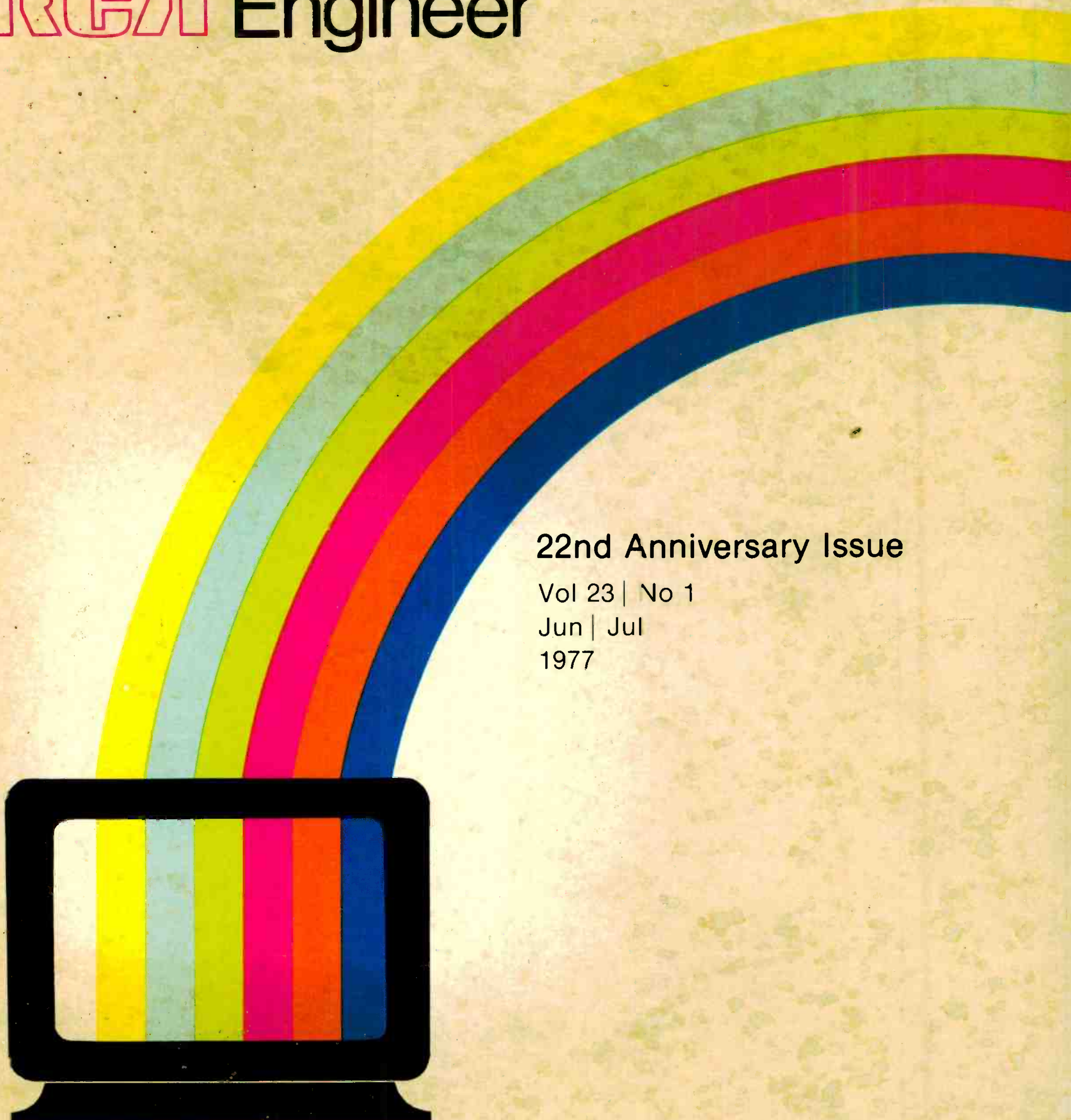
RCA Engineer



22nd Anniversary Issue

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RCA Engineer

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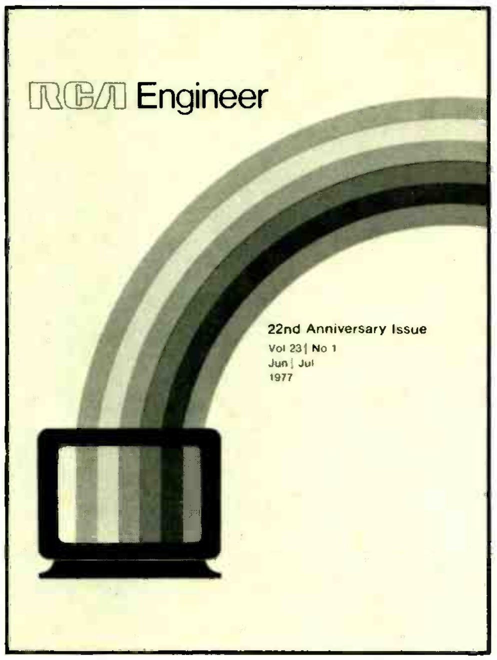


The familiar color-bar test pattern represents color tv, one of RCA's traditional and primary business interests. Our 22nd anniversary issue has three color-tv-related articles—"The XL-100 XtendedLife chassis," "US color television fundamentals," and "Electronic displays."

- 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.

A message to engineers

I welcome this opportunity to salute the *RCA Engineer* on its 22nd anniversary and to greet RCA engineers throughout the company. Any corporation as large, complex, and diverse as ours depends for success on a variety of different skills and disciplines. But given our essential stake in technology, none of these seems quite so central to RCA's well-being as engineering. From the conception of products and services, through their development and realization, to the task of keeping them going at their best, we depend on the talented, conscientious people who make up RCA's engineering community.

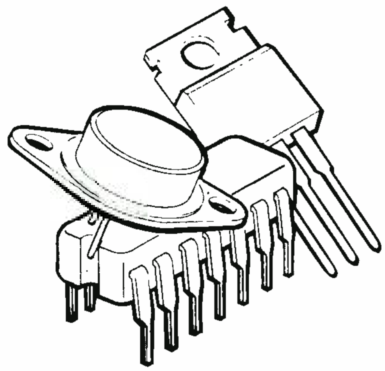
I can assure RCA engineers that your contribution has never been more appreciated or needed. In all electronics and communications businesses, the pressure of heavy competition demands the most of us in quality and reliability, not only in products and services themselves, but in how we tool up to deliver them and how we maintain them. Against that kind of competition and the steady inroads of inflation, we must apply equal ingenuity and effort to attain the highest possible cost effectiveness across the board.

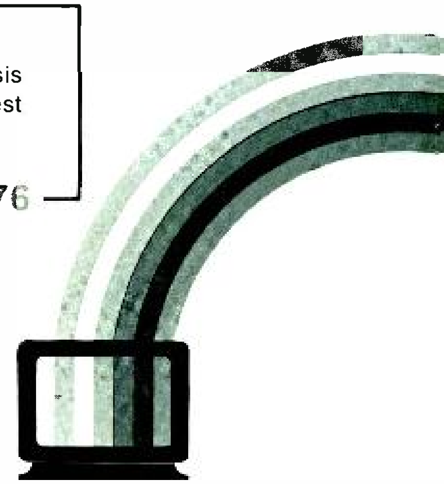
The company also looks to the engineering community for the products of tomorrow. Technological innovation is a proud RCA tradition. It is so vitally needed for our future success that I consider it, along with sustained earnings growth, as one of the company's primary goals.

