entry point.

Digital signals cable

A cross-section of the digital signal ribbon cable (Fig. 8) shows the 23 rectangular conductors and the 0.0015-inch copper foil shield above and below. The shield is tied to the end wires.

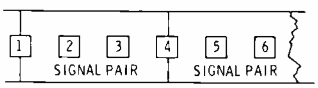

Fig. 8—Digital ribbon cable cross-section.

The conductors are divided into signal pairs. Each pair is separated from its neighboring pair by a conductor grounded to the shield system. Cable shield grounding is done only at the antenna entry point and at the module.

DC power bus

Each array module requires the following DC power:

38-V at 1.1-A average current (7.1-A peak)
+12V at 1-A
−12V at 0.43A

These voltages are provided via laminated low-impedance bus-bar sections, which are made up of +38 V, 38 V return, +12 V, −12 V, and +12 V and −12 V return lines in the forms of ribbons in each encapsulated section (see Fig. 9).

To minimize bus size, but most of all to favor reliability in the event of bus failure, the antenna is divided into eight groups of DC power feeds. Four group inputs enter the left side of the antenna and the other four inputs are at the right side. Each group has capacity of 38 V at 30 A, +12 V at 20 A, and −12 V at 10 A. The problem here was how to keep the +38-V line drop below 0.8 V, even under the pulsed load. Less stringent voltage drop of 2% on the 12-V line was more easily met.

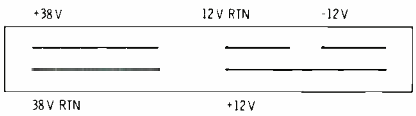

Fig. 9—Typical power bus section.

The power bus shown in Fig. 9 consists of conductive copper strips of cross-section area required to meet voltage drop requirements at specified current characteristic. Thin insulation provides isolation between layers but permits maximum capacitance and minimum inductance. A tight moisture seal is obtained by potting the stack of layers.

Screw terminals on each bus section conveniently allow interconnection of bus sections and power takeoff to modules.

Overload current stresses that could result in bus failures were minimized by limiting the output current of the power supply and fusing the loads. The bus was so designed that short-circuit currents available would not cause damage to the bus.

Simulated electrtrical tests

To verify that cable characteristics were adequate, tests were performed on simulated cables between the antenna and the beam-steering controller, and on cabling within the beam steering controller.

The tests demonstrated that line reflections are well within allowable limits, risetimes and falltimes required can be supported by the transmission lines, and crosstalk limits of 15 mV were not exceeded. Signal integrity was maintained with common mode levels of 2 volts.

Cable installation and selection

From the antenna structure wall to the outside of the receive waveguide and duplexers, a distance of 4 inches is allowed so that free access can be maintained to the driver cards. This then allows an average space of approximately ¼ inch for cabling along the wall for the digital cabling and DC bus and a relatively small additional space for the distribution junction (MIL Connector) close to the receiver phase shifters.

Also the digital cable junctions must be as close to the array module distribution board as possible to comply with electrical-transmission-line-effects requirements. This made it mandatory to locate the distribution junction close to the position indicated. The junction system is shown in Fig. 10. Note the analog signals emerging from the matrix junctions on the rear of array, being grouped with digital signals from the internal vertical run, and the DC bus straps from the main bus on the rear inside flanges. The cabling is collected

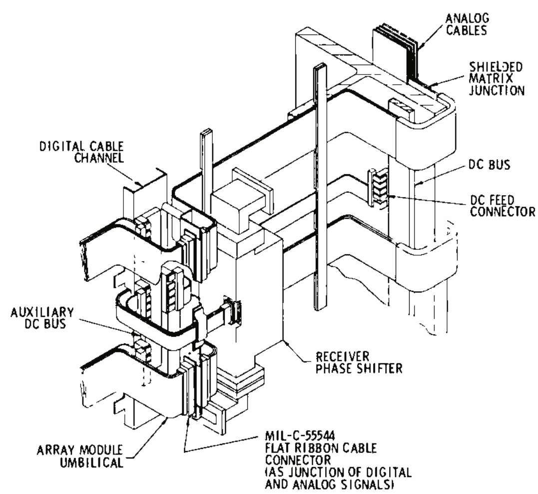

Fig. 10—Ribbon-cable array module and receiver phase shifter junctions.

Table IV—Cable system tradeoff study.

Characteristic	Conventional Shielded Twisted Pair	Twisted Pair in Ribbon Belt	Shielded ribbon cable
Cable volume (in.^{3})	6300	5100	3500
Connector volume (in.^{3})	3500	2900	2200
Separate branching (in.^{3}) device volume	6100 (wire wrap)	6100 (wire wrap)	700 (flex-welded matrix)
Shielding effectiveness	Braided shielding terminated at connector. Branching requires a separate shielded junction housing.	Braided overlay terminated at connector. Branching requires a separate shielded junction housing.	Copper foil terminated at connector. No separate housing required since shield is continuous at Matrix.
Relative final array assembly time	3	3	1
Reliability comparison	Use of wire wrap or soldered. Branching not as reliable as welded.	Use of wire wrap or soldered. Branching not as reliable as welded junction.	Welded. Termination at branches & connectors.
Relative cost	2	3	4

in the three-tier wafer/receptable or "connector as a junction box" in the manner shown. The final objective of conveying the signals and power to the array module distribution board is accomplished by means of the umbilical 3-tier cable run which must be positioned along the channel wall. The array module umbilical cable, in particular, must be constructed with a minimum of volume since severe space restrictions exist at the point of connection of the "magic tees" to the array module, considering allowance of room for disconnect flanges and for the cooling baffle system in this area.

The overall design also requires that the complete array module must be removable for major overhaul, without disturbing the main cable system. The minimal size umbilical emerging from the single connector, as indicated, accomplishes this objective.

The approach of obtaining more volume by movement of the column walls, or "flaring" of the structure could not be considered because of the prohibitive weight increase for the structure, and the prohibitive size and weight increase for the ship's deckhouse. In any event, the front distribution of the umbilical runs must be maintained within the volume as allotted, to comply with the basic array principle of maintaining the element phase shifters on a prescribed, repeated grid for phased-array RF operation.

All of these restraints served to establish the criteria for the choice of cable technique. The effort involved constructing layouts with the minimal cable volume necessary to contain the various systems and to ascertain if the approach could be accommodated within the space. The requirement for shielding was also prevalent throughout all of this effort. That is, adding to the bulk of cable and junction box or connector problem was the necessity to carry a completely shielded and grounded system from the input of the array to the array module distribution board and drivers.

The overall results of the cable tradeoff study are as indicated in Table IV. For the array module umbilical cable, the comparative space consumed by conventional twisted-pair versus shielded ribbon-cable is shown in Fig. 11. Also indicated are the comparative sizes of the connectors. The twisted-pair cable could not be used in this application in the position shown since the cable must not block the air intake to the driver-card nest. Placing such a cable along the structure wall would not be possible considering the access requirements to the input waveguide connection indicated, and the problem of providing an air baffle in this area. The ribbon cable consumes a minimum of volume and satisfies the access requirement as well as allowing removal of the array module for servicing.

Ribbon-cable fabrication

The present state of art in the manufacture of ribbon cables offers a wide variety of configurations and materials, available from a number of manufacturers.

The cable has a high flexibility and would provide long life in applications where chassis removal or other motion is required. For the AEGIS phased-array antenna, the cable remains fixed except for the instance where the array modules are installed or removed, and this amount of flexing is negligible. The cable is highly reliable in comparison with bundled wires. The shield provides improved cut-through and abrasion resistance. All conductors are of the same length, which causes all conductors to share equal stresses, providing higher mechanical strength than round wires. Conductor size is thus reduced to electrical requirements needs and not mechanical requirements.

Assembly time is speeded using the flat-ribbon configuration since the cable is completely preformed to a relatively precise mechanical shape conforming to the structure. The cable electrical characteristics of impedance, capacitance, and inductance are repeatable within close limits for succeeding assemblies, thus reducing their effect on radar performance.

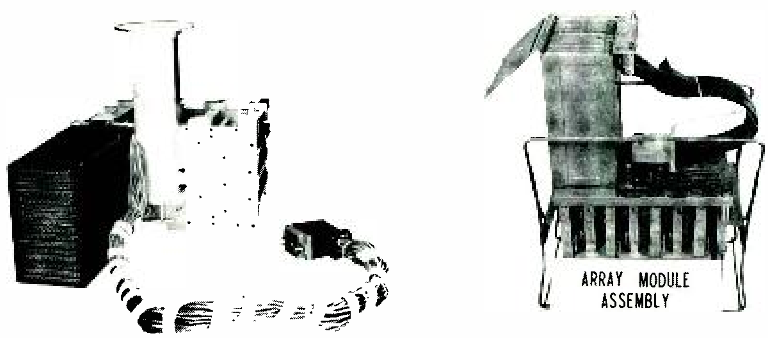

Fig. 11—Comparison of space consumed using twisted-pair cabling (left) and ribbon cabling (right).

For AEGIS, the dielectric supporting the conductors is FEP teflon providing toughness and high temperature resistance for manufacturing operations, potting etc. This material provides means for heat sealing the laminate to the outer copper shield. The teflon, though opaque in thick layers, is still sufficiently transparent to allow the welding junction to be viewed through the optical positioning head when forming matrix welds.

The conductors are silver plated to aid conductivity but also to provide a means for improving the bond strength of matrix welds, and welds to the connecting pins. The silver melts, forming a brazed junction fillet at the weld point under the application of the flex weld process which markedly increases strength of the junction.

The major steps in the manufacture of the ribbon cable are illustrated by Figs. 12 through 17.

Fig. 12—Typical operation in preparation of ribbon cable for mating with the connecting wafer. Shown is a DC power conductor, with the ribbon being connected by weld terminations to a number of parallel wires which will in turn be welded to the connecting pins.

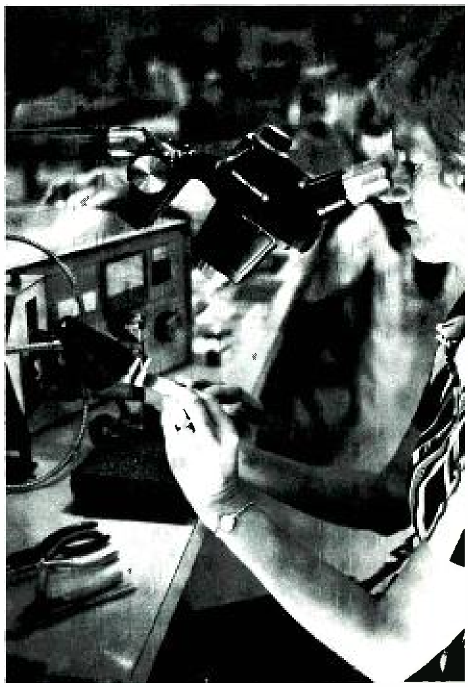

Fig. 13—The normal connection to the wafer and pins is made directly to the laminated ribbon strips using the flex-weld process. In this photo, the operator is viewing the weld junction under the scope for centering. The weld tips are heated and forced through the teflon dielectric which is melted at the junction. Pressure is applied and when the proper joint resistance is obtained, the weld energy is released forming the junction.

Cable assembly

The assembly of the ribbon cables to the antenna is illustrated by Fig. 18, 19, and 20. The assembly shown in Fig. 19 and 20 is repeated on each of the four main vertical flanges of the structure (see Fig. 18). Figs. 19 and 20 also show the digital-cable run under the internal vertical channel, with branches emerging at each array module position to merge with the analog cables at the 3-tier connector. The matrix junctions, with the strain-relief potting, are shown on the rear flange.

The DC bus connection strap is also shown emerging from the rear main bus run to an auxilliary short bus feeding two array-module connectors and the receive phase shifter. As indicated, the receive phase shifter is fed with a ribbon cable of one inch in width terminating in a one inch shielded (MIL-E-55544) connector.

The junction assembly area is located in a relatively small free space behind the driver nest baffle and the vertical receive beam-former. The small volume consumed by the ribbon cable and the flat connectors used made the assembly possible without increasing the depth of structure with attendent increase in weight, deckhouse size, and cable length.

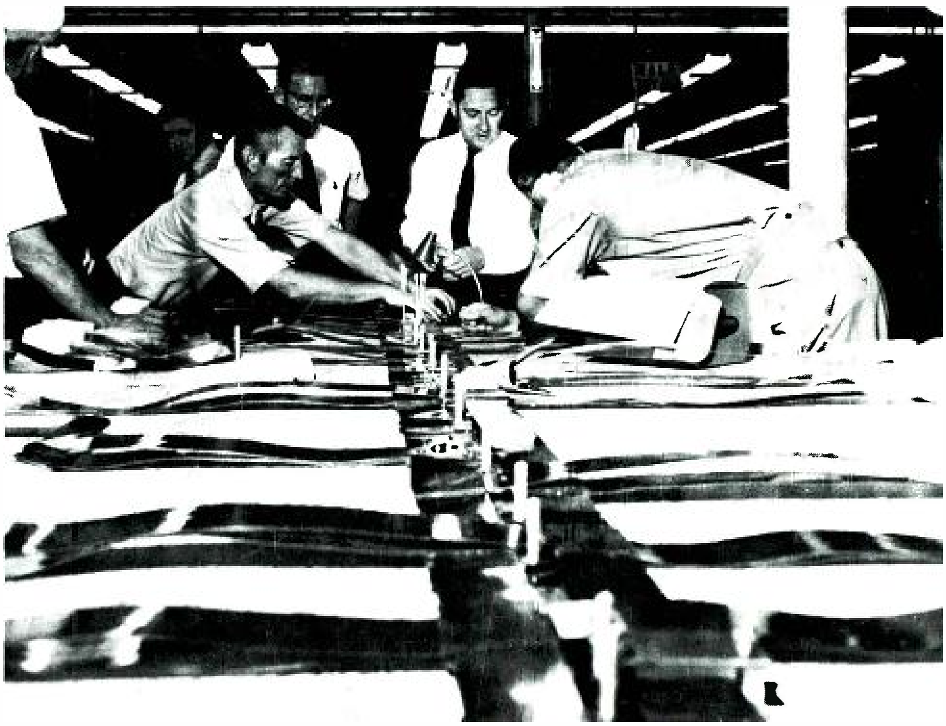

Fig. 17—The completed assembly being readied for shipment. The cable is placed on a plywood board and secured against travel stresses as indicated. The board holds the cable in position for a direct transfer to the rear flanges of the array, with consequent saving in assembly line.

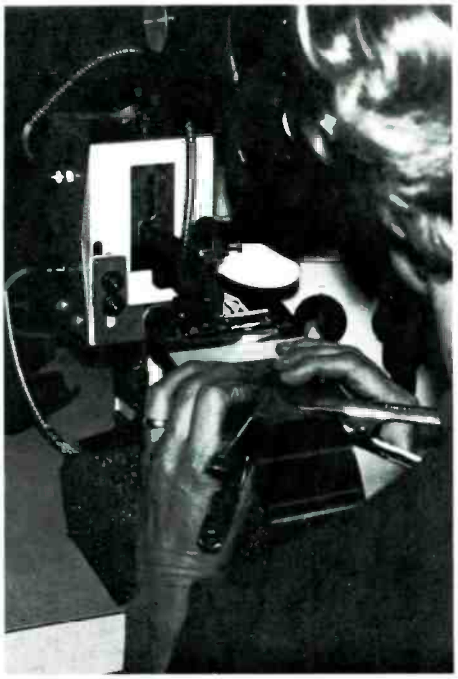

Fig. 14—Another view of the welding process. Here connection is being made to one of the 2½-inch wafer/pin combinations. The wafer has built-in provision for accepting the laminated conductor strips and positioning these under the connecting pins while maintaining all conductors on the 0.05-pitch. Welding is performed through a slot in the wafer which is sealed with an epoxy potting compound after the welding operation.

Fig. 15—The matrix-welding operation showing the ribbon cable with the outer shield stripped back and the weld junctions being performed by the flexweld process. All junctions are later visually and electrically inspected, with 100% of all weld junctions coming under scrutiny.

Fig. 16—The outer shield being placed back in position with a hand-soldering operation being performed to form a continuous shielded junction. The cable is positioned in the tool as shown and is immediately passed through the potting operation to form a final matrix junction with strain relief provisions.

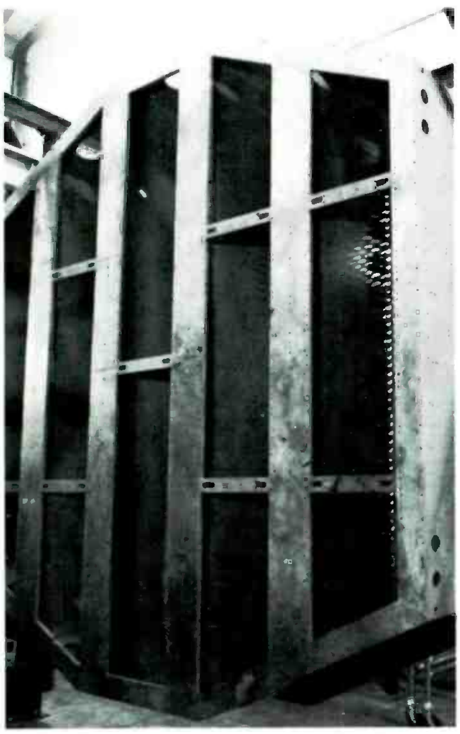

Fig. 18—The structure ready for assembly. Note the four main vertical flanges of the antenna structure.

Fig. 19—Emplacement of the analog cables on the rear flange of one column. The assembly shown is repeated on each of the four main vertical flanges.

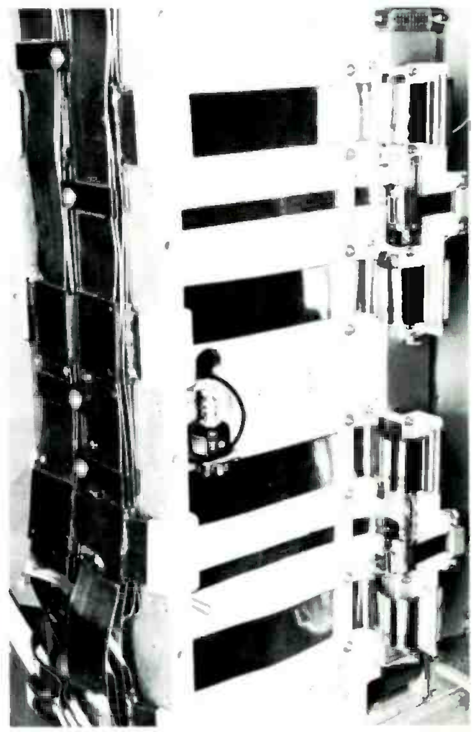

Fig. 20—Close-up view of the junction area where connection to the array module is made. The assembly shown is repeated on each of the four main vertical flanges.

Executive program scheduling for large command and control systems

W. G. Phillips

A large-scale tactical command-and-control system referred to in this paper is designed for shipboard applications and is a complex of radar, weapon-direction, and display subsystems controlled by general-purpose computers. Each of these computers contains tactical and tactical-support programs that are centrally monitored and scheduled by a real-time executive program. The fast reaction time, high firepower, and constant operational availability of such a system requires unprecedented performance by the computer programs that control the system, specifically the executive program. This paper presents the basic methodology for the design of a real-time executive program for such a system, and explores the methods and rationale for the various types of task-scheduling mechanisms.[1]

The program for a computerized command-and-control system is generally a combination of critically time-constrained real-time tasks, which directly control the tactical mission environment, and non-real time tasks, which support the system. This computer program structure is the basis for determining the allocation of the total available processing time for a complete mission cycle.

Timing allocation

Since tactical command-and-control systems (Fig. 1) are triggered by a series of predictable and non-predictable events, the computer-program task allocations must be designed for complete flexibility within the total available processing time period. In the case of predictable event triggers, the design may be simple to the extent of repetitive processing of a single chain of tasks, called a "thread". In the case of unpredictable event triggers, such as special-threat target detections, the design must be more complex to the point of interleaving threads. The process of interleaving presents an interesting timing problem within this type of system because of the requirement that a real-time thread must complete its processing in a predefined critical time period. This time period is frequently a function of the design requirements of the interfacing tactical equipment.

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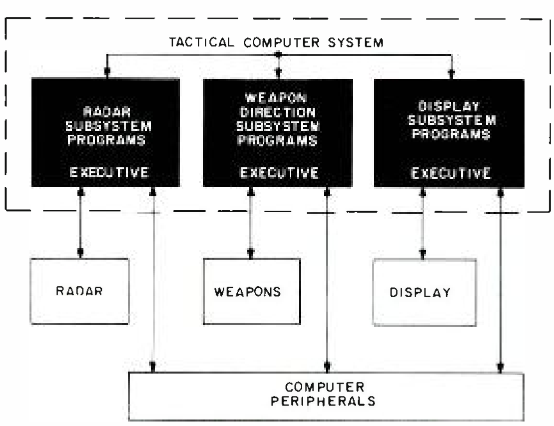
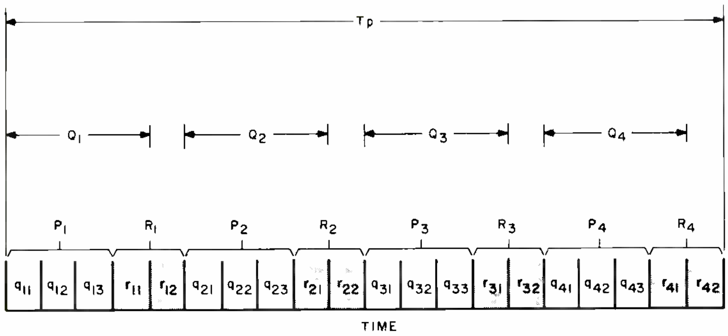


Fig. 1—Command and control computer program complex.



T_p = Total available processing time for a mission cycle

Q_i = Allocation of Critical time period within which real-time thread P_i must be completed

P_i = Processing thread i, consisting of a processing sequence of real-time tasks, q_{ij}.

R_i = Processing thread i, consisting of a processing sequence of non-real time background tasks, r_{ij}.

Fig. 2—Processing time allocation non-interleaved.

Fig. 2 illustrates a processing sequence where the triggering events are predictably separated and therefore the thread allocations (P_i) and their respective critical time periods (Q_i) are predictably separated. The slots which occur between threads (R_i) are available for processing of non-real time tasks. The real-time tasks (q_{ij}), as individual items, must all satisfy their individual time allocations within their respective critical time thread period Q_i. This timing constraint can be represented by the following inequality:

$$Q_i > \sum_j t(q_{ij}) \qquad (1)$$

where $t(q_{ij})$ is the time allocation associated with task q_{ij}.

If the non-real-time tasks are also time constrained to a fixed completion period (T_p), then the general equation for timing allocation within a complete processing sequence (T_p) is:

$$T_p > \sum_i (P_i + R_i) \qquad (2)$$

which describes the inequality to be satisfied by the combination of real-time and non-real time tasks over the total available processing period, T_p. This period represents a complete cycle of tactical events, such as radar-track processing, weapons assignment and firing, and special-threat target processing. The critical time-thread period (Q_i) of Ineq. 1 represents intervals of tactical events, such as radar-target detection, weapons designation, and special-threat target-assignment processing.

An added perturbation to the system-timing allocation is the introduction of the executive program tasks that support the scheduling and dispatching of the system tasks. This additional allocation can be represented by expanding Ineq. 2:

$$T_p > \sum_{ij} [t(q_{ij}) + t(e_{ij})] + \sum_{ik} [t(r_{ik}) + t(e_{ik})] \qquad (3)$$

where $t(e_{ij(ik)})$ is the time allocation associated with task e_{ij} or e_{ik} and $t(r_{ik})$ is the time allocation associated with task r_{ik}.

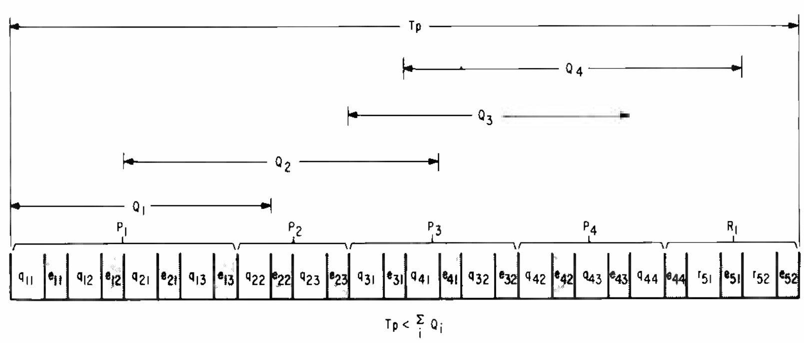
This general inequality must be satisfied for timing allocation over the period T_p; it includes the real-time task times, $t(q_{ij})$; the non-real time task times, $t(r_{ik})$; and the executive task times, $t(e_{ij})$ and $t(e_{ik})$. We can also expand Ineq. 1 for the critical-thread periods (Q_i) to include the executive tasks:

$$Q_i > \sum_{ij} t(q_{ij}) + t(e_{ij}) \qquad (4)$$

It is apparent from Inequalities 3 and 4 that there are many unknowns: in addition to ascertaining the processing-time allocations for the real-time and non-real-time tasks, we must also determine the time expenditures of the executive tasks. This is further complicated by the fact that executive-task durations may vary because of the varying types of services to be performed (such as I/O scheduling), the type of real-time task scheduling (i.e., immediate with or without messages, time delayed, etc.), and the scheduling queue backlogs. Until all of these unknowns are determined, or at least closely predicted, Inequalities 3 and 4 cannot be credibly satisfied.

A practical solution to this problem is to arbitrarily allocate a budget of a fixed percentage of the total available processing time (T_p) to the executive tasks $\Sigma t(e_{ij})$ and $\Sigma t(e_{ik})$. A more precise procedure is to further allocate a fixed percentage of the available critical-thread period Q_i to the executive tasks $\Sigma t(e_{ij})$. A typical allocation, at the beginning of system development, is 10 to 15% for both of these periods. As the development progresses and the task timings become more defined, the terms of the inequalities must be adjusted. This, in fact, is an excellent method for ensuring that the task design is meeting its timing allocations; for if the inequalities fail to be satisfied, the system integrity is compromised, and the system must be redesigned.

Real-time command and control systems differ in complexity. A simple system, with predictably sequenced trigger events, has its real-time-



e_{ij} = PROCESSING TIME ALLOCATION FOR EXECUTIVE TASK ij

Fig. 3—Processing time allocation—interleaved.

thread critical periods (Q_i) allocated somewhat as in Fig. 2, with the required condition that the following inequality be satisfied:

$$T_p > \sum_i Q_i \qquad (5)$$

However, some systems are more complex because of unpredictable sequences of trigger events. These types of systems frequently require that real-time threads overlap each other, but that each thread must still complete processing in its allocated critical period, as illustrated in Fig. 3. This figure shows the critical real-time periods, Q_i, overlapping the non-real time tasks, R_i, naturally being delayed until the completion of all real-time threads. This allocation permits us to then concentrate on the critical real-time periods, Q_i, and to process the low level, R_i, tasks, in a background mode, if and when time is available during T_p. This overlapping (interleaving) process is described by the following inequalities:

$$\sum_i Q_i > T_p \qquad (6)$$

$$Q_i > \sum_j t(q_{ij}) + e_t + \sum t(q) \qquad (7)$$

where e_t represents the total fixed executive overhead time allocated for the period, Q_i, and $t(q)$ represents the tasks interleaved in Q_i.

This type of complex system requires that the executive program, through a scheduling mechanism, manage the interleaving process to ensure that inequalities 3 and 7 remain satisfied during task processing. To accomplish this, the executive-program scheduling mechanism must be designed to manage a dynamic queue based on task priorities and to resolve any timing conflicts between competing tasks across threads, as described by inequality 7.

It is not unusual to encounter system requirements that dictate that the first task within a thread, q_{i1}, (Fig. 3)—and therefore the thread itself—shall be repetitively triggered at some frequency relative to the occurrence of an event; that is, the thread initiates a processing sequence, P_i, (Fig. 3) repeatedly at some frequency after some initial event trigger. This may occur for three general reasons in a command and control system:

1) Periodic interface requirements with time-pulsed radars or other similar equipment.
2) Periodic interface requirements with display consoles, which require refreshed data.
3) Periodic polling of interfacing equipments for input messages.

In the case where a thread is scheduled in constant intervals, relative to a single event (i.e., the triggering event always occurs at the same time within each T_p interval), the thread timing allocations in Fig. 3 are identical for each succeeding T_p interval. However, in complex systems, the possibility exists that some periodic threads will be scheduled some constant frequency after, or possibly before, the occurrence of an unpredictable event. This case will then cause the thread critical allocation times, Q_i, to drift from one T_p period to another, as illustrated in Fig. 4. This drifting would also occur for those cases where a thread was scheduled with a variable frequency.

Let us now summarize the four common types of critical real-time tasks:

1) The dynamic task that must be scheduled strictly according to a priority sequence.
2) A periodic task that must be scheduled repetitively at a fixed frequency relative to a predictable event occurrence.
3) A periodic task that must be scheduled repetitively at a fixed frequency relative to an unpredictable event occurrence.
4) A periodic task that is scheduled repetitively at a variable frequency relative to a predictable event occurrence.

Since a mixture of these type tasks may be required to complete processing within the same critical-thread period and since each task will perform a unique tactical function, a priority scheduling philosophy must be developed, which will ensure the hierarchy of tasks in relation to one another. This is especially true in the case where a periodic task, and possibly its associated thread, is unpredictably triggered while a lower relative priority task is processing. Inequality 7 represents the total time allocated to a complete mix of real-time tasks over a critical processing period, Q_i, assuming, of course, that random-interrupt processing is included in the appropriate allocation; and therefore is the principal timing requirement to be satisfied by the design of the executive scheduling mechanism.

Executive design approach

The executive program, to satisfy the above timing allocations, must provide efficient mechanisms for performing the following functions:

Scheduling critical real-time tasks according to a dynamically changing priority-sensitive environment.
Interleaving processing threads.
Monitoring the processing of all tasks and threads to ensure the critical time periods and total available processing time periods are not violated.

If a unique task program is equivalenced to each timing allocation, q_{ij}, in Fig. 3, we can state the following general priority characteristics of threaded tasks in this type of command and control system:

$$q(L_{i1}) \geq q(L_{i2}) \geq \cdots \geq q(L_{in}) \qquad (8)$$

where $q(L_{ij})$ is the priority of task q_{ij}, and

$$P(L_i) = q(L_{i1}) \qquad (9)$$

where $P(L_i)$ is the priority of thread P_i.

Inequality 8 shows that tasks are always structured within their respective threads in descending priority order,

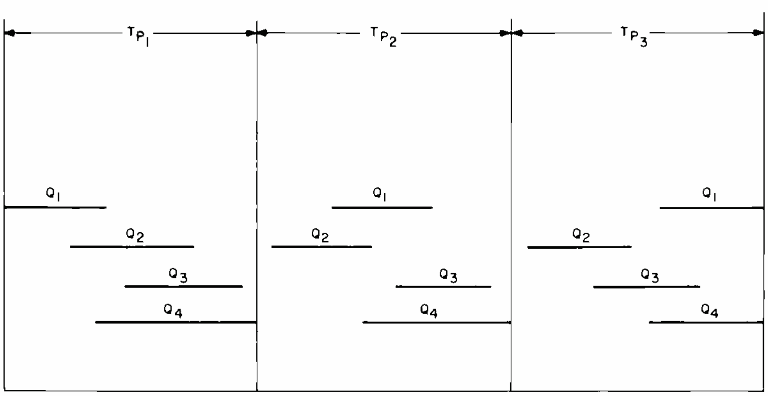


Fig. 4—Drifting critical time periods.

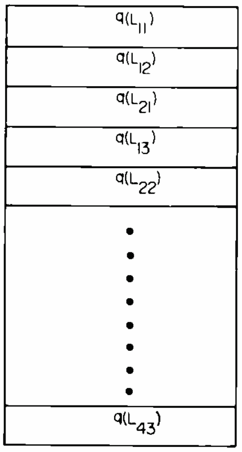


Fig. 5—Single-level queuing model.

i.e., they are not independently dynamic. As established in Eq. 9, the priority of thread P_i is dictated by the priority of its first task, q_{i1}. These characteristics show that the only dynamically changing priorities in the system are those associated with the "lead" task of each thread; thus, a simple queuing model can be structured to satisfy this scheduling requirement. Fig. 5 illustrates a standard queue structure in which the tasks, q_{ij} (Fig. 3), are randomly dispersed and are serviced by the executive according to their respective priorities. This queuing model will satisfy the task-scheduling requirements of our system, but will not provide the executive with an adequate mechanism to monitor the thread critical time periods for possible overrun conditions.

An approach to provide an executive time-monitoring capability is to further structure the basic queue with time bounds which correspond to the *critical thread periods*, Q_i, illustrated in Fig. 3. The priorities of these time bounds could then be established according to the priorities of the threads they represent, P_i (Fig. 3). All of the tasks associated with a thread critical period, *including interleaved thread tools*, would then be contained within the corresponding thread priority level in the queue, as shown in Fig. 6. This structuring is possible because of the characteristics described by Eqs. 8 and 9. If we now associate an overrun time parameter with each thread level and with each task, it is possible to predict the probability of achieving the required critical period constraint of Q_i (Eq. 7) and T_p (Eq. 3). If an overrun occurs at the thread level—i.e., Q_i is not satisfied—the only recourse is to transfer to some error-processing state. However, it is simple to predict the varying probability of achieving Q_i by carefully monitoring each intra-thread task for an overrun condition. If a timing problem should arise, the executive program has the capability to temporarily suspend the interleaved Q_{i+j} tasks (Fig. 6), which are processing within the $P(L_i)$ thread priority level, in favor of keeping the $P(L_i)$ tasks within their time constraint, Q_i. This is a simple process whereby the tasks, which are interleaved, are simply moved to their normal thread priority level, thereby allocating the entire critical period, Q_i, to q_i tasks only.

For example, task q_{41} (Fig. 6) would be moved out of the thread critical period, Q_3, and into the thread critical period, Q_4, if task q_3, was in a time overrun condition, which jeopardized the completion of $P(L_3)$ tasks within the thread critical period, Q_3. This methodology is possible because of the common priority structure of these type systems, as described in the following inequality:

$$q(L_i) \geq q(L_{i+j}) \qquad (10)$$

for a thread critical period, Q_i.

Inequality 10 states that interleaved tasks (q_{i+j}) have a priority less than or equal to non-interleaved tasks, (q_i), within the same thread critical time period (Q_i). This is likely to be the case, except in the rare instances where a high priority task may be dynamically interleaved into a thread period, in which case the high priority task would be processed in priority order within the thread and the lower priority non-interleaved tasks could overrun their critical thread period. This requires a tradeoff on the part of the system analyst/designer of the tactical priority structure to determine whether it is more important to satisfy a critical thread period or immediately process a high priority task.

Under certain circumstances, a complete thread of tasks, may require immediate processing because of the arrival of some unpredictable high priority event. If the priority of this event is higher than the thread priority level of the currently processing task, the executive program will initiate a special suspension process called "preemption". It is intuitively obvious from the previous scheduling queue structure discussions that a preemption could occur as the direct result of 1) the current processing task requesting the scheduling of a higher-thread-level successor, or 2) an external interrupt from a decrementing clock or an input/output operation. The most frequent cause for preemption is the arrival of an external interrupt from another subsystem announcing "special-threat" target detections. This event arrival will cause any processing task, and its' associated thread, to be suspended during normal executive interrupt processing, and the appropriate higher priority event processing thread will be placed into its appropriate priority position in the scheduling queue. The executive will then examine the scheduling queue in search of the highest priority pending task (which in most cases would be the suspended task). In this hypothetical case, how-

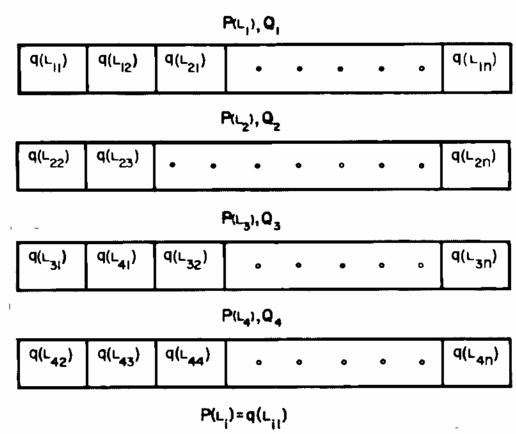


Fig. 6—Multiple-level queue structure.

ever, the highest priority pending task is the new arrival. This special case causes the executive to preempt the previously interrupted thread/task and save all registers and volatile data-base contents. Processing control is then transferred to the new candidate. The executive then increases the priority of the preempted task to the highest within its predefined thread level. This procedure ensures that the preempted task is "awakened" prior to any other pending candidate selection in its (the preempted tasks) thread priority level. It should be interjected here that this type of system does not lend itself to a multiprogrammed environment with fixed quantum periods, because tactical real-time solutions require fixed sequential complete processing, both at the task and thread level.