Given these high priorities, engineering has a bright future indeed at RCA. On a personal note, I can add that as an individual without a technical background, I have particular respect and admiration for those who do. I urge you to do all that you possibly can to make this a stronger corporation, while those of us who are business managers will do our best to keep giving you the tools and resources you need to succeed in your vital tasks.

Edgar H. Griffiths
President
RCA Corporation

22nd anniversary issue





Upcoming issues

Our next issue (Aug/Sep) has a **hybrid technology** theme, plus individual articles on **fusion power, Sensurround,** the new **CMOS/SIS** semiconductor technology, and more.

Future issues will cover **advanced communications, radar, software,** and **space technology.**

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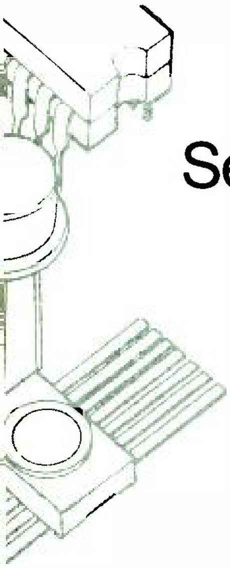

Semiconductors 1971-1981—a ten-year perspective

For over 20 years, semiconductor technology has been the catalyst accelerating the electronic drive of our society. This review examines semiconductor technology as a science, a business, and a socio-economic force, and endeavors to shed light on some of its limits.

B. A. Jacoby

1948 ... with the invention of the transistor came the promise of decreased size and power and improved reliability for electronic equipment. As a result, scientists in the military and telecommunications industries particularly became very interested.

1959 ... the invention of the integrated circuit promised improvements in speed and cost, and the computer industry became very interested.

1977 ... VSLI—Very Large Scale Integration—promises the penetration of the cost threshold for distributed data processing, and another electronic revolution is in the making. For all, the dream of extending intellectual capacity through personal data processing seems possible in much the same way that muscle power has been multiplied by the harnessing of energy sources.

The semiconductor science

The semiconductor industry is one of high technology characterized by rapid product obsolescence, with typical product life as low as five years. Our 10-year span of reference has more innovation and change than the previous 50 years that started with the mass production of the radio. Semiconductors are at the leading edge of the increase in technical knowledge, which now doubles about every five years. Appropriately, semiconductors offer the key to the efficient library and rapid recall this mass of knowledge requires.

Most classes of semiconductors are still in the introductory or growth phase of their life cycle, as shown in Fig. 1. A few have reached maturity, and several discrete devices have started to decline because of the availability of more cost-effective alternative semiconductors.

Semiconductor technology, although often referred to as a homogeneous unit, is in reality a number of technologies. Even though silicon is the base material for more than 90% of all semiconductor products and there is a strong technology interrelationship among the various solid-state devices, the separating factors are still significant both in technology and applications.

Discrete semiconductor—10% per year growth until 1981.

Discrete devices (including some multiple devices such as Darlington power transistors and arrays of light-emitting diodes for displays) will continue growing at a rate of about 10% per year until 1981. Diodes and signal transistors have peaked and are rapidly being replaced by ICs. Power transistors, thyristors, and optoelectronic devices all have strong future growth. The volt-ampere/speed tradeoff of these devices has been improving at about 20% per year, and progress will continue for more than a decade before some fundamental phenomenon, such as heat transfer, limits performance improvement.

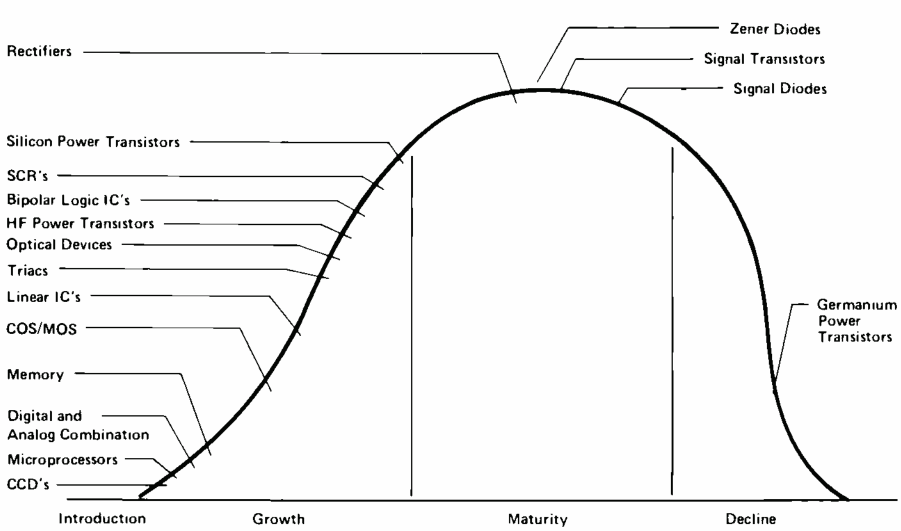

Fig. 1
Semiconductor-products life cycle. Note that a few have reached maturity and germanium devices have started to decline but most are in the growth portion of the life-cycle.

Optoelectronics is the fastest-growing segment of discrete devices, with an estimated compound growth rate of 20% over the 10-year period of 1971-1981. Based primarily on III-V compounds like gallium arsenide, the technology is entering a mature phase. Cost reduction is the major thrust in use of LEDs (light-emitting diodes) as displays, but strong competition is emerging from vacuum fluorescents and liquid crystals. Laser diodes, while still a small segment of total optoelectronics, have significant opportunities in fiber-optic communications techniques.

Linear integrated circuits—21% per year growth until 1981.

The linear IC compound growth rate from 1971 to 1981 will be about 21%, with the growth led by new devices for data systems interface and additional applications for consumer and automotive custom circuits.

RCA has pioneered in linear IC technology, particularly for custom tv functions. The RCA-originated biMOS process (MOS and bipolar technology in combinations for better optimized performance) promises an additional dimension of freedom to the systems designer by providing high input impedance, picoampere input current, microvolt offsets, and fast slew rates. These near-ideal operational-amplifier parameters, plus the combining of digital and linear functions leading to LSI density, are among the dominant trends in this field for the next few years.

Digital integrated circuits—23% per year growth until 1981.

Nowhere has the improvement in cost effectiveness and its impact been more impressive than in digital electronics. Over the past five years, the cost of a logic gate in an assembled subsystem has dropped from 35 cents to 7 cents, as shown in Fig. 2. With the introduction of microprocessors, the cost of a gate took a step-function drop to the one-cent level, and is expected to continue on a slope that will further reduce the cost by better than two orders of magnitude by 1981. The fundamental thrust of large-scale integration is in memory and microprocessor circuits. The overall growth rate for digital ICs from 1971 to 1981 is 23% per year; in the three major categories the individual growth rates are 15% for logic devices, 27% for microprocessors, and 37% for memories.

Ben Jacoby, as Division VP of Systems, Services, and Strategic Planning at the Solid State Division, directs MIS, Central Engineering, Purchasing, Manufacturing Services, and Strategic Planning. He joined RCA in 1952 and held positions as Operations Director of SSTC (1969), Manager of Solid State Power Devices (1970), Division V.P. of Solid State Power Devices (1972), and Division V.P. of Marketing (1974).