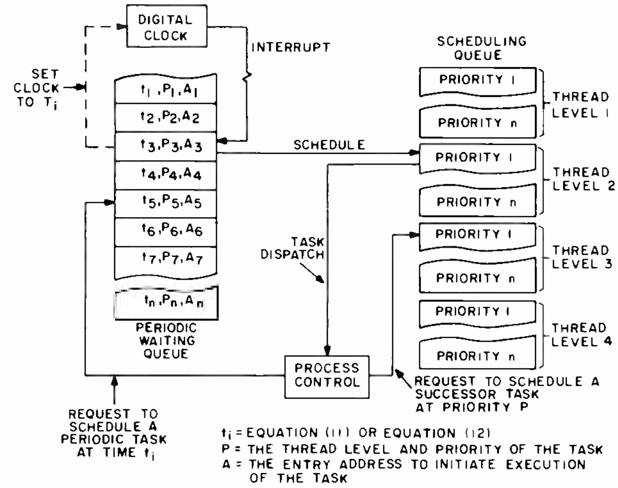


Fig. 7—Executive scheduling philosophy.

This scheduling logic and queuing model enables the executive program to manage the critical processing periods, T_p (Eq. 3) and Q_i (Eq. 7); to provide instantaneous response to special high priority events while maintaining the system integrity; and to permit task interleaving between threads.

Let us now examine periodic task scheduling requirements which are represented by either of the following process initiation triggers:

$$t_i = t_1 + \sum_{i=1}^{j} \Delta t_i \qquad (11)$$

or

$$t_i = t_l + \Delta t \qquad (12)$$

Eq. 11 is the scheduling-time calculation for determining when to begin processing predictable periodic tasks. This is obvious because the term t_1 represents the first time the task was processed and Δt_i represents the fixed frequency; therefore, the next processing time will always be initiated some Δt factor after the first processing time. These types of periodic tasks are scheduled for processing in an identical manner to non-periodic tasks, as earlier described.

Eq. 12 represents the scheduling time required for unpredictable periodic tasks. This is evident because the term t_l is the *last* time the task was processed and Δt is a constant time increment, therefore in the event the last processing time t_l was triggered by a random event, this type of task would not always be scheduled in exact Δt intervals relative to the first scheduled time. As mentioned earlier, periodic tasks may be more critical than non-periodic tasks, especially those represented by Eq. 12. This then requires that periodic tasks must begin processing in relation to their relative priority, when compared to all other system tasks. The executive program could satisfy this requirement by inserting all periodic tasks, which are ready for processing, per Eq. 11 or 12, into the scheduling queue, according to their thread level and priority. This technique will avoid having high priority pending tasks delayed because of lower priority periodic tasks instantly being processed upon achieving their respective scheduling times.

We can represent this design concept in Fig. 7, where the "periodic waiting queue" is a "holding table" of unordered frequency dependent tasks awaiting their scheduling times, (t_i), as represented by Eqs. 11 or 12. Periodic tasks are selected from the "periodic waiting queue" and inserted into the scheduling queue according to their respective thread level and priority; i.e., they will compete for processing time with the entire set of system tasks.

Conclusions

The performance criteria for today's sophisticated tactial command and control systems imposes severe timin requirements on the computer programs, particularly the executive program. These timing requirements vary with the changing tactical environment and are difficult to predict at the outset of system development. Therefore, some plan or procedure must be developed and followed to ensure that the design and implementation process is controlled and the completed product satisfies its timing requirements. This paper has presented an approach to control this development process through the use of basic timing inequalities, which must be satisfied by designing to the controls rather than around the controls as is frequently done into todays large-scale sophisticated systems.

The computer program designer, and specifically the executive program designer, must apply innovative techniques to produce a program that will satisfy the intended mission requirements within the allocated constraints of core and timing. Although some of the techniques discussed here are not new to the computer sciences, the method of implementation to solve the tactical problem is noteworthy.

Acknowledgments

I wish to express my gratitude to the following individuals who assisted in the review and preparation of this paper: Mr. Izadore Goldhirsh of Auerbach Corporation, Dr. James A. Ward of Naval Ordinance Systems Command, and Mr. Ralph Swavely and Mr. L. J. Crandon of RCA.

Reference

1. The problem is approached from a radar-system-design viewpoint by Weinstock, W. in "Computer control of a multifunction radar" in this issue.

Socio-economic implications of new communications services

Harold A. Jones

The impact of new communications services—in particular, those which can emerge from the land mobile service involvement in the 900-MHz band—will be positive. The order of magnitude will be a function of how astutely we relate the technical and marketing facts to the future needs of government, business, and the individual citizen. Greater vision than ever before applied to spectrum planning will be essential if we are to properly relate the dynamics of seemingly infinite technical ingenuity to the real world requirements of working communications systems.

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received the BSEE from Northwestern University in 1946 and joined Motorola in Chicago as a TV research engineer. Later he transferred to Motorola's Communications Division and became responsible for the management of its technical publications, advertising, publicity, and public relations. He advanced to national sales manager of the Division in 1956. From 1957 to 1966, Mr. Jones served as a Marketing Vice President in various posts, including several years in field management of mobile communications sales and service. Mr. Jones was named to head planning for Motorola's Consumer Products Division in 1966, and later directed the Division's financial and administration activities. His latest position with Motorola was Vice President and Director of Operations for Motorola Systems, Inc., a unit of the parent company which handles institutional marketing of communications and electronic systems He joined RCA and was appointed to his present position on July 13, 1971.

One characteristic of human beings that most strongly differentiates them from other earth creatures is the ability to communicate. Also setting apart human beings is their ability to cooperate. Cooperation plays an extremely important role in the rise or fall of our standard of living. And of course without communications, the ability to cooperate is severely limited.

Can we measure or even accurately estimate the socio-economic impact of new radio communications on our society? Probably not, but here's an equation which suggests an exponential relationship exists between the people factor, intergroup cooperation, radio communications and the spectrum—economic impact (E) is equal to people (P) to the x power, plus radio communications (R) times a spectrum factor (S), plus cooperative effort (C) to the y power, the social complex exponent:

$$E \propto P^x + R \cdot S + C^y$$

Our high standard of living is directly related to a rise in the complexity of the systems that support higher economic levels. The complexity of these life support systems—whether they be electrical distribution, transportation or communications—is increasing. We've come a long way since the pony express, and our world of today would come unglued without the speed of communications made possible with the development of radio communications operating in that invisible media known as the electromagnetic spectrum.

Mobile spectrum frontiers

As has been stated many times before, the electromagnetic spectrum is essentially a service resource as opposed to a natural resource, such as iron, coal, or petroleum. The electromagnetic spectrum is not consumed by use but neither can more spectrum be created. We must maximize its usefulness by properly relating technology and need through timely, well-planned spectrum administration. As a next step, the FCC is to be commended for assigning a portion of the 900-MHz range to land mobile services, thus creating another new spectrum frontier.

Let's go back a few frontiers, as shown in Fig. 1. With the inauguration of FM, we pioneered the low band. The 25 to-54-MHZ frequencies were inherently long range. We suffered, then controlled, the manmade interferences and our county sheriffs, state police, power utilities, to name a few, enjoyed full-range communications and thus provided the public with improved services.

Even though low band was inherently a rural-area frequency range, these channels soon became congested. Adjacent-channel and adjacent-area interference and the inevitable skip interference from the sun-spot cycle forces the industry to seek additional spectrum space and improved communications at higher frequencies. We were motivated to solve the technological problems of the higher bands and so we pioneered the 160-MHz frontier. This breakthrough brought frequency relief for urban-area public safety systems and numerous new commercial services. Again the economy and the community benefited from improved radio-equipped government services and service industries.

The opening of the high band created a burgeoning expansion of land mobile users, and even after advanced technology provided for several channel splits, congestion was sufficiently severe and demand for channel space so unsatisfied that the industry was again forced upward in the spectrum to explore UHF opportunities in the 450-MHz range. Again the industry met the challenge and soon provided economical, operational equipment to further expand usable communications for all governmental and commercial interests. Each move higher up into the spectrum brought systems into being which were inherently shorter range and higher cost systems but with performance equal or superior to equipments operating at lower frequencies.

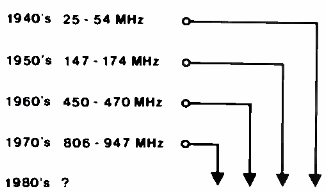


Fig. 1—Mobile spectrum allocation.

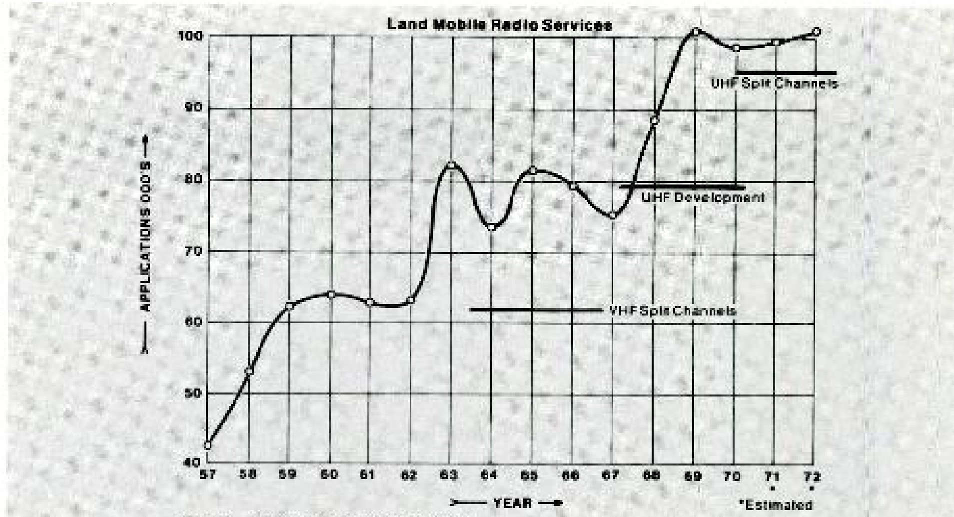


Fig. 2—FCC applications received.

The trend in annual license applications received by the FCC from the non-common carrier services is plotted in Fig. 2. Here is a clear picture which relates unsatisfied demand to the technological breakthroughs which generated more channels. The higher plateau commencing in 1958 was brought about by VHF split-channel allocations. The next step-up in the early 60's was a result of 450-MHz development, and by '68 we were into the era of UHF split channels.

Today, we find the 450-MHz channels rapidly congesting, so we look to new frontiers as history repeats itself and we seek the technology and strategies for pioneering that part of the 900-MHz band now allocated for the land mobile services. Again, let's not pretend we can quantify the social and economic implication of the new communications services that could be derived from this 115-MHz channel in the 900-MHz band, but we can identify the principal factors which impact upon the achieveable potential.

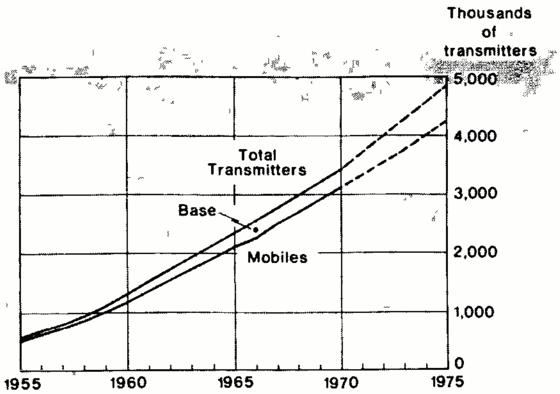
What is the unsatisfied backlog? In the past, each time we entered a new spectrum frontier, FCC applications received from existing services increased an average of 2000 per month. What new demands will be created? What new technology is emerging that will make possible new equipment and new services?

New technology to satisfy the demand

We are on the threshold of new technologies which not only apply to improving communications capability in the lower bands of the spectrum but are absolutely essential for a breakthrough to 900-MHz utilization. The availability of complex low-cost integrated circuits will cope with the technical challenge and offset the trend toward higher equipment cost at higher frequencies.

Integrated circuits

Integrated circuits will make possible the frequency synthesizers which will be required to meet the system design dictates for multi-channel operation requirements of both transmitters and receivers in new radio system concepts. Varactor-diode frequency multipliers will enable us to achieve reasonable power levels to drive presently available power transistors. Higher power output transistors for operation close to 1 GHz promise to be commercially available in the next few years. Minicomputers which can economically interface with our mobile systems requirements are on the scene. Integrated-circuit antenna techniques become feasible at these higher reaches. Advances in power cells and energy sources will ally with integrated circuit break throughs, allowing significant advances in portable communications equipments.



New systems services

The availability of new spectrum space has always spurred the development of new equipment to implement new systems concepts. New equipment and new concepts will create new demands which can be satisfied only by expanding the available spectrum. Already upon us is the new technology for vehicular data communications. With new digital developments, we can provide fully automatic and almost instantaneous vehicle identification, status, and location as well as two-way signalling, digital message transmittal, and remote frequency control.

There is the growing need for mobile repeater systems to provide for better portable-to-mobile and base communications. Such systems will involve vehicular and fixed repeater installations along with complex satellite voting systems. In the field of mobile radio telemetry, there is the need for bio-medical and industrial-scientific protable and mobile systems.

Other unsatisfied new demands created by new technology involve voice-privacy systems and integrated command and control for large system administration including computer assisted dispatching, two-way store and forward data links, environmental detection and status display to visually assist control headquarters.

And finally, new technologies can give us a visual component in our mobile communications system including teleprinters, facsimile, and narrow-band video.

The user

To design the necessary systems concepts for maximum impact on the economy, we must identify the various types of systems and users that must participate and interrelate:

Private dispatch systems which require complete and sole control of its total facilities and a dedicated channel or group of channels;

Common-user dispatch systems which requre the functional essentials of a private dispatch system but can tolerate a shared-channel and shared-time situation;

Radio common carrier systems which serve individuals or small fleet operators who need only central radio dispatch and message service; and

Common-carrier mobile telephone systems for the individual subscribers who need wide-area mobile radio service and regular access to a telephone exchange.

We must next evaluate the cost effectiveness that is possible in the ultimate systems allocation plan. Assume the 115-MHz slice of the whole pie is adequate to supply the near-term demands of all land mobile services. Some considerations arise from the relative allocation to telephone common carrier and non-common carrier services. The 75-MHz portion between 806 and 881 MHz, if finally allocated to the common carrier, will increase that service's available spectrum by some forty times. The 40-MHz remainder available for non-common-carrier use would only double its operating room. It may be that the maximum potential for favorable impact on the economy will not be achieved with this limited allocation for private dispatch systems. Some market researchers doubt the demands for consumer mobile telephone service will develop in this proportion during this decade. Some industry experts insist that provision of private dispatch system service by the wireline telephone monopoly will inhibit the competitive forces essential to advancement of the industry. Is it probable that more favorable impact on society and our economy could be achieved by allocating more than 40-MHz for private systems to inaugurate these new systems services? Perhaps we will see a rising prominence of common-usage systems with facilities provided by non-wire line common carriers or a new form of cooperative or multiple-license entity.

Always in the past, new allocations accompanied by new technologies have brought new users into the market, resulting in a powerful influence on the community (see Fig. 3) As mobile radio entered the 1950's we had only 200,000 licensed transmitters. Step by step, we advanced the technology so that now we are approaching four million licensed transmitters. Where do we go from here?

Conclusions

We must devise a plan to use the new spectrum frontier so that all systems and services that can contribute to the expansion of our economy and serve our society will enjoy an environment in which they can function and grow. Importantly, we must utilize all of the forces of competition. The plan must motivate both private industry and the regular common carrier to commit the venture capital necessary for equipment and systems development. And after all of the technologies have been applied and the complex system requirements overlaid, we must make certain that the spectrum administration relating the spectrum to the advanced technologies and sophisticated systems can efficiently and effectively assign and monitor.

We are entering a new decade of communications technology. What lies ahead will inevitably impact favorably upon our society and our economy. Inept though we may have been in the past, if indeed we have leanred well all of the lessons taught from pioneering past spectrum frontiers, then we will enjoy most of the fabulous achievable potential which is inherent in 900 MHz and beyond.

Angle to sine/cosine digital conversion

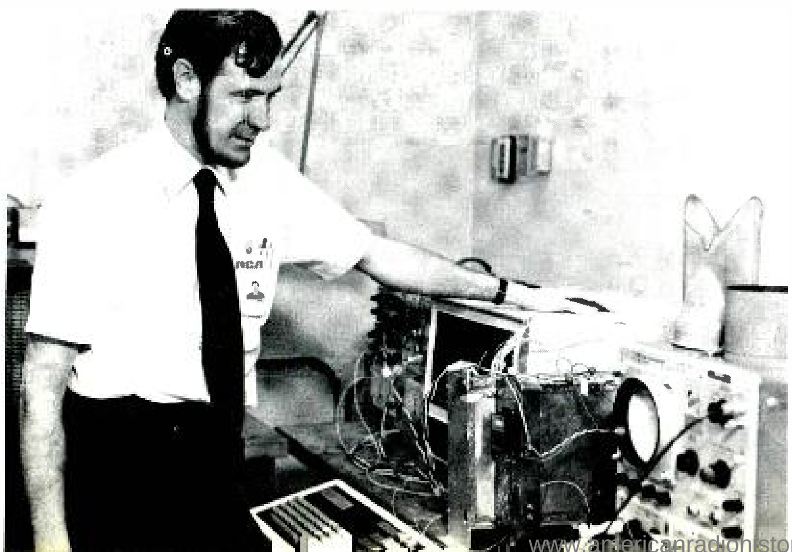
L. W. Poppen

A technique has been devised for directly converting angular-change pulses from an encoder into 10 bits of sine and cosine information representing antenna angle. This technique uses rate multiplication as opposed to a digital differential analyzer. Computer programs were used for the solution, and a computer plot of error in sine and cosine over a 90° sector developed. With the assistance of the computer, a final system configuration was selected that uses three sets of 9-bit rate multipliers to make the sine and cosine change 1023 counts in 90°.

THE DISPLAY SYSTEM used as a basis for this technique presents search radar sweeps on a plan position indicator (PPI). Antenna angular information is provided by an optical incremental encoder which generates 8192 pulses/360° (or 2048/90°) of antenna rotation. A maximum antenna speed of 15 r/min gives a 4-second scan over the 360°. The maximum pulse rate from the antenna is then (8192 pulses/4 seconds) or approximately 2000 pulses/s. These pulses are incremental in that they do not tell the actual antenna position. Quadrant information is provided by 2-bit quadrant data: the north-east quadrant is 00; southeast is 01; etc.

To display PPI sweeps, it is first necessary to resolve the angle data into x and y coordinates. These coordinates are provided by the sine and cosine of the antenna angle measured from north. Range information can then be used to move the PPI sweep radially, with the instantaneous beam position being given by $x=r\sin\theta$ and $y=r\cos\theta$.

L. W. Poppen, Ldr, Military Display Design, Electromagnetic and Aviation Systems Division, Van Nuys, Calif., received the BSEE with highest distinction, from Purdue University in 1956 and the MSEE from the University of Southern California in 1958. Mr. Poppen has had extensive experience in military display design. At RCA, he was program director on the AN/TPQ-27 display subsystem, which consisted of two alphanumeric displays, one of which was capable of displaying radar PPI data. He also participated in the preliminary study effort on the three-dimensional AN/TPS-59 radar displays, consisting of PPIs and RHIs using storage CRTs. Mr. Poppen has just completed development programs on a digital vector generator and on a 4000-character alphanumeric display. Prior to joining RCA, Mr. Poppen was leader on the three-dimensional AN/TPS-32 radar display subsystem at ITT Gilfillan, and on the MTDS command and control system at Litton DSD. He is a member of Tau Beta Pi, Eta Kappa Nu, the IEEE, and the SID.



Conversion details

To generate sine and cosine from angle data, two techniques are frequently used: rate multipliers and digital differential analyzers. Rate multipliers are chosen in this case because the same circuit is used to perform the $r\times\sin\theta$ and the $r\times\cos\theta$ multiplication.

Basic theory

The basic technique of angle to sine/cosine conversion with rate multipliers uses two fundamental trigonometric identities:

$$\sin(\theta+\Delta\theta)=\sin\theta\cos\Delta\theta+\cos\theta\sin\Delta\theta \quad (1)$$

$$\cos(\theta+\Delta\theta)=\cos\theta\cos\Delta\theta-\sin\theta\sin\Delta\theta \quad (2)$$

where $\Delta\theta$ is the increment between antenna pulses and represents 0.04° (90°/2048). Since this is a very small angle, the approximations $\cos\Delta\theta=1$ and $\sin\Delta\theta=\Delta\theta$ may be applied. The equations now become:

$$\sin(\theta+\Delta\theta)=\sin\theta+\Delta\theta\cos\theta \quad (3)$$

$$\cos(\theta+\Delta\theta)=\cos\theta-\Delta\theta\sin\theta \quad (4)$$

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These equations make the following statement: the sine (or cosine) of the present angle is equivalent to the sine (or cosine) of the previous angle, plus (or minus) the change in angle multiplied by the cosine (or sine) of the previous angle. A sine (cosine) counter is made to change dependent upon the product of the incoming pulses and the cosine (sine). Rate multipliers are used to perform the $\Delta\theta\times\sin\theta$ and the $\Delta\theta\times\cos\theta$ multiplication. The system in which this unit is used is a 9-bit system and hence the rate multipliers are 9-bit. The basic problem therefore is to use 9-bit rate multipliers and 10-bit sine and cosine storage registers. The 2048 pulses are to change these 10-bit registers from all zeros to all ones in 90° (for the sine) and from all ones to all zeros in 90° (for the cosine).

Three basic questions are raised:

1) Will 2048 pulses cause the sine (or cosine) counter to change exactly 1023 counts?
2) If the sine changes from all zeros to exactly all ones in 90°, will the cosine change from all ones to exactly all zeros?
3) Even if both sine and cosine change 1023 counts in 90°, how close are they to the proper value of sine and cosine at all other angles?

The answers to these questions were found by computer simulation.

Rate multiplier operation

To show that the computer simulation program does in fact represent the rate-multiplying technique, it is necessary to explain how rate multiplying works. A rate multiplier (Fig. 1) accepts pulses

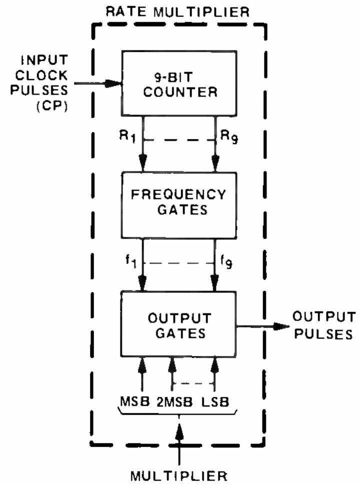

Fig. 1—Basic rate multiplier.

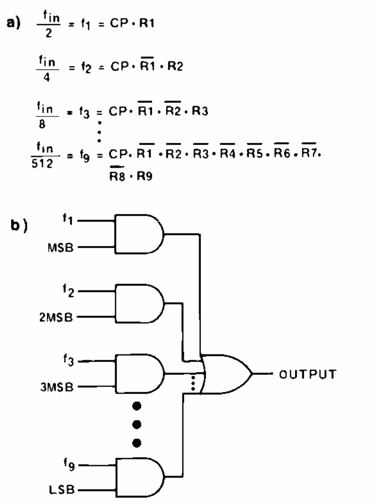

Fig. 2—Rate multiplier logic (a) and circuit (b).

in and allows a percentage of those pulses to leave. The percentage that leaves depends upon the parallel number (the multiplier) entered into the rate multiplier. For example, if the parallel number is all zeros, no pulses will come out; if it is all ones, 511 out of 512 pulses will be passed (all pulses are not sent out due to the finite 9-bit limitation). The circuit and logic are shown in Fig. 2.

The input clock pulses are fed to a 9-bit counter. *R1* is the first output of this counter and therefore changes state at every input pulse; *R2* changes at ½ this rate; *R3* changes at ½ the *R2* rate; and so on through *R9*. The logic of Fig. 2a shows the generation of nine pulse trains, each at a frequency one-half of the one above it and, very importantly, containing none of the pulses of any other pulse train. This is shown further in Table I.

Table I—9-bit counter clock pulses.

Initial pulse No.	*R1*	*R2*	*R3*	*R4*	*R5*	*R6*	*R7*	*R8*	*R9*	*Pulse train containing that pulse*
	0	0	0	0	0	0	0	0	0	
1	1	0	0	0						f_1
2	0	1	0	0						f_2
3	1	1	0	0						f_1
4	0	0	1	0						f_3
5	1	0	1	0						f_1
6	0	1	1	0						f_2
7	1	1	1	0						f_1
8	0	0	0	1						f_4

Pulse train	*Pulse number*	Δ
f_1:	1, 3, 5, 7, 9, 11, · · ·	2
f_2:	2, 6, 10, 14, 18, · · ·	4
f_3:	4, 12, 20, 28, 36, · · ·	8
⋮	⋮	⋮
f_9:	256, 768, · · ·	512

Every pulse is assigned to one specific pulse train and, as shown in Fig. 2b, if the most significant bit (MSB) of the multiplier is true and all other bits are false, pulses 1, 3, 5, · · · will be at the output. If the first and third MSB (MSB and 3MSB) are true, pulses 1, 3, 5, · · · and 4, 12, 20 · · · will be passed.

Computer program for changing cosine 1023 counts in 90°

The first program determines how many counts are necessary to change the cosine from 1023 to 0. The program starts at $\theta=0°$ (sin 0°=0; cos 0°=1023) and stops when the $\cos\theta=0$. The program print-out records the number of pulses required to achieve 90° of cosine change. There are two rate multipliers and two up/down counters in the system (see Fig. 3). The parallel number entered into each rate multiplier is the value of sine or cosine stored in the counter.

This program was run on the Hewlett-Packard 9100A Calculator. The basic technique uses the fact that pulse train f_{n+1} consists of odd-numbered pulses when the pulse numbers are divided by 2^n: for example, pulse train f_1 consists of odd-numbered pulses (1, 3, 5, · · ·); the pulse numbers in pulse train f_2 (2, 6, 10, · · ·) are odd numbers when divided by 2; those in f_3 are odd when divided by 4 (2^2); etc. The number of the pulse train to which a specific pulse belongs is the number of times (plus one) that the pulse number has to be divided by two, to be an odd number. Table II shows an example, using input pulse No. 312.

Table II—Pulse-train identification.

Number	*Divide by two (n)*	*Pulse train (n+1)*
312		
156	1	
78	2	
39 (odd)	3	f_4 (3+1)

Since 312 had to be divided-by-2 three times before it was odd, it belongs to f_4 and pulse 312 will be allowed through if 4MSB of the multiplier is true. Since the program operates on sine and cosine in order rather than simultaneously (as they are in the actual system), precautions were taken to make sure that neither changed until both multiplications ($\Delta\theta \times \sin\theta$ and $\Delta\theta \times \cos\theta$) were accomplished.

The program must perform a decimal-to-binary conversion for sine and cosine to determine the value of each bit.

The conversion is explained in the following example, assuming the sine value is 500 (out of a possible 1023). Since the sine and cosine are to be determined to an accuracy of 10 bits, the value of the MSB is 2^9 (512).

initial value of sin	500
value of MSB	512

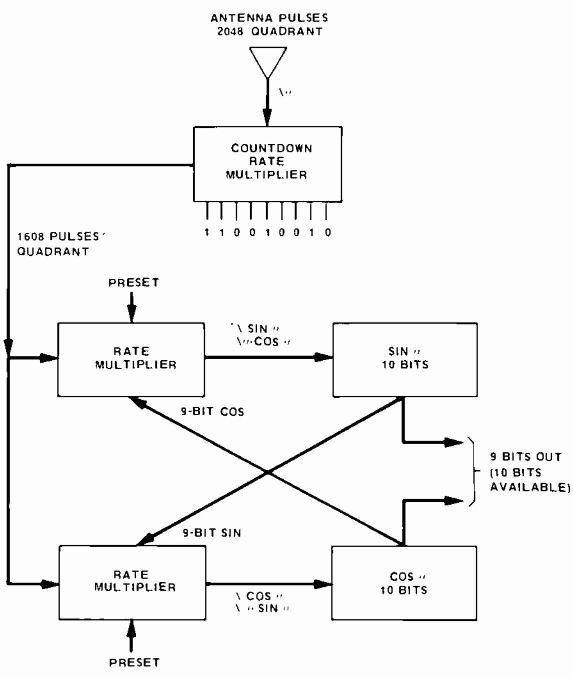

Fig. 3—Block diagram of counter.

512 is >500, hence MSB=0	
remaining value of sin	500
value of 2×MSB	256
256 is <500, hence 2×MSB=1	244
remaining value of sin	244
value of 3×MSB	128
128 is <244, hence 3×MSB=1	116
remaining value of sin	116

⋮

It is not necessary to store the value of any specific bit, since the value of the bit is only important if the pulse train affects that bit; i.e., if the pulse is in pulse train f_6, only the 6MSB of the sine and cosine are significant. The remaining value of sine and cosine (after subtraction of the bit value) is stored in registers e and f, respectively. This process is continued until the pulse being evaluated is found to belong to a specific pulse train; i.e., after n divisions-by-2, an odd number results and therefore the pulse belongs to f_{n+1} and the $(n+1)$ MSB is significant. When the process is stopped by finding that a specific pulse belongs to (for example) f_6, then if the 6MSB of sine is one, the cosine is decremented by one count. Likewise, if the 6MSB of cosine is a one, the sine is incremented by one count.

The program required 1611 steps to decrement the cosine register from 1023 to 0. Since 2048 pulses are available per quadrant, these must be reduced to a number in the vicinity of 1611. The existing rate multiplier design was used to do this. Since 2048 is 2^{11} and the rate multiplier is 9-bit, the count-down can only occur in steps of $2^{11}/2^9=2^2=4$. Since 1608 is a multiple of 4, it is a satisfactory choice. Other numbers (such as 1612) may produce identical or better results, but 1608 was tentatively chosen.

Computer program for final solution

We have now answered our first question: it takes 1611 pulses to make the cosine go from all ones (1023) to all zeros. The second question asked whether the sine is now at all ones (1023). The answer is no; the result of the previous computer run gave the sine value as 1017. (If 1608 pulses are used, the resulting final values are sine=1015 and cosine=3.) The only parameter that can be varied to correct this discrepancy is the *number* that the *first* pulse is called. This can be varied by presetting the counter in the rate multiplier (see Fig. 1) to a specific value.

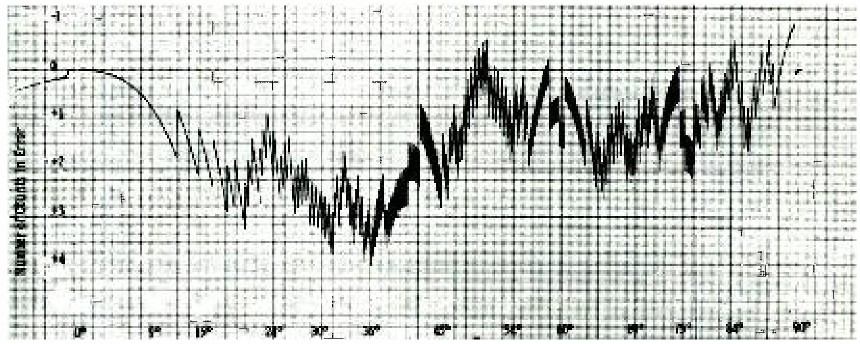

Fig. 4—Sine error plot.

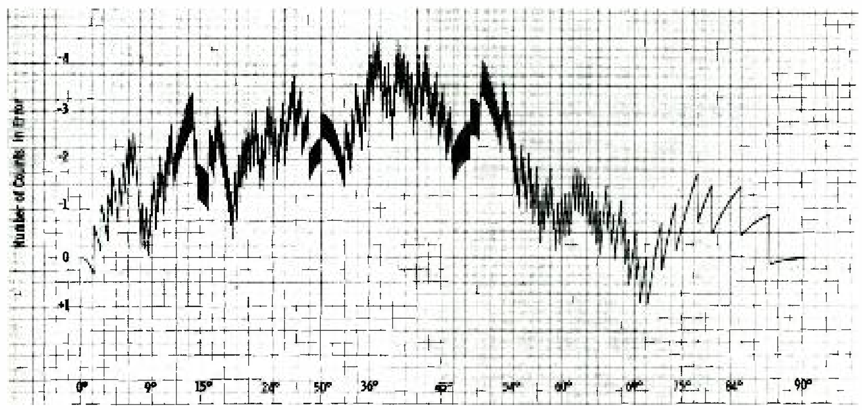

Fig. 5—Cosine error plot.

A new program was prepared to determine the counter preset value (the number of the first pulse) which would give the desired sine and cosine results after 1608 pulses. A FORTRAN program was written to start at a specified pulse number, count for 1608 pulses, and then read out the value of the sine and cosine. This was done for pulse numbers starting with 0 and going to 102. Since the HP calculator takes 5 minutes to run the program once, the RCA Basic Time Sharing System (BTSS) was used. Of all these numbers, only the preset value of 6 gave results of sine=1023 and cosine=0. The two programs are essentially similar, except that the stop point is 1608 steps and not where the cosine equals zero.

Computer program for plot of sine and cosine variation

The sine and cosine deviation from a perfect waveform was plotted over 90°, with the vertical scale being the difference between the actual value of the sine (cosine) and the computer value, expressed in terms of number of counts. Negative numbers mean that the computed value is higher. These plots are shown in Figs. 4 and 5.

Final configuration

The block diagram of the final configuration is shown in Fig. 3. The count-down rate multiplier used a fixed multiplier (110010010). This represents 1608, with an MSB of 1024. The count-down rate multiplier does not have to be preset since it counts a power-of-2 (2^{11}) number of pulses in the prescribed time. The preset requirement in the other multipliers is brought about because 1608 is not a power-of-2 and therefore the rate multiplication is effectively truncated.

A computer was used to determine the preset values if 10-bit rate multipliers are used. These results covered pulse numbers 0 through 225 and yielded four preset values (80, 158, 172, and 178), in contrast to the single value for 9-bit rate multipliers.

The system was built using the calculated parameters (1608 pulses, starting with number 6) and performed as predicted. Quadrant information was used to preset the sine and cosine counters to the proper values at each 90° point, although this is actually only necessary on initial turn-on.

HoloTape system

W. J. Hannan

The HoloTape® system is one of several systems RCA is currently developing for the prerecorded video market. As implied by its name, HoloTape is a plastic tape that has holograms and sound tracks embossed on its surface, each hologram corresponding to a frame of a color movie. The HoloTape system concept was demonstrated at a press conference in 1969 and received a great deal of publicity. However, at that time much work remained to be done on the system; pictures were noisy, there was no sound, and color quality was poor. Since then an extensive research effort has led to the demonstration of entertainment quality color pictures plus excellent sound from replicated HoloTapes.

Since the introduction of the HoloTape system in 1969, some notable technical breakthroughs have been made.[1] The HoloTape system incorporates the following features:

Low-cost replication—Relief phase holograms, which are essentially contour maps of diffraction patterns, can be embossed on low-cost vinyl tape.

Scratch and dirt resistance—Highly redundant holograms can be scratched, spotted with dirt, and otherwise mutilated without serious image degradation.

Image immobilization—Fraunhofer holograms produce stationary images even though the holograms are continuously moving through the readout beam. Flicker-free images can be obtained at any tape speed without the need for servo control between tape speed and TV scan rate. Unlike all other prerecorded video systems, HoloTape is completely compatible with any foreign TV standard, and can be played in fast, slow, or stop motion.

Reliability—There are no high-speed moving parts to wear out, and optical alignment is not critical.

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received the BSEE from Drexel Institute in 1954 and the MSEE from the Polytechnic Institute of Brooklyn in 1955. From 1951 to 1956 he worked in RCA's Industrial Products Division. From 1956 to 1966 he worked in Applied Research. In 1959 he was promoted to Group Leader and spent the following seven years working mainly on laser systems. Since 1966 he has been a Group Head at RCA Laboratories, working in the field of holography. In 1970 he received an RCA Achievement Award for his holographic research and in 1972 his research group received the David Sarnoff Outstanding Team Award in Science for the development of a holographic prerecorded video system. He is a Senior Member of IEEE and a member of OSA.