Contact him at: **Systems, Services, and Strategic Planning; Solid State Division; Somerville, N.J.; Ext. 6855**

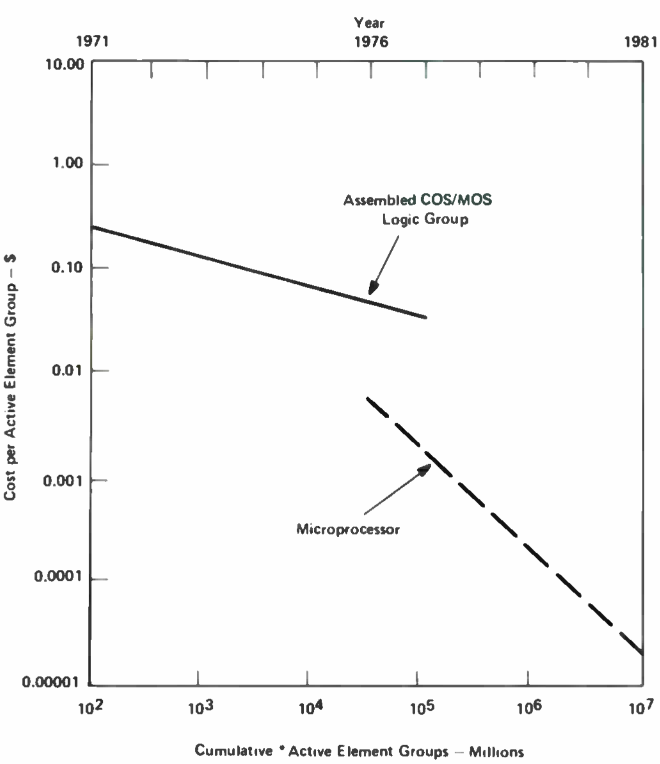

Fig. 2
Cost per active element group (AEG) for CMOS and microprocessors. The microprocessor caused a step-function drop in cost/AEG.

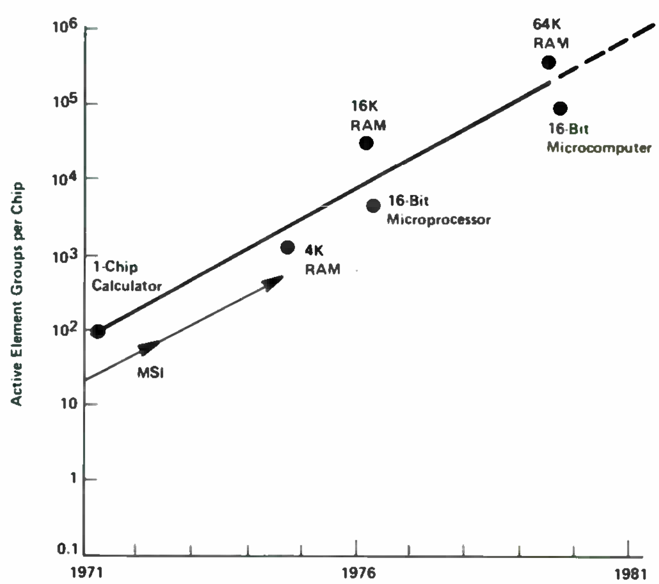

Fig. 3
Product evolution of digital ICs. Density/chip should double each year through 1981.

Functional density—by 1981 we should see a 16-bit microcomputer on a single chip.

Fig. 3 shows the impact of density per chip increasing at approximately two times per year. 1971 saw the LSI 4-function calculator chip, 1975 the 4000-bit RAM (random-access memory), and 1977 the first volume production of 16,000-bit RAMs. In 1981, a 16-bit microcomputer representing close to 100,000 active element groups on a single chip of silicon will be practical. (An active element group is the equivalent of a single gate or memory bit.)

Two major factors of this increased function count per IC are minimum dimensions per element and die size. Minimum dimensions (5 microns in production today) will reach 2 microns, or close to the limits of today's optical systems, in the next three years. Electron beams, which have the advantages in resolution of extremely small images coupled with a favorable depth of field, will move from mask-making to exposing patterns directly on silicon in the next five years, opening the way to 1-micron elements. Die-size limitations are set by yield economics and heat-transfer requirements. Defects introduced in processing are continually being reduced, which should allow for a tripling in practical die areas to 75,000 square mils by 1981.

Fig. 4 shows the effect of die size and pattern dimension and includes a third major consideration, the contribution of structure and circuit cleverness. In fact, many of the newer technologies such as CCD (charge-coupled devices), I^2L (integrated injection logic), and C^2L (closed complementary logic) are structural, rather than processing, innovations. As we run into fundamental physical limitations

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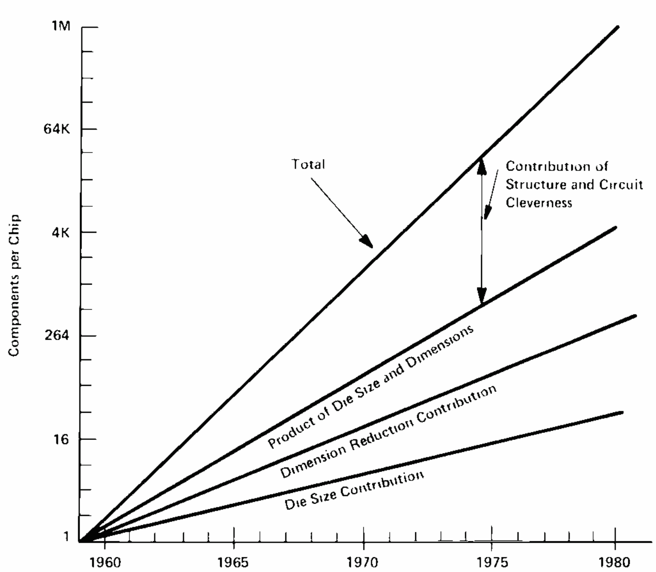

Fig. 4
Elements of increasing complexity as a function of die size, pattern dimension, and circuit cleverness.

Table I
MOS LSI technology progress over the ten-year period: 1971-1981.

	1971	*1976*	*1981*
Structure	PMOS CMOS (metal gate)	NMOS C^2L CSOS (Si. gate)	MESFET (diffused MOS)
Imaging	Non-contact print	E-beam mask projection print	E-beam direct write
Processing	Ion implant plasma etch	Plasma nitride	Dry continuous process
Metallization	1½ levels	2 levels	3 levels
Density	4-bit calculator 8-bit microprocessor	16-bit MPU 16k RAM 64k CCD	64k RAM 16-bit microcomputer 256k CCD

on pattern and die size, we will depend more and more on structure and circuit innovation to maintain this rate of density increase. There is a strong opinion that the increase in active element groups per die will slow to 1.5 times per year by the later 1970s. In the past, however, forecasters have tended toward overly pessimistic assumptions when they invoked theoretical limitations on semiconductor performance. In fact, the horizons on performance have continued to move forward by the application of combinatorial solutions to singular problems (i.e., circuit, structures, materials, and processes). Table I shows some of these relationships in the development of MOS LSI technology.

Semiconductors as a business

Semiconductors represent about 5% of the total value of electronic sales, and increasingly are the foundation of the electronics industry's real growth rate of about 1.5 times that of the GNP. It is expected that, with broader use of digital techniques for basic communications coupled with a host of new semiconductor-rich equipment such as watches, calculators, and microcomputers, the solid-state portion of electronic system cost will increase by 0.5% per year, reaching approximately 10% by 1985.

Design and manufacturing costs of a new function must be spread over many applications.

With increasing complexity, and in spite of liberal use of computer aids, the cost of designing a new LSI function is magnitudes higher than that for a simple gate function. However, the overall cost of design can be lower if the component manufacturers spread the cost of one new function over many applications. LSI, which can be produced economically, could not be designed economically without the microprocessor approach, which transfers uniqueness from the hardware to the software level. The task of training a cadre of software specialists is now well underway at both component and system manufacturers. In the next few years, development lead times will decrease radically, initial design cost will be lower, and user skill requirements will diminish because software will replace new chip development. The resulting reduced design, assembly, and interconnect cost at the systems level is the key to the distributed processing era.

Unfortunately, the continuous technology change in the semiconductor business does not always lend itself to automation. In the U.S., with relatively expensive labor and good access to innovative capital equipment, the semiconductor industry performs the capital-intensive complex technology operation of wafer manufacturing. Since the later 1960s, it has increasingly sought lower-cost offshore areas for the more labor-intensive operations of device packaging, thus conserving large amounts of capital to invest in technology development and wafer processing capability.

Jelly beans cost more than active semiconductor devices.

No discussion of the semiconductor business is complete without a look at the price experience. The Boston Consulting Group may have highlighted the experience-curve concept, but certainly its major practitioner is the semiconductor industry. This practice is understandable when considered in the light of the demand elasticity with price for this type of basic commodity and the manufacturing process which, by nature, is one of low starting yields. Since the inflation pull from materials has been second order, and labor content has been reduced by offshore assembly, yield improvements are the predominant cost driver.

Figs. 5 and 6 show the price-experience curves for ICs and discrete devices. Since the early 1960s, every time volume has doubled, prices have declined in excess of 25%. This relationship is particularly significant in light of the fact that this experience covers the total spectrum of semiconductors sold. Therefore, the price declines have continued in the face of continuous increased value per package. It is reasonable to postulate that a 75% price-experience curve translates to a 50% increase in value every time the volume doubles.

The cumulative volume of devices sold to date is about 55 billion units. When a factored multiplier is used to equate integrated-circuit sales with discrete components, the active device count quickly moves into the 10^{15} range. Only nails, buttons, pins, and jelly beans approach these use figures. In fact, using equivalent active device count makes jelly beans more expensive per unit.

The dividends have been minuscule.

Table II summarizes the broad financial highlights of the U.S. semiconductor industry. The composite average return on investment for 1971-1975 would be deemed modest by most industrial organizations. The investment in inventory, fixed assets, and receivables to increase sales is high, and the ability of the industry to expand at the market demand comes, in good part, from the nature of available funds.

Table II
1971-1975 composite performance measurements of eight major U.S. semiconductor companies.

	5-year composite
Return on investment	13%
Return on sales	6%
Sales $/employee	$18,000
Inventory $/sales $	17%
Net fixed assets $/sales $	24%
Depreciation $/sales $	4%
Total asset increase per sales-dollar increase	73¢

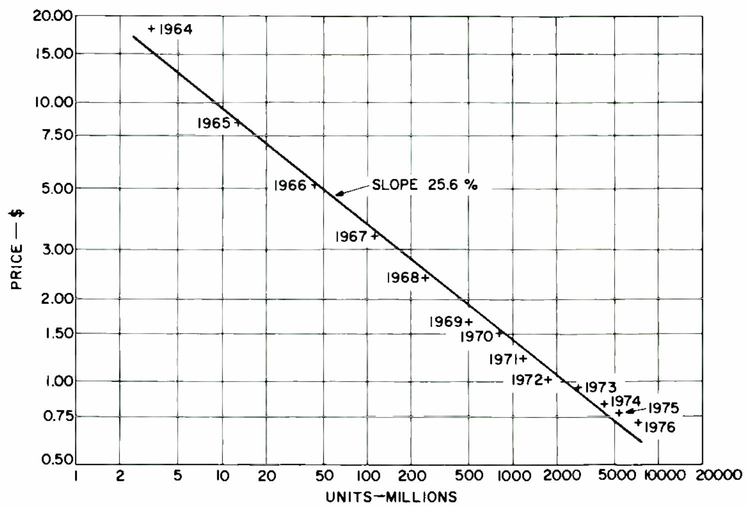

Fig. 5
Price-experience curve for integrated circuits. Every time volume has doubled, prices have declined by more than 25%.

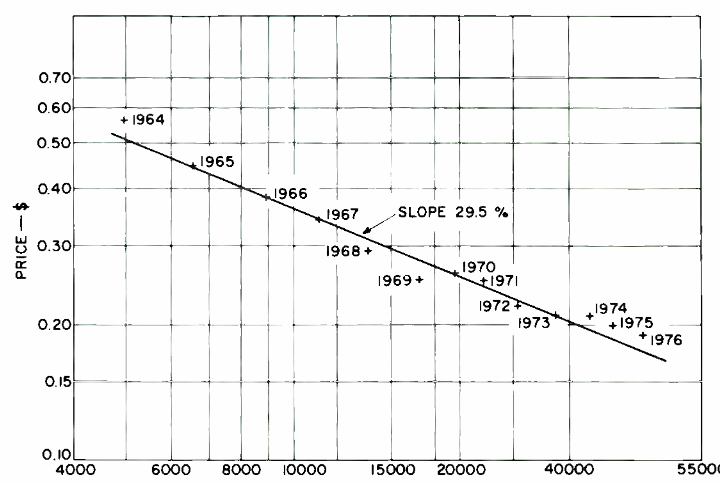

Fig. 6
Price-experience curve for discrete semiconductors. The experience here is similar to that for ICs.

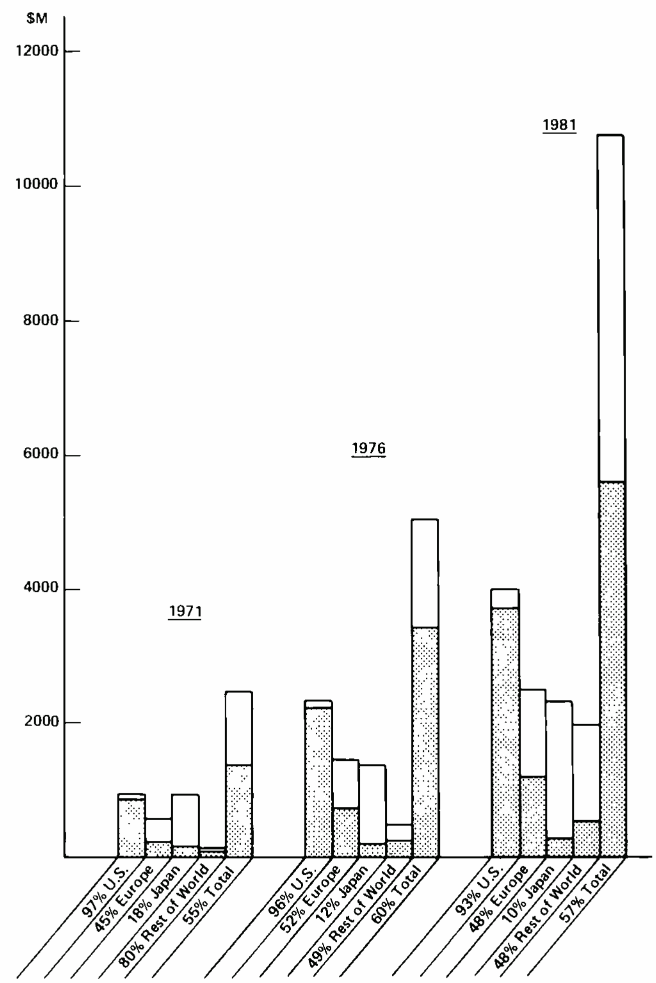

Fig. 7
Semiconductor sales of U.S.-based manufacturers by geographic region. Note that U.S. strength is presently 60% in the world market, which will be under increasing pressure through 1981.