HoloTape player

The HoloTape player consists of a small laser, a tape transport, a vidicon-type camera, a sound pickup head, and associated electronics. Connected to the antenna terminals of a TV receiver, this player lets the viewer "see what he wants when he wants to see it." Fig. 1 shows how a beam from a HeNe laser passes through clear vinyl tape that has holograms embossed on its surface and projects a motion picture image into a TV camera.

Manufacturing process

The manufacturing process (Fig. 2) is essentially the same as the one used in 1969,[2] but it has been refined considerably. The holographic recording mater-

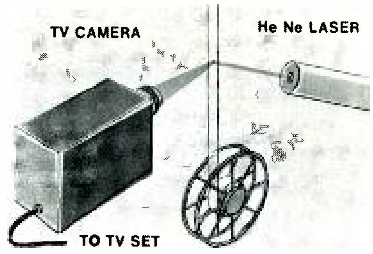

Fig. 1—HoloTape player.

ial is AZ-1350, a positive photoresist, which is coated on Cronar (Fig. 2a), a high-quality substrate material produced by DuPont. Color encoded movies, recorded on black and white film by means of an electron beam recorder (Fig. 2b), serve as the object transparencies from which holograms are recorded. The holographic recording system (Fig. 2c) includes a He-Cd laser, photoresist tape and object film transports, and a variety of lenses, mirrors, and beam splitters. It also includes a special optical component, discussed later, which enables highly redundant holograms to be recorded. The recording system functions automatically, producing a sequence of holograms corresponding to the frames of the color encoded movie. After the photoresist tape is exposed, a developing machine (Fig. 2d) washes away the areas exposed to more intense light, leaving the surface corrugations which form the phase holograms. An electroforming process (Fig. 2e), similar to the one used to make nickel masters for phonograph records, is used to produce a nickel master tape from the original photoresist tape. Finally, plastic replica tapes are manufactured by a hot embossing

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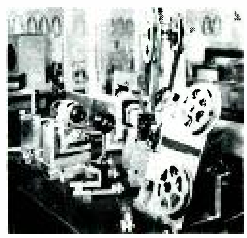
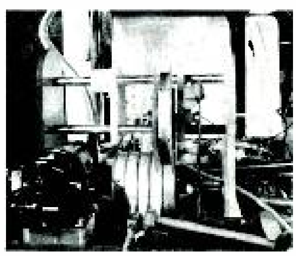
a) Coating.

b) Encoding.

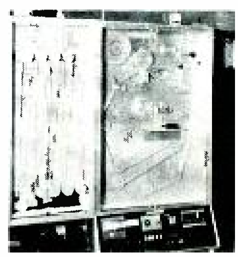


c) Recording.

d) Developing.



e) Plating.



f) Replicating.

Fig. 2—Tape manufacturing process

process (Fig. 2f) in which the nickel master tape and plastic tape are sandwiched between two rollers.

Noise in coherent imaging systems

By far the most challenging problem faced in the development of the HoloTape system involved finding ways to obtain an acceptable signal-to-noise ratio (S/N) from embossed holograms. It is difficult, if not impossible, to define just what an "acceptable" S/N is, because what one person may accept as a good picture another may not. The 40-dB S/N frequently quoted as acceptable for broadcast TV is not really applicable to HoloTape, because the noise prevalent in a HoloTape image is not like the "white" noise seen on a home TV set. Instead, it is more prominent at low frequencies where, unfortunately, it is more apparent to the viewer. To further complicate the situation, inherent nonlinearities introduce intermodulation noise which causes the S/N to be strongly dependent on the structure of the pictures themselves; i.e., holograms of complex scenes with much fine detail and dark background yield higher S/N than holograms of scenes with broad white areas.

In addition to intermodulation noise, there are other sources of noise which can be lumped in a general category known as "cosmetic" noise. This noise is directly attributable to the use of coherent light for imaging. With coherent light, large blemishes are produced by small cosmetic defects such as dust in the optical components of the system; reflections cause highly visible interference patterns; small phase errors, due to thickness variations on the order of a fraction of a wavelength, can produce visible defects. Fig. 3 shows what a typical picture looks like when it is projected with coherent light. The cosmetic noise is quite evident.

Experience has shown that it is not possible to build an optical system that is so free of defects, and keep it so clean,

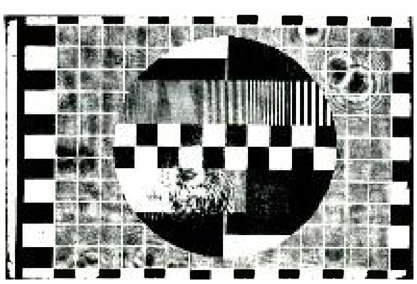
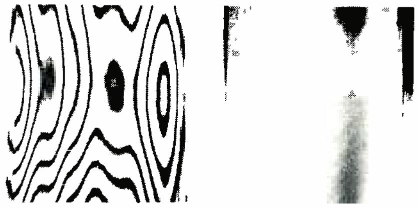


Fig. 3—Cosmetic noise evident in non-redundant hologram.



a) Vinyl tape. b) Polyester tape.

Fig. 4—Interferogram comparison between HoloTape replica and polyester film.

that the cosmetic noise is reduced to an acceptable level.

One of the main advantages of the HoloTape system is its insensitivity to such defects, in particular its ability to produce good pictures from a low-cost release medium with poor optical quality. Fig. 4a illustrates one measure of the quality of typical vinyl used for HoloTape replicas. In the interferograms shown, each dark line represents a change in thickness of half a wavelength or 0.3 μm. A uniform flat material would be a uniform shade of gray. The thickness fluctuations are obvious. For comparison, the measurement of a high-quality polyester film is shown in Fig. 4b.

One way to eliminate cosmetic noise is to avoid the use of coherent light, since cosmetic defects are usually indiscernible with incoherent light. But, this approach would eliminate the scratch resistance and image immobilization benefits of holography. Since these benefits are highly desirable, ways to overcome the cosmetic noise problem had to be developed. A major step in this direction is the redundant holographic recording technique described below.

Hologram redundancy

It is well known that the highly redundant nature of holograms recorded with diffusely illuminated or diffusely reflecting objects renders them practically immune to cosmetic noise.[3] But such holograms are plagued by speckle noise which is particularly severe in small holograms like those required for the HoloTape system. Therefore, a key question that had to be answered was: Is it possible to record highly redundant holograms without introducing speckle or some other spurious background pattern? The answer is yes; it can be accomplished by illuminating the object transparency with a carefully generated multiplicity of beams.[4]

The noise suppression afforded by redundancy in holograms is somewhat analogous to the noise suppression that is seen when a motion picture projector is switched from static to dynamic projection. Noise that is uncorrelated from one frame to the next tends to average out. Multiple beam illumination produces a similar noise suppression effect in coherent imaging systems.

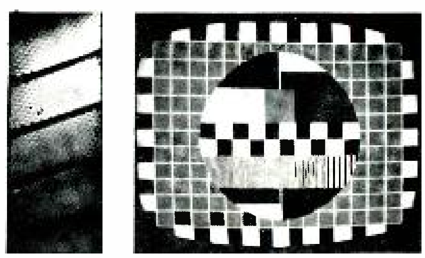
Multiple beam illumination is based on the principle that the paths of rays going through any optical system can be altered by changing the location of the source of object illumination, without changing the location of the image. Therefore, if an object is illuminated by many different sources of light, each in a different location, the light from each source will experience different degradations. And, as in the case of dynamic readout of motion pictures, noise introduced by optical defects will be diminished.

An early attempt to record redundant multiple beam holograms[4] involved illuminating the object transparency with a beam that had passed through a two-dimensional phase grating. This type of grating has a transmission given by[4]

$$T(x,y) = \sum_{n=-\infty}^{\infty} \sum_{m=-\infty}^{\infty} J_n(\phi) \exp(j2n\pi x/\Delta)\, J_m(\phi) \exp(j2m\pi y/\Delta),$$

where J_n is the n^{th} order Bessel function of the first kind, Δ is the spatial period of the grating, and ϕ is the peak phase shift introduced by the grating. By constructing a grating with $\phi = 1.43$ radians, we were able to produce nine equally intense beams and thus achieve ninefold redundancy in the holograms. However, although such holograms were speckle-free and had reasonably good dirt and scratch resistance, it was apparent that further improvement could be realized by employing more than nine illuminating beams.

Theory indicates that the amount of redundancy that can be beneficially employed is dependent on the area of the hologram, the required resolution of the reconstructed image, and the fidelity of the overall optical system.[5]



a) Highly redundant hologram. b) Image reconstructed from one hologram in a).

Fig. 5—Example of high-quality image reconstructed from redundant hologram.

Advanced techniques that take advantage of the interference properties of the coherent illumination, and use components produced by precise photomechanical methods, can achieve 200-fold redundancy in a 0.4 x 0.25-inch hologram. A photo of a HoloTape with these highly redundant holograms and a photo of an image reconstructed from one of them are shown in Fig. 5.

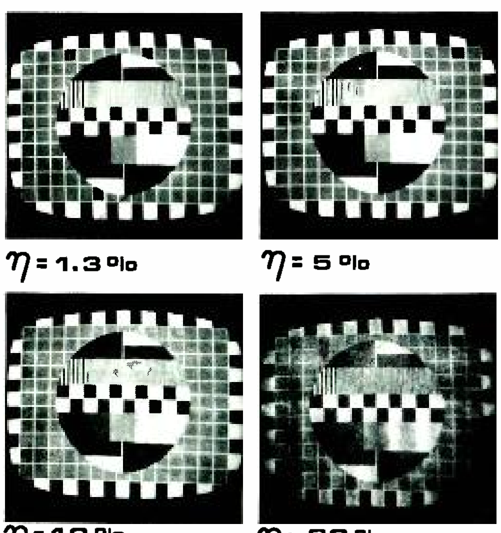
Hologram efficiency

The efficiency of phase holograms recorded on photoresist-coated tapes can approach 30% when the object is, for example, a small white dot on a black background. However, for typical images the efficiency is restricted to about 3% in order to reduce intermodulation noise to a tolerable level. An example of the tradeoff between hologram efficiency and intermodulation noise is given in Fig. 6. These particular images were reconstructed from holograms recorded on AZ-1350 photoresist, using light with a wavelength of 632.8 nm.

Sound

To keep HoloTape replication costs to a minimum, the condition was imposed that the sound track must be replicated by the same process as the picture. Fortunately the technology for recording sound as a contour modulation has been under development for the past 100 years.

Sound for the HoloTape system has been recorded in a groove having dimensions comparable with usual record practice. It has been possible to achieve high-quality stereophonic sound by this technique. It is hard to imagine a simpler sound playback system than a conventional phonograph



η = 1.3 % η = 5 % η = 10 % η = 20 %

Fig. 6—Example of tradeoff between hologram efficiency (η) and intermodulation noise.

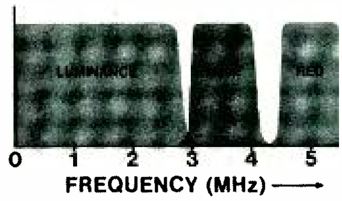


Fig. 7 (left)—Spectrum of color encoded signal.
Fig. 8 (right)—Color encoded image; thin vertical stripes convey the color information.

cartridge. The depth of the sound groove is about two orders of magnitude larger than the contours of the holograms, which imposes some limitations on the materials and processes of replication. The presence of the groove, for stylus guidance, sets a lower limit on the tape thickness, and therefore a limit on the playing time of a given size reel of tape.

However, it is possible to record a sound track without the guiding groove, and to playback such a "grooveless" soundtrack with a conventional phonograph pickup. Research is currently underway on such a system.

Color encoding

Using Fraunhofer holograms to provide image immobilization and scratch resistance necessitates the use of monochromatic light for playback. Consequently, playback of color pictures calls for recording holograms of color encoded images on monochrome film. Basically, color encoding amounts to recording the color signal as a modulated carrier wave which shows up on the object transparency as a modulated grating pattern. There are, of course, many different color encoding schemes, the choice of a particular scheme depending on performance limits of the system in which it is used.

The first experimental HoloTape system used the Kell-SRI (Stanford Research Institute) encoding shown in Fig. 7. Here, luminance information is recorded as a 0 to 3-MHz baseband signal, and blue and red information as amplitude-modulated 3.5- and 5.0-MHz subcarriers. Actually, the subcarrier frequencies differ slightly from these values, the true values being multiples of the horizontal scan frequency. In the encoded image the color information appears as the amplitude-modulated grating patterns shown in Fig. 8. In a live TV camera, the encoded signal is generated by an optical "stripe" filter; in the HoloTape system the electronically encoded image is recorded on black-and-white movie film which subsequently serves as the object from which holograms are recorded.

During playback, the HoloTape produces a faithful reproduction of the encoded image exactly as it appeared on the original black-and-white film. Accordingly, the output of the TV camera consists of a 3-MHz luminance signal and 3.5- and 5.0-MHz subcarriers that are amplitude modulated by the blue and red signals respectively. Appropriate filtering and envelope detection separate the blue and red signals; the green signal is obtained by subtracting the red and blue signals from the luminance signal. Finally, the color signals are passed through a color matrix circuit that combines them in the proper proportions to reproduce the hues and saturations of the original color image.

Despite the intensive research effort devoted to Kell-SRI and similar encoding schemes which include both luminance and chrominance information in a single frame (and thus allow the encoded image to be read out with a single TV camera tube), none of the one-frame encoding schemes has yet produced a satisfactory color picture in HoloTape systems. In fact, even direct readout of 16-mm color encoded transparencies leaves much to be desired. For this reason, the present HoloTape system employs the two frame F/2 encoding scheme[6] illustrated in Fig. 9. Briefly, this encoding method amounts to recording luminance and chrominance information in two separate frames, the chrominance information being recorded as an NTSC-type carrier at 2 MHz. Because of the scan nonlinearities inherent in all TV cameras, it is not possible to use the "burst" technique of conventional TV for generating the phase reference carrier required for proper detection of the color carrier. Instead, a continuous phase reference must be recorded along with the chroma carrier. This phase reference is recorded as a carrier at half the chrominance carrier frequency, hence the name F/2 encoding. In HoloTape, F/2 corresponds to 1 MHz. During playback the F/2 carrier is detected and doubled to provide the 2-MHz phase reference needed for proper decoding. Two-frame encoding offers these advantages:

Camera noise—An S/N of 40 dB is considered adequate for a conventional picture, but it has been found that 50 to 60 dB is required to obtain an acceptable picture with one-frame encoding. The greater demand on S/N stems from the poor noise performance of vidicons at high frequencies (due to aperture response and capacitance loading) and the subjective degradation of overall S/N caused by

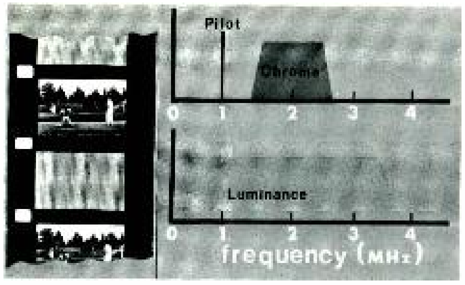


Fig. 9—Two-frame color encoding.

translating noise from high to low frequencies during color demodulation. With two-frame encoding both luminance and chrominance information are recorded at the low end of the spectrum; hence, the *S/N* requirement should be the same as that of conventional TV, implying that two-frame encoding has about a 10-dB advantage over one-frame encoding.

Hologram redundancy—Recall that the *S/N* of Fraunhofer hologram images can be improved by increasing hologram redundancy. However, with one-frame encoding, the degree of redundancy is severely restricted by the necessity of preventing beats between the grating or pinhole array (used to record redundant holograms) and the color encoding stripes. Recording luminance and chrominance information in two separate frames avoids the beat problem in the luminance frame and reduces it in the chrominance frame, thereby providing a substantial improvement in *S/N*.

Dynamic range—About 50% of the dynamic range is required to accomodate color information in a one-frame system. Sacrificing this much range is particularly disheartening because the dynamic range is already severely restricted by linearity requirements. With two-frame encoding, the full dynamic range can be used for both luminance and chrominance signals.

Fail-to-luminance—Encoding methods which convey some, but not all, of the chrominance information in carriers suffer from hue shift with changes in frequency response. With SRI encoding, for example, poor focus at the edge of the raster causes the image to have a green border. Two-frame, F/2 encoding fails-to-luminance, a failure mode which is much less disturbing to the TV viewer. Therefore, with F/2 encoding, frequency response is not as critical a parameter. In live cameras, it is possible to control focus and other parameters affecting frequency response and thus obtain reasonably good pictures. In the HoloTape system, however, it is difficult to maintain a specified frequency response because the encoded signal must undergo additional photographic and holographic processing.

Direct translation to VHF carrier—Another feature of F/2 encoding is that the encoded color carrier is identical to the NTSC color carrier except for carrier frequency; therefore it can be translated directly to the standard chrominance subcarrier frequency; i.e., it is not necessary to go through decode and re-encode steps to generate the desired VHF carrier. The simplicity of this approach leads to greater reliability and lower cost.

Tape transport—Two-frame encoding allows chrominance information to be recorded in the low-frequency portion of the spectrum without luminance-to-chrominance crosstalk problems. Since the color encoding stripes are relatively coarse (compared to those of a one-frame system), frame-to-frame registration problems (imposed by vidicon lag) are not as severe. Therefore, the tolerances in the tape transport can be relaxed considerably. Also, since there are no high-speed or close-tolerance parts in the HoloTape transport, and flickerless playback at any speed is possible with film in continuous motion, a long and trouble-free life is anticipated.

Growth potential—In a one-frame system, such as the Kell-SRI system, it is not possible to increase luminance or chrominance bandwidth without changing system standards. This is not a severe problem as far as live cameras are concerned because standards can be changed without affecting operation of equipment already in the field. However, once HoloTape standards are set it will be difficult, if not impossible, to change them. Future R&D efforts will undoubtedly yield improved camera tubes, recording materials, etc., which, in turn, will enable higher resolution images to be realized. But if system bandwidth is set by rigid standards, rather than component limitations, improvements will not be possible. Two-frame systems do not suffer from this limitation.

Bivicon color camera

Although early experiments with a two-vidicon color camera (one vidicon for the luminance and the other for the encoded color) were quite successful, the two-vidicon approach had two serious drawbacks—high cost and registration problems.

A major step toward solving both problems was achieved by developing a new camera tube, the Bivicon.® As illustrated in Fig. 10, the Bivicon is essentially a two-gun vidicon with a split target. Since the beams from both guns are deflected by a common field, excellent registration is readily achieved. And, since only one deflection yoke and focus coil are needed and resolution requirements are less stringent than those of a single vidicon color camera, the cost of a Bivicon camera is comparable to that of a conventional single-frame color camera.

Evaluation of experimental Bivicon cameras in HoloTape players reveals: overall frequency response is flat to 4 MHz, laser power of 1 mW incident on HoloTape produces a good color picture, crosstalk between targets is less than 1%, and frame registration accuracy of 1% can be achieved.

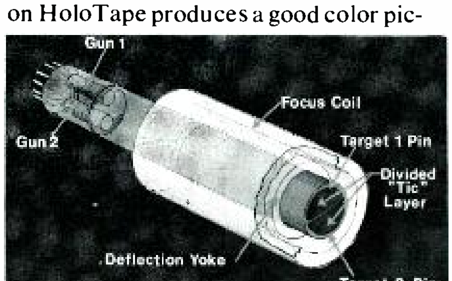


Fig. 10—Bivicon; a two-beam vidicon

Although the Bivicon was developed specifically for HoloTape by RCA's Electronic Components Division, Lancaster, Pa., it is evident that this new tube will find application elsewhere. In particular, it may be used in low-cost film cameras for educational and industrial applications.

Conclusion

Development of a technique for recording highly redundant holograms coupled with the development of the Bivicon has enabled entertainment quality color pictures to be obtained from Holotape.

Acknowledgments

The HoloTape system described here was developed at RCA Laboratories, Princeton, N.J. Among the members of the technical staff who have made significant contributions to the development of this system are:

W. J. Hannan (Group Head)

Holography: M. Lurie (Leader), R. A. Bartolini, C. B. Carroll, A. H. Firester, E. C. Fox, and T. E. Gayeski.

Video, Color and Sound: R. E. Flory (Leader), W. E. Barnette, W. G. Bibson, and E. Ludedicke.

Materials and Replication: R. J. Ryan (Leader), R. R. Demers, J. R. Frattarola, H. G. Scheible, F. W. Spong, and J. Bordogna (consultant).

Special recognition is given to D. Karlsons, who died October 4, 1971, for outstanding holographic research and for leadership in development of the HoloTape system. Other staff members who have made major contributions during the six-year course of the project are: N. Feldstein, J. T. Fischer, H. G. Gerritsen, D. L. Greenaway, C. S. Ih, E. James, R. D. Kell, C. H. Morris, E. G. Ramberg, J. P. Russell, R. E. Werner, and J. A. Zenel.

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Computer telex exchange

I. K. Given

Definitions

CTE	Computer Telex Exchange.
Lines	Terminations connected to RCA telex subscribers directly.
Trunks	Terminations connected to overseas channels, intercity exchange trunks, Western Union Telegraph Co., etc.
CPU	Central processor unit
IAS	Immediate access subsystem

Computer Telex Exchange (CTE) automatically communicates with, and establishes communications between, various types of teletype communication devices within the United States, with carriers in other countries, and within the exchange itself. In addition, the CTE communicates with and establishes communications between automatic and manual communications equipment which are part of the existing network, and TWX and Western Union exchanges. The CTE must accomplish all this while continually troubleshooting its own operations. Lastly, the CTE must operate continuously with a very small probability of total system breakdown.

INTERNATIONAL TELEX COMMUNICATIONS was first introduced by RCA Global Communications, Inc. in 1948, between the United States and the Netherlands. It was a teleprinter-to-teleprinter service similar to the domestic TWX service in the U.S. It was made possible by the use of automatic request for repetition (ARQ) equipment over high-frequency radio circuits.

In approximately 1963, automatic telex was started. This inaugurated toll dialing with telex. Today there are more than 50 countries throughout the world that can be reached by toll dialing from telex networks operated by RCA Glōbcom and Western Union in the United States.

The toll dialing required sophisticated equipment and maintenance techniques. It also stimulated the growth of this service. Today the industry market is about $6 million per month, and growing at an annual rate of 20 to 30%. The original terminal equipment was manual, with operators completing the connections. With automatic service, the apparatus was borrowed from telephone service, first step-by-step, and then common control—but all mechanical. It had all of the known disadvantages: costly to maintain, slow to expand, and long lead times in the planning and expansion.

In the mid-60's RCA Glōbcom decided to design, build and operate a Computer Telex Exchange which would be easy to maintain, reliable, and simple to expand. The resulting Computer Telex Exchange (CTE) was built by Astrodata, Inc., and installed at the RCA Glōbcom Operating Center in New York in December of 1968. It was the first completely computer-controlled telex center operating in the world. It handles inbound, outbound, and bidirectional overseas channels, and meets all of the known type-A, type-B and type-C signalling. These signalling types are those designated by the *CCITT* as standard world-wide for telex operation.

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Call processing

When an off-hook condition occurs on any of the lines and trunks connected to the CTE, the CTE must immediately recognize, check the validity of, and acknowledge the condition. The CTE must then communicate with the calling party and determine the reason for the off-hook condition. Should the calling party require operator assistance, the CTE connects the calling party to an operator. Should the calling party desire to place a call, the CTE determines the validity of the called number.

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If the called party is not valid, the CTE so informs the calling party. If the called number is valid and the called party is available, the CTE will establish and test a communications path between the two parties. When the call is established, the CTE records the time of day, call serial [there is a separate serial number assigned to every attempt to establish a call both into and out of the Computer Telex Exchange], and terminator number [terminator number identifies the trunk or line assignment]. When an on-hook condition signals the end of the call, the CTE records accounting data and breaks down the call.

System Requirements

The requirements of the CTE can be separated into two groups:

1) Call processing and system control and
2) Connecting the CTE to external equipment and switching to permit communication between external equipments.

Call processing

Call processing (Fig. 1) involves recognizing a call request, acknowledging the request, determining what the request entails, and connecting the requesting (calling) party to a called party, if required. Since each line or trunk is connected to a terminator which reflects the status or condition of the line or trunk, the terminators are continually checked for call requests. The scanner distributor performs the checking operation. Because many calls may be requested at any one time, and many calls may be in process at the same time,

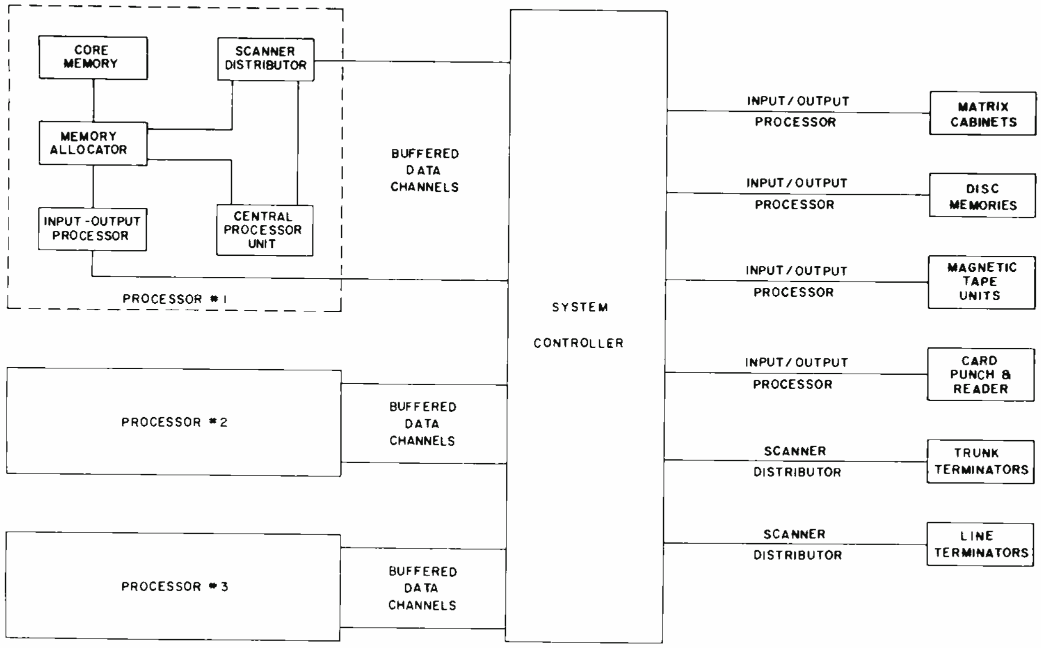

Fig. 1—Block diagram of computer telex exchange.

and due to the time required to process a call, call processing by the CTE is time multiplexed or time shared. The CTE processes a small portion of one call, then processes a small portion of another call, and so on. When an off-hook condition is detected, a predetermined sequence of signals is exchanged between the central processor unit (CPU) and the scanner distributor and between the scanner distributor and the terminator. Signals are also exchanged between the CPU and the disk memory and, when required, between the CPU and the input/output processor and between the I/O processor and switch arrays or an operator's console. Call processing is controlled entirely by the program stored in the core memory, as are almost every operation and function performed by the CPU and all other equipments in the CTE.

Switching

The system controller interfaces the three computers (processors #1, #2 and #3) with themselves and with the peripheral equipment; provides clock functions necessary for system timing; and performs evaluation, control, and display of system operation.

The system controller has two channels (A and B) of redundant logic to increase system reliability. Either channel A or B could malfunction, and no degradation or other impairment of system operation would result. Each channel contains 12 buffered data channels to interface the I/O processor and scanner distributor with the peripheral equipment.

The system controller is set to operate in a tridundant mode, automatically selecting the signal most representative of the three processors' inputs for delivery to the peripheral equipment. The selection is made using majority voting logic on each bit, with the resultant signal being gated to the proper buffered data channel.

In delivering signals from the system controller to the peripheral equipment, additional reliability is built in by the use of backup cabling to all controllers of peripheral equipment and the equipment itself. This refers to line terminators, trunk terminators, magnetic tape units, etc.

Central processing unit

The central processing unit (CPU) directly or indirectly controls all CTE operations: It performs all CTE processing functions not performed by the I/O processor and scanner distributor. It reads the change in condition from the core memory, determines the necessary procedures, and stores the appropriate command in the core memory. If the processing procedures involve further communication between the terminator and the CPU, the scanner distributor reads the command from the memory and transfers the information to the particular terminator. If the processing procedures require a connection between two terminators, the I/O processor reads the command from the memory and selects the switches and cables which provide a communication path between the particular terminators.

The CPU also can communicate directly with the I/O processor and scanner distributor without using core memory.

The core memory, which is common to the aforementioned units, is selected for use by one of the processors on a priority basis. The memory allocator schedules the use of the core memory by the three processors. The core memory, memory allocator, CPU, scanner distributor, and I/O processor are all assembled in one cabinet.

When the CTE is initially turned on, the memory is void of information and must be loaded manually by means of the computer display unit shown in Fig. 2.

Fig. 2—Memory display console.

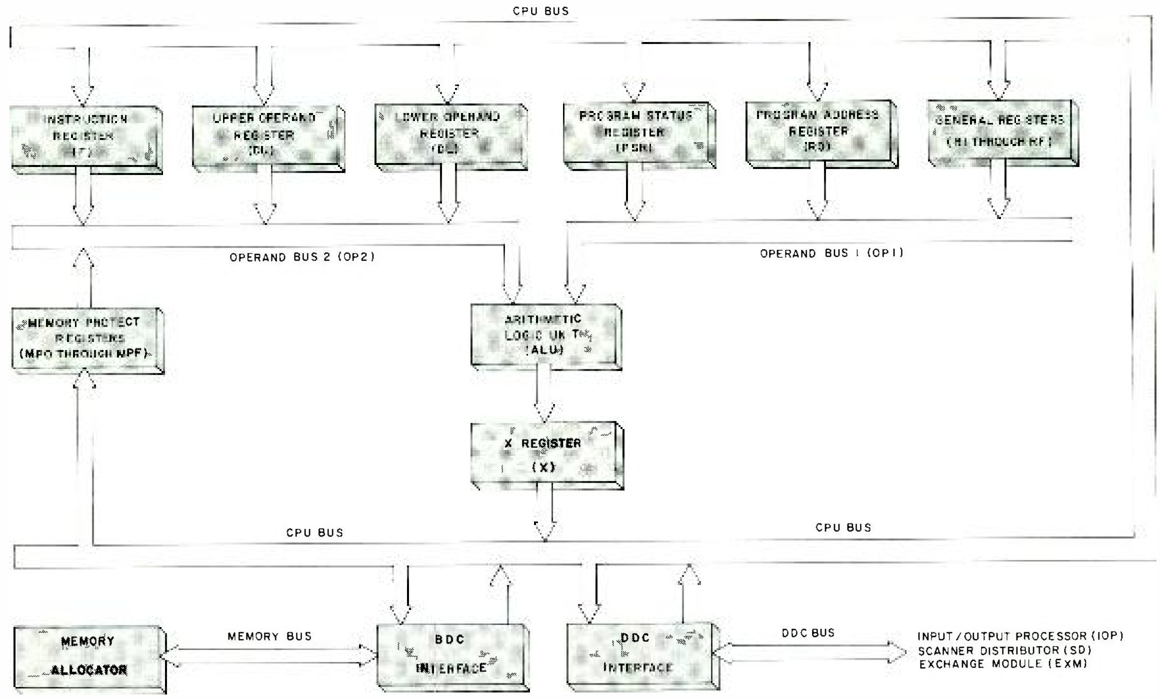

Fig. 3—Simplified central processor unit, block diagram.

Because of the large amount of information to be loaded into the memory, a leading program has been developed to instruct the CPU to load memory from disk memory or from other peripheral devices.

Initially, with no calls to process, the CPU cycles through the program without performing call processing functions. However, one of the instructions in the CPU program is to start the scanner distributor through a program. In turn, a command in the scanner distributor program checks the terminators and stores their status in the core memory. Another instruction in the CPU compares the present status of the terminators against past status. When a terminator status change is detected, call processing procedures begin.

Information exchanged between the core memory and the major registers of the CPU is transmitted over common lines within the CPU, which are referred to as the CPU common bus (see Fig. 3). Since the information on the common bus is simultaneously applied to all registers, each register is provided with input gating circuits to ensure that the information on the common bus will be loaded into the appropriate register.

In processing information, the CPU first addresses the core memory for an instruction, then performs the operations specified by the instruction. After the programmed routine has been performed the CPU removes another instruction from the memory and again performs the required operations, so that incoming call requests are processed continuously. During periods of low call activity, the instruction removed from memory may require the CPU to read the next instruction from memory and store the read instruction word in the memory. In this case, the CPU does nothing more than address the core memory for an instruction that requires processing.

Several programs are permanently stored in the core memory for access by the CPU. Two—the Executive program and the interrupt program— are used primarily for call processing.

The executive program addresses the memory, removes an instruction, stores the instruction in the appropriate registers, performs the routine required by the instruction, and requests the next instruction. Further, it periodically checks the status of the interrupt requests. When an interrupt is detected, the executive program is temporarily discontinued and the CPU initiates the interrupt program. The interrupt program is used when the scanner distributor or I/O processor requires communication with the CPU.

Logical operation of the CPU is synchronized to a four-phase clock, which is developed from a single-phase clock supplied by the system controller. A master or slave oscillator in the system controller develops the single-phase clock applied to the three CPU's, so that the operation of all three CPU's is accomplished via the CPU common bus, operand bus 1, or operand bus 2.

Normal communications between the CPU and scanner distributor of I/O processor are accomplished via a buffered data channel. During such communications periods, the scanner distributor and I/O processor perform call processing under control of their internal programs. If a command processed by either unit requires further CPU processing, the command address is stored in the memory queue area. This allows the CPU to access the commands sequentially for subsequent processing. Thus, the memory acts as a buffer between the CPU and scanner distributor or I/O processor.

The storage cycle speed is not directly related to the internal cycling of the CPU, thereby permitting an efficient relationship of CPU speed to storage access. Fetching and storing of data by the CPU are not affected by any concurrent input/output data transfer. If a CPU and a channel concurrently refer to the same memory location, the accesses normally are granted in a sequence that ensures sufficient priority to references by channels. If the first reference changes the contents of the location, any subsequent storage gathering provides the new contents.

Scanner distributor

The scanner distributor is a special-purpose, stored-program, synchronous processor, which provides an easily programmed and controlled link between storage and individual communications-channel terminators. It performs sensing and control of the state of selected terminators as to on-hook/off-hook status, input character synchronization and assembly, mark/space control of output lines, and disassembly of output characters.

Input from and output to the individual terminators are via the four buffered data channels. Each may be connected to 15 terminator cabinets, containing up to 256 terminators each. The scanner distributor can directly address one of 15,360 terminators. It also contains an interface to storage and to the direct data channel, and a control section that performs command, fetch, interpretation, and execution programs.

In the tridundant CTE system, each of two separate redundant output channels (CH A or CH B) of each scanner distributor is connected to one of two redundant majority-decision logic modules. The output of each majority module consists of four output channels. The four redundant input channels are combined and the two resultant redundant channels (A and B) are returned to the scanner distributor. The data and parity lines are bidirectional. The scanner distributor checks parity on both input channels and performs a bit-by-bit comparison between the two channels. Any discrepancy arms an interrupt alarm that indicates which channel or channels contained the parity error, and whether or not a bit error was detected. If the parity of CH A is correct, CH A input data will be accepted; otherwise CH B data will be accepted, even though CH B may also have incorrect parity.

The scanner distributor performs its system functions through execution of a cyclic program which is entered once every millisecond. The timing is controlled by a SYNCHRONIZE command that allows the scanner distributor to be synchronized with a real-time clock. The total program consists of a number of sub-programs, which are executed at multiples of the 1-ms basic-execution interval. This is implemented by using the COUNT BRANCH command, which bypasses portions of the total program except on those passes on which they are to be executed; this command causes a branch to be made conditionally in a particular field, consequently determining the character timing. Utilizing the basic 1-ms cycle and the COUNT BRANCH command, sub-program executions of 1000, 500, 333, and 200 times/second can be obtained. Due to the flexible nature of the SYNCHRONIZE and COUNT BRANCH commands, other synchronous super multiples of the basic rate can also be obtained.

The primary communication route between the scanner distributor and the CPU is via the scanner distributor command list and data areas in storage. The direct data channel interface is used primarily to monitor the progress of the scanner distributor program, to issue function codes, to set up information to the scanner distributor, to process its interrupts, and to diagnose scanner distributor and terminator problems.