Major financing has come from two classes of equity investors: those who see the tong-term implications and believe that broad pervasiveness of the product and resulting volume will have a significant longer-term payoff, and a larger group who have invested because of the leading-edge technology. The dividends that semiconductor companies as a group have paid their stockholders have been minuscule. The industry has been a classic example of futures with a major motivation: volume growth will continue and accelerate since semiconductors are the very fabric of the expansion of electronics into almost every phase of working and living.

The data of Table II becomes more incongruous when you consider that although semiconductors are at the heart of electronic progress, they represent only 5% of the electronic industry's product sales value; 1% more, or $400 million, would have doubled the semiconductor industry return of sales, and added 50% to the return on investment, and probably could have been accomplished without affecting demand. Over-reliance on the learning-curve concept, with continued willingness to price for future demand, has served as the key force for volume success and a disappointing return on equity. The last few points on both the IC and discrete-device price learning curves show a slight departure from the long-term slope and may augur a more mature approach to marketing semiconductors.

(In the U.S., only RCA among the established active-device suppliers has continued to pursue a relatively broad participation in both ICs and discrete semiconductors. GE and Westinghouse have dropped out of ICs, and Sylvania and Philco out of all semiconductors.)

An additional impediment to sustained semiconductor profitability has been the extreme cyclicality in spite of the rapidly broadening base of usage. The industry has had three major cycles since 1964, with a period of about 4 years from peak to peak. The "up" market usually spawned about 2.8 years of growth, with a sharp breakover to a "down" market of about 2 years. While the major driver of these cycles has been the economy, sharp changes in semiconductor inventory in the hands of equipment manufacturers have greatly multiplied their magnitude. These inventory changes were far more a product of methodology than necessity. A combination of techniques for forecasting true consumption and a strong resistance in industry to inventory accumulation should dampen this phenomenon during the next economic swing. Artifically exaggerated demands have limited semiconductor profits even during the boom portion of the cycle because of the abnormal production buildup.

Semiconductors as an international economic force

The economics of production and the elasticity of demand, coupled with the need to create high-volume markets, have caused the U.S. semiconductor industry both to optimize its international production and to aggressively seek markets throughout the world. This rationalization of production and markets has resulted in a favorable balance of payments of $400 million per year for semiconductors, and strongly influences another $1.5 billion in electronic equipment exports; thus it contributes significantly to U.S. employment. In fact, the semiconductor industry is the definitive U.S. example of a domestic-based international industry (rivaled in magnitude only by Japanese consumer electronics). In addition to the trade surplus, the U.S. semiconductor industry contributes significantly in royalty income to the balance of payments.

Some may be concerned about the dangers of exporting technology. In an open society such as ours with the rapidity of technical communciations, it is impossible to imprison technology for long. When stagnant, technology is at best a fleeting asset. Experience has shown that technology seems to thrive best and be of most value in an open climate of world-wide free-market competition.

Market distribution—U.S. manufacturers hold a 60% share of the world market.

The price/volume relationship continues strongly as a competitive factor favoring U.S. manufacturers. Fig. 7 shows that U.S. strength in the worldwide market has grown to 60% of the total, and is projected to be 57% in 1981. To achieve this percentage, U.S. companies have had to be opportunistic toward market participation in Europe. The 52% penetration in Europe in 1976 was reached by building on the volume and technology leverage of the earlier-developing U.S. market.

U.S. manufacturers have been less successful in Japan as a result of a more competitive indigenous industry with a much stronger stake in electronics, aided by a fabric of tariff and non-tariff barriers. These barriers include restrictions on foreign ownership of production entities in Japan, quotas on the import of high-technology items, and complex local trading relationships.

Worldwide tariff barriers ranging from 12 to 55% indicate why U.S. semiconductor companies have established more than 20 manufacturing plants abroad. These local-market-oriented plants usually strike a balance between the third-party cost-savings (tariffs, taxes, and transportation) and the minimization of technology duplication and capital investment. Of no minor consequence is the desirability of local plants as an on-site market presence (visible and visitable). These plants often satisfy government telecommunication equipment requirements as to locally manufactured content, and better couple with specialized technical requirements of the area (e.g., the PAL and SECAM tv systems in Europe).

Vertical integration is a significant force.

Japan is rapidly building production for large-scale-integrated circuits to support its growing computer industry. The Japanese learned from their experience in the calculator market, where our integrated-circuit superiority allowed U.S. manufacturers to reverse a trend and to vertically integrate, as shown at the top of Fig. 8. The Japanese have a large stake in watches and are trying to avoid a repetition of the calculator example.

Strong efforts are also underway by European and Japanese manufacturers, who are generally highly vertically integrated, to actively compete in the U.S. market. The recent acquisitions of Signetics by Philips and of Dickson by Siemens and expanding Japanese exports (extending beyond their traditional consumer emphasis into LSI devices for computers) are examples.

U.S. semiconductor vertical integration into new equipment with a high solid-state content, as shown in Fig. 9, is both cause and effect of this activity by foreign manufacturers. In Europe and Japan, today's indigenous volume semiconductor producers were also the established electrical/electronic giants and principal vacuum-tube suppliers.

Essentially few of these have made aggressive forays into games, watches, and calculators, but they have actively applied ICs and transistors to other consumer entertainment products ahead of U.S. companies. Broadly, their semiconductor and equipment operations appear the more interactively coupled, resulting in balanced product design trade-offs on cost and reliability, as contrasted to the separation that exists in the application of semiconductors to entertainment products in the U.S.

The vertical integration thrust by U.S. semiconductor manufacturers into new end-equipment is stimulated by the

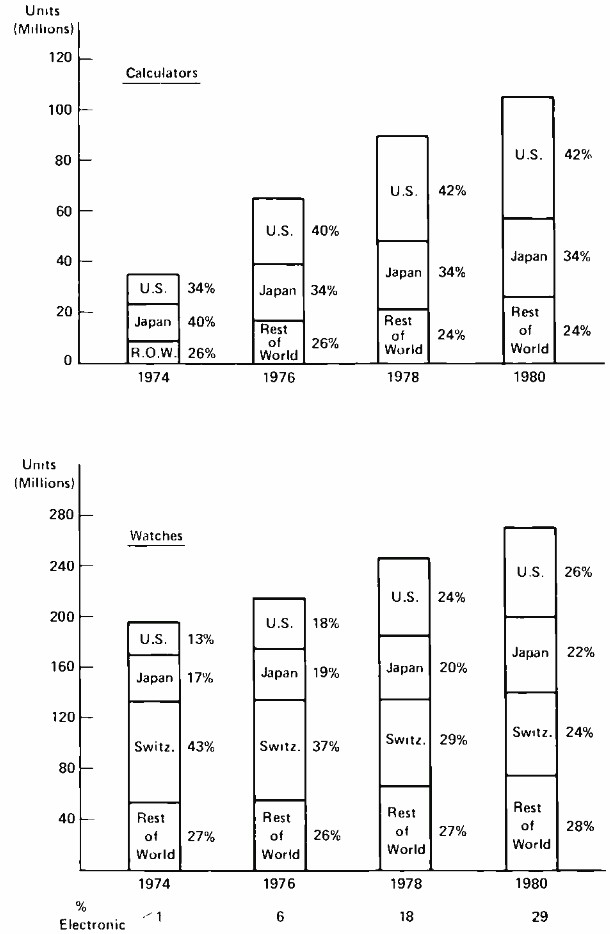

Fig. 8
Calculator and watch production by manufacturers' country of origin.