The CPU can communicate with either the scanner distributor or the terminators attached to the buffer data channels. When communication is between the CPU and a terminator bay, the scanner distributor completes the communication path and converts the direct data channel connect words.

Input-output processor

The input-output processor (I/O processor) is a stored-program controller that obtains its commands directly from the core memory banks. If the processing procedures require a connection between two terminators, the I/O processor reads the command from the memory and selects the switches and cables which provide a communication path between the particular terminators.

The I/O processor can operate in two modes: In the first mode, it controls buffered data transfers between four channel buffers and the core memory banks and permits execution of the stored program. In the second mode, it becomes transparent and allows the CPU to communicate directly with a device on the buffered data channel. Thus, the CPU communicates through the core memory and I/O processor to peripheral equipments which perform auxiliary functions. The I/O processor takes no active part in the data transfer, and operates only as a transmission medium.

Operational and interrupt status may be obtained from the I/O processor by the CPU over the direct data channels. Since status transfers may be occurring concurrently with buffered operations between the buffered data channels and the memory, an output register for holding the appropriate status word is provided. The I/O processor also processes interrupt requests from devices on the buffered data channels. An interrupt priority structure is established in the hardware that determines the order in which simultaneous interrupt requests are serviced by the CPU.

The I/O processor services each channel on an "as required" basis. Each service request is processed as far as possible without waiting for a channel response. While the channel buffer is either filling or emptying, service requests are processed on other channels. When the channel buffer is full (or empty), it will request the I/O processor to begin processing. At the next convenient opportunity, the request will be processed. When multiple simultaneous requests exist, service is granted on a priority basis.

Service is granted to the requestor with the highest channel number. Each time a new service request is acknowledged, the I/O processor reevaluates the channel numbers of the requestors. Since the same rule is applied again, it is possible that a high channel number requestor can gain many consecutive accesses to the I/O processor. Normally, the highest-data-rate devices should be placed on the higher numbered channels.

Interrupt requests that are generated within the I/O processor are serviced ahead of other requests on the same channel, but only after any request on a higher-numbered channel. Interrupt requests that are device-originated on busy channels are not transmitted to the CPU. Conversely, interrupt acknowledge signals are routed to the highest-numbered non-busy channel.

I/O processor generated interrupt requests are transmitted immediately to the CPU. The I/O processor can service interrupt-acknowledges and read-interrupt function codes even on busy channels, when these signals are in response to its own internally-generated interrupt request.

System controller

The three system computers communicate with the switching equipment and peripherals over six data channels in the system controller (Fig. 4). There are also six expansion channels not used in the initial system controller configuration.

The system controller provides clock functions necessary for system timing, and performs evaluation, control, and display of system operation. Two channels of redundant logic (A and B) and a system control section are used to perform these functions. Channels A and B each contain 12 data channels to interface the I/O processor and scanner distributor sections of the system computers with the peripheral equipment. These two channel groupings are functionally identical: inputting, processing, and outputting data in parallel from and to the same locations. In addition, each channel group of redundant logic has its own power supply.

To reduce the possibility of error or failure affecting service, majority logic in the system controller compares the outputs of the three computers for each data channel. Each bit from a computer is compared with the same bits from the other two computers. The bit transmitted over the channel by the system controller is the bit received from at least two of the computers. If the bit from the third computer is of the opposite logic level, an interrupt is generated. When all three computers are transmitting and receiving in synchronization, the system is in the tridundant mode. One or two computers can be placed in the down condition by the computers, or by the control panel in the system controller. When one or two computers are down, only one computer, termed the survivor, transmits and receives data. If only one computer is down, the computer that is neither down nor survivor is termed the backup. The backup continues to receive data through the system controller and continues to transmit data in synchronization with the survivor. The outputs of the backup computer to the data channels are disabled by the system controller. However, the survivor and backup outputs are compared and any discrepancy generates an interrupt. The backup computer is thus held in immediate readiness for switching to survivor status in the event of failure in the survivor. A down computer also receives and transmits data to the system controller, as far as its disabled inputs permit. However, the outputs of the down computer are not compared with the survivor and backup outputs. A computer is normally placed in the down condition preparatory to placing the computer off line. Off line is a maintenance condition in which the computer no longer operates in synchronization with the other computers. An off-line computer does not send or receive normal call processing data, although it can communicate with switching equipment and peripherals over an off-line lettered channel.

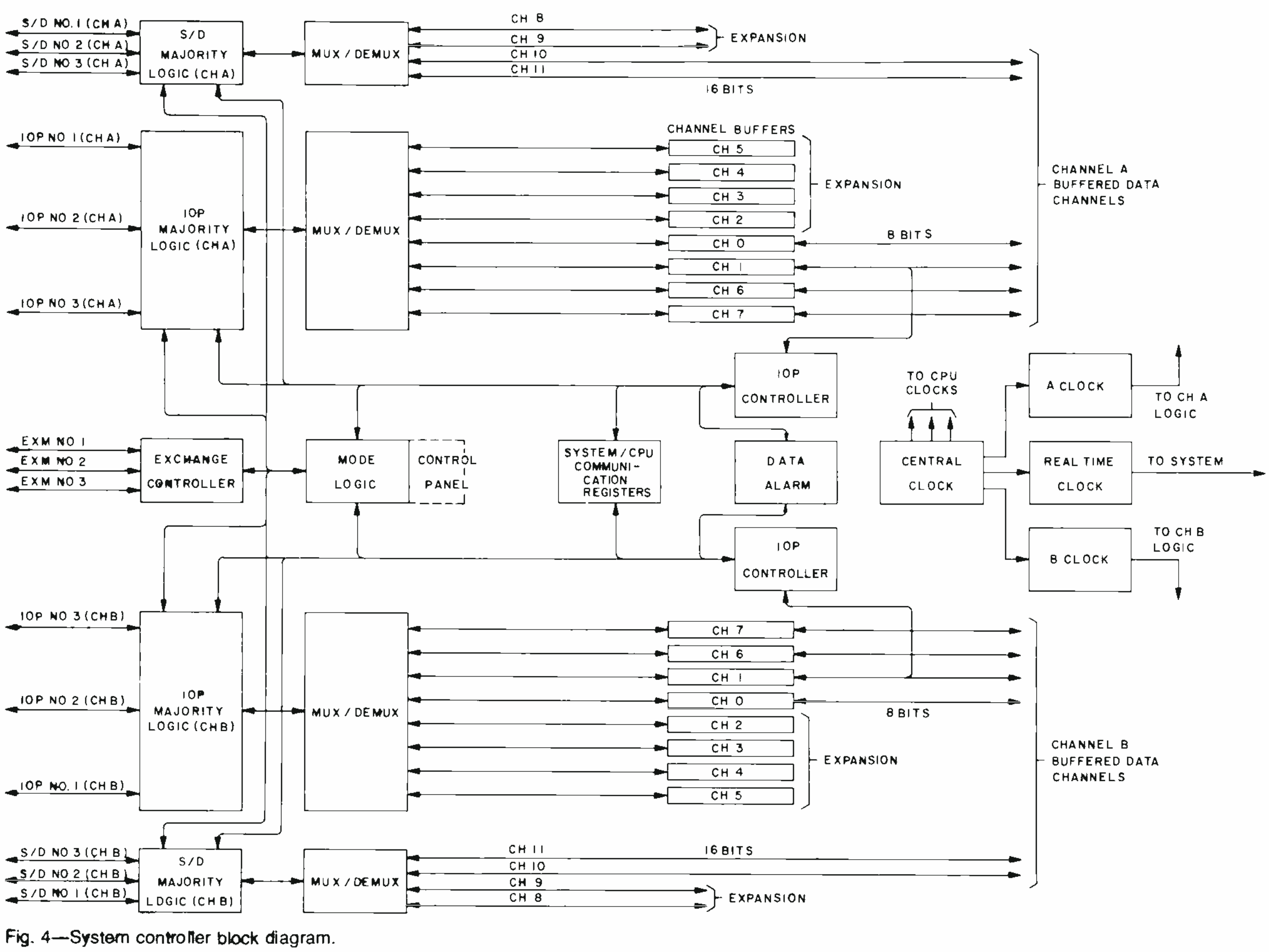

Fig. 4—System controller block diagram.

If desired, front panel controls may be operated to select a single or dual combination of computers for output to the peripherals, overriding the majority logic selection. In addition, front panel controls may be used to select outputs from either or both channels A and/or B for distribution to the peripheral equipment.

Time sharing is required for the individual buffered data channels to transfer I/O processor or scanner distributor data. However, because the I/O processor and scanner distributor are independent of one another, no time sharing is required between these two computer sections. An I/O processor channel may be operated in conjunction with, or separately from, scanner distributor channel.

Bi-directional lines are used to input/output data from the system controller to the computers and peripherals. Data coming from the peripherals are directed to channels A and B for gating at the proper time to all three computers. Again, time sharing is required for individual scanner distributor or I/O processor channels. No majority voting logic is used for these data coming from the peripherals.

The system controller clocks consist of a central clock and three subsidiary clocks: A, B, and real-time. The central clock provides master timing pulses for the three system controller subsidiary clocks, and for subsidiary clocks in the CPU's. Clocks A and B provide timing and synchronizing pulses for the logic in channels A and B, respectively. The real-time clock generates the real-time clock pulses to control CTE program cycling.

Disk memories

The disk memory equipment comprises two memory units, two electronic gages, and two disk controllers. The disk memory equipment supplies the CTE with memory space for 3,276,800 16-bit words, with a maximum access time of under 1/17 of a second. Each memory unit holds this many words. Two memory units are used to provide redundancy. Memory space in each unit is contained on four rotating disks, Fig. 5. Both faces of each disk are used, making eight faces available. Each face is divided into an inner zone and an outer zone, with each zone having 50 tracks. Each track contains 256 usable

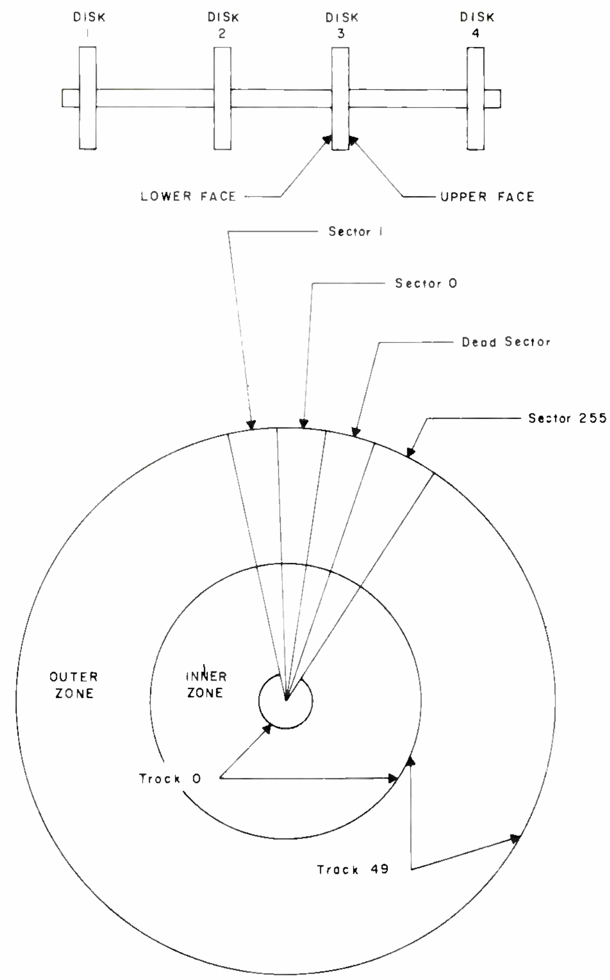

Fig. 5—Disk physical characteristics.

sectors, and each sector contains memory space for 16 data words of 16 bits each.

A read/write head is provided for each track. Data is read or written serially as the disk rotates under the head.

Each memory unit and its associated electronics and controller function as a unit to provide data storage space. The memory units operate independently of each other, and communicate with the CTE independently. There is no direct communication between the two units. During normal CTE operation, data stored in one of the memory units is also stored in the other. The redundant nature of the disk memory operation results from programming, and is not reflected in the hardware. Since both memory units operate in the same manner, only the operation of one is described.

The memory unit, via the disk controller, informs the I/O processor of the existence of interrupt conditions when they occur. When one such occurs, the disk controller sets a circuit associated with that particular condition. Then, when timing conditions permit, the disk controller sends an interrupt request signal to the I/O processor. Upon receipt of this signal, I/O processor knows that one or more interrupt conditions exist in a controller on channel 7 (for memory unit #1). However, because of a plurality of controllers on this channel, it does not know which is sending the signal. The I/O processor determines the source by sending an interrupt acknowledge on channel 7, which is received by the controller that originated the interrupt request, then waits for the acknowledge before transmitting its address. If more than one controller is sending an interrupt request simultaneously, priority logic in the controllers selects the one to transmit its address.

Switch network

Each communication path into the CTE is connected through a main distribution frame into a terminator. When two parties wish to communicate with each other, terminator-to-terminator, the path is established through a switching network by the CPU program stored in the core memory.

The network makes connections in such a manner that the two output wires of one terminator are connected to the two input wires of the other, and vice versa. Connections are made as directed by the I/O processor, with instructions transmitted on buffered channel 1.

Terminators

The terminators provide interfaces between a Telex line or trunk and the CTE. The CTE requires many different terminator cards, all of which are variations of a basic set of circuits. The various terminators each meet different interface requirements.

A terminator performs a number of functions:

- Regenerates a received Telex signal and transfers it to the common control (CPU) and another terminator via a metallic path;
- Transmits a Telex signal to a line or trunk from inputs of the common control or a connected terminator;
- Tests the paths between the terminators connected by the switch network;
- Bypasses the regenerator when commanded;
- Transmits the received signal through the network to the connected terminator;
- Receives the transmitted signal from the connected terminator through the network; and
- Provides an output to enable monitoring the transmitted and received data.

Each terminator is assigned a five-digit octal number which is associated with a particular switch, or card, in the trunk, bipolar, ARQ, incoming and outgoing (to the mechanical Automatic Telex Exchange) interface, GS (for transit) interface, MSCS (Mixing Selector—Channel Set) interface, distortion analyzer, distortion terminator, repeater, and Telex-to-TWX converter location.

Call accounting (magnetic tape) units

Message (call) accounting is produced off line from a magnetic tape provided by the CTE. Data for each record is taken from the call register corresponding to the particular call.

Information supplied is: start of message symbol, time of seizure, call serial number, call designator (complete or

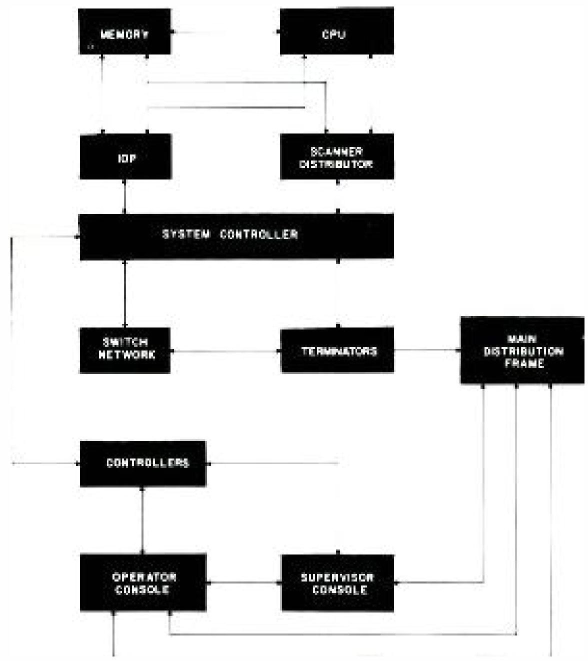

Fig. 6—Block diagram of operator assist console relationship to other equipment.

incomplete), calling terminator number, time of trunk seizure, calling answerback, called number, outgoing terminator number, called answerback, incomplete call designator [such as OCC (occupied), NC (no connection), ABS (machine turned off—party absent), etc.] start of chargeable time, time of disconnect, chargeable time, disconnecting party, end of message.

The information is stored in one of three tape units that are manipulated by controllers which allow the I/O processor to communicate with them. Each tape unit stores data on tape in the form of a series of records, each of which is made up of a series of characters. The number of records on a tape is variable, as is the number of characters in a record.

The tape is divided into two channels —channel A and channel B. A character written into one channel is simultaneously written into the other. When data is retrieved, both channels are read. Each character is then compared to its counterpart from the other channel. A character is represented by a six-bit code plus a parity bit and a clock bit. A stack of 16 write heads, each writing on its own track, is used to write the bits of a character into both channels in parallel.

The I/O processor controls the tape unit by transmitting sequences of commands. For example, the I/O processor stores a block of 154 characters with the sequence consisting of a connect command and 154 output data commands. After receiving the end-of-operation command from the controller, the I/O processor verified the accuracy of the record. If the I/O processor has not disconnected from the controller, the accuracy is verified by adding another command to the sequence. When the end-of-tape warning has been detected, the I/O processor rewinds and unloads the tape. The progress of rethreading a new reel by the technician can be followed by appropriate command sequences.

Of the three tape stations involved with the CTE, one is on line at all times, with the remaining two as backup. End-of-tape or other difficulty with the on-line device results in automatic switch-over to one of the redundant stations. If all three fail, arrangements can be made to utilize a high-speed printer to accumulate the accounting information. It is also possible to obtain accounting information from the Immediate Access Subsystem described later.

Accounting records for each call are written on to the accounting tape in the order in which the calls are disconnected, and not necessarily in serial order. A new tape is mounted at the beginning of each day, at midnight.

Other peripherals

Of the remaining peripherals to the CTE, the most important are the operator consoles, supervisor console, and card reader.

Although the CTE is an automatic system, human involvement in some instances is a necessity. In these instances, connnections between some communication paths cannot be established automatically, and must be processed through an operator. Examples are when a calling party experiences difficulty in establishing communication with another party, or when some specific type of information is required, such as the number of another party, etc. It is the prime function of the Operator/Supervisor Console Control Subsystem (Fig. 6) to establish the links and process the calls during the time that an operator is required.

The normal subsystem involves one operator controller, one controller-operator position, 15 operator consoles (two positions each for a total of 30 operator positions), and one supervisor console. Additional subsystems are added as the CTE is expanded.

The operator console is connected through the controllers to the I/O processor for communication with the system. The printer associated with each operator console connects to a terminator, as do the printers external to the CTE. The operator can communicate with the I/O processor through the control panel on the operator console, or communicate with the scanner distributor through the printer keyboard.

The supervisor console contains a control panel for communicating with the I/O processor, and for selecting the desired operator position to monitor. The control panel also provides an indication of a faulted condition existing on any operator position, and contains controls to block or inhibit the position. It also has a TTY machine to monitor the call on-line and any operator position.

Each Operator Console can be designated for either assistance or information functions. Each console contains two positions (left and right), and either position may be designated as "out-of-service" or assigned the service function of assistance or information. The assignment of functions, as well as the "out-of-service" designation, are under program control of the computer, and may change depending upon the particular program. In addition, the service status of each operator console is under control of the supervisor console; thus, the operator position supervisor may designate a position as being "out-of-service."

In assigning calls to operator positions there is a specific pattern of assignment: an odd-numbered position that is idle and is designated for the class (information or assistance); an even numbered position that is idle and is designated for the class; and any idle position, regardless of its classification. All odd-numbered are left-hand positions; and all even-numbered, right-hand. Selection is done on a non-homing basis. If all positions are occupied, including alternate routing to the Automatic Telex Exchange booking positions, an NC (no connection) will be sent to the calling party and the call disconnected.

The card reader is another peripheral device used extensively with the CTE. It enables personnel to change the program rapidly and accurately as required. It is a photoelectric device that reads punched cards (each containing 80 columns of data) at a speed of approximately 400 cards/minute, then outputs the data to the computer. The reader can be started, stopped, and reset.

Other peripheral devices used in the CTE, but not described here, are the card punch, high-speed line printer, and maintenance console.

Immediate access subsystem (IAS)

This computer subsystem has an abbreviated CTE central processor, but no scanner distributor function. It permits immediate access to the abstracts generated on each Telex call for accounting. These abstracts are used for commercial, statistical, and maintenance purposes. The IAS enables rapid answers to queries and complaints from overseas correspondents and subscribers. With this subsystem, without monitors, answers to questions about calls can be provided on the same day the calls happen. Typical information supplied from the IAS is: number of chargeable minutes on a call, from subscribers, or from overseas correspondents wishing to know if a given booked call has been completed: and if so, when, and for how many chargeable minutes.

The information is transmitted to the IAS through a coupler-buffer connected to the I/O processor. All accounting records are written to IAS at the same time that they are written to the CTE tape stations. The IAS has its own disk on which the abstracts are written for immediate interrogation; when that disk is full, the abstracts are written onto IAS magnetic tape stations.

The disk holds the last 3060 accounting messages written. The IAS tape stations hold 88,000 accounting messages, or, at least five hours of Telex call information at a rate of five new call attempts per second. Disk-to-tape transfer occurs at the end of every 12 accounting messages.

Interrogation and printout is done by means of a Teletype Model 35 ASR machine. A software function code is entered either by keyboard or tape. There is a choice of eight criteria for "finding" the information required.

Most search for information will be on the tape. Tape search is conducted by reading backward from the most recently written block of 12 records until the search is successfully completed. The search rate is nearly 300 accounting records per second.

Conclusion

The computer telex exchange has been installed and operating for approximately 3½ years at RCA Global Communications, Inc. It has demonstrated a superiority over electromechanical switching exchanges in several ways: large numbers of channels can be added quickly; it is relatively insensitive (from a labor/cost viewpoint) to substantial load additions; and hardware maintenance is not a serious problem.

Two critical areas require additional work for the future: 1) stabilization of software with added changes and 2) increased reliability of software as changes are made to it. The main objective will be directed toward increasing the general system reliability.

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joined RCA Lancaster as a design and development engineer in October 1958 after receiving the BSEE from the Milwaukee School of Engineering. He received the MS in Physics from Franklin and Marshall College in 1972. Mr. Butterwick's total experience has been in the design and development of image tubes. He designed the current RCA magnetically-focused tube line, the first ceramic image tubes, the two stage light shutter tube, a small IR tube and the gamma camera image tube. In addition, he was responsible for various customized image tubes for specific laboratory use. During the past four hears he has led the Image Tube Product Development Group, having the primary responsibility for image tube development under both government contracts and RCA-sponsored programs. His primary area of development responsibility in recent years had been for second-generation image intensifier tubes.

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received BA in physics from the College of Wooster in 1940 and the MS in Physics from Syracuse University in 1942. He joined RCA in 1942 as a design engineer on multiplier phototubes. Since 1953, he has held various positions as engineer and engineering leader in design, advanced development, and application engineering related to image tubes and image intensifier tubes. Mr. Stoudenheimer is a member of the American Physical Society and a Senior Member of IEEE. Mr. Stoudenheimer served on the IEEE Standards Committee and was a past chairman on the Subcommittee for Phototube and Image Tube Standards.

Second generation image intensifiers in law enforcement applications

G. N. Butterwick | R. G. Stoudenheimer

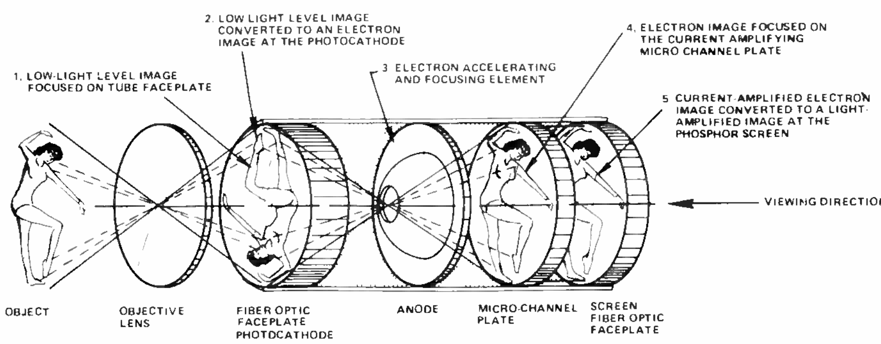
Image intensifier systems have been used by police organizations throughout the country for night surveillance work over the past three years. The effectiveness of such systems has recently been extended with the introduction of the more compact second-generation image intensifiers. The surveillance device can now be hand held making it possible for the patrolman on routine night patrol to observe scenes in dark shadows at night. Such a device can also be coupled to a standard 35-mm camera for photographic recording.

NIGHT SURVEILLANCE of potential riot or crime areas was possible only with artificial illumination before 1969. Surveillance in shadow areas was often inadequate to detect or identify criminal acts or suspicious persons. In 1969, first-generation image intensifiers were removed from government security classification and made available to law enforcement agencies for various types of night surveillance. These intensifiers were placed in various systems for direct viewing, remot viewing with low-light-level TV, and photographic recording of suspected illegal or criminal acts at night. The utility of image intensifier systems for property protection and for secretly observing suspected illegal actions at night was demonstrated so effectively that intensifier systems were procured by police departments around the country to improve their effectiveness in law enforcement.

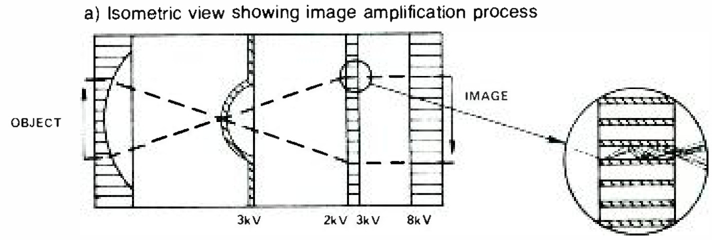
In July of 1971, second-generation image intensifiers were declassified. This paper is intended to compare some of the characteristics of first- and second-generation intensifiers and indicate under what conditions second-generation intensifiers may be preferred.

Principles of low-light image amplification

Image intensification in first-generation intensifiers is accomplished in the following manner. The scene to be observed is optically focused onto the photocathode of an image intensifier. The photocathode converts the light image into an electron image which is accelerated and focused onto a phosphor screen at a voltage of 12,000 to 15,000 V. The phosphor screen converts the energy of the high-voltage electron image into an amplified light image. The light amplification of such



a) Isometric view showing image amplification process



b) Cross-section showing operational voltages and a magnified view of the current-amplifying micro-channel plate.

Fig. 1—Second-generation image intensifier tube, image inverter type.

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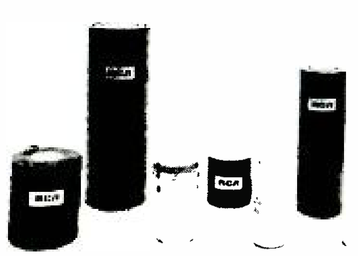
a single-stage image-intensifier tube is in the range of 25 to 100. To provide the intensification of 25,000 or more needed for direct-view systems, three stages are cascaded to make a first-generation intensifier.

Another approach to high-gain intensification is the placement of a current amplifier in the plane of the electron image to amplify the space current before it hits the phosphor screen. The current amplifier is the heart of the second-generation image intensifier tubes. This current amplifier is a micro-channel plate which in many ways simulates the human eye. It is a flat wafer having a thickness of about 0.020 inch and contains more than a million tiny open channels through the wafer.

The wafer has electrodes on the two faces across which a voltage of 500 to 1000 V is applied. The walls of each channel are coated with a high-resistance coating which is also a good secondary emitter. Primary electrons that hit the front surface release secondary electrons that are accelerated down the channel where they again strike the wall and release more secondary electrons as illustrated in Fig. 1. In this way, the current is amplified while maintaining the image information. Each tiny channel (1/10th the diameter of a human hair) has a current gain that is a function of the input-current density and the voltage across the entire plate. The voltage across the plate can be readily adjusted for the light gain needed in a particular surveillance application.

The complete intensifier assembly consists of the intensifier tube and power supply potted within a cylindrical housing. The power supply is a transistorized oscillator and high voltage multiplier of the Cockcroft-Walton type. The power supply may include either a manual or automatic gain control, or both, to provide optimum screen brightness over a wide range of incident illumination levels.

Fig. 2—Image intensifiers. Left to right: 25-mm second generation, potted; 25-mm first generation, potted; 25-mm second generation, unpotted; 18-mm second generation, potted; 18-mm second generation, unpotted; 18-mm first generation, potted.



Characteristic	1st Gen.	2nd Gen.	Units
Resolution:			
Center	30 to 40	25 to 35	1 p/mm
Edge	30 to 40	25 to 36	1 p/mm
Low-Light-Level (10^{-6} fc)	12 to 16	10 to 14	1 p/mm
Gain	35,000 to 75,000	25,000 to 75,000	
Distortion	12 to 18	3 to 7	%
Length (potted)	5.8	2.010	in
Diameter (potted)	2 075	2.076	in.
Brightness Uniformity	4:1	3:1	
Screen Brightness (Max.):			
Point	10,000	15	fL
With Automatic Brightness (or Gain) Control	100 to 200	1 to 5	fL

Table I—Characteristics of first- and second-generation image intensifiers.

Fig. 2 is a photograph comparing the size of first- and second-generation intensifiers. The smaller size of the second-generation intensifiers is one of the most important features. A night viewer having a short-focal-length objective lens and a second-generation intensifier provides a policeman with a small portable viewing device for investigating the presence of intruders in unoccupied homes, warehouses, stores, and other business places. The viewer is also ideal for close-range investigations in dark alleys, backyards, parking lots, etc. A long-range night surveillance device, which must have a large lense of long focal length to see detail in distant objects, cannot be small and, consequently, cannot be as compact as the short-range viewer. Second-generation intensifiers can also be used in long-range viewers but size of the system must necessarily increase as the size of the objective lens increases.

First- and second-generation intensifiers compared

One cannot claim superior performance in all respect for either first- or second-generation intensifiers. Each has certain better characteristics than the other. First-generation intensifiers have a somewhat higher center resolution in line-pairs per millimeter at both high and low light levels than second-generation intensifiers. Second-generation intensifiers, however, have less distortion, a more uniform brightness in the displayed picture, and, in general, better edge resolution than first-generation intensifiers. The relative distortion of first- and second-generation intensifiers, may be compared in Figs. 6 and 7. A more comprehensive comparison of the characteristics may be obtained from Table I.

A unique feature of second-generation intensifiers is a saturation characteristic of the micro-channel-plate output current which limits the maximum brightness of a reproduced scene on the output screen. This saturation is related to the strip current through the plate resulting from the voltage applied across it. The output current and related screen brightness are proportional to the input current until the output current density reaches about 10% of the strip-current density. As input current density increases further, the output-current density increases at a slower rate and, at the knee, approaches a value essentially equal to the strip-current density. The relation of screen

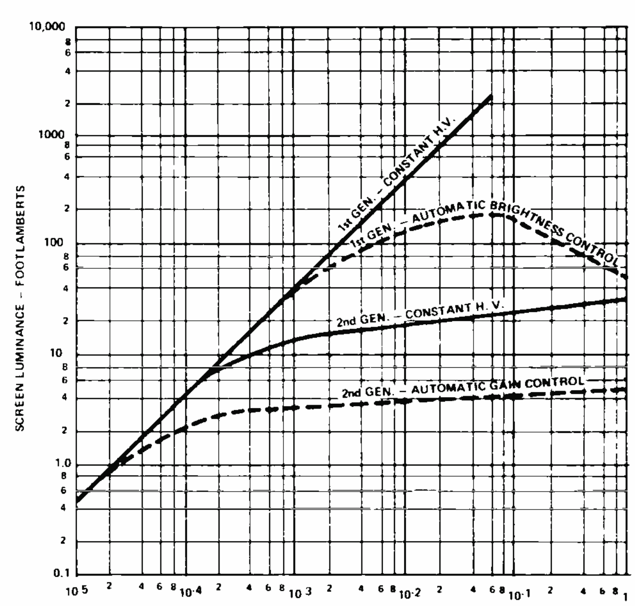


Fig. 3—Gain characteristics of first- and second-generation image intensifiers.

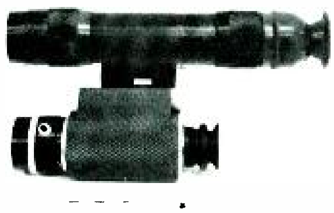


Fig. 4—Low-light-level viewers: (top) 18-mm first generation; (bottom) 18-mm second generation.

luminance to incident illumination is shown in Fig. 3 which illustrates and compares the gain characteristics of both first- and second-generation intensifiers.

The saturation of the output screen brightness has significance in two ways:

1) Bright sources in the field of view are seen with attenuated brightness relative to the brightness of adjacent shadow areas. The scene can consequently be viewed with more eye comfort.
   Scattering of light after the intensifier from highlight areas into shadow areas is also less likely to degrade contrast in the shadows. However, scattering of light within the intensifier or ahead of the intensifier is not diminished as a result of microchannel-plate saturation, and improved ability to see more detail in shadow areas is not always achieved as a result of the bright source attenuation.
2) If the intensifier is operated at an output screen brightness limited by the microchannel-plate current saturation, the saturation characteristic reduces contrast in the displayed picture. To avoid this loss of contrast, gain control—either automatic or manual—is essential in second-generation intensifiers. Too much screen brightness reduces contrast and too little screen brightness results in loss of the scene. Second-generation image intensifiers are now usually equipped with automatic gain control and operate below the screen brightness level determined by plate saturation.

Second-generation intensifier systems

Three types of systems are of interest for night-time surveillance and law enforcement: (1) direct-view systems; (2) photographic-recording systems, and (3) remote-viewing (low-light-level TV) systems.

Direct-view systems and photographic systems are desirably hand-held devices for most types of patrol and routine investigations. Small size and weight should greatly increase the usefulness of these devices in most police departments.

A compact, direct-view intensifier instrument made at RCA to demonstrate and evaluate second-generation intensifiers is shown in Fig. 4. This viewer incorporates the RCA C33106P1, 18-mm second-generation image intensifier. Movement of prowlers can be observed with great clarity in dark shadow areas at night. Recognition and identification of individuals is also possible at close range. Because the size of the optical image on the intensifier increases with long-focal-length telephoto lenses, resolving ability for distant objects may be improved by replacing the standard objective lens with interchangeable telephoto or zoom lens. The most versatile viewing systems will be equipped with interchangeable telephoto lenses which may be kept in an instrument case carried in the patrol car.

This viewer may also be adapted to a 35-mm camera for a photographic recording desired for court evidence or for police records in an investigation. Fig. 5 shows the viewer adapted for low-light-level photography with a 35-mm camera. Adaptations may be made to cameras having an electric-eye automatic exposure control for foolproof low-light-level photographs.

However, the lower brightness of the output image in second-generation intensifiers makes the selection of suitable relay lenses and photographic film more ciritical than with first-generation. To expose the film with relatively short exposure times, the relay lens must have a very low *f*-number. Only the very fastest film can be properly exposed with exposure times of less than 0.1 second. Fig. 6 illustrates the picture detail possible with a second-generation intensifier. Fig. 7 is another picture taken through a first-generation intensifier to compare distortion in the first- and second-generation intensifiers.

Fig. 5—Second-generation image intensifier camera.

The viewers and cameras illustrated were built by RCA for the purpose of evaluating the performance of the image tubes and are not commercial items. Similar instruments are available from other manufacturers who specialize in complete systems.

Second-generation intensifiers have been adapted to low-light-level TV systems and have been successful in some military applications. However, our studies have not been extensive enough to disclose significant advantages over existing low-light-level TV systems which have advanced to a high degree of perfection in recent years.

Conclusion

Second-generation intensifiers are now available for night surveillance in law enforcement. These intensifiers have performance very similar to first-generation intensifiers, but are smaller in size. Their greatest value in law enforcement appears to be in their portability, low image distortion and the uniform brightness of the displayed picture. They are recommended for routine night patrol for the detection and observation of intruders in unoccupied homes, stores, warehouses, and other dark areas at close range.

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Fig. 6—Low-light-level photograph taken through a second-generation image intensifier with 18-mm image size.

Fig. 7—Low-light-level photograph taken through a RCA 4550 18-mm first-generation image intensifier.

Worst-case circuit analysis using the moment method

F. E. Oliveto

The moment method of worst-case analysis allows the circuit designer to achieve a desirable probability of success while placing less stringent limitations on individual part tolerances. Thus, unnecessary redesign to compensate for an unrealistic "worst-worst-case" condition can be avoided. This technique also permits a sensitivity analysis of each input and part parameter to determine which ones have the most effect on the dependent variable. The mathematics underlying this technique are given in some detail, and a simple example is included to illustrate the technique and its advantages.

THE MOMENT METHOD is a statistical analysis technique used to evaluate circuit performance and behavior and to determine the probability of success (or failure) of a circuit or parameter in question. Based on the frequency distributions of the independent variables (input and part parameters) the mean (μ) and variance (σ^2) are computed and used to estimate the mean and the variance of the dependent variables (circuit output parameters). Therefore, the moment method of statistical worst-case analysis can be used to predict the mean (μ) and standard deviation (σ) of the frequency distribution for each output variable provided the necessary data exists for the input and the part parameters.

Input data and assumptions

To determine the probability of success (or failure) of a circuit or a particular parameter, the variations of each input and part parameter must be known or assumed. Some sources of variation are part parameter tolerances, signal-input or power-supply fluctuations, noise, aging, and environmental conditions. The frequency distributions describing such variations must also be known, assumed, or determined.

Frequency distribution is determined from available data or by performing simulation procedures. The simulation could be accomplished by statistical sampling techniques; however, the sample sizes must be sufficiently large to ensure a good experimental counterpart of the real population. Ideally, the exact frequency distributions of the part or input parameters should be known or determined. In practical situations, however, the frequency distribution usually is not known or cannot be determined due to lack of the necessary data. In such cases, it is common practice to assume that the frequency distribution follows normality even though distributions describing a particular physical phenomenon are seldom exactly normal.

If the exact frequency distribution can not be determined but can be assumed or known to be normal, the first two

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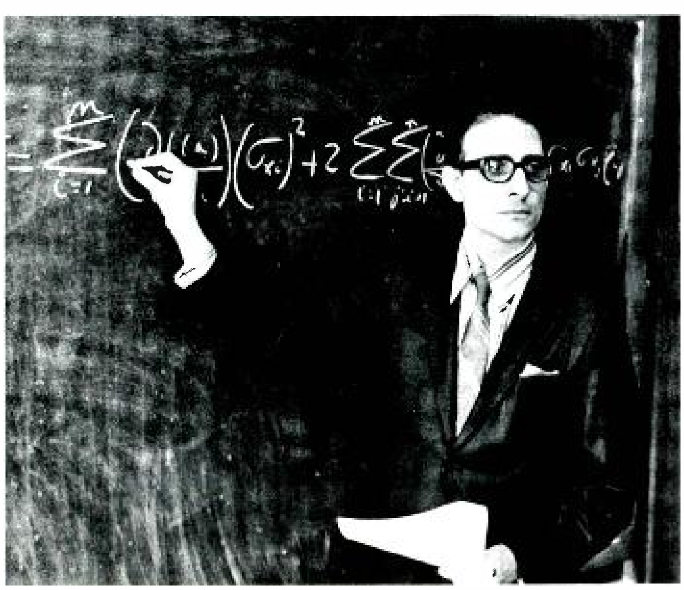

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Equations

$$(\Delta f)^2 = \left(\frac{\partial f}{\partial x}\Delta x\right)^2 + \left(\frac{\partial f}{\partial y}\Delta y\right)^2 + \left(\frac{\partial f}{\partial z}\Delta z\right)^2 + 2\left(\frac{\partial f}{\partial x}\frac{\partial f}{\partial y}\Delta x\Delta y\right) + 2\left(\frac{\partial f}{\partial x}\frac{\partial f}{\partial x}\Delta x\Delta z\right) + 2\left(\frac{\partial f}{\partial y}\frac{\partial f}{\partial x}\Delta y\Delta z\right) \quad (2)$$

$$(\sigma_f)^2 = \left(\frac{\partial f}{\partial x}\right)^2(\sigma_x)^2 + \left(\frac{\partial f}{\partial y}\right)^2(\sigma_y)^2 + \left(\frac{\partial f}{\partial z}\right)^2(\sigma_z)^2 + 2\left[\frac{\partial f}{\partial x}\frac{\partial f}{\partial y}\sigma_x\sigma_y\rho(x,y) + \frac{\partial f}{\partial x}\frac{\partial f}{\partial z}\sigma_x\sigma_z\rho(x,z) + \frac{\partial f}{\partial y}\frac{\partial f}{\partial z}\sigma_y\sigma_z\rho(y,z)\right] \quad (3)$$

$$(\sigma_f)^2 = \left(\frac{\partial f}{\partial x}\right)^2(\sigma_x)^2 + \left(\frac{\partial f}{\partial y}\right)^2(\sigma_y)^2 + \left(\frac{\partial f}{\partial z}\right)^2(\sigma_z)^2 \quad (4)$$

$$f(x) = f(a) + \sum_{j=1}^{m}\frac{1}{j!}\left\{\sum_{i=1}^{n}\left(\frac{\partial f(a)}{\partial x_i}\right)^j (x_i - a_i)^j\right\} \quad (5)$$

$$E[f(x) - f(a)] = E\left[\sum_{i=1}^{n}\left(\frac{\partial f(a)}{\partial x_i}\right)^2 (x_i - a_i)^2 + 2\sum_{i=1}^{n}\sum_{j=i+1}^{n}\frac{\partial f(a)}{\partial x_i}\frac{\partial f(a)}{\partial x_i}(x_i - a_i)(x_j - a_j)\right] \quad (8)$$

$$E[f(x) - f(a)]^2 = \sum_{i=1}^{n}\left(\frac{\partial f(a)}{\partial x_i}\right)^2 E(x_i - a_i)^2 + 2\sum_{i=1}^{n}\sum_{j=i+1}^{n}\left(\frac{\partial f(a)}{\partial x_i}\right)\left(\frac{\partial f(a)}{\partial x_i}\right)E(x_i - a_i)(x_j - a_j) \quad (9)$$

$$\sigma^2 = \sum_{i=1}^{n}\left(\frac{\partial f(a)}{\partial x_i}\right)(\sigma_{x_i})^2 + 2\sum_{i=1}^{n}\sum_{j=i+1}^{n}\left(\frac{\partial f(a)}{\partial x_i}\right)\left(\frac{\partial f(a)}{\partial x_j}\right)(\sigma_{x_i})(\sigma_{x_j})\rho_{ij} \quad (10)$$

moments of the distribution—the mean (μ) and the variance (σ^2)—describe it completely. The worst-case calculation can then be performed, and the following assumptions (usually accepted) can be made:

1) The component part parameter values have a normal (Gaussian) distribution.

2) The part parameter tolerances are not large relative to the nominal value.

3) If the component part parameters are dependent and interacting and if the correlation coefficients are not known, it could be assumed that the part parameters are independent and not interacting (correlation coefficients of zero).

4) The component parts are randomly combined (randomly chosen).

5) The performances variations will also follow a normal frequency distribution.

6) When tolerance limits are specified for a given parameter, it is assumed that they are based on a large sample size of the component and that the parameter values are distributed over a certain range (say within $\pm 3\sigma$) of an orderly frequency distribution. Also, some small failure fraction of the frequency distribution is outside of the tolerance limits (for example, 27 in 10,000 for 3σ limits).

Therefore, gathering valid data for determining the frequency distribution of the input and part parameters is a necessary condition for the moment method. It definitely determines whether or not to use this particular statistical technique of circuit analysis.

Thus, the mean value (μ), the standard deviation (σ), and the correlation coefficients between parameters (if they do exist) are necessary information for each input and part parameters' frequency distributions. These values, as previously stated, should be known, assumed, or statistically estimated from available data or data obtained from a properly designed statistical sampling scheme. It should be emphasized, once again, that although the exact frequency distribution is not used and, in the practical situation, distributions describing a particular phenomenon are seldom exactly normal, the accuracy is believed to be within reason for most work if normal distribution is assumed.

Propagation of variables

The moment method is based upon a statistical equation called the propagation of error and often referred to as the theorem on the Propagation of Variables. Specifically, the moment method is an application of the propagation of the mean-square error (or variance). This equation will now be derived.

One-variable case

Let us calculate for small errors (Δx) in a function of one variable. Using the linear term in Taylor's Series to express the effect on $f(X)$ of a small error in x:

$$\Delta f = \frac{df}{dx}\Delta x$$

This is the equation for the propagation of error in a function of a single variable where df/dx is the first derivative of $f(X)$, evaluated at the point $[x, f(x)]$.

In practice, however, the true value of x is not known, but it is usually sufficient to evaluate df/dx at a near-by point, such as a point whose coordinates are determined experimentally; df/dx remains constant while Δx and Δf vary.

Thus, errors in $f(x)$ will be proportional to the error in x and the derivative df/dx is the factor of proportionality.

It should be pointed out, however, that this expression is *not* exact: Δf is not strictly proportional to variations in x, except when $f(x)$ is linear. It is, however a good approximation for actual use if Δx is small enough, or if higher derivatives of f are negligible. Fortunately most functions used in experimental work satisfy these requirements.

Three-variable case

Let f be some function of x, y, and z and Δx, Δy, Δz be the variations respectively. The Taylor series can be used to express the variation, Δf:

$$\Delta f = \frac{\partial f}{\partial x}\Delta x + \frac{\partial f}{\partial y}\Delta y + \frac{\partial f}{\partial z}\Delta z \quad (1)$$

Thus, Δf is proportional to Δx, Δy, Δz and the partial derivatives are factors of proportionality.

To develop a relationship between f and the mean-square error (variance) of x, y, and z, square both sides of Eq. 1: (See **Equations,** 2.)

Letting Δx, Δy, Δz take all possible values within their allowable ranges of variation, each term in Eq. 2 is replaced by its average value: (See **Equations,** 3.)

where $(\sigma_x)^2$ is the variance of x and $\rho(x, y)$ represents the correlation between x and y.

If the tolerance variations in x, y, and z are independent, the correlations are zero, and Eq. 3 reduces to (see **Equations,** 4.)

General case

To derive a general expression of the variance, assume f is a function of n variables $(x_1, x_2, \ldots, x_n)$.

Letting a represent the mean value of the input parameter, the Taylor series expansion is: (See **Equations,** 5.)

where $f(a) = f(a_1, a_2, \ldots, a_n)$; and $f(x) = f(x_1, x_2, \ldots, x_n)$. In practice, the variations in part and parameter tolerances are limited to the extent that terms above the second degree $(m=2)$ can be eliminated. Thus,

$$f(x) = f(a) + \sum_{i=1}^{n} \frac{\partial f(a)}{\partial x_i}(x_i - a_i) \quad (6)$$

and

$$[f(x) - f(a)] = \sum_{i=1}^{n} \frac{\partial f(a)}{\partial x_i}(x_i - a_i) \quad (7)$$

Squaring both sides of Eq. 7, and taking the expected value, E: (See **Equations,** 8.)

Let us now refer to some of the well-established statistical theories:

1) The expected value of a constant (k) times a variable is equal to the constant time the expected value of variable:

$$E(kx) = kE(x)$$

2) The expected value of a sum is equal to the sum of the expected values:

$$E(x_1 + x_2 + x_3 + x_n) = E(x_1) + E(x_2) + E(x_3) + E(x_n)$$

3) Combining 1) and 2) it follows that:

$$E\left[\sum_{i=1}^{n} k_i x_i\right] = \sum_{i=1}^{n} k_i E(x_i)$$

Then, from Eq. 8: (See **Equations,** 9.)

Variance $(\sigma)^2$ is defined as $(\sigma)^2 = E[f(x) - f(a)]^2$ and the correlation coefficient, ρ_{ij} is

$$\rho_{ij} = \frac{E[(x_i - a_i)(x_j - a_j)]}{\sigma_{x_i}\sigma_{x_j}}$$

If the second term in Eq. 9 is multiplied and divided by $(\sigma_{x_i})(\sigma_{x_j})$ and the definitions of variance and correlation coefficient applied: (See **Equations,** 10.)

This is the general equation used for the moment method of worst-case statistical analysis. Again, if errors in $x_1, x_2, x_3, \ldots x_n$ are independent $(\rho_{ij}=0)$, Eq. 10 reduces to:

$$\sigma^2 = \sum_{i=1}^{n}\left(\frac{\partial f(a)}{\partial x_i}\right)^2 (\sigma_{x_i})^2 \quad (11)$$

Applying the moment method

To use the moment method of worst-case analysis, follow the step-by-step procedure outlined below:

1) Study the circuit carefully with a thorough understanding of its operation and intended function.
2) Determine the appropriate mathematical model. This model should describe the functional operation of the circuit as accurately as the mathematical formulation permits.
3) Obtain the partial derivatives of the dependent variables with respect to each input and part parameter (independent variables).
4) Multiply the partial derivatives by the respective mean (nominal) value.
5) Substitute the product obtained in 4) above, the variances of the input and part parameters, and the correlation coefficients (if they exist) in the general propagation of various formula (Eq. 10 or 11).
6) Calculate the numerical value of each of the partial derivatives by substituting the mean (nominal) value of each input and part parameter in the partial derivative expression. The numerical value of the means are either known, assumed, or obtained from data reduction.
7) Substitute the numerical values of the tolerances (the sigma limits of each input and part parameter independent variable) in the general propagation of variance formula (Eq. 10 or 11).
8) Substitute the numerical values of the correlation coefficients in the general formula.
9) Compute the numerical value of the propagation of variance formula. The value obtained is the total variance of the dependent variable. As stated previously, the frequency distribution of the dependent variable was either known or assumed to be normally distributed.
10) Using the normal (Gaussian) distribution probability curve, estimate the probability of the circuit success and failure.
11) Calculate the minimum and maximum values of the output dependent variable using a) the total variance of the output dependent variable, b) the mean (normal) value, and c) the specified range of the output dependent variable.
12) Use the standard tables for normal distribution to find the area under the "bell-shaped" curve falling above and below the maximum and minimum values calculated above. It was assumed the output variable is normally distributed.
13) Determine the probability of success of the circuit or the output dependent variable by computing the area falling outside the minimum and maximum value of the normal distribution table. The probability of success can be improved by observing which independent variable (partial derivative) has the most effect on output (dependent) variable. Then, the most sensitive parameter can be changed by tightening the tolerance or by changing the original nominal value. The next most sensitive partial derivative, if necessary, can be treated in the same manner; the 3rd, etc.
14) Again, from the new value of the total variance and from the new nominal values, if changed, determine the probability of success and failure.
15) If the calculation is satisfactory stop the procedure; if it is not satisfactory, repeat steps 13) and 14).
16) If choosing tighter tolerances and different nominal values of the independent inputs and part parameters becomes exhaustive and the dependent variable still

does not meet the desired probability of success, choose another approach; e.g. redesign the circuit.

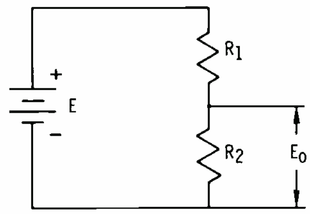

Fig. 1—Voltage divider network.

Example

The network of Fig. 1 is chosen as a simple example to illustrate the technique. The variations introduced into the output (E_0) by variations in component values are calculated.

The following are the values of the component parts and the associated tolerance limits of the network in Fig. 1:

$E = 10$ V $\pm 10\%$ (9 to 11 V)
$R_1 = 800$ ohms $\pm 5\%$ (760 to 840 ohms)
$R_2 = 200$ ohms $\pm 1\%$ (198 to 202 ohms)
$E_{0\,(\text{specified})} = 2$ V $\pm 10\%$ (1.8 to 2.2 V)

The output potential (E_0) is

$$E_o = \left(\frac{R_2}{R_1 + R_2}\right) E$$

$$E_o\ (\text{nominal}) = \frac{200}{800 + 200}$$

$$E_o\ (\text{nominal}) = 2\,V$$

$$E_o\ (\max) = \left(\frac{R_2\ (\max)}{R_1\ (\min) + R_2\ (\max)}\right) E\ (\max)$$

$$= \frac{202}{760 + 202}\quad 11$$

$$E_o\ (\max) \approx 2.31\,V$$

$$E_o\ (\min) = \left(\frac{R_2\ (\min)}{R_1\ (\max) + R_2\ (\min)}\right) E\ (\min)$$

$$= \left(\frac{198}{840 + 198}\right)\ 9$$

$$E_o\ (\min) \approx 1.72\,V$$

Therefore, the "worst-worst" case output potential is 2.31 V (max) and 1.72 V (min) and does *not* meet the specified value of 2.2 to 1.8 V.

Using the moment method, we find partial derivatives with respect to each input variable:

$$\left.\begin{aligned} \frac{\partial E_o}{\partial E} &= \frac{R_2}{R_1 + R_2} \\ \frac{\partial E_o}{\partial R_1} &= \frac{-R_2 E}{(R_1 + R_2)^2} \\ \frac{\partial E_o}{\partial R_2} &= \frac{E}{R_1 + R_2} - \frac{R_2 E}{(R_1 + R_2)^2} \end{aligned}\right\} (12)$$

Assuming the component parts (inputs and part parameters) follow normality, the mean is the nominal value and the tolerance (standard deviation) in this case, is 3σ. Thus, the following data can be used.

Parameter	Nominal	Standard deviation (3σ)	Variance (3σ)²
E	10 V	$E \pm 10\%$	$(E)^2(\pm 10\%)^2$
R_1	800 ohms	$R_1 \pm 5\%$	$(R_1)^2(\pm 5\%)^2$
R_2	200 ohms	$R_2 \pm 1\%$	$(R_2)^2(\pm 1\%)^2$

With the correlation of coefficient at zero, the expression for total variance $(3\sigma E_0)^2$ can be taken from Eq. 11

$$(3\sigma_{E_0})^2 = \left(\frac{\partial E_0}{\partial E}\right)^2 (\sigma_E)^2$$

$$+ \left(\frac{\partial E_0}{\partial R_1}\right)^2 (\sigma_{R_1})^2 + \left(\frac{\partial E_0}{\partial R_2}\right)^2 (\sigma_{R_2})^2$$

Substituting the partial derivatives (Eq. 12) and variance

$$(3\sigma_{E_0})^2 = \left(\frac{R_2}{R_1 + R_2}\right)^2 (E)^2\ (10 \times 10^{-2})^2$$

$$+ \left(\frac{-R_2 E}{(R_1 + R_2)^2}\right)^2 (R_1)^2\ (5 \times 10^{-2})^2$$

$$+ \left(\frac{E}{R_1 + R_2} - \frac{R_2 E}{(R_1 + R_2)^2}\right)^2$$

Substituting the numerical values,

$$(3\sigma_{E_0})^2 = 4.665 \times 10^{-2}$$

and

$$\sigma_{E_0} = 7.2 \times 10^{-2}$$

The maximum value, $E_0(max)$ is

$$E_0\ (\max) = \frac{\text{specified maximum} - \text{nominal}}{\text{calculated standard deviation}}$$

$$= \frac{2.2 - 2.0}{7.2 \times 10^{-2}}$$

$$\approx 2.78$$

The minimum value, E_0 (min), is

$$E_0\ (\min) = \frac{\text{specified minimum} - \text{nominal}}{\text{calculated standard deviation}}$$

$$= \frac{1.8 - 2.0}{7.2 \times 10^{-2}}$$

$$\approx 2.78$$

The area under the normal bell-shaped curve for 2.78 is 0.0027; this is the area that falls outside the 2.78 point. Therefore, the probability that the output potential E_0 will exceed 2.2 is 0.0027; likewise the probability that E_0 will fall below 1.8 is 0.0027.

The overall probability of failure, $P_f = 0.0027 + 0.0027 = 0.0054$. Thus, the probability of success (P_s) for the output potential (E_0) is $P_s = 1 - P_x = 1 - 0.0054 = 99.46\%$.

Conclusion

Worst-case analysis using the moment method is a very useful technique for realistical appraisal of a circuit. By being able to predict the probability of the circuit success/failure, the designer can determine whether the circuit is adequate for a particular application or a higher probability is required. The importance of this method is that circuits will not have to be redesigned to meet 'worst-worst-case" conditions if 100% probability of success is not absolutely essential.

The technique, however, is not restricted to electrical circuitry, but can be applied to any scientific and engineering disciplines where tolerances of the elements making up an entity can be expected—for example, electrical power distribution, structural and mechanical design, and civil engineering.

Acknowledgment

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Integrated circuit for AM radio

L. Baar

An integrated circuit for use in AM radio applications can assume many forms, depending on the class of service in which it is to be used. The RCA type CA3088E is designed for use in high-quality AM superheterodyne receivers. It provides the basic functions of signal conversion, IF amplification, detection, and audio preamplification sufficient to drive a separate power amplifier. Auxiliary functions supplied are: a supply-voltage regulator, internal AGC for the first IF amplifier, AGC voltage for an optional external RF stage, and an amplified signal to drive a tuning-meter output. This device is housed in a 16-lead dual-in-line plastic package. Intended for use in commercial AM broadcast receivers, the circuit is equally suited for most AM receiver applications up to a frequency of 30 MHz. In addition, since most functions are externally accessible, this device is also a general-purpose amplifier array. The possible number and variety of uses of the CA3088E are largely a function of the needs and imagination of the designer.

VARIOUS STAGES of the CA3088E are designated in AM-radio functions because this is the primary function of the device; the AM-radio terminology is continued throughout the paper for continuity.

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received the BSEE from Rutgers University in 1952. Upon graduation, he joined RCA as a test engineer in the Receiving Tube Division. From 1955 through 1957 he served with the U.S. Navy. He returned to RCA in 1957 as an engineer in the Receiving Tube Applications Laboratory. During 1965 he gradually phased into semiconductor responsibilities, with subsequent experience in bipolar and MOS applications work. He is presently an applications engineer with responsibilities in Linear Integrated Circuits at the Solid State Division. Mr. Baar is the author or co-author of two other papers.

The heart of this integrated circuit (see Fig. 1) is the second IF amplifier-detector combination. The IF amplifier consists of Q7, Q9 and Q10 with their associated components. Q7 and Q10 are emitter followers which isolate the gain stage, Q9. The supply voltage to the collectors is regulated by the zener diode, Z1. The quiescent operating point is stabilized by connecting the emitter of Q10 to the base of Q7 through R14. The connection is made by externally tying pin 7 to pin 8 through a suitable impedance. For DC stabilization, pin 7 should be at AC ground potential, otherwise signal feedback will modify the basic characteristic of the stage. The output of Q10 is fed directly to Q12, an emitter follower operating at a quiescent current of approximately 100 μA. This stage becomes a detector by connecting the proper filter circuit to the emitter; the emitter is brought out on pin 9. The rectified emitter current develops a voltage at the junction of R20 and R21; the junction is connected to the bases of the AGC and meter amplifiers.

Q11 is an emitter follower normally used to drive a tuning meter at pin 12. Q11 is biased *off* with no signal and will deliver approximately 150 μA with a maximum signal as indicated in Fig. 2.

Q8 is an AGC amplifier intended to control an optional external RF amplifier. Collector voltage, applied through a load resistor to pin 13, provides a decreasing voltage at pin 13 with increasing signal. The voltage drop across diode D5 must be overcome by the drive voltage to the base of Q8, thus introducing a delay in the application of gain control to the rf stage. The AGC curve of a typical circuit is shown in Fig. 2.

Q5 is the first IF amplifier and is biased to draw 1 mA under zero-signal conditions. This condition is set by the biasing circuit of Q2, Q3, Q4 and diodes D1 through D4. A nominal current of 1 mA is established in Q3, which is a mirror of Q5, thus determining the cur-

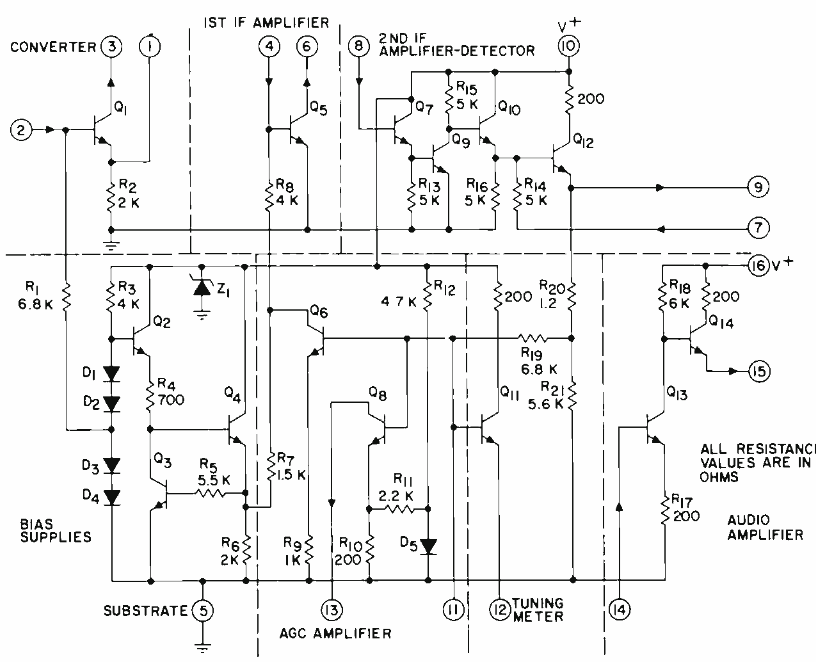


Fig. 1—Schematic diagram of the RCA CA3088E.

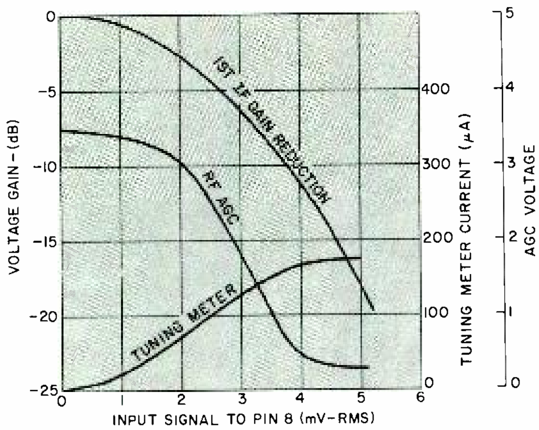


Fig. 2—Typical performance curves for the CA3088E.

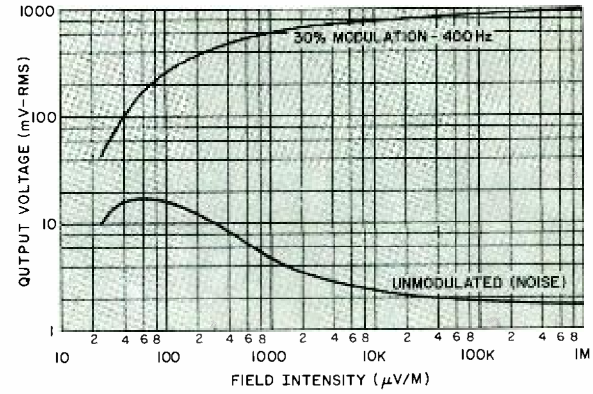


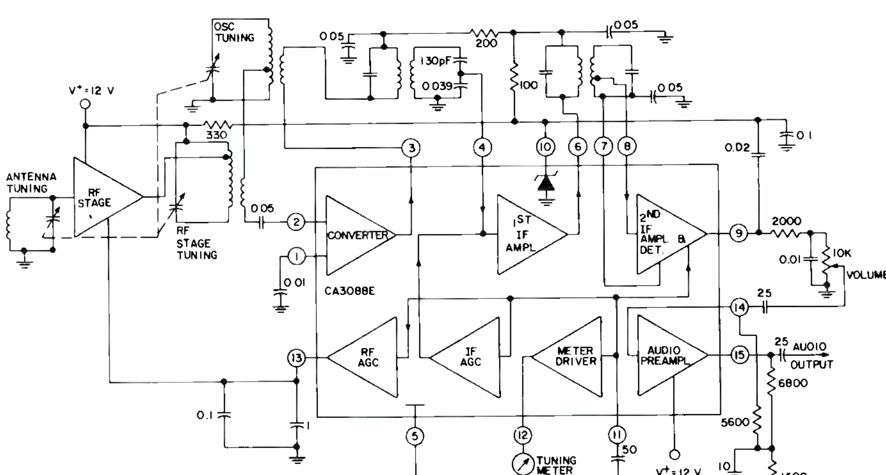
Fig. 4—Performance curves for an AM receiver with an RF stage using the CA3088E.

rent in Q5. The supply voltage to the biasing circuit is also regulated by Z1. With no signal, Q6 is cut off and has no effect on the operating point of Q5. As signal strength increases and the base drive voltage increases, Q6 conducts some of the base current being applied to Q5 and reduces the collector current and, thus, the gain, as shown in Fig. 2.

Q1 is normally used as a converter stage. It is biased to a nominal current of 0.35 by diodes D3 and D4 in combination with the source resistor, R2. The emitter is brought out of pin 1; this terminal may be bypassed or may be used to apply a local-oscillator signal to the emitter.

Q13 and Q14 form the audio driver stage, a grounded emitter stage coupled directly to an emitter follower. The emitter follower provides a low-impedance drive for an external audio amplifier. This stage must be externally biased; a convenient method is to feed a portion of the DC potential on the emitter of Q14 to the base of Q13 with the proper network connected between pins 14 and 15. A nominal voltage gain from pin 14 to pin 15 of 30 times is determined by the ratio of resistor R18 to R17.

In addition to the voltage regulation provided by the zener diode, Z1, the circuit is temperature compensated by the bias circuit described previously. Transistors Q1, Q5, and Q13 are large-geometry devices which provide low-noise performance in the CA3088E. All emitter follower stages which have the emitters brought out to external terminals are protected against inadvertently shorted terminals. The size of the chip is 52×52 mils.



ALL RESISTANCE VALUES ARE IN OHMS
ALL CAPACITANCE VALUES ARE IN MICROFARADS

Fig. 3—Typical AM broadcast receiver using the CA3088E.

Applications

AM broadcast receivers

When would a designer use the CA3088E as the basic subsystem of an AM radio? The typical low-cost table model or portable radio ordinarily has neither an RF amplifier stage nor a tuning meter; therefore, two features of the CA3088E have no use in simple AM radios. Furthermore, economic considerations make it diffícuut for integrated devices to compete with discrete devices in these minimal-performance receivers. On the other hand, the high-performance console receiver is an application in which all of the features of the CA3088E are usable. The CA3088E, in which the biasing of most stages is accomplished internally, provides savings in the number of components to be specified, purchased, handled, and connected.

Fig. 3 shows the circuit for a typical AM receiver using the CA3088E. Double-tuned transformer-coupled circuits are shown here, but any of the other forms of bandpass filters may be used that best suit the needs of the designer. The RF stage may take on any of several forms and so is shown only as a gain block. The intention here is not to present an optimum receiver design, but to show how a specific device, the CA3088E, may be used. Fig. 4 shows performance curves obtained in a receiver using the CA3088E in conjunction with an external RF stage.

In addition to commercial broadcast-receiver, a multitude of receiver applications exist in communications equipment of all forms. The CA3088E will suit many of these applications with the extra features available in the circuit.

The CA3088E may be used as a straight IF amplifier for use with a separate tuner, or it could serve as a subsystem in a double-conversion receiver. Amateur radio receivers are a natural for the circuit. Narrow-band or fixed-tuned systems, such as remote control systems, and hand-carried receivers, systems in which the space saving features of an integrated circuit could be important, could make good use of the CA3088E.

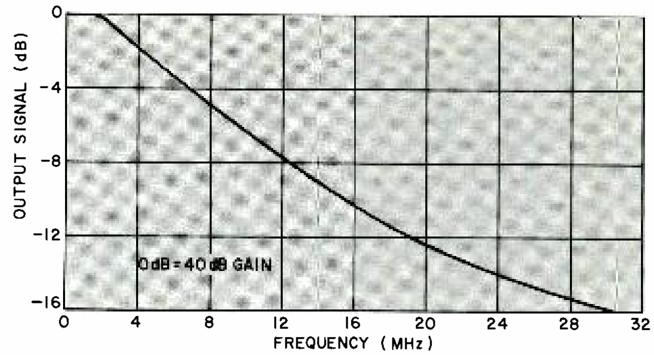


Fig. 5—Plot of voltage gain as a function of frequency for the second-IF-amplifier/detector stage of a CA3088E.

Table I—Input and output impedance data.

	C_{IN} (pF)	C_{OUT} (pF)	C_{lb} (pF)	1 MHz R_i Ω	30 MHz R_i Ω	1 MHz R_o Ω	30 MHz R_o Ω
Q_1	12	5	1.5	3500	2000	100 K	9 K
Q_5	17.0	5	1.5	2000	1000	100 K	9 K
Q_7	3.5	—	—	75 K	45 K	—	—

High-frequency applications

Many receivers use IF amplifiers at the higher frequencies; therefore, the high-frequency characteristics of the CA3088E are important. Table I shows some of the four-pole characteristics of the individual signal stages of the CA3088E at 1 MHz and 30 MHz. The forward transconductance is not significantly affected in the frequency range considered.

The high-frequency performance of the second-IF- amplifier/detector stage is determined within the chip. Fig. 5 is a plot of the voltage gain of the stage as a function of frequency. The gain is down about 6 dB at 10 MHz and about 16 dB at 30 MHz. The nominal gain of this stage is 40 dB; therefore, this stage has considerable gain at these frequencies.

The converter and first-IF stages will operate at higher frequencies, but stability considerations will control the practical gain. Calculations of maximum useable gain (MUG) and maximum available gain (MAG), using the data in Table I for the unneutralized single-stage amplifier, show that about 10 dB of power gain must be sacrificed to maintain good stability at 30 MHz. More gain can be obtained by neutralizing, but at the expense of circuit simplicity.

The audio-preamplifier stage may also be used as another IF stage provided that the low output impedance of the emitter follower is not detrimental to performance. The stage may be used to drive a crystal or ceramic filter in which the typical matching impedances are quite low. The frequency response of this stage is very similar to that of the second-IF stage with about 6 dB drop in gain at 10 MHz. This stage may also be controlled by the output from pin 13 as is the case with the external RF stage.

Fig. 6 shows the circuit of a 10.7 MHz IF amplifier using two ceramic filters. This circuit shows how the use of the CA3088E with low-impedance filters can simplify a design. Stability is maintained by the low-impedance terminations used with the filters. The first two stages are coupled together with a single-tuned circuit which provides impedance matching. A 50-μV input signal with 30% modulation produces a detected audio signal of 22 mV at the detector output. The audio stage may be used as an audio driver or as an additional IF stage to drive the input ceramic filter.

General-purpose amplifier array

The CA3088E is versatile enough to be used as a general-purpose amplifier array. Q1 and Q5 are internally biased and require only a collector load to produce an amplifier. These devices may be operated to a maximum collector voltage of 16 V. With the addition of external biasing, the operating points of these stages may be varied from the internally established quiescent point. The second-IF-amplifier/detector combination is biased externally as discussed previously. Q12, which is normally connected as an envelope detector may be connected as another emitter follower by loading resistors R20 and R21 with an external resistor.

The audio preamplifier is independent and biased externally. The gain-control circuits may be used as in the AM-radio applications. If Q12 is not used as a detector, the gain-control voltage can be applied on pin 11. Q11 provides a positive-going voltage with increasing signal and Q8 provides a negative-going voltage.

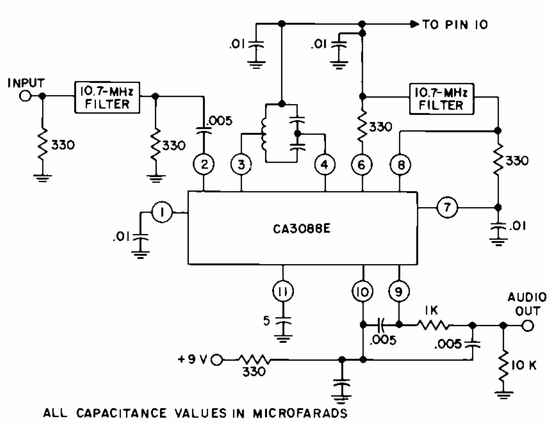


Fig. 6—A 10.7-MHz IF amplifier using the CA3088E and two ceramic filters.

Processing wideband information with narrowband channels

J. F. Balcewicz

It is theoretically possible to transmit a wideband signal using *n* parallel, narrowband channels (or *n* successive uses of the same channel) by sampling the signal and commutating every *n*th sample onto the same channel. The performance of such a technique is limited by amplitude- and phase-distortion effects and by the generation of spurious outputs. The sources of these anomalies are identified and quantitative measures of the resulting performance degradation are given. A method or easily and accurately predicting the frequency response of such a processor is described as well as a way in which the technique may be used to tradeoff transmission time for transmission bandwidth.