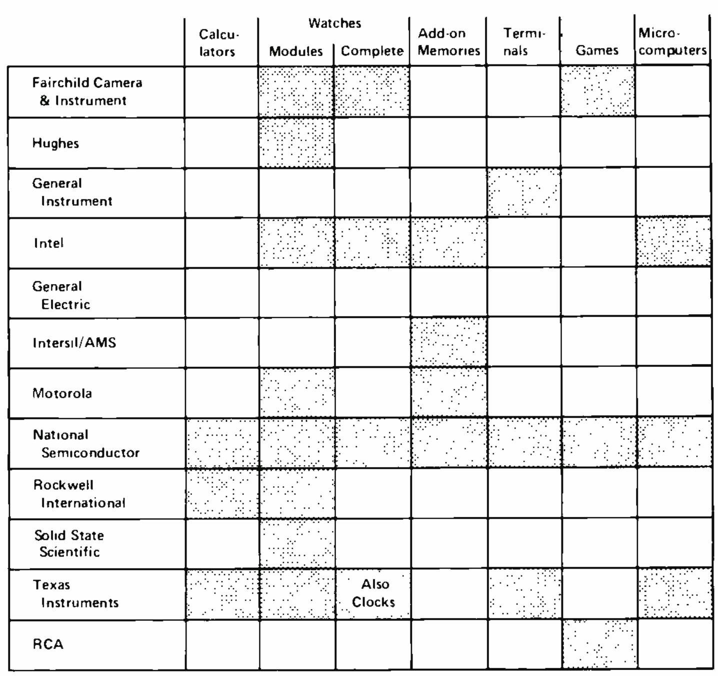

Fig. 9
Vertical integration into new equipment (1976) in the U.S. semiconductor industry.

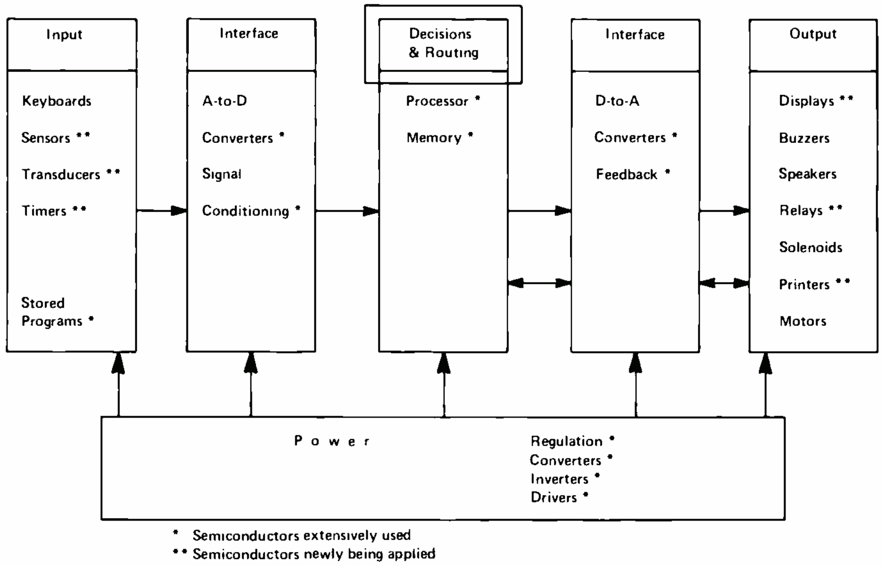

Fig. 10
Key elements of applications of semiconductor technology. Items marked with an asterisk are now dependent on semiconductor-based circuit technology, and those with a double asterisk have begun to see the inroads of new semiconductor approaches.

increasing semiconductor contribution to product cost and a desire to diversify into less-capital-intense counter-cyclical markets. The results so far have been more successful in regard to volume than profit. Classic problems in retail distribution, service, styling, and a host of other areas were often too lightly considered. Games and watches are the latest battleground. These new consumer items can turn into multimillion-unit markets overnight, with a demand skew of 60% of annual volume compacted into the three-month pre-Christmas season. Vertical integration from a semiconductor base has its dedicated practitioners, with scars and dropouts fairly common.

The other side of the vertical integration trend has to do with dedicated semiconductor plants, which do not sell in the merchant market. In 1976, 11% of total consumption was supplied by dedicated facilities. IBM and Western Electric are long-standing examples, but some large computer manufacturers such as DEC, NCR, and Burroughs have become active in providing a small portion of their LSI logic and memory circuits. While this trend will continue at a modest pace (dedicated supply is estimated to be 13.5% in 1981), it is not feasible for a significant number of equipment manufacturers to do more than establish a limited capability in the face of the breadth of technology required. Even large producers such as IBM and Western Electric procure large portions of their semiconductor requirements from outside sources. Alternate-source arrangements are a recent development between semiconductor suppliers and equipment manfuacturers where process technology is transferred to semiconductor users.

Applications—the future

A host of new electronic servants made possible by advances in semiconductor technology are continuing to offer significant advancements in the way we perform our business tasks and are now beginning to impact the home environment. Fig. 10 shows the fundamental elements of many of these systems.

A key function is decisions and routing, realized by using a microprocessor set (which essentially allows the equipment manufacturer to take very dense groups of active elements on a very few chips of silicon and, through software, customize interaction or interconnection).

A growing amount of memory is required for storing instructions and creating files. It is the high-speed recall of data through low-cost semiconductor memory which provides the linch-pin of these new systems. Also critical is the ready availability of combinations of low-cost linear and digital functions (recently available on one silicon chip) for interfacing these files and data processors with the outside world.

Assessments

Semiconductor management requires the solution of an unusual set of simultaneous equations. Windows into markets are narrowing, while demand magnitude and build rate are increasing rapidly. The minimum set of skills and the capital equipment required to design and manufacture new semiconductors such as very-large-scale integrated circuits are increasing (e.g., the addition of software capability as well as coping with extremely minute tolerances).

Enormous new markets for semiconductors and the products they make possible will be a continuum, and profit opportunities for the flexible and the excellent will be significant. Multinational product rationalization and market participation are growing in importance.

Policy decisions on vertical integration, both downward and upward, need to be studied carefully and promptly resolved by semiconductor manufacturers and also by some of their major customers. The rewards will go to those who manage the accelerated decision-making and execution required.

FUTURE SHOCK in electronics

Rapid developments in semiconductor technology also mean rapid obsolescence. Engineers must anticipate technology trends at least five to ten years into the future of their designs.