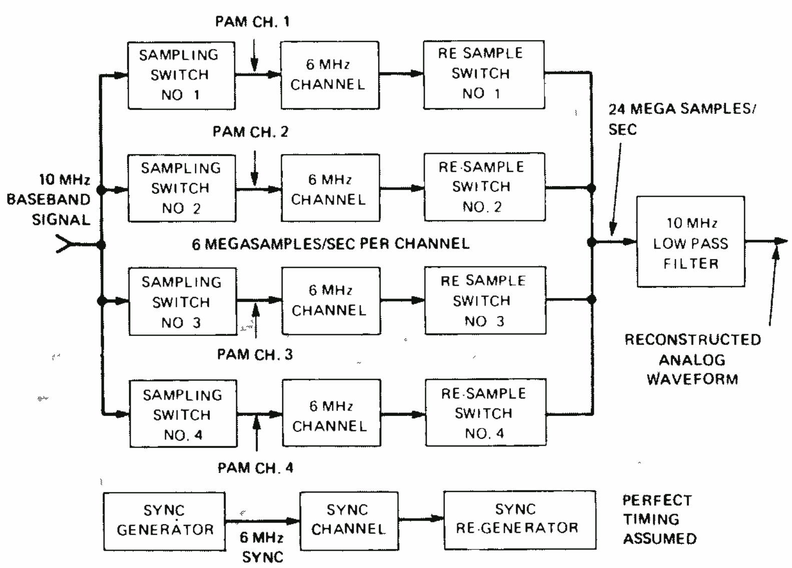
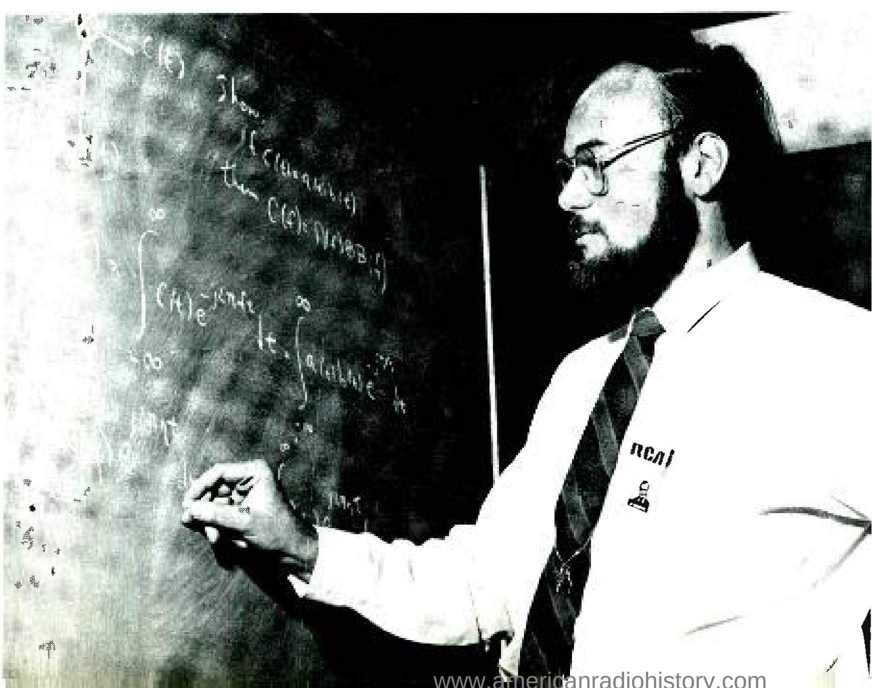


Fig. 1—Four-channel, 10-MHz signal processor.

Joseph F. Balcewicz, Communications and Data Processing, Astro-Electronics Division, Princeton, N.J., received the BSEE and MSEE from the Massachusetts Institute of Technology in 1966 and 1967, respectively, and has been with AED since then. Mr. Balcewicz has designed communications subsystems for use in the next generation of ITOS meteorological satellites. He also participated in a study of binary PSK modulation in a Rician fading environment, the design of microwave components for communication satellite transponders, and a design study of multiplexer and demultiplexer configurations for use in association with spacecraft radiometers. He was appointed an MIT non-resident instructor and has taught a course in system analysis to a group of undergraduate co-op students and has presented seminars on digital communication techniques. He has maintained an active interest in information and coding theory and statistical communications. Mr. Balcewicz has written several technical papers. He is a member of the IEEE, Tau Beta Pi, and Eta Kappa Nu.



THE SIGNAL PROCESSING TECHNIQUE described in this paper has been experimented with for many years. While "looking good on paper", breadboard models have not been able to meet preliminary expectations. This paper identifies certain areas that limit the performance of such a processor and thereby indicates ways of improving the performance characteristics. Specifically, a mathematical model is formulated for the four-channel processor shown in Fig. 1. The frequency response of this type of process is derived for finite-bandwidth channels. Examination of this response reveals an irregular amplitude response and a nonlinear phase response, which is the source of processor harmonic distortion.

By assuming linear, but not identical, phase characteristics for the four transmission channels, the source of spurious distortion products is identified. It is estimated that for three identical channels and one channel which differs from the others by only 10° at 6 MHz (a 4.6-ns differential delay), the best signal-to-spurious-distortion ratio (SSDR) achievable is only 20.3 dB.

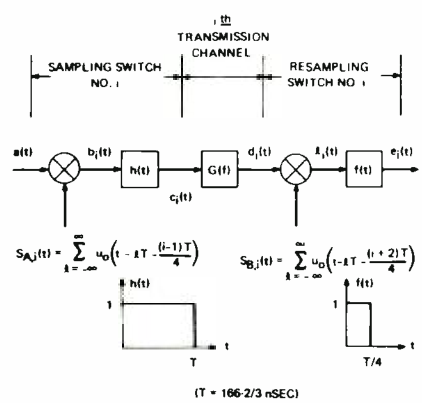


Fig. 2—Mathematical model of the *ith* processor channel [$U_o(t)$ is the unit impulse function].

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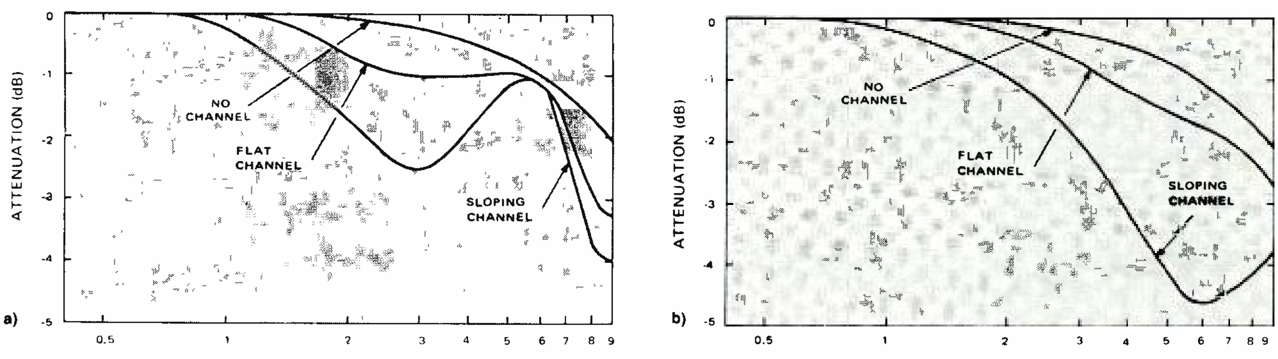

Fig. 3—Mathematically predicted frequency responses. a) four-channel processor; b) two-channel processor.

An intuitive consideration of the processor operation then results in a method of approximating the frequency response and distortion levels for an n-channel configuration. Finally two applications of this processing technique are described:

1) Improving the transmission channel frequency response, and
2) Providing a means to trade off transmission-time and bandwidth.

Frequency response of a four- and two-channel processor

A mathematical model for the ith channel of the four-channel processor is shown in Fig. 2. The input signal is assumed to contain useful informaton in the frequency range from DC to 10 MHz. A composite sampling rate of 24 megasamples/second is assumed for the processor—a 6 megasample/second rate in each channel. The sampling switch [multiplier followed by $h(t)$] is modeled as a sample-and-hold switch. The switch is driven by an infinite impulse train and holds each sample for $T=166\frac{2}{3}$ ns. The channel waveforms are therefore pulse-amplitude modulated (PAM) in nature. The four transmission channels [$G(f)$] are assumed, for the present, to be identical, 6-MHz, lowpass, finite-bandwidth channels. The two specific channel models to be considered are a flat unity-gain channel and a sloping channel whose gain decreases linearly from unity at DC to 0.5 at 6 MHz.

The resampling switch [multiplier followed by $f(t)$] is also of the sample-and-hold type. The sampling is delayed by 125 ns (¾ of the PAM pulse duration) from the first switch sampling and the hold internal is $T/\% = 41\frac{2}{3}$ ns. It is assumed here that there is no delay through the transmission channel.

The timing in the four channels is staggered by $T/4$ ($41\frac{2}{3}$ ns). To form the processor output signal, the outputs of the four parallel processing paths [the $e_i(t)$] are summed and passed through a rectangular, distortionless 10-MHz lowpass filter.

The analysis is more conveniently handled in the frequency domain. Using standard notation for the Fourier transform of a time waveform, it may be verified that[1]:

$$E_i(f) = \left\{\left\{\left[A(f) * S_{A,i}(f)\right] \cdot H(f) \cdot G(f)\right\} * S_{B,i}(f)\right\} \cdot F(f) \quad (1)$$

where * denotes a convolution operation.

The spectrum of the output signal, $A(f)$, is just a 10-MHz filtered version of

$$\sum_{i=1}^{4} E_i(f)$$

Without loss of generality, $A(f)$ may be assumed to be a flat, rectangular spectrum from DC to 10 MHz and zero thereafter. The $E_i(f)$ may be calculated from Eq. 1 and the information contained in Fig. 2. The $\Sigma E_i(f)$, from DC to 10 MHz, is the processor frequency response. This frequency response is evaluated for both the flat and the sloping transmission-channel models. Inasmuch as the channel characteristics and input signal spectrum are finite in bandwidth, graphical convolution techniques may be employed. The resulting frequency response for the four-channel configuration is presented in Fig. 3a. The result for $G(f)=1$ for all frequency is also given. This is the no channel case and the only effect is a sin x/x rolloff due to the resampling switch, $F(f)$.

The above analytic technique was also applied to a two-channel configuration. The same transmission channel models were assumed, but each switch now operated at a 12 megasamples/second rate. The re-sampling switch continued to sample-and-hold for the final $41\frac{2}{3}$ ns of each PAM bit period. The response of the two-channel processor is presented in Fig. 3b.

As is evident from Fig. 3, the processor frequency response contains a ripple component due to the finite bandwidth of the transmission channels which is accentuated by non-rectangular channel characteristics. This response is modulated by a sin x/x rolloff due to the sample-and-hold nature of the resampling switches.

While Fig. 3 presents only the magnitude of the frequency response, the phase response is also derived from the analysis. As might be expected, this phase response also contains a ripple making it distinctly non-linear. This non-linear phase characteristic causes harmonic distortion in some types of input signals. It is evident from Fig. 4 that a 1.5-MHz squarewave input to a four-channel processor with sloping 6-MHz channels will result in a distorted output. The fundamental frequency in the input signal will be delayed by 17.1 ns, while the third harmonic will be advanced by 5.7 ns,

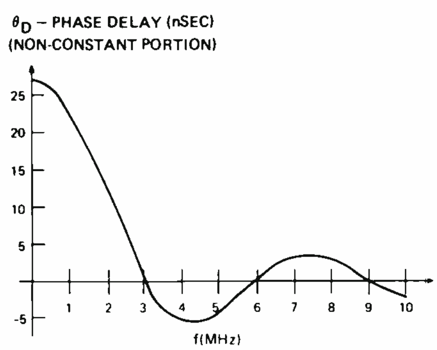

Fig. 4—Phase delay through four-channel processor with sloping, 6-MHz channels.

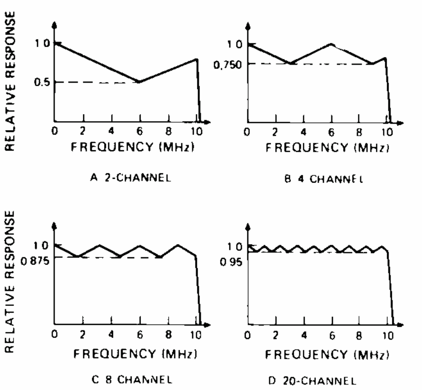

Fig. 5—Predicted frequency responses for various processor configurations.

relative to a constant delay of 145.8 ns for all frequencies. A signal-to-harmonic-distortion ratio (SHDR) can be defined for a squarewave input, as a function of frequency f, as:

$$\text{SHDR} = -20 \log_{10} (f \cdot |\Theta_{D0} - \Theta_{D1}|) \quad (2)$$

where Θ_{D0} is the phase delay of the fundamental, through the processor, and Θ_{D1} is the corresponding phase delay of the third harmonic. The SHDR is a minimum of 30.7 dB at a squarewave frequency of 1.5 MHz.

The ripple in the processor amplitude response is also responsible for harmonic distortion. For instance, it can be seen from Fig. 3a that, for a 3-MHz squarewave input, the fundamental will be attenuated by 3.6 dB, while the third harmonic is attenuated by 5.6 dB. This effect further degrades the processor SHDR. In general, the SHDR indicates how well the processor will operate in the limit as all the components (switches, channels, filters) become mathematically ideal.

In sampled-data processors, the interpolation filter is designed to yield a sharp-cutoff characteristic. Such filters usually have non-linear phase response and some sort of equalization network is used to linearize their phase response. The harmonic distortion caused by amplitude and phase non-uniformities may also be reduced by designing the proper equalization network. The non-uniformities are predictable and a network can be synthesized which, when placed at the processor output, will be able to compensate for them.

Frequency response of an *n*-channel processor

An intuitive discussion of the operation of the four-channel, 10-MHz processor leads to the method of predicting the amplitude response of a general, n-channel configuration almost by inspection. The sampling rate in each of the four channels is 6 megasamples/second—$1/n \times f_s$, the composite sampling rate (n=4, f_s=24 megasamples/second). For an input sinusoid of frequency f_j, between DC and 3 MHz, the lowest signal frequency in the sampled waveform is at f_j. For an f_j of 3 MHz, assuming sample-and-hold switches, the waveform sent over the transmission channel "looks like" a 3-MHz squarewave.

For f_j greater than 3 MHz and less than 6 MHz, the lowest signal frequency in the sampled waveform is 6 MHz minus f_j until, at an f_j of 6 MHz, a DC level is again being transmitted over the channel. Similarly, for input signals between a 6 MHz and 9 MHz, the lowest transmitted frequency is f_j minus 6 MHz; and at an f_j of 9 MHz, the transmitted waveform is again a 3-MHz squarewave. For frequencies between 9 MHz and 10 MHz, the lowest transmitted frequency is at 12 MHz minus f_j. Thus, for any signal input frequency between DC and 10 MHz, the channel waveform will contain a fundamental component between DC and 3 MHz. The major effect of the channel is on this fundamental component so, as a first approximation, the frequency response of the transmission channel between DC and 3 MHz will really determine the frequency response of the entire processor.

Generalizing this result, the effect of the transmission channel on the processor frequency response may be found by letting the processor response equal the channel response for input frequencies from DC to $f_s/2n$. For frequencies from $f_s/2n$ to f_s/n, the processor response is set equal to the channel response from $f_s/2n$ to DC, respectively. This is repeated for input frequencies from f_s/n to $2f_s/n$, $2f_s/n$ to $3f_s/n$, etc. until the entire processor passband has been covered.

This procedure has been carried out for a 10-MHz processor with n at 2, 4, 8, and 20 (f_s=24 megasamples/second) and the results are presented in Fig. 5 for the sloping, 6-MHz channel. It is apparent from Fig. 5 that, as n increases, the passband ripple increases in frequency but decreases in amplitude. The phase response non-linearities will also decrease with increasing n, reducing the processor harmonic-distortion level.

The actual processor frequency response can be more closely approximated by including the effects of $H(f)$ and $F(f)$ in Fig. 2. $H(f)$ can be included in the transmission channel frequency response: i.e., let the channel response by $H(f) \cdot G(f)$ in the preceding approximation. To include the effects of non-zero-width resampling pulses in the final approximation, multiply the processor response (determined previously) by $F(f)$. In this way, an accurate prediction may be made.

Spurious responses

The distortion discussed above ("Frequency response of a four- and two-channel processor") was caused by non-linearities in the processor frequency response. As a result, different frequencies in the spectrum of the input signal were treated differently by the processor (in both amplitude and phase). In the present analysis, it will be shown that slight mismatches in the amplitude and phase characteristics of the transmission channels can give rise to spurious outputs that fall within the passband of the processor. This type of distortion cannot be corrected at the processor output; it can be minimized only by carefully matching the transfer characteristics of the n processing paths.

Consider the following modification to the processor model of Fig. 2. Assume an input signal of $a(t)$=1 and that the impulse samples, $b_i(t)$, are transmitted through the channel in place of the PAM waveforms. This sets $h(t)=u_o(t)$, the unit impulse function. In addition, assume that the transmission channel does not distort these samples but merely delays them. Therefore, $|G(f)|$=1 and the angle of $G(f) = -Kf$ where K is a non-negative constant. The resampling switch is not required; $S_{B,i}(t)$=1 and $f(t)=u_o(t)$.

Without loss of generality, it may be assumed that the transmission channels

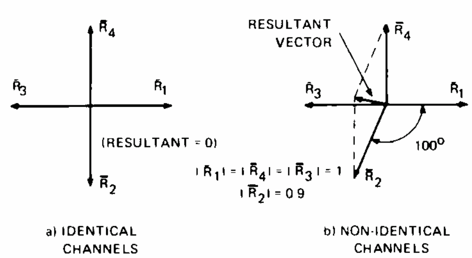

Fig. 6 - Source of spurious, 6-MHz output.

have zero delay ($K=0$). All four channels contain energy at 6 MHz, 12 MHz, 18 MHz, and so forth. The energy at DC, 24 MHz, 48 MHz, . . . adds "in phase" while the energy at the other frequencies sums to zero. Fig. 6a shows a graphical summation of the four-channel outputs at 6 MHz with four identifcal transmission channels. The resultant is zero.

Should one of the channels add 10° of phase shift to the 6/MHz signal component ($K=0.0291$ radiansMHz, a 4.63 ns delay) and should it also attenuate that component by 10% (0.92 db), the resultant signal component at 6 MHz will not be zero. Fig. 6b shows this summation graphically. The magnitude of the resultant vector is 0.386 (normalized) while the magnitude of the component at DC is 4. A signal-to-spurious-distortion ratio (SSDR) can be defined as:

$$\text{SSDR} = -20 \log_{10} \frac{\text{desired signal amp}}{\text{spurious signal amp}} \qquad (3)$$

Applying this definition to the previous example, $\text{SSDR} = 20\log_{10}(4/0.386) = 20.32$ dB. This means that for the conditions specified above, the reconstituted DC level will have a spurious 6-MHz oscillation, approximately 20 dB down, superimposed upon it.

A plot of the best SSDR obtainable for various phase and amplitude mismatches for a two-channel processor is given in Fig. 7. This graph is useful in predicting approximate performance levels for various degrees of channel parameter mismatch for any processor configuration. A more mathematically detailed derivation appears in Ref. 1.

Since the spurious outputs described above fall within the processor bandwidth, they cannot be eliminated by post-interpolation filtering. It was thought that, by keeping the input-signal bandwidth constant but varying the composite sampling rate and the number and bandwidth of the parallel transmission channels, all of the unwanted outputs could be shifted out of the processor bandwidth and filtered out by the interpolation filter. Ref. 1 contains a proof that such manipulations will not produce the desired results. Thus, the most effective way to improve processor performance is to carefully design the different switches and channels to ensure the phase cancellation of unwanted outputs.

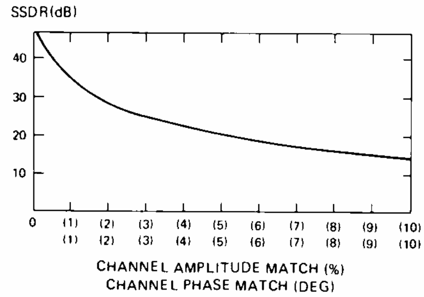

Fig. 7—Spurious distortion level as a function of channel mismatch parameters (two-channel processor)

Applications

The signal processing technique under consideration has a variety of potential applications. One such application is to improve or extend the frequency response of a channel. Fig. 5 demonstrates how the 'poor' frequency response of the sloping, 6-MHz channel could be improved (and extended) by using 4, 8, or 20 of these channels in parallel. In the $n=20$ case, a channel whose response decreases to 0.5 at 6 MHz is transformed to a channel whose transmission characteristics is never less than 0.95 in the range from DC to 10 MHz.

Another application is as an interface between a wideband information source and a multi-track tape recorder. The wideband source is sampled by the bank of n-sampling switches. The PAM output of each switch is recorded on one of the n-recorder tracks. Several clock tracks will also be required to establish PAM-bit timing upon playback and to remove the skew that may exist between the n-tracks. The tape recorder is played back into the n-resampling switches which are driven by clock signals recovered from the recorded clock tracks. These samples are summed and filtered to reconstitute the original wideband information.

An extension of this application that may be used to trade transmission time for bandwidth is shown in Fig. 8. In Fig. 8a, the wideband source is separated into n parallel PAM channels and recorded. In Fig. 8b, the n-tracks are played back sequentially through a single narrowband channel. The bandwidth of this channel needs to be only $1/n$ times the original signal bandwidth but the transmission time is n times the duration of the original message. At the receiving terminal, each transmission is recorded on one of n-tracks of a second, n-channel recording device. To recover the original signal (Fig. 8c), the second recorder plays back the n-tracks simultaneously through the resampling switches and interpolation filter. Time-varying characteristics of the transmission channel would, of course, cause the same spurious outputs as the channel-to-channel mismatches previously considered. Sufficient synchronization information must be included with the data allow n-tracks to be played back synchronously.

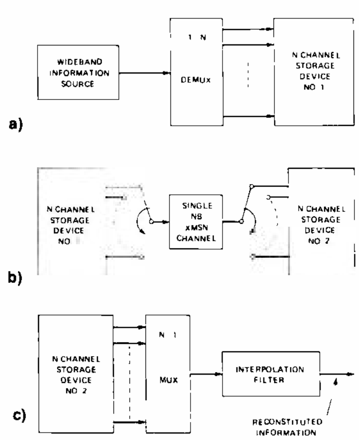

Fig. 8—Sequential transmission technique: a) record, b) transmit, c) playback.

Conclusions

A signal processing technique has been considered, which can be used to transmit a wideband signal over several parallel channels of reduced information bandwidth. The performance is limited by three effects:

- The processor amplitude response contains a ripple, which results in harmonic signal distortion;
- The processor phase response is non-linear, also producing harmonic signal distortion; and
- Slight mismatches in the characteristics of the parallel transmission paths cause spurious outputs, which cannot be removed by filtering.

These limitations make the technique unsuitable in certain applications.

The first two effects may be minimized by equalizing the processor amplitude and phase responses or by choosing a processor configuration with a large number of transmission paths, to reduce the magnitude of these ripples. The spurious responses can be minimized only by carefully matching the phase and amplitude (and timing) characteristics of the parallel processing paths.

Reference

1. Balcewicz, J. F., "A Signal Processing Technique to Reduce Transmission Bandwidth Requirements"—*First Western Space Congress Proceedings* (Oct. 1970)

Multi-phase energy-pump voltage regulator

E. Lachocki

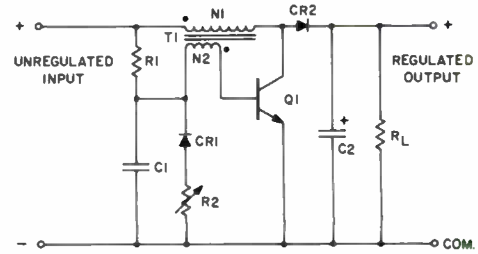

Fig. 1—Simplified single-stage energy-pump regulator.

Voltage boosting capability of the energy pump regulator without a step-up transformer can be used to extend useful life of a primary battery, or any variable power source, reliably and very often inexpensively. An extended power range and high efficiency of the multiple-stage regulator offers potential savings in heat generation of heavy current demanding systems. The operational advantages that have given the energy-pump regulator wide application for a number of years in space, military, and commercial equipment are maintained in the new design.

STIMULATED BY AN EVER-GROWING DEMAND by communication equipment for more regulated power, a new technique—an energy pump—has been developed which overcomes the power limitations of an efficient switching voltage regulator. The energy pump alternately stores energy in a linear inductor and dumps it into a capacitor integrator. Voltage boosting and regulation are achieved by controlling the peak charge current in the inductor.

The energy pump has been developed in several configurations. A one-stage regulator operates at 50% duty cycle and requires a large capacitor to integrate a single pulse to a DC level. It is limited in operating frequency and power output, and a high output ripple voltage is present that often requires additional filter circuitry.

A dual energy-pump regulator operates over a wider range of input voltage, switches at a higher rate for improved efficiency, and provides a higher output power. Each stage is composed of two free-running oscillators which are triggered by a pulse from the stage completing its energy cycle. This arrangement holds the circuits in synchronization, but it does not permit overlapping current pulses of adjacent stages. Thus, the average output current is limited by the peak performance of each stage. A practical power limit is also imposed by the types of transistors available.

The multiple energy-pump regulator transcends the power limitations imposed by single and dual regulators. An unlimited number of stages can be employed according to the power requirements. The stages are sequentially triggered by a common time base, and the energy-supplying cycles of adjacent stages overlap to increase the average output current. This technique permits application of such a circuit in equipment requiring higher power levels.

Basic circuit

The principle of operation of this regulator is more readily explained using a simplified schematic of the energy pump portion presented in Fig. 1.

The circuit alternately stores energy in the inductor, N1, and discharges it through the diode, CR2, into a capacitor integrator, C2. Voltage boosting and regulation is achieved by controlling peak-charge-current in the inductor by variable resistor, R2. This resistor is replaced by transistor, Q2, in the actual circuit shown in Fig. 2.

The starting circuit is formed by Q5, R1, and CR3 (Fig. 2). When output is at "zero" voltage level, the Q5 base current will flow through CR3 and R6,

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received the BSEE from London University in 1950. Upon his arrival to the United States he was employed by General Instrument Corporation and later by Philco-Ford Corporation. He joined RCA in 1962 as a member of the Power Supply Design Group. He has designed power supplies for military transceivers, airborne missiles, airborne transceivers, laser equipment, tactical computers, and linear UHF amplifiers. Presently, Mr. Lachocki is engaged in space-program work, and has designed power supplies for Ranger, Appollo, LM VHF transceiver, the lunar communications relay unit, and the coherent synthetic aperature radar. He developed unique and efficient circuits such as a magnetic-boosting regulator, ripple-control regulator, single and multiple-phase energy pump regulator, high-power solid-state relay, and a three-phase DC/AC inverter. Mr. Lachocki also serves as a technical advisor for power supply design reviews and technical proposals. He has applied for several patent disclosures and has two patents pending.

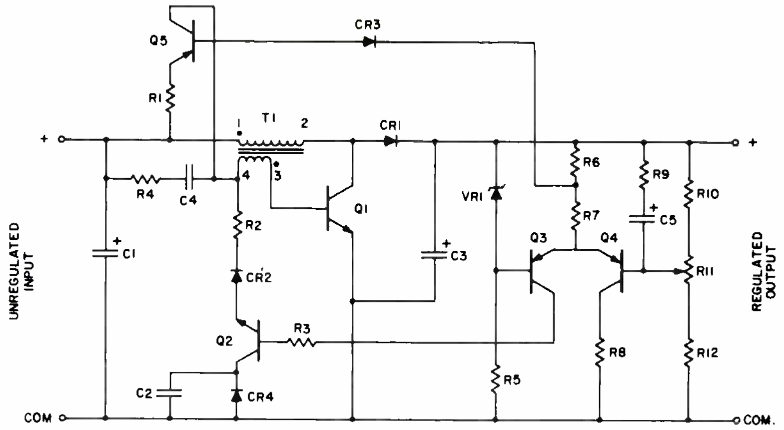

Fig. 2—Single-stage energy-pump voltage regulator.

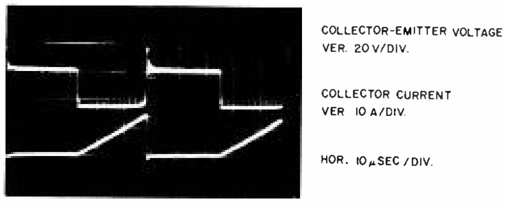

Fig. 3—Transistor switching characteristics. The regulator is loaded to 160 W with resistive load. Input voltage is 28 V; output voltage is 32.5 V.

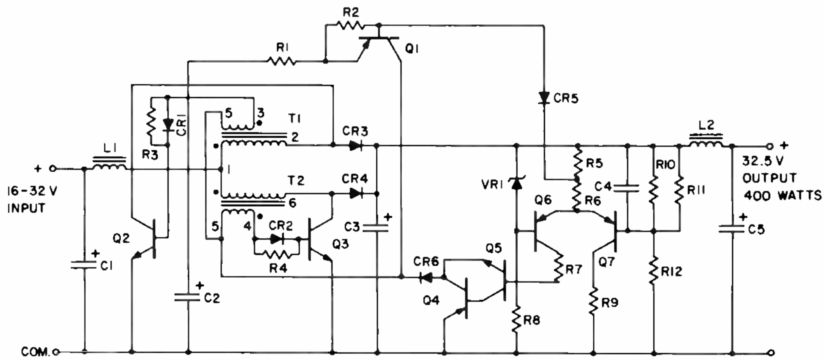

Fig. 4—Dual energy-pump voltage regulator.

and Q5 collector current will initiate a pulse current through T1 (3,4) and Q1 base. This will trigger collector current in Q1 through T1 (1, 2) and induced voltage in (3, 4) will increase this current until Q1 reaches saturation. Oscillation will continue, and as soon as voltage at the R6, R7 junction reaches blocking value for CR3, the starting transistor, Q5, will be disconnected from the circuit.

Transistors Q3 and Q4 form a differential amplifier which senses the output voltage. It compares this voltage with the reference voltage developed across VR1 and controls the current to the base of Q2, thus adjusting the peak current in Q1 and storing energy in T1 according to the formula:

$$W = \frac{1}{2}Li^2 \qquad (1)$$

where L is the inductance in N1 and i is the peak current in N1.

Transformer T1 and transistor Q1 have been arranged in a regenerative circuit through secondary winding which allows the circuit to free run, alternately storing energy in the primary of the transformer and discharging it in the second half of the cycle to the storing capacitor, C3. The transistor switching characteristics are presented in Fig. 3.

A two-stage energy pump regulator is shown in Fig. 4. The energy stored in noncoupled magnetically transformers is transferred through diodes CR3 and CR4 in the succeeding half cycles to the capacitor, C3.

One-stage and two-stage circuits have free-running oscillators each synchronized to preceding cycle or stage. The average current is limited by the individual stage peak performance because the circuit does not permit overlap in operation of adjacent stages.

The new concept of the multiple-stage regulator (Fig. 5) can increase the power capability quite significantly by triggering multiple stages sequentially from a common time base. Overlap in operation of adjacent stages is thus made practical with resulting increase in average output current, which is evident in Fig. 6 which illustrates the additive current wave curve of the three-stage regulator.

Principle of operation

In the multiple-stage regulator, shown in Fig. 5, a positive pulse, applied to point **A**, will trigger the stage into operation. Q1 will be biased into its active region and collector current will flow from the positive side of the unregulated input, through the primary winding of T1 to ground. Increasing current through the primary of T1 will induce a voltage in its secondary winding. Since the silicon-controlled rectifier, Q2, has been triggered on by the input pulse at **A**, base current will continue to flow in Q1, limited by the magnitude of the induced voltage and resistance presented by Q3. By this regenerative action, the collector current and forward bias on Q1 will continue to increase until the transistor saturates. Upon saturation of Q1, the magnetic field created by the increase of collector current through the primary of T1 will

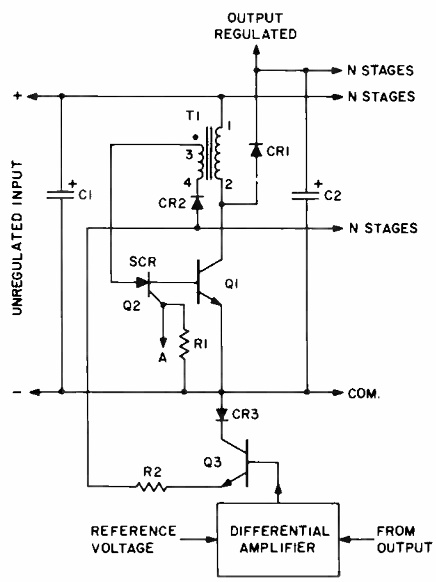

Fig. 5—Simplified multi-phase energy-pump voltage regulator.

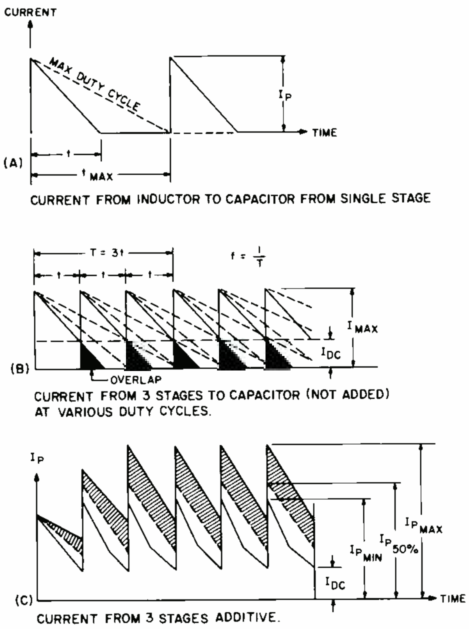

Fig. 6—Theoretical current waveforms for three-stage energy-pump regulator.

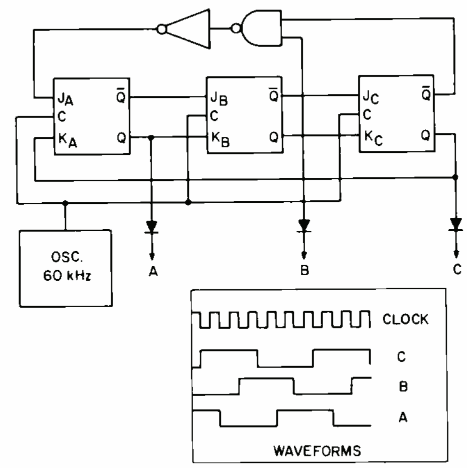

Fig. 7—Three-phase driver.

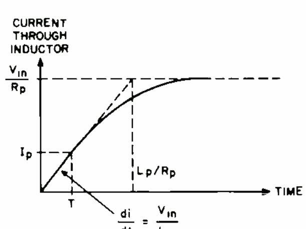

Fig. 8—Collector current risetime.

collapse rapidly. The magnetic energy stored by this inductance during the charging cycle will now be supplied to the output of the energy pump through CR1. The decreasing current in the primary of T1 will cause the voltage induced in the secondary to reverse its polarity. The SCR will be reverse-biased and Q1 will be cut off during this discharge cycle. Upon completion of the discharge cycle, the voltage induced in the primary of T1 will again reverse its polarity. No base current will flow in Q1 since the SCR is still off. Theoretical current wave forms depicting the various cycles of the three-stage energy pump regulator are presented in Fig. 6. The current flow from single-stage inductor to integrating capacitor is shown in Fig. 6a. Fig. 6b represents currents flowing to a capacitor from three energy-pump stages. The dotted lines indicate different switching duty cycles. The additive currents from three stages at various duty cycles are presented in Fig. 6c. Note that increased overlap in switching currents significantly increases the DC component.

To provide trigger pulses to each of the three stages sequentially, a three-phase driver circuit is used (Fig. 7). The time base for the driver is a relaxation oscillator whose frequency is 90 kHz. Three flip-flops generate binary outputs which are decoded by a NAND gate to provide the A, B and C triggers.

Design considerations

The output power can be increased by increasing the number of stages and by increasing charging time of each stage so that more energy can be stored in the inductor for relase to the load during following discharge cycle.

The average input current may be expressed by the following formula:

$$I_A = \frac{P_o}{V_{in}\eta} \qquad (2)$$

Where P_o is the output power of the energy pump; V_{in} is the input voltage; and η being the efficiency of the circuit. This current will divide among the stages of the pump according to the charging time of each stage and the number of stages used.

For a given circuit configuration, the peak collector current in each stage may be calculated as follows:

$$I_p = 2KtI_A/T \qquad (3)$$

where I_p is the peak collector current per stage; N is the number of stages; t is the time period between triggering of adjacent stages; T is the length of charging cycle; and $K=2$ for $N=1$ and $K=1$ for $N>1$.

It is required that $T \leq Nt/2$ to allow for equal charge and discharge times. The K factor adjusts for the fact that, when only one stage is used, that stage must charge and discharge during the time interval t.

Where $\tau = T/t$, and "overlap" constant, Eq. 3 becomes:

$$I_p = 2KI_A/\tau \qquad (4)$$

for $\tau \leq N/2$.

During the charging cycle of a stage, the primary inductance of the transformer associated with that stage will allow collector current to increase exponentially, according to the relationship:

$$I = [V_{in}/R_p][1-\exp(-R_pT/L_p)] \qquad (5)$$

where V_{in} is the input voltage to the energy pump; R_p is the resistance of the primary circuit, comprising source and winding resistances and the saturation resistance of the transistor; L_p is the inductance of the transformer primary; and T is the charging time. The rise of collector current is depicted in Fig. 8.

It can be seen that, by limiting I_p to about 10% of V_{in}/R_p, the current rise during the charge time, T, will be approximately linear. When this limitation is imposed, so that $T << L_p/R_p$, a simplified expression may be used to calculate the correct value of primary inductance for T1, L_p. Considering worst-case conditions of maximum power output with maximum input voltage, the following relationship exists:

$$L_p = \eta N^2 (V_{in(max)})^2 / 8\,Kf(P_{o(max)}) \qquad (6)$$

Two limitations on use of the above equations should be mentioned. First, it has been assumed that the charge and discharge times of a given stage are equal. While this appears to be a reasonable approximation, unequal resistances in the charge and discharge circuits will cause variations in these times. It was assumed here, however, that the input resistance, composed mainly of the saturation resistance of the transistor, could be made equal to the output resistance, which comprises mainly the forward resistance of the diode.

A second limiting factor is the practicality of the proposed inductor value. Inductance and current capability without saturation should be considered, along with maximum coupling and minimum losses. Some compromise among other parameters may be necessary to achieve a practical transformer design. Wire size for primary winding should be as heavy as practical since a DC resistance built to the primary inductance will limit the peak pulse current, thus affecting energy storage and efficiency of operation.

Regulator performance characteristics

A four-stage energy pump regulator has been qualified to a MIL-E-5400, Class II environment; it has been produced for use on UHF manned aircraft transceiver. This power supply is shown in Fig. 9. It measures 4⅛ × 4½ × 8⅜ inches and weighs 7.0 pounds.

The schematic of the four-stage regulator is shown in Fig. 10. A four-stage ring counter is used to provide trigger pulses to each of the four energy-pump stages sequentially. The time base for the counter is a relaxation oscillator whose frequency is 100 kHz. Fig. 11 shows the efficiency and regulation characteristics of the four-stage regulator.

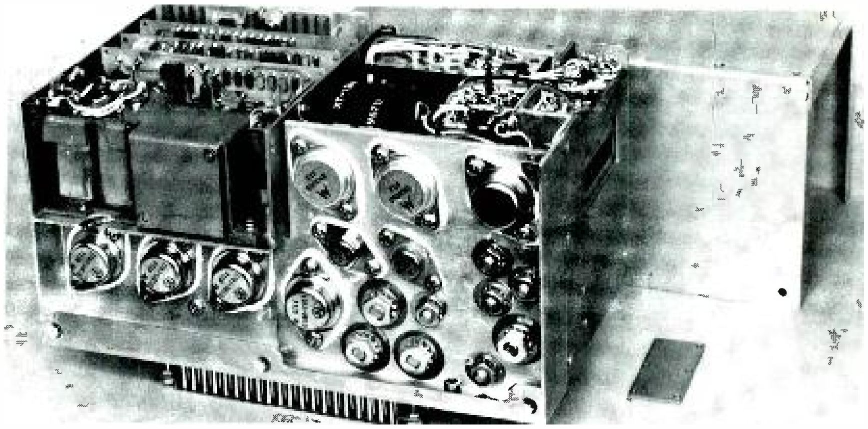

Fig. 9—This UHF tranceiver power supply operates on DC power of 16-32 volts using the four-stage energy-pump regulator. Regulated outputs, totaling 600 watts, include a self-test and the 400-Hz inverter for an air blower.

Conclusions

Single and dual-stage regulators are widely used in space and military equipment, but the multiple-stage energy-pump regulator has been proven as the most practical method to meet the challenge for high levels of regulated power demanded by the equipment designed for future space and military applications.

The basic multiple energy-pump regulator consists of three stages. However, this basic design is expandable to any number of parallel stages, and the circuit requirements can be compromised readily for a particular application. In a parallel arrangement the output of each stage is integrated by a common storage capacitor.

The cost of the switching components and capacitors, and the size of the regulator and its performance characteristics can be determined for specific applications. For applications requiring a small power regulator, it is often economical to use a multiple-stage energy pump with small and inexpensive transistors switching at a higher rate with the current pulses integrated by a small capacitor. For applications requiring higher power levels, an infinite increase in the number of stages may not be practical economically but potential savings may result from the lower heat generated versus the large currents produced.

Acknowledgment

Thanks to Mr. R. G. Erdmann and Mr. J. A. Davis for their helpful comments.

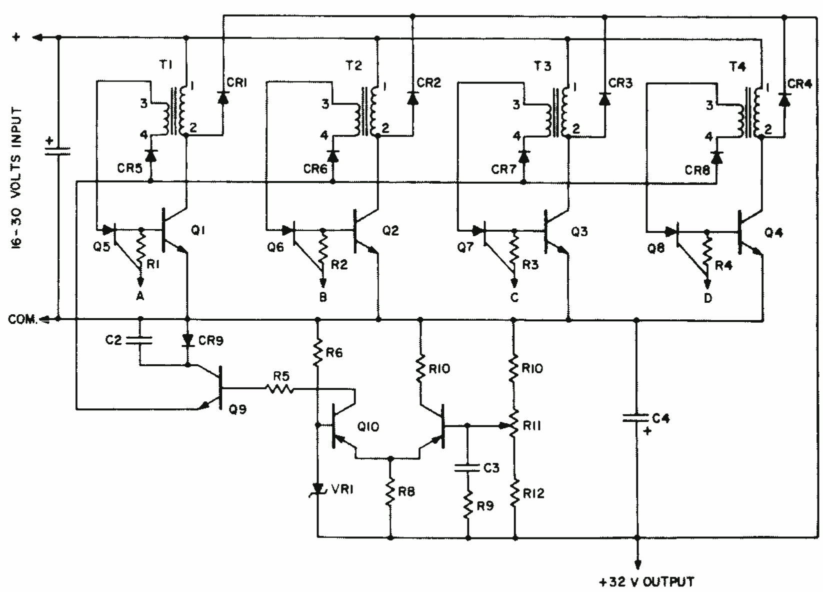

Fig. 10—Four-stage energy-pump regulator.

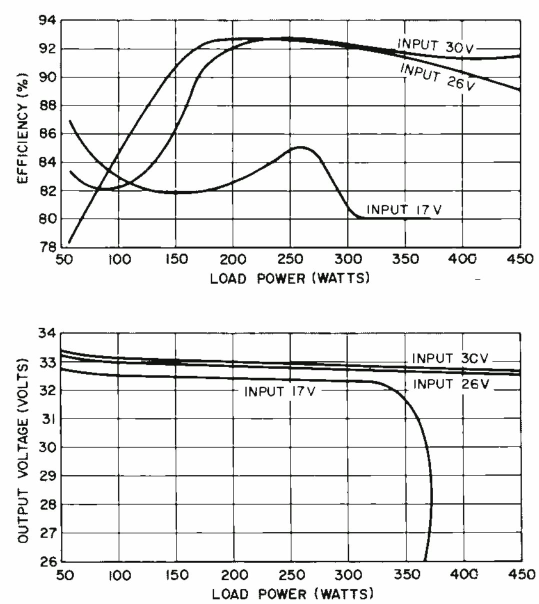

Fig. 11—Four-stage energy-pump regulator performance characteristics.

Software for automatic testing of disc files

J. H. O'Connell

Computer-controlled automatic testing improves testing speed, efficiency, and accuracy. A major part of the development of such systems is to specify and design the software, since software costs are usually higher than the hardware costs, and the testing efficiency is primarily determined by the software design. A desirable approach is to adapt existing software and add unique functions required by the application. This paper describes the design and development of a software package for automatic testing of RCA's 70/564 Disc File. The automatic test system was successfully installed and used in a factory environment to perform final tests. Significant results were the identification and solution of performance problems and a dramatic decrease in the number of defects detected when the disc file was installed in a computer system. The software performed effectively and aided the problem troubleshooting process.

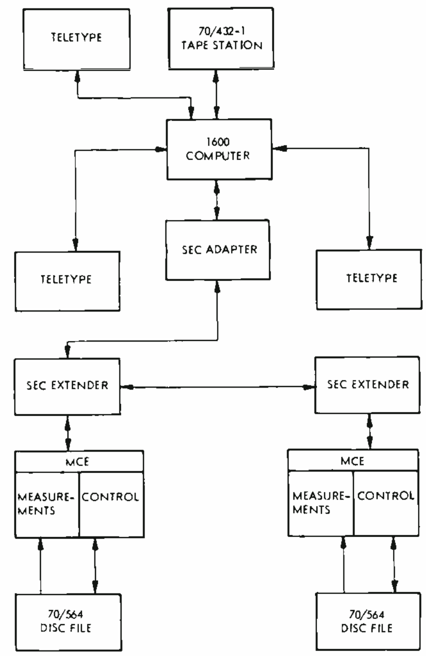

Fig. 2—Disc file tester block diagram.

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FINAL FACTORY TESTING of the RCA 70/564 Disc File was originally done manually, with standard test equipment and a special-purpose controller. Recognizing that this test process required a long time, gave inconsistent results, allowed testing errors, and did not yield a satisfactory number of defect-free units, Computer Systems performed a feasibility study with Corporate Staff and contracted with the Aerospace Systems Division to design and validate an automatic tester.

This article describes the tester and emphasizes the design and use of software functions. Within RCA, there are many applications being considered for automation. The software design task is essential to achieve an efficient and reliable operating system. Possibly, some of the features incorporated in this tester may be applicable to other automatic monitoring, testing, and control systems.

Tester description

Before discussing the software functions, it is first necessary to describe briefly the test hardware and how it interfaces with the computer. In Fig. 1, the computer with its peripherals are on the right; two test stands connected to disc file units are on the left. The tester functional relationships are shown in Fig. 2. An RCA 1600 Central Processor is used for test control and test data processing. A magnetic tape station stores the test program library, and a teletype is used to control com-

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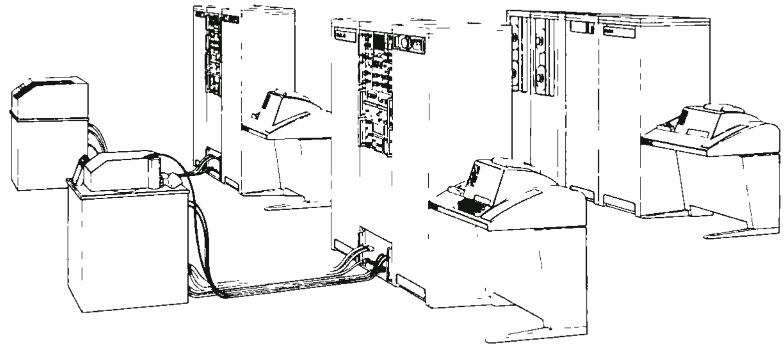


Fig. 1—Disc file tester.

puter executive functions. The interface with the test stations is a special equipment controller (SEC) which transfers data from computer memory to set program control lines. The SEC also includes the return path to memory for measured data.

Each test stand uses a teletype connected to the computer for control of the test routines. The test stand contains a SEC extender which contains the program control lines, programmable test equipment, and special-purpose control circuitry. The interface to the disc file consists of the standard controller interface and test adapters for performing specific tests.

The types of measurements that may be performed by the combination of programmable test equipment and control circuitry are:

1) Voltage measurements using a digital voltmeter;
2) Waveform measurements, either amplitude or time duration using a sampling oscilloscope;
3) Time measurements using a time-interval counter;
4) Max-min measurements of recorded pulse parameters using special purpose controll circuitry; and
5) Disc file status by sampling control lines and recorded signals through control circuitry.

A normal test sequence consists of 1) the computer sending data to set the program control lines, 2) the control circuitry and measurement equipment executing the test, 3) the control circuitry interrupting the computer at test completion, and 4) the computer reading the test data to compare it to limits and deciding which test to perform next.

Software description

The software consists of additions and modifications to an available software package called Testran. Testran was developed by RCA Corporate Staff, Manufacturing Systems and Technology, to provide a standard collection of software functions applicable to a wide variety of computer-controlled test applications. It is presently limited to use on the 1600 computer and SEC. Its primary features are that users may design their own test programming language for control of the test equipment and that users may add modular software functions to the on-line control program for real-time test control and data processing operations. It also includes an off-line compiler to translate the test programs into reference tables used by the on-line test control program.

To adapt this package to a specific application, the user must determine his requirements and insert them into the program. A flow chart illustrating this process is shown in Fig. 3. The oval-shaped balloons show points at which the user inserts his requirements. The first step is to define the control requirements for the SEC program lines to arrive at a suitable programming language based on test hardware and language definition statements. These statements are compiled off line on a Spectra 70/45 computer to form a directory which, in effect, becomes the test programming language words. Included in the test language definition are words to call up software processing routines executed by the controll program at run time.

The test requirements are recorded on coding sheets using the defined test program language. These statements are compiled by a test program generator which produces test programs on magnetic tape. The on-line software functions (test program controller programming) are written using the RCA 1600 assembler programming language, and a complete operating system is created through the macro assembler.

At run time, the computer receives

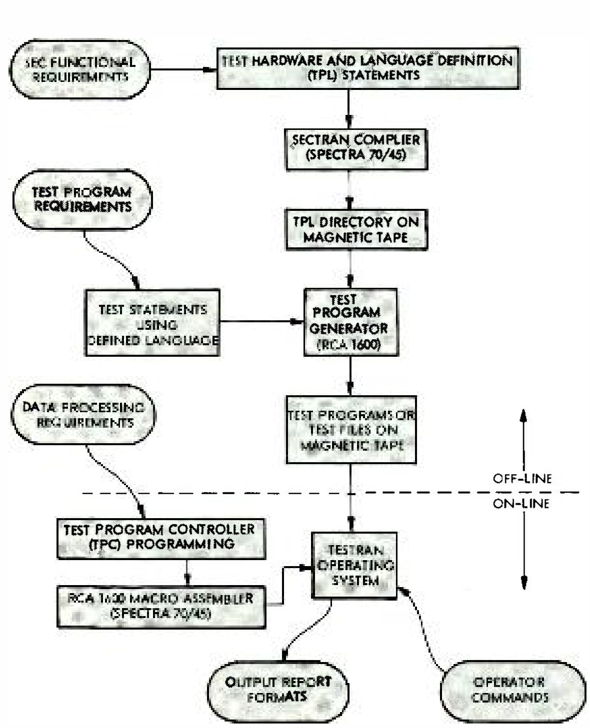


Fig. 3—Testran flow chart.

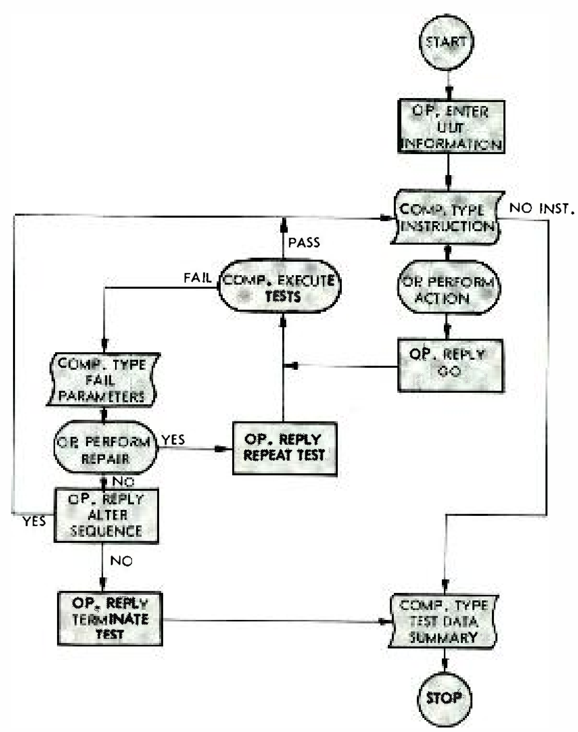


Fig. 4—Test process flow diagram.

Table I—Operator commands.

Format	Description
Normal sequence	
E or Enn	Enter and start a test program.
G	Go to next test and continue.
Fault isolation	
R or Rnnn	Repeat test and continue
Lnnn or Lnnn. nnn	Loop test or group to tests
S or Snnn	Single-step test and stop
Z	Zero and reset disc cylinder
Control and printout	
W or WD	Wait and reset testing
Dnnn or Dbb. nnn	Data printout from a test
P	Print test data summary

Notes: nnn represents a test number
bb is a block number

commands from the operator and produces a wide variety of output reports. The formats for operator command and output reports must be defined by the user.

Operator commands and control

The method by which the operator interfaces and controls the test functions has a large impact on test efficiency. The design goals were to provide sufficient commands to operate in different test modes and to provide output responses which are readily understood and contain essential information to make decisions. A teletypewriter was selected for the interface rather than lighted pushbutton switches and annunciators because it can easily provide a wide variety of input commands and an almost unlimited variety of formats for output information. It is also easy to operate and provides hard-copy records of test progress and results. It is also capable of expansion without hardware modifications to other test functions such as automatic fault isolation.

A typical test process is shown in Fig. 4. Particular emphasis is placed upon how the operator controls the test sequence and performs essential functions. The test routine is initiated by the operator entering descriptive information which identifies the unit under test (UUT). The computer automatically responds by printing the first instruction. The operator performs the required action and commands the computer to perform an automatic series of tests. This process terminates when the operator must perform some other action to continue testing. The required operator actions were minimized, but some actions were essential—e.g., interchanging disc packs and attaching special test adapters. This procedure or test loop continues until test completion, at which point the computer prints a complete test data summary.

If, however, a test failure occurs, such as a measured value falling outside of limits, the computer prints a description of the test failure and halts testing awaiting operator intervention. The operator may use one of several options; however, a typical situation is to repeat the test to confirm the failure, take corrective action, repeat the test again, and if the test is passed, resume automatic testing. Other options are to alter the test sequence, loop a test or series of tests to manually locate the failure, or terminate the test because a repair must be performed by the factory.

The operator sends a command to the computer by typing a single letter code and (optionally) some modifying numeric data. The single letter code was selected because it is easy to use and it is quickly learned. The complete set of commands are shown in Table I.

The normal use of commands is to type E (enter) for test initiation and G (go) to resume testing after performing manual actions. To diagnose failures, the operator may use R (repeat) to repeat a test, L (loop) to loop a test, S (single step) to single step a test, and Z (zero) to return the disc to a reset condition. Other commands for test control are W (wait) to stop testing and obtain the current test number, D (data) to obtain the measured value of any test, and P (print) to obtain the test data summary.

An example of the operator/computer interface is shown in Fig. 5. Each time the computer is ready to receive a command, it types the double question marks. On the following line, the operator types a command. The command is accepted by the computer when the operator presses the return key. The next line may be a test failure printout or an instruction from the computer. The example shows several test failures that occurred while debugging this test routine and the corresponding operator responses to verify the failures. However, it was not possible, in every case, to correct the problem.

The test program sequence shown in Fig. 5 does not include the entering of disc file descriptive information because it was used to debug test blocks 07 and 08 which were a small part of the complete test program. It will be shown later what information must be entered which appears on the test data summary.

```
??
E07
??
W
T003
??
R
MOUNT WORK DISC PACK - PRESS START - TYPE G
??
G
TN013   FAILED, CYLINDER=006 , VALUE= -   578.3
??
G
TN013   FAILED, CYLINDER=008 , VALUE= -   583.1
??
G
TN013   FAILED, CYLINDER=010 , VALUE= -   574.8
??
G
TN013   FAILED, CYLINDER=016 , VALUE= -   571.3
??
G
TN013   FAILED, CYLINDER=017 , VALUE= -   593.2
??
G
TN013   FAILED, CYLINDER=018 , VALUE= -   609.4
??
G
TN013   FAILED, CYLINDER=020 , VALUE= -   581.8
??
G
07 DONE
SET TRIGGER TO MINUS - TYPE G
??
G
TN023  MEAS COMPL INT OCCURRED
??
G
??
W
T025
??
R24
SET TRIGGER TO PLUS - TYPE G
??
G
T037 VALUE=      363.8
(      340       320  )
??
G
??
W
T043
??
R42
T047 VALUE=      17.02
(        5         0  )
??
G
08 DONE
```

Fig. 5—Sample program execution.

Some of the information is coded or abbreviated to shorten the printing time. For example, when the measured value falls outside of limits, the computer prints the test number, measured value, and limits. Such a failure is shown in Fig. 5 for test number 37(T037), measured value 363.8 and on the next line limits 340 and 320. This abbreviated form of printing is quite easy to learn because, in a dynamic test situation, the motions of the disc carriage and the displays on the tester clearly show whether a test is in progress or halted for a failure.

Test data output report

After completion of the test program, the operator may obtain a printout of the test data summary. The first section of the summary contains the test status and the second section lists the test measured values. The test status is used by the operator and quality control inspector to determine how many tests

```
??
P
ALIGN TTY PAPER, HIT SPACE BAR TO CONTINUE
    TEST STATUS SUMMARY PT 1

STATION  A                    OPER NO.
DATE MM/DD/YY                 UUT ID 70/564/
                              SERIAL NO.


     ALL TESTS COMPLETED


     NUMBER OF TESTS FAILED: 002


    TEST FAILURE STATUS
TEST ID     FAIL CNT   FAIL     VALUE UNITS

BL07 T013     007           -   476.1 MV
                            -   609.4 MV
                                 095  CYL
BL08 T037     001        X      363.8 MV
BL08 T047     001        X       505  MV
                                17.02  C
```

Fig. 6—Test data summary—test status section

have passed, how many have failed, and how many remain to be performed. It may also be useful to test engineers for failure analysis because it prints the number of times a test fails and its last measured value. The list of measured values was originally intended to be delivered with the unit as a proof-of-performance summary; however, this purpose cannot be achieved because the present format required modification and interpretation to determine performance factors. However, this section is useful to design engineers for analysis and for monitoring performance trends.

A sample of the test-status section is shown in Fig. 6. This sample was obtained from the test sequence of Fig. 5. Operator command P caused the printout, and the computer responded by instructing the operator to align the report to the top of the page. The first three lines contain disc file descriptive information (data not entered for this sample) followed by a summary of all the tests completed. If some tests had not been finished, a list of the unfinished tests would be printed. The next line lists the number of failed tests and this number must be zero to successfully pass the disc file. The last portion contains a list of all tests which failed, the number of failures, the failure or pass status, and the last measured value. An X in the fail column means that the test failed the last time it was run.

```
ALIGN TTY PAPER, HIT SPACE BAR TO CONTINUE
                 TEST DATA


DATE MM/DD/YY                UUT ID 70/564/
                             SERIAL NO.


 TEST ID    PASS     VALUE UNITS

BL07 T013    *    -   476.1 MV
                  -   609.4 MV
                       095  CYL
BL08 T025    *         453  MV
     T029    *         249  MV
                      58.11  C
     T037    F        363.8 MV
     T043    *         599  MV
     T047    F         505  MV
                      17.02  C
```

Fig. 7—Test data summary—measured values section.

The measured-values section is shown in Fig. 7. This listing repeats the disc file descriptive information so that it may be separated from the test-status section. For each test, the listing contains the test block number, test number, pass or fail indicator (F means fail), measured value, and units of measurement. For some tests, a calculated value is compared to limits; these calculated values are shown as a C.

Test programming language

A primary feature of the Testran software package is the ability to define a test programming language. The language is used to set the SEC control lines and to select computer subroutines for processing test data. To simplify the test program compilation (translation), acronyms for control lines and test functions are used extensively.

The basic structure of the language is shown in Fig. 8. Each test contains a test number followed by optional information. The usual sequence is to define the SEC control line conditions, select an output/read function, and specify the processing of test data. At run time, the computer interprets this information to output the SEC line conditions, wait for an interrupt, read in the test measured value and process the value. The processing usually consists of comparing the measured value to limits and halting the test if the value falls outside the limits.

Fig. 8 also contains a typical test statement which uses the digital voltmeter (DVM) to measure a voltage located internal to the disc file. The SEC lines for the DVM and signal routing are programmed as follows. The DVM range is selected to one volt (1), direct current (DC). The signal routing (DR)

STRUCTURE

```
TEST NO. (SEC LINE CONDITIONS $ OUTPUT/READ
FUNCTION $ DATA PROCESSING FUNCTIONS)
```

SAMPLE TEST STATEMENT

```
T5 (DVM = 1, DC $ DR = 28 $ SECD (MSMC) C
$ STAT (34, V) $ LIMT (0.68, 0.56) $ FACT)
```

Fig. 8—Test programming language.

is selected by a two digit decimal number (28). The computer output/read function (SECD) outputs the SEC line conditions and waits for a measurement complete interrupt (MSMC). The computer then reads the DVM measured value and reserves a memory location for storing it by using the staticizing function (STAT). This function also stores the test block No. (34) and the units of measurement (V). The measured value is compared to limits by the limit function (LIMT). This function contains the upper limit (0.68) and the lower limit (0.56). The failure accounting function (FACT) will halt testing and print a test failure message if the limit function detects an out of limit condition.

The functional requirements for the SEC control lines were determined by the disc file tester design. This design determined where each line was connected and the function it performs. These requirements were incorporated into the programming language by using the Testran language definition procedures. A summary of the SEC programming functions is listed below:

- Oscilloscope measurement
- Digital voltmeter measurement
- Disc file unit control
- Counter measurement
- Power supplies voltage programming
- Test measurement control

The SEC input lines that are read by the computer to obtain the measurement results are automatically programmed by selecting the signal routing to a measurement instrument. These lines are multiplexed between the following equipments.

- Time-interval counter
- Max-min register
- Digital voltmeter
- Sampling oscilloscope
- Disc file status

The programming language also includes the acronym for computer processing functions which are executed at run time. Each function, which may be an output/read routine or a measured value processing subroutine, requires the execution program to be resident in the test control software, and it is called by an acronym appearing in the test program statement. The functional categories are listed below:

- Output/read
- Measured value processing
- Test equipment control
- Disc file control
- Test program control

Test program description

A test program simply consists of several test statements that specify tests to be performed and measured data to be checked. However, the writing of a test program requires an understanding of the test's purpose, the test method which includes hardware and software functions, and the sequence of control and measurement operations for automatically performing the test. Other factors that influence the test program design are rearrangement of the operational sequence to minimize testing time, use of general purpose hardware and software functions rather than unique functions, and reduction in the number of interruptions for manual actions.

The design requirements for the disc file tester were determined primarily by a technical study which specified that 19 major tests must be performed on the disc file. Each major test was specified as to its purpose and the performance parameters which must be measured. The tester design procedure consisted of selecting test methods for implementing the tests. The test methods included both hardware and software functions, and several hardware/software tradeoffs were performed to achieve an effective test method at minimum cost.

During the hardware design and construction phase, the software designers wrote a test program to prove the feasibility of the hardware and software functional design concept. This task produced the complete test program before the hardware construction was completed and determined several specific design details. The program contained approximately 1350 test statements and was segmented into test blocks (each block corresponds to a major test) to simplify test debugging and correction.

```
//TPC ( DTP1,D34T )
T1  ( ZERO $ INIT $ SECD() $ AUX1(T24 ) )
T2  ( SECD(TOUT) )
T3  ( TYPE ("CONNECT CABLES -","MOUNT OE PACK -"," PRESS START - T",    C
          "TPE OF") $ SSPD )
T4  ( DSUC=MC,S $ DDR $ ND $ SECD( ) $ STAT(34) $ TEST (HDXL,LO,T5  )  C
                                               $ FACT )
T5  ( DVM=1,DC $ DR=28 $ SECD(MSMC) $ STAT(34,V) $                     C
                        LIMT(0.68,0.56) $ FACT )
T6  ( DR=48 $ DVM=2,AC $ SECD(MSMC) )
T7  ( DR=45 $ DVM=2,AC $ SECD(MSMC) $ STAT(34,V) $ LIMT(-2.06,-2.10) $ C
      FACT )
T8  ( DSUC $ INIT)
T9  ( TYPE("PRESS START - T","PE OF") $ SSPD )
T10 ( ND $ SECD )
T11 (       C=T1,US $ CR=15 $ SECD(TOUT,MSMC) $ STAT(34,US) $           C
      LIMIT(1800,1600 ) $ FACT )
T12 ( SAME(T5  ) $ LIMT(0.04,0.00) )
T13 ( NOP )
T14 ( NOP )
T15 ( NOP )
T16 ( ND $ DDR $ SECD(TOUT,OAIT) $ STAT(34) $ TEST(HDXL,HI,T17 ) $     C
      FACT )
T17 ( DSU=00,CYL $ ND $ SECD )
T18 ( DSUC $ C=T1,US $ CR=9 $ SECD(MSMC) $ STAT(34,US) $               C
                        LIMT(25500,24500) $ FACT )
T19 ( SAME(T5  ) )
T20 (NOP )
T21 ( NOP )
T22 ( NOP )
T23 ( TYPE("34 DONE") )
T24 ( SSPD )
//END
```

Fig. 9—Sample test program.

An example of one of the test blocks is shown in Fig. 9. This test block (34) measures disc file performance during the turn-on sequence and contains measurements of internal logic voltages and disc rotational speed. Without going into all of the details, some of the features may be identified by referring to specific test statements. T3 causes a message to be typed which tells the operator to mount a disc pack and connect the test cables. T5, T12, and T19 cause the digital voltmeter to measure internal logic voltages. T11 uses the time interval counter to measure rotational speed when an up-to-speed signal is detected and T18 measures the final speed. T23 is a typed message indicating completion of test block 34 and T24 suspends the test process. The no-operation (NOP) test statements are liberally used to facilitate corrections and additions to the test program.

Test program validation

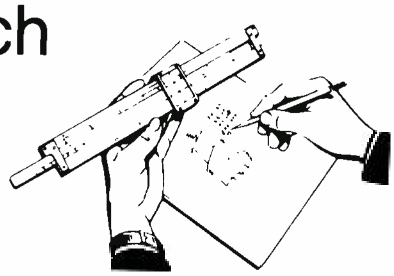
Upon completion of the test hardware construction phase, the most difficult task was to prove that the test program accurately performed the 19 major tests. Since the hardware and software were debugged at the same time, a team consisting of a hardware designer, software designer, disc-file test engineer, and system designer validated the tests. Whenever a problem was encountered, the cooperation of all team members was needed to locate the source of the problem and implement corrective action. Some of the major problems were adjusting the timing of commands to the disc file, debugging some of the complicated software data processing functions, learning the correct techniques for programming the sampling oscilloscope, and debugging the test hardware for measuring maximum and minimum pulse intervals. The validation effort successfully proved that all 19 major tests performed properly and the tester was accepted for normal factory acceptance testing.

Results

The disc file tester was used successfully in a factory environment to final test 70/564 disc files. Test times were shortened and fewer defective disc files were installed in computer systems. These achievements justified the original goals which were to develop a tester for fast, accurate, and thorough final tests of the disc file.

This article emphasized the software design and support of the tester. The advantages of modifying and extending an existing software package were that the software design and implementation effort was significantly reduced, and all software objectives were easily achieved. The existing Testran software package contained practically all of the required executive and compilation functions so that the major software task was dedicated to implementing the unique software functions required by the tester.

Engineering and Research Notes



Brief Technical Papers of Current Interest

Build a dual-tracking voltage regulator for less than $8.00

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It is possible to build a dual-tracking voltage regulator for $8.00 by using an IC voltage regulator and two inexpensive IC transistor arrays as shown in Fig. 1. The resultant regulator can handle unregulated input voltages ranging from ±8 to ±40 V, and provide regulated output voltages ranging from ±3 to ±36 V. The maximum difference-voltage between input and output (E_{in} to E_{out}) must not exceed 15 V. This circuit can deliver load currents ranging from 1 to 100 mA. The load and line regulation are 0.02%/V of input change. The dual output voltages track within 0.01%, and the output circuit is short-circuit proof. A fixed output voltage can be obtained by replacing R_1, a variable resistor in Fig. 1, with a fixed resistor. The output voltage is defined by the equation

$$E_{out} = \frac{R_1 + 2000\Omega}{1000\Omega} \; (1.6\ \text{V})$$

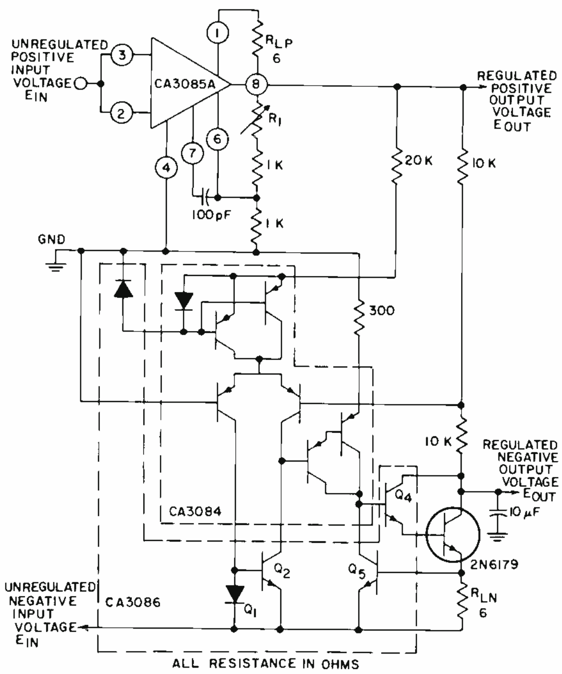

Fig. 1—Schematic diagram of the dual-tracking regulator.

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Asynchronous drive system

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The drive system shown in Fig. 1 allows a pulley driven by a belt to vary its rotational speed with respect to a driver pulley without slipping of the drive belt.

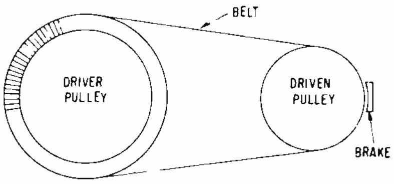

Fig. 1—Asynchronous drive system.

A resilient coil spring (Fig. 2) whose free ends are joined to make no appreciably stiffer coil in the spring (e.g., by solder) is wrapped about the periphery of the driver pulley. As shown in Fig. 3, the inner circumference of the coil spring is fixed around the periphery of the pulley (e.g. by a flexible adhesive) to allow the spring to flex at its outside circumference. The belt that couples the pulleys runs on the outside circumference of the coil spring.

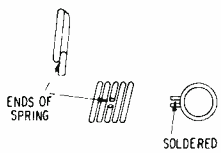

Fig. 2—Details of spring connections.

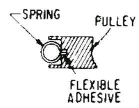

Fig. 3—Spring mounting.

When the system is in motion and there is no retarding force on the driven pulley, the spring acts as a normal solid pulley. When a retarding force is applied to the driven pulley, that part of the spring in contact with the belt flexes incrementally at its outside circumference, keeping in contact with the belt and moving at the belt's velocity. The rest of the pulley and spring continue at the original speed.

One coil of the spring is used in Fig. 4 to show the principle. At X, the coil of the spring contacts the belt. As the belt is being retarded, the coil has flexed at Y. The angular velocity of the belt on the coil has been reduced. The angular velocity of the rest of the pulley remains unchanged. At Z, the coil has reached maximum deflection. On breaking contact with the belt, the coil returns to its original position W.

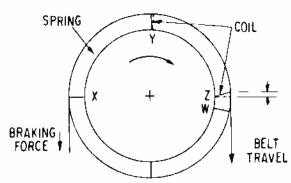

Fig. 4—Single-coil illustration of asynchronous drive principle.

The spring can be replaced by radially mounted cantilever leaf springs or wire hoops. Alternatively, the spring member can be wrapped about the driven pulley with the retarding force still applied to the driven pulley.

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Alloying electrodeposited solder on printed circuit boards by a hot-oil wave technique

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The causes of poor soldered boards are many, and may be blamed, among other causes, on an inadequate process, the operators not following an adequate process, atmospheric conditions and black magic. It is desirable, therefore, to use a process which eliminates or automatically compensates for the conditions which have caused problems. The hot-oil-wave process now in use at the Space Center appears to conform to these requirements.

A properly alloyed solder coating makes unnecessary the use of gold plating. There has been a strong trend away from gold plating in recent years because of 1) evidence that the plating is dissolved in, and floated away by, the solder and (2), expense. In essence, the solder attached to the circuitry under the gold.