D. Shore

We live in an exciting era of geometric growth in technological capability. Servan Schreiber, in *The Challenge of America,* pointed out the ever-decreasing time span from scientific invention until manufacture of product. The time lag was 112 years for photography, 56 years for the telephone, 35 years for radio, 15 years for radar, 12 years for television, 6 years for the atomic bomb, 5 years for the transistor, and 3 years for the integrated circuit.

NASA described this revolution at the 1977 AIAA Washington meeting as a 100-fold increase in semiconductor functional density every decade while the cost per function declines by a factor of 10. We have seen the cost of scientific pocket calculators decrease by 20 to 1 and digital watches by 30 to 1 in less than five years.

David Shore is Division Vice President of Advanced Programs Development for the Government Systems Division. This group is responsible for anticipating the needs of, and developing conceptual systems for, the Department of Defense, NASA, and other governmental agencies.

Contact him at:
Government Systems Div.
Moorestown, N.J.
Ext. PM-2507

Consequences of the solid-state revolution

But the other dimension of this revolution is just emerging—the rapid obsolescence of semiconductor devices and the grave consequences to the support of military equipment.

For example, one of the major programs at the Government Systems Division is now moving into the production phase. A key signal processor for the program was designed five years ago using standard T^2L devices available from multiple sources. On going back to the vendors for production quotes, we were informed they had decided to stop producing those T^2L devices. Competition had eliminated profitable sales, and the devices had been superseded by more cost-effective LSI. While this problem was eventually solved, a clear danger exists that similar problems will be a way of life. Obsolescence may well become the most important aspect in the design of defense equipment.

The normal gestation period of a commercial product of modest technology is 36 months. Defense products, however, take 8 to 10 years from initial concept to the delivery of production units to the military user. Unless extraordinary efforts are taken, this time lag means that many products will be fielded with solid-state devices that are no longer in production. The military-equipment development cycle takes, perhaps, twice as long as a new LSI device will be in production.

But that is only a part of the defense-product problem. Operation and maintenance already cost more than the original cost of producing the equipment. The military expects to use their weapons and equipment for 10 to 20 years. How will they do it when the electronic components will have been out of production for many years?

Before addressing what we must do, it would be good to review some solid-state technology trends in more detail.

Life cycle of a semiconductor technology

Fig. 1 shows a road map of semiconductor technology proliferation during the past two decades. Each of these technologies developed into a production phase and was designed into systems. The oldest technologies have long since disappeared at great cost in system redesign. Fig. 2

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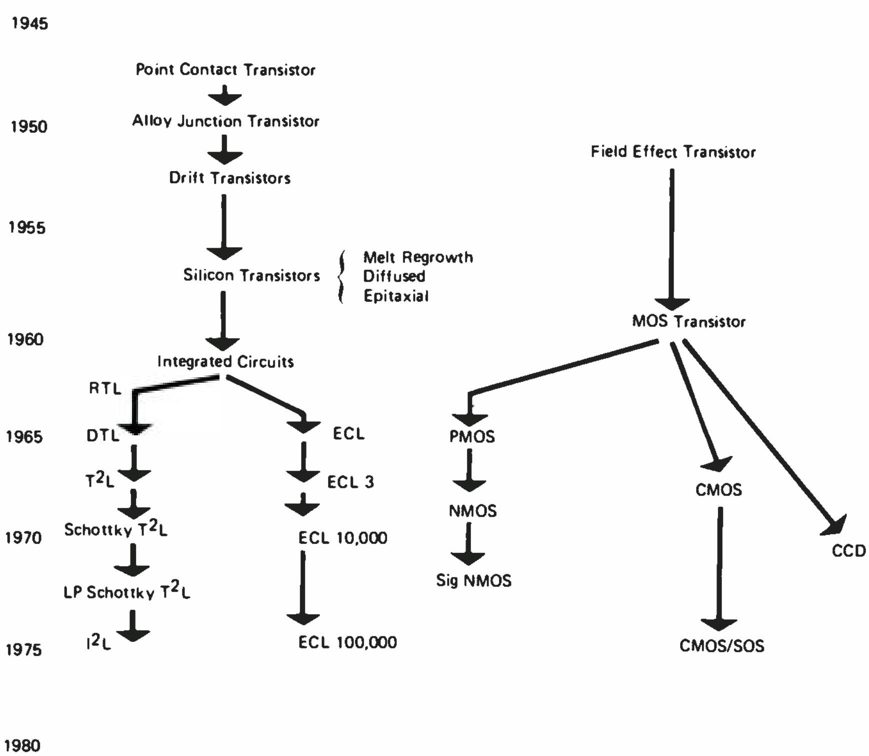

Fig. 1
Each advance in semiconductor technology pushes the earlier technologies toward obsolescence. Expensive system redesigns must take place as products are phased out of the marketplace.

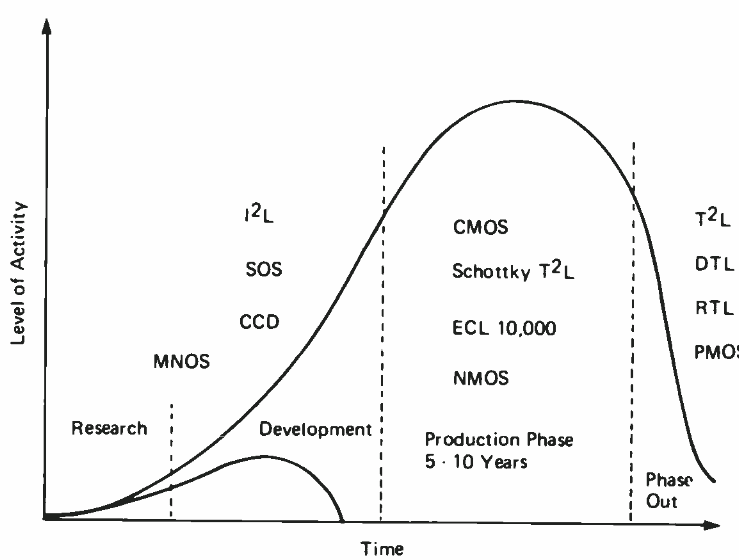

Fig. 2
Life of a semiconductor technology fits into three phases—development, production, and phase-out. Figure shows where technologies stand today, but military systems designers need to know where technologies will be as much as ten years in the future.

shows the typical evolution of each of these semiconductor technologies. The research phase begins in a laboratory, such as RCA's Solid State Technology Center, with just a few people working intensively in a narrow area. During the development phase, second sources are developed, process and design rules are standardized, and production equipment for that technology evolves. The production phase, which may last up to 10 years (but recent trends are for shorter life), involves vast facility investments, large labor forces, and a highly competitive marketplace. New technology makes the older production techniques and even the older technology obsolete. In a shrinking marketplace the old technology is often subject to suicidal pricing wars, drowns in a sea of red ink, and is phased out of production. Fig. 2 shows the key candidates for the production phase in the next few years, the production-phase occupants of the moment, and the has-beens, which are increasingly difficult to procure.

Superimposed upon this evolution into new technologies are the shifts that occur within a single technology (Fig. 3). The cost per gate for an integrated circuit has a minimum point, which is determined by the yield capability of that technology in building large chips. This minimum point moves downward by better than a factor of ten during the lifetime of any one technology as yields improve. An IC design that is optimum at the beginning of a technology's production phase will not be cost-effective by the time that technology reaches its full capability. If we wish to make the optimum use of a technology, we must design chips larger than those that are most cost-effective during the design phase so that when we come to the production phase we are near the minimum cost.