Gold plating had been justified because it was proven to be an excellent resist to etchants. Solder plating can be used to greater advantage, however, provided that the chemicals, solution and process are controlled. Also, there is considerable evidence that it is possible to electro-deposit solder on a copper surface that is not chemically clean. It is not, therefore, safe to assume that a circuit-board acceptance of electro-deposited solder implies that the copper was satisfactorily conditioned. Experience has shown that soldering problems are minimized when a 63:37 alloy is used; that is 63% tin and 37% lead, (there is an acceptable tolerance here of up to 65% tin.)

This is a eutectic alloy with a melting point of 361° F (Tin melts at 450°, lead at 621°). The thickness of the electro-deposited layer should be between 0.0003 and 0.0008 inch, with 0.0006 inch preferred.

The Reflow Technique

Electrodeposited tin-lead forms on the copper circuitry in minute nodules of tin and lead. This configuration may permit air to reach the copper and result in oxidation during storage. By subjecting the electrodeposit to a hot oil bath, the tin-lead reflows and forms an alloy.

Reflow by a hot-oil-wave gives a minimum loss of plating thickness. This overhang will flow onto the sides of the circuits and form a wedge of solder at the base of the copper and the laminate. Plated-through-holes become uniform in size; small pits and voids fill with solder.

Stringers—the overhang of electrodeposited tin-lead—are easily broken off during handling and are a major cause of short circuits. These melt and flow to the circuit path sides during reflow.

Hot-oil-wave process

The hot-oil-wave equipment (Fig. 1) was developed by modifying commercial equipment which was on hand, but not in use, at the RCA Space Center. It consists basically of an oil heater, an oil fountain and a conveyor that moves the printed circuit board slowly through the hot oil. The hood removes the oil fumes and contains fire extinguishers that blanket the working surface with 30 lbs. of "C" dry chemical in case of fire. An automatic conveyor eliminates the need for high operator skill and ensures uniformity of board exposure as well as a uniform (high) production rate.

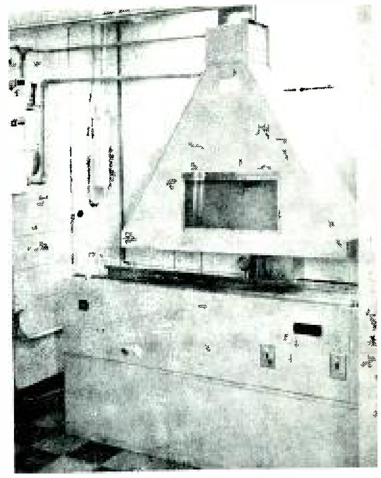

Fig. 1—Hot-oil-wave equipment.

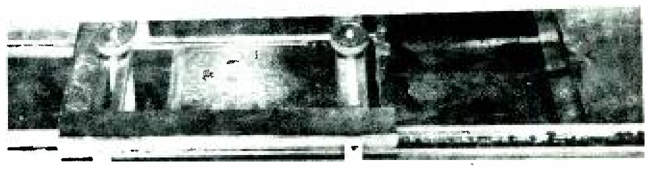

Fig. 2—Printed circuit board entering the hot-oil fountain.

A photograph of a printed circuit board entering the oil fountain is shown in Fig. 2. After passing through the oil bath, the board is carried to a separate detergent bath, which removes all residual oil. The change in appearance of a reflowed board is quite noticeable, as can be seen in Fig. 3. The solder acquires a gloss and the outlines of the metallic paths are sharpened. Visual inspection will show quickly if any portion has not properly reflowed.

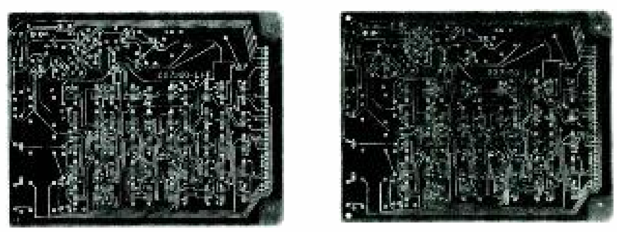

Fig. 3—Comparison of circuit boards before and after reflow soldering.

The characteristics of the oil are important, and several types were tried before one was found to be suitable. To obtain rapid heating to above the eutectic point of the tin-lead, 361°F, it is desirable to have the oil at a temperature near 500°F.

The oil selected, Hydro Fol Tin Fat #50, has a flash point of 570°F and a fire point of 630°F. Hydro Fol Tin Fat #50 comes in flake form for convenient storage and handling. For safety, the equipment's oil tank was limited to 5 gallons, with a minimum fountain opening. Overtemperature warning lights and safety controls are built into the equipment. No significant safety problems have been experienced since the start of operations.

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Array of electrically controlled light valves for use in an optical memory

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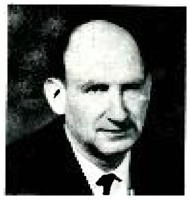

A latrix is an array of semiconductor flip-flop memory elements wherein each flip-flop controls a respective light valve and can be controlled by a photosensor.[1] The information electrically stored in the array of flip-flops is transferred to an optical storage medium such as manganese bismuth by shining laser light through the light valves to the recording medium. An array of flip-flop storage elements and sensing elements has been constructed in integrated circuit form on a silicon chip.[2] The surface of the silicon chip is covered with a liquid crystal material. Each flip-flop controls the state of the liquid crystal material. Each flip-flop controls the state of the liquid crystal material covering the photosensitive area and thereby causes it to either scatter incident light or to let it be specularly reflected on the surface of the silicon.

An alternative construction is described in this note, as illustrated in part in Fig. 1. The integrated-circuit chip (8) containing an array of flip-flops is covered by a liquid (12) which is maintained in place of a glass plate (14). The liquid is preferably an easily evaporated liquid such as trichloroethylene. The flip-flops are constituted by the n-type silicon substrate (10), diffused p+ regions (16), silicon dioxide insulating layers (18), and a pattern of conductors 20.

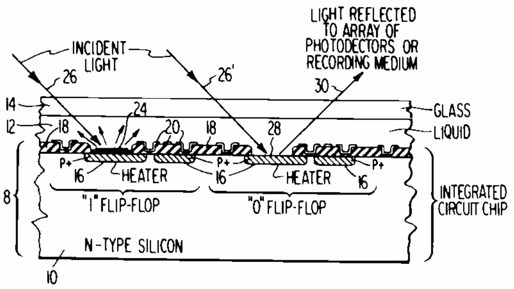

Fig. 1—Part of light-valve array.

In operation, the "1" or "0" state of each of the flip-flops in the array is set by conventional electrical means, or by optical means. A flip-flop storing a "1" causes the generation of heat at the interface between the semiconductor chip (8) and the liquid (12). This results in the formation of vapor bubbles, as illustrated at (24), which disperse or diffuse incident light (26). On the other hand, a flip-flop storing a "0" does not cause heat or vaporization to be produced as at (28). In this case, incident light (26') is reflected along a path (30) to a holographic recording medium. The silicon substrate (10) is characterized in that about half of the light (26') incident to its surface (28) is specularly reflected along path (30), and the remainder is transmitted through the substrate (10). The half of the light reflected along path (30) is adequate for the transfer to the storage medium of information giving the electrical state of the associated flip-flop. The described assembly is thus useful as a "page composer" for the transfer to an optical storage medium of information electrically stored in flip-flops.

The described assembly can be simultaneously useful as a sensing array; thus it can serve all the functions of a latrix. To read information out of the hologram, and set the flip-flop of the array accordingly, all the flip-flops are set in state "0". Because of a special circuit provision, such as gating-off the common lead of the heater power supply, the heaters are not activated. Then the reference beam is directed on the desired page to be read out. This causes the elements, which were in the state "1" during writing, to receive light and thereby now to be set to state "1" anew, and causes no light to shine on the elements which were in state "0" during writing.

References

1. Rajchman, J. A., "An optical read-write mass memory" *Applied Optics*, Vol. 9 (Oct. 1970) p. 2269.
2. Stewart, W. C. and Cosentino, L. S., "Optics for a read-write holographic memory" *Applied Optics*, Vol. 9 (Oct. 1970) p. 2271.

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Directional air-slide system

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A section of an air-slide system is shown in Fig. 1. This system supports and propells semiconductor wafers (12, shown in phantom) without the necessity of a physical barrier, or fence, on opposite sides of a slide (14) to prevent the transported wafer (12) from sliding off the slide (14). By eliminating fences, the air-slide system (10) can accommodate wafers of different sizes and can transport them in a random mix along the slide (14).

The air-slide system is formed with a plurality of paired and opposed slots (16, 16a, 18, 18a, 20, 20a, etc.) for directing air in jets toward the longitudinal axis of the slide (14). A series of openings (22, 24, 26, etc.) are formed through the slide (14) along its longitudinal axis and aimed so as to move (blow) the wafer (12) in the direction of the arrow (28). The wafer (12) is prevented from falling off the sides of the slide (14) by the jets of air from the paired and opposed slots (16, 16a, etc.). All wafers whose diameters are slightly larger than the distance between a pair of opposed slots can be handled by this arrangement.

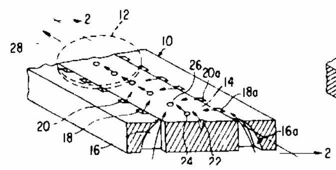

Fig. 1—Section of air-slide system.

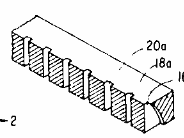

Fig. 2—Centering pad.

Fig. 2 shows a variation of the air slide system for holding the wafer (12) in place on the air slide. A centering pad (30) of the air slide is formed with a plurality of transverse openings (32, 34, 36, 38, etc.) for directing air toward the center of the centering pad (30). Thus, the wafer (12) floating above this array will be centered automatically. If desired, a hole (40) located in the center of the centering pad (30) can be connected to a vacuum source, as shown, to hold the wafer (12) fixedly in the center of the centering pad (30).

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Pen and Podium

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125 Physics

electromagnetic field theory, quantum mechanics, basic particles, plasmas, solid state, optics, thermodynamics, solid mechanics, fluid mechanics, acoustics.

ANISOTROPIC PLASMAS, Strong Field Electromagnetic Wave Interaction with—M. P. Bachynski, B. W. Gibbs (Ltd., Canada) *Canadian J. of Physics*, Vol. 50, No. 8; 1972

ELECTROMAGNETIC-WAVE INTERACTION with Plasma, Strong Field—M. P. Bachynski (Ltd., Canada) Seminar, Univ., of Western Ontario, London; 3/8/72

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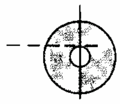

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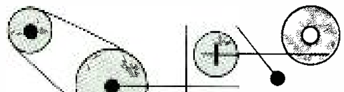

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Method for Photodepositing Smaller Size Image Screen Areas for Cathode Ray Tube from Larger Size Mask Apertures—N. Feldstein (Labs., Pr.) U.S. Pat. 3661581, May 9, 1972

Frequency Modulation by Light Impingement on a Solid-State Oscillator—J. F. Dienst (Labs., Pr.) U.S. Pat. 3662289, May 9, 1972

Manifold for Fountain-Type Liquid Dispenser—E. C. Giaimo, Jr. (Labs., Pr.) U.S. Pat. 3664298, May 23, 1972

Self-Pulsed Microwave Oscillator—S. Liu (Labs., Pr.) U.S. Pat. 3665339, May 23, 1972

Method of Electroless Deposition of Metals with Improved Sensitizer—N. Feldstein, T. S. Lancsek (Labs., Pr.) U.S. Pat. 3666527, May 30, 1972

Semiconductor Electron Emitter—H. Kressel J. I. Pankove (Labs., Pr.) U.S. Pat. 3667007, May 30, 1972

Method of and Apparatus for Reproducing a Colored Image by Electrophotographic Means—D. A. Ross (Labs., Pr.) U.S. Pat. 3667841, June 6, 1972

Entertainment Tube Division

Method of Rebuilding an Evacuated Electron Tube—A. P. Haines (EC, Lanc.) U.S. Pat. 3663862, May 16, 1972

Visible-Emitting Cerium-Activated Calcium Aluminum Oxide Phsophor—M. R. Royce (EC, Lanc.) U.S. Pat. 3657138, April 18, 1972

Method of Manufacture of Cathode Ray Tubes Having Frit-Sealed Envelope Assemblies—J. A. Files (EC, Marion, Ind.) U.S. Pat. 3658401, April 25, 1972

Photographic Method for Producing a Cathode-Ray Tube Screen Structure—E. E. Mayaud (EC, Lanc.) U.S. Pat. 3661580, May 9, 1972

Dates and Deadlines

As an industry leader, RCA must be well represented in major professional conferences . . . to display its skills and abilities to both commercial and government interests.

How can you and your manager, leader, or chief-engineer do this for RCA?

Plan ahead! Watch these columns every issue for advance notices of upcoming meetings and "calls for papers". Formulate plans at staff meetings—and select pertinent topics to represent you and your group professionally. Every engineer and scientist is urged to scan these columns; call attention of important meetings to your Technical Publications Administrator (TPA) or your manager. Always work closely with your TPA who can help with scheduling and supplement contacts between engineers and professional societies. Inform your TPA whenever you present or publish a paper. These professional accomplishments will be cited in the "Pen and Podium" section of the *RCA Engineer*, as reported by your TPA.

Calls for papers—be sure deadlines are met

Date	Conference	Location	Sponsors	Deadline Date	Submit	To
NOV. 28-DEC. 1, 1972	**Conference on Magnetism and Magnetic Materials**	Denver Hilton Hotel Denver, Colorado	S-MAG, AIP	**8/4/72**	abst	A. E. Berkowitz, Gen'l. Elec. Co., POB 8, Schenectady, NY 12301
DEC. 4-6, 1972	**Int'l. Electron Devices Meeting**	Washington Hilton Hotel, Washington, DC	G-ED	**8/18/72**	abst	R. W. Haitz, Hewlett-Packard, 620 Page Mill Road, Palo Alto, Calif. 94309
DEC. 11-15, 1972	**G-AP Int'l. Symposium & Fall USNC/URSI Meeting**	William & Mary College, Williamsburg, VA	G-AP, USNC/ URSI	**9/7/72**	abst & sum	C. T. Swift, NASA, 168 Deane Dr., Newport News, VA 23602
JAN. 28-FEB. 2, 1973	**IEEE Power Engineering Society Winter Meeting**	Statler Hilton Hotel, New York, NY	S-PE	**9/15/72**	ms	J. W. Bean, AEP Service Corp., 2 Broadway, New York, NY 10004
MARCH 6-8, 1973	**Diagnostic Testing of High Power Apparatus in Service**	London, England	IEE, IEEE UKRI Section	**8/28/72**	ms	IEE, Savoy Place, London, W.C. 2R OBL, England
MARCH 20-22, 1973	**AIAA/ASME/SAE 14th Structures, Structural Dynamics and Materials Conference (with participation by ASCE)**	Williamsburg Lodge & Conference Center, Williamsburg, VA		**9/20/72**	abst	Dr. B. Walter Rosen, President, Materials Sciences Corp., Blue Bell Office Campus, 1777 Walton Rd., Blue Bell, PA 19422
MARCH 26-29, 1973	**IEEE International Convention (INTERCON)**	Coliseum & N.Y. Hilton Hotel, New York, NY	IEEE			J. H. Schumacker, IEEE, 345 E. 47th St., New York, NY 10017
APRIL 29-MAY 2, 1972	**Offshore Technology Conference**	Astrohall, Houston, Texas	TAB Oceanography Coor. Comm. et al	**10/1/72**	abst	IEEE Headquarters, 345 E. 47th St., New York, NY 10017
APRIL 30-MAY 2, 1972	**Southeast-CON**	Galt House, Louisville, KY	Region 3	**10/1/72**	abst	R. D. Shelton, Univ. of Louisville, EE Dept., Louisville, KY 40202
JUNE 20-22, 1973	**1973 Joint Automatic Control Conference (JACC)**	Ohio State Univ., Columbus, OH	AIAA, AIChe, ASME, IEEE, ISA, SIAM, TAPPI, ITE and SCi	**1/19/73**	papers	JACC Program Chairman: Dr. Robert E. Larson (1 Copy), Systems Control Inc., 260 Sheridan Ave., Palo Alto, Calif. 94306 and AIAA Program Committee Representative: Dr. Herman Rediess (5 Copies), Chief, Flight Cont. Analysis, NASA Flight Research Center, P.O. Box 273, Edwards, Calif. 93523
SEPT. 11-14, 1973	**Western Electronic Show & Convention (WESCON)**	Civic Audit., & Brooks Hall, San Francisco, CA	Region 6, WEMA			WESCON Office, 3600 Wilshire Blvd., Los Angeles, Calif. 90010
SEPT. 30-OCT. 4, 1973	**Electrical/Electronics Insulation Conference**	Palmer House, Chicago, Illinois	G-EI, NEMA	**9/1/72** **2/1/73**	abst ms	NEMA, 155 E. 44th St., New York, NY 10017
OCT. 2-5, 1973	**Automatic Control in Glass Manufacturing Conference**	Puedue Univ., Lafayette, Ind.	S-IA, IFAC, AACC, ISA, Purdue Univ.	**10/1/72** **2/1/73**	abst ms	IEEE Headquarters, 345 E. 47th St., New York, NY 10017

Dates of upcoming meetings—plan ahead.

Date	Conference	Location	Sponsors	Program Chairman
AUG. 23-25, 1972	**The Physics and Chemistry of Silver Halide Crystals**	University of Montreal Montreal, Canada	SPSE	Society of Photographic Scientists and Engineers, Incorporated in District of Columbia, 1330 Massachusetts Ave., N.W., Washington, DC 20005
SEPT. 4-8, 1972	**Int'l. Broadcasting Convention**	Grosvenor House London, England	IERE, IEE, IEEE UKRI Section et al	The Secretariat, IBC, IEE, Savoy Place, London W.C. 2R OBL, England
SEPT. 10-14, 1972	**Jt. Power Generation Technical Conference**	Sheraton Boston Hotel, Boston, Mass.	S-PE, ASME, ASCE	C. J. Wylie, Duke Power Co., POB 2178, Charlotte, NC 28201
SEPT. 11-12, 1972	**AIAA/AAS Astrodynamics Conference**	Palo Alto, Calif.		American Institute of Aeronautics & Astronautics 1290 Ave. of the Americas New York, NY 10019
SEPT. 11-13, 1972	**2nd Atmospheric Flight Mechanics Conference**	Palo Alto, Calif.		American Institute of Aeronautics & Astronautics 1290 Ave. of the Americas New York, NY 10019
SEPT. 11-13, 1972	**1972 ASMÉ Aviation and Space Division Conference**	Disneyland Hotel Anaheim, Calif.		J. J. Donohue, Jr., Manager, Conferences and Divisions, ASME, 345 E. 47th St., New York, NY 10017 or Carroll F. Bower, McDonnell Douglass Corp., Dept. A3-725-8; 5301 Bolsa Ave., Huntington Beach, CA 92647
SEPT. 11-15, 1972	**Conference on Gas Discharges**	London, England	IEE, IPPS, IERE, IEEE UKRI Section	IEE, Savoy Place, London, W. C. 2R OBL England
SEPT. 12-14, 1972	**Computer Conference (COMPCON)**	Jack Tar Hotel, San Francisco, Calif.	S-C	Algirdas Avizienis, Dept. of EE, UCLA, 3732F Boelter Hall, Los Angeles, Calif. 90024
SEPT. 12-15, 1972	**European Solid State Device Research Conference**	University of Lancaster Lancaster, England	Inst. of Physics, IEEE UKRI Sec., et al	Inst. of Physics, 47 Belgrave Sq., London S.W. 1 England
SEPT. 13-15, 1972	**Int'l. Conference on Engineering in the Ocean Environment**	Newport Harbor Treadway Inn, Newport, .R.I.	IEEE Oceanography Comm., Providence Sect.	Charles Polk, Dept. of EE, Univ. of R. I., Kingston, R.I. 02881
SEPT. 13-15, 1972	**AIAA 7th Aerodynamic Testing Conference**	Palo Alto, Calif.		American Institute of Aeronautics & Astronautics 1290 Ave. of the Americas New York, NY 10019
SEPT. 19-22, 1972	**Western Electronic Show & Convention (WESCON)**	L. A. Convention Ctr., Los Angeles, Calif.	Region 6, WEMA	WESCON, 3600 Wilshire Blvd., Los Angeles, Calif. 90010
SEPT. 19-22, 1972	**Int'l. Conference on Magnet Technology**	Brookhaven Nat'l. Labs., Upton, N.Y.	S-MAG, IUPAP, AEC	J. P. Blewett, Accelerator Dept., Brookhaven Nat'l. Lab., Upton, NY 11973
SEPT. 20-22, 1972	**Conference on the Automation of Testing**	Univ. of Keele, Staffordshire, England	IEE, IEEE UKRI Section	IEE, Savoy Place, London W.C. 2R OBL England
SEPT. 25-29, 1972	**Intersociety Energy Conversion Conference**	Hilton Inn, San Diego, Calif.	G-ED, G-AES, ACS et al	B. S. Baker, Energy Res. Corp., 15 Durant Ave., Bethel, Conn. 06801
SEPT. 26-29, 1972	**Conf. on Metering, Apparatus and Tariffs for Electricity Supply**	London, England	IEE, IERE IEEE UKRI Section	IEE, Savoy Place, London W.C. 2R, OBL, England
OCT. 1-5, 1972	**Conference on Engineering in Medicine and Biology**	Americana Hotel, Bal Harbor, Florida	G-EMB, AEMB	W. T. Maloney, Conf. Coordinator, 6 Beacon St., Suite 620, Boston, Mass. 02108
OCT. 4-7, 1972	**Ultrasonics Symposium**	Statler Hilton Hotel Boston, Mass.	G-SU	L. P. Claiborne, Texas Instr. Inc., POB 5936, MS 118, Dallas, TX
OCT. 8-15, 1972	**23rd Congress of the International Astronautical Federation**	Vienna, Austria		American Institute of Aeronautics & Astronautics 1290 Ave. of the Americas New York, NY 10019
OCT. 9-11, 1972	**National Electronics Conference**	Regency Hyatt House Chicago, Illinois	Region IV et al	Richard Horton, Dept. of EE, Iowa State Univ., Ames, Ia. 50010
OCT. 9-11, 1972	**12th Biennial Mechanisms Conference**	San Francisco, Calif.	Design Engrg. Div. of ASME	Paul Drummond, Manager, Conferences and Divisions, 345 East 47th St., New York, NY 10017
OCT. 9-12, 1972	**Int'l. Conference on Cybernetics and Society**	Shoreham Hotel, Washington, D.C.	S-SMC	K. S. Narendra, Yale Univ., 10 Hill House, New Haven, CT 06520
OCT. 9-12, 1972	**Industry Applications Society Annual Meeting**	Marriott Motor Hotel, Phila., Pa.	S-IA, Phila. Section	W. R. Harris, Westinghouse Elec. Corp., 4454 Genesee St., Box 225, Buffalo, NY 14240

Engineering News and Highlights

Professional activities

Aerospace Systems Division

Several ASD engineers were honored at the Annual Meeting of the IEEE Boston Chapter: **M. M. Miller** as Chairman of the Education Group Chapter for 1971-1972; **N. A. Teixeira** as Chairman of the Engineering Management Chapter, 1971-1972; **E. M. Stockton** and **K. E. Palm** for their organizational effort on the lecture series covering Computer-Controlled Automatic Test Systems; and **N. L. Laschever** as 1971-1972 Boston Section Executive Committee Member in charge of Special Events.

RCA Laboratories

Dr. Nathan Feldstein has been appointed Divisional Editor for the Journal of the Electrochemical Society. Dr. Feldstein will be active in the Electrodeposition Division and will specialize in papers related to electroless and electronic plating.

Missile and Surface Radar Division

Engineers from the Missile and Surface Radar Division presented papers at the *Tri-Service Radar Symposium* at the Naval Post Graduate School in Monterey, California on June 6, 1972. **Captain W. E. Meyer,** Program Manager for the AEGIS Weapon System, served as chairman of the special afternoon session devoted to AEGIS. In a letter to P. A. Piro, Vice President and General Manager, M&SR, Captain Meyer complimented the AEGIS engineers on the professional quality of their presentations:

"I want to express my gratitude and pleasure for the participation and services provided by your AEGIS groups in support for our AEGIS delegation to the Tri-Service Radar Symposium at Monterey the week of 5 June . . . .
We cannot take on such a profound task without good engineers and managers and proper support. I have repeatedly said that all of our endeavors should be as professional as we are capable.

The team which I led to Monterey was truly professional. They spoke expertly, confidently, humbly, and in union. They had good material, ably presented, and, thanks to the Moorestown presentations group, viewable. I had many compliments on their performance . . . .

I would appreciate your making it a matter of record of the participation of the following speakers:

Mr. I. A. Schottenfeld	RCA
Dr. W. T. Patton	RCA
Mr. C. C. Phillips	APL/JHU
Dr. R. Daly	Raytheon
Mr. R. A. Baugh	RCA

These fellows should be identified as contributing authors:

Mr. C. R. Lorant	Raytheon
Mr. B. Kopeloff	Raytheon
Mr. W. H. Zinger	APL/JHU
Mr. E. C. Prettyman	APL/JHU
Mr. N. R. Landry	RCA
Mr. H. C. Goodrich	RCA
Mr. R. M. Scudder	RCA
Mr. R. W. Ottinger	RCA

Of course, **Dr. Josh Nessmith's** contributions were invaluable, assisted by **Mr. Bob Renfrow** and **Dr. W. W. Weinstock.**"

Staff Announcements

President and Chief Operating Officer

Anthony L. Conrad, President and Chief Operating Officer has announced that **Howard R. Hawkins,** Executive Vice President has been elected Chairman of the Board and Chief Executive Officer, RCA Global Communications, Inc., and will also have the responsibility for Random House, Inc., and RCA Records.

Edgar H. Griffiths as Executive Vice President, in addition to continuing his present responsibilities for RCA Service Company, The Hertz Corporation, Computer Systems, and Parts and Accessories, will assume responsibility for: Banquet Foods Corporation, Coronet Industries, Inc., and Cushman and Wakefield, Inc.

Robert F. Adams, President, RCA Service Company, will assume responsibility for the Education Systems organization.

RCA Global Communications, Inc.

Eugene D. Becken has been appointed President, RCA Global Communications.

Howard R. Hawkins, Chairman of the Board and Chief Executive Officer, RCA Global Communications, Inc. has announced his organization as follows: **Robert J. Anglis,** Executive Vice President, Services; **Eugene F. Murphy,** Executive Vice President, Operations; and **Philip Schneider,** Executive Vice President, Leased Facilities and Engineering.

Research and Engineering

Jan A. Rajchman, Vice President, RCA Research Laboratories, Inc., (Tokyo) has announced the appointment of **Dr. Bernard Herschenov** as Director of Research, RCA Research Laboratories, Inc., (Tokyo).

Electromagnetic and Aviation Systems Division

Carl J. Cassidy, Director, Government Marketing, has announced the appointment of **J. M. Dunleavy** as Manager, Army Electronic Warfare and Special Projects Marketing.

Government and Commercial Systems

David Shore, Division Vice President, Government Plans and Systems Development, announced the appointment of **Kassel K. Miller** as Manager, Systems Development.

Dr. Harry J. Woll, Division Vice President, Government Engineering, has appointed **Harold E. Hayes,** Staff Engineer.

RCA Service Company

Joseph F. Murray, Division Vice President, Government Services, has appointed **Howard W. Johnson** Division Vice President of Government Services Administration.

Promotions

Entertainment Tube Division

D. C. Ballard from Sr. Eng. Prod. Dev. to Engrg. Ldr., Product Development (R. H. Zachariason, Mgr., Picture Tube Product Engrg., Lanc.)

Industrial Tube Division

R. W. Fitts from Eng. Ldr. Mfg. to Mgr. Mfg. & Production Engrg. (J. A. Zollman, Mgr., Image & Display Tube Operation, Lanc.)

R. A. Helvy from Eng. Ldr. Product Dev. to Mgr., Product Design Engrg. (J. A. Zollman, Mgr. Image & Display Tube Operation, Lanc.)

T. T. Lewis from Engr. Product Dev. to Engrg. Ldr., Product Dev. (R. C. Pontz, Mgr. Photo Tube and Solid State Opto Electronics Oper., Lanc.)

D. E. Persyk from Engr. Product Dev. to Engrg. Ldr., Product Dev. (R. C. Pontz, Mgr. Photo Tube and Solid State Opto Electronics Oper., Lanc.)

W. E. Rohland from Superintendent Electro Optics Products Mfg. to Mgr. Mfg. & Production Engrg. (J. A. Zollman, Mgr. Image & Display Tube Oper., Lanc.)

Government and Commercial Systems

R. F. Kenville from Ldr., Engrg. Staff to Mgr., Electro-Optics Lab. (P. Wright, Advanced Tech. Labs., Camden)

Licensed engineers

When you receive a professional license, send your name, PE number (and state in which registered), RCA division, location, and telephone number to: RCA Engineer, Bldg. 2-8, RCA, Camden, N.J. As new inputs are received they will be published.

Global Communications, Inc.

Fricis Ginters, Glōbcom, New York, PE-047848; N.Y.

Awards

Electronic Components

Thomas R. Krebs of Thermoelectric Products and **Dr. Max J. Schindler** of Solid-State Product Engineering received the 1971 Engineering Awards.

The Microwave Devices Operations Department/Thermoelectric (MDOD/TE) Engineering Recognition Award is given each year to the two RCA engineers who have made the most outstanding engineering accomplishments. MDOD/TE engineers nominate their choice as a regular function of the Microwave Engineering Education Committee (MEEC) activities. The recipients are selected by secret vote, so that each winner is truly "an engineer's engineer."

MEEC Chairman, Paul Puri (left) presents a handsome desktop pen and clock set to Thomas Krebs (right) as a token of engineering esteem. John Kucera (center) Manager of Planning and Controls approves.

Thomas Krebs has developed fabrication techniques to produce modules from bismuth telluride thermoelectric materials which have shown a superior efficiency and stability, and have provided RCA with an entry into the field of commercial applications. His enthusiasm, dedication and high professional standards have been an example for all his fellow employees.

MEEC Chairman, Paul Puri (left) presents a handsome desktop pen and clock set to Dr. Max J. Schindler (right) as a token of engineering esteem. John Kucera (center), Manager of Planning and Controls, approves.

Dr. Schindler has contributed heavily to microwave design by using the computer to analyze and optimize microwave integrated circuits with lumped and distributed elements. He was essential in the conversion of the Transferred Electron Amplifier from a laboratory device into a useful marketable product. He is on the Executive Committee of the North Jersey Section of the IEEE.

Aerospace Systems Division

The team of **Raymond T. Boyle, Richard H. Holder, William B. Locke, Peter J. Nesbeda** and **Earl D. Wyant** received the Technical Excellence Team Award for June 1972 for their work on the Automatic Monitoring of TV Broadcast Transmitters.

This team received the Technical Excellence Award for innovating an automatic monitoring system based on techniques and disciplines accrued on previous successful programs such as Disney (AM&CS) and FTA. The effort was one requiring creativity in engineering, program management, vendor interfaces and customer interfaces. The team had seven weeks to install a demonstrable system for display at the National Association of Broadcasters Convention in Chicago.

In addition, four ASD employees were presented AEGIS Excellence awards

Dick Cahoon of Engineering for his mechanical design efforts on the ORTS hardware.

Hank Laporte of Manufacturing for his assembly work on the Test and Monitor Console, Deckhouse Rack, and Status Chassis.

Berenice McCaffrey of Administration for here timely preparation of monthly reports and secretarial support to the AEGIS Program.

Bob McCarthy of Manufacturing for his demonstrated resourcefulness in applying his polymer know-how to resolve hybrid bonding problems and producing a conformal coating process to meet tight humidity and reliability requirements.

The citations were presented by **Dan McCarthy**, Manager of Integration and Test on the AEGIS Program, Moorestown and the awards by **Lt. Robert F. Brasil**, Officer in Charge, Naval Training Unit, AEGIS.

Communications Systems Division

Glen A. Houck of the Engineering Technical Support Activity, Government Communications System, received the second Technical Excellence award of 1972. He is being recognized for his outstanding work in the specialized area of Electromagnetic Compatibility/Electromagnetic Interference Engineering. Mr. Houck has made significant contributions on various programs and over the last year has demonstrated technical excellence on the LCRU and Integrated Radio Room Programs.

National Broadcasting Company

Julian Goodman, President of NBC, recently received the highest honor of the International Radio and Television Society—the 1972 Gold Medal—for his achievements in and contributions to broadcasting, in which he has worked for more than 25 years. The citation read ". . . a faithful reporter, a daring innovator, a tireless and effective champion of freedom, a forceful and timely spokesman for the broadcasting industry. . . "

Missenda is Ed Rep for Commercial Communications

Andrew M. Missenda has been appointed Editorial Representative for Commercial Communications Systems at Meadowlands, Pa. In this capacity, Mr. Missenda is responsible for planning and processing articles for the *RCA Engineer* and for supporting the Corporate-wide technical papers and reports program.

Mr. Missenda received the BSEE and MSEE from the University of Pittsburgh in 1960 and 1966, respectively. From 1960 to 1962, he did applied research on nuclear radiation affects on quartz crystals and X-band propagation for the U.S. Signal Corps Research Labs at Fort Monmouth New Jersey. From 1962 to 1964, he did circuit design work on infrared gas analysis equipment for Mine Safety Appliances Company of Pittsburgh. He joined RCA in 1964 as a member of the technical staff of the Mobile Communications Engineering Department. Since that time he has worked in the Receiver Design, Base Stations Systems, and Advanced Development groups. In 1970, he established a Mobile Communications Resident Group for IC design at the RCA Somerville facility. He is presently Leader, Advanced Development, for Mobile Communications at RCA, Meadowlands Pa. Mr. Missenda is a Member of the IEEE and has served on the Administrative Committee of the Professional Group on Vehicular Technology since 1969. From 1968 to 1970, he was Chairman of the Vehicular Technology—Communications Society, Pittsburgh chapter.

RCA-built TV to be used in ERTS

The Earth Resources Technology Satellite (ERTS) is being launched by NASA in July. With the help of the ultra-high-resolution TV system developed by Astro-Electronics Division, the satellite could revolutionize space technology for practical purposes. Each of the three RCA cameras carried by the satellite will employ 4,000 horizontal scanning lines to produce its images. From the 490-nautical-mile high orbit of the spacecraft, all three cameras will view the same 100-by-100 nautical-mile square of the earth below. Potentially, the cameras could aid farming by spotting blight in crops; also they could map the entire earth in one year or less and perform other missions such as detecting sources of water pollution.

Editorial Representatives

The Editorial Representative in your group is the one you should contact in scheduling technical papers and announcements of your professional activities.

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Aerospace Systems Division	**P. P. NESBEDA*** Engineering, Burlington, Mass. **J. J. O'DONNELL** Industry Systems Burlington, Mass.
Electromagnetic and Aviation Systems Division	**C. S. METCHETTE*** Engineering, Van Nuys, Calif. **J. McDONOUGH** Engineering, Van Nuys, Calif.
Astro-Electronics Division	**I. M. SEIDEMAN*** Engineering, Princeton, N.J. **S. WEISBERGER** Advanced Development and Research, Princeton, N.J.
Missile & Surface Radar Division	**T. G. GREENE*** Engineering, Moorestown, N.J.
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Solid State Division	**E. M. McELWEE*** Chairman, Editorial Board, Somerville, N.J. **J. DIMAURO** Solid State Division, Mountaintop, Pa. **S. SILVERSTEIN** Power Transistors, Somerville, N.J. **E. M. TROY** Integrated Circuits, Somerville, N.J. **J. D. YOUNG** Solid State Division, Findlay, Ohio
Consumer Electronics	**C. HOYT*** Chairman, Editorial Board, Indianapolis, Ind. **R. BUTH** Engineering, Indianapolis, Ind. **R. C. GRAHAM** Radio Engineering, Indianapolis, Ind. **F. HOLT** Advanced Development, Indianapolis, Ind. **E. JANSON** Black and White TV Engineering, Indianapolis, Ind. **W. LIEDERBACH** Ceramic Circuits Engineering, Rockville, Ind. **J. STARK** Color TV Engineering, Indianapolis, Ind. **P. HUANG** Engineering, RCA Taiwan Ltd., Taipei, Taiwan
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RCA Service Company	**M. G. GANDER*** Consumer Products Administration, Cherry Hill N.J. **W. W. COOK** Consumer Products Service Dept., Cherry Hill, N.J. **R. M. DOMBROSKY** Technical Support, Cherry Hill, N.J. **R. P. LAMB** Missile Test Project, Cape Kennedy, Fla.
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