What can the designer do?

Let's review some of the key aspects of this technology evolution as it affects military systems design. The evolution of semiconductor technology is driven by economics and results in lower cost. We need to hitch the military systems wagon to that cost-reduction driving force.

The evolution of new technology and the improvement in functions per dollar seem likely to continue steadily. To build military equipment we need reliable parts, and reliable parts are available during the production phase when the technology is well-understood and the process well-controlled.

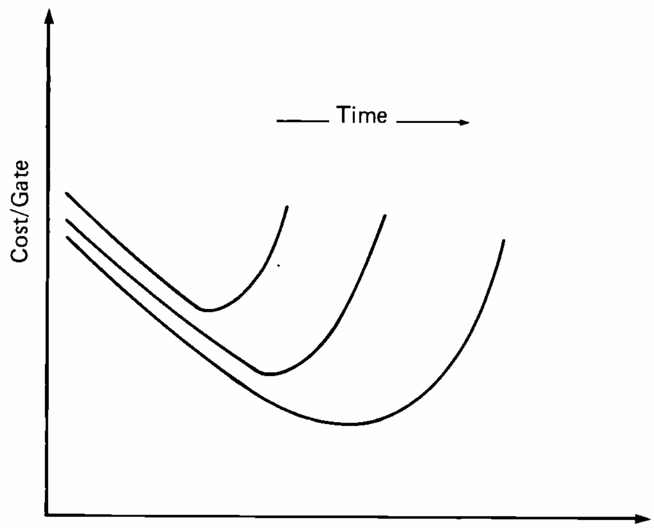

Fig. 3
Cost per gate for a given technology has a minimum value at any point in time. This minimum level improves with time and may change by a factor of 10 as yields improve. Engineers wishing to make optimum use of a technology must therefore design chips that are "ahead of their time" in chip size. At the same time, they can't anticipate too far.

The engineers making the technology choices involved in equipment design must take the evolution of semiconductor technology into account. If we are to make the optimum choice, we need to lead this moving target. Equipment may be subject to long delays in the development phase before committing it to production. Such delays may well result in equipment using technology that has become obsolete. Obsolete technologies are expensive, and redesign may be required. Realistic planning for system production requires that new systems should use new technology. Of course, there is a risk in reaching out too far. Some new devices never make it. The new device should have, at least, been made in quantity adequate for characterization.

The RCA designer is fortunate to have a number of information sources to guide his decisions on semiconductor technology. In the Government Systems Division, for example, Jack Hilibrand of the Government Engineering staff keeps in close touch with this changing situation.[1] RCA Laboratories' Solid State Technology Center is not only a source for advice, but of special LSI as well, and the Solid State Division can indicate their long-range plans for devices they supply.

Equipment-production planning needs to fit into a five-year semiconductor production cycle. During that production period we need to order our spare parts; they may not be available later on. Semiconductor parts are reliable—a modest level of spares should accommodate almost all the part types. Those parts that are unreliable, where the spares are exhausted, need redesign and should get it. Indeed, business opportunities already exist for new-technology replacements of operational-equipment parts no longer available. (See the article by Higbee, this issue.) Our government customer is becoming aware of his problem, but will need advice from industry on how to solve it best.

Older equipment cannot be kept in production indefinitely, since the semiconductor parts from which it is built will become unavailable. We need to deal with this by upgrading these older systems to provide the advantages in performance, size, and maintainability offered by current technology.

Fortunately, the time and cost to custom-design and fabricate a new LSI device has been reduced through design automation. You can start with the logic of the no-longer-procurable component and generate a new set of masks with the latest device technology in days. The masks can then be used in quick-reaction facilities to produce the new devices with the desired quantity, reliability, and performance. This can be done in a few weeks.

Again, the RCA engineer is fortunate in having an extensive design-automation library of tools available in his own organization and in SSTC.[2] He should avail himself of these tools at an early stage in his design.

Should you use commercial devices—a great-sounding strategy for low cost—remember that the vendor is driven by his commercial customers' needs for millions of devices. Here obsolescence is a matter of months, not years.

Avoid such components or make sure that all the parts needed to last the full inventory life are purchased. The government customer may find it difficult to fund for, store, and then supply such devices.

Captive lines have been proposed to keep obsolete technology available. With such facilities, it's hard to know who is the captive. Such a line is a white elephant, providing expensive parts whose reliability heritage may well have decayed along with the production volume in that technology.

I should also point out that programmable systems based on microprocessors, for which updating software can be written, will be no more free from problems with the evolution of technology than any other subsystem. The hardware will be superseded by faster, more-reliable microprocessors and memories. The firmware and the software will be subject to replacement for improved speed and more complex functions.

In conclusion, we can live with "future shock" in electronics. We must recognize it is here, plan how best to enjoy the fruits of technical progress while minimizing its dislocations, and make fullest use of the skills and facilities available to us in RCA.

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1. Hilibrand, J.; "LSI technology choices," *this issue.*
2. *What is design automation?* Available from your RCA library or from SSTC, this brochure lists CAD programs available to RCA engineers, along with contact information.

LSI technology choices

J. Hilibrand

Large Scale Integration (LSI) is giving way to Very Large Scale Integration (VLSI). What are the qualified LSI/VLSI technologies of today and which ones will be the VLSI technologies of the future?

Digital systems are being built using increasingly larger pieces of silicon with more and more logic on each chip. The 100 gates/chip of LSI is being replaced by the 1000 gates/chip of VLSI. As this evolution progresses, it is important for the designer to understand the advantages and disadvantages of the various LSI/VLSI technologies.

The criteria for success as an LSI technology are simple:

High yield—Failure of any one of the devices on a chip will cause a defective chip. This compounds device yields, so there must be a potential for perfect results from production processes.

High packing density—It is necessary to build very small drive and load devices.

Good interconnection capability—The interconnection net for random logic is complex, requiring multiple crossovers and closely packed signal buses.

Low power dissipation—Since a great many devices must appear on each LSI chip, and since the practical dissipation capability of a single chip is between 1/2 watt and 1 watt, the elemental power dissipation level must be significantly under a milliwatt. The lower the dissipation, the lower the operating temperature, which in turn gives better device reliability and performance margins.

These four basic criteria must be supplemented by good on-chip noise immunity and the ability to drive circuits on the next chip in the system.

A limited number of technologies qualify (see Table I). Of these, only I^2L is available in the bipolar technology and the verdict is not yet in on several of the criteria (yield and interconnection capability among them). Some MOS technologies have qualified, but only silicon gate (SiG) NMOS, and CMOS are in contention currently. NMOS now dominates in the LSI memory and microprocessor markets, but CMOS has grown steadily since its introduction by RCA in 1967, and is increasingly dominant as the LSI technology for random logic. The following paragraphs compare the advantages and limitations of these technologies and examine their potential for extension into VLSI.

Yield potential is the fundamental criterion for any LSI technology.

MOS devices enjoy a basic advantage over bipolar devices in that their structure has no equivalent to the bipolar devices' submicron spacing between the emitter and collector junctions. This tight spacing results in device failure from small-diameter diffused regions (pipes) that short between the emitter and collector regions. Also, MOS devices use fewer high-temperature process steps that can cause structural degradation. SOS devices benefit further from their very small p-n junction areas. The well and substrate junctions are dielectric/semiconductor interfaces and are free from defect problems. SOS, C^2L, and NMOS benefit from the self-aligned silicon gate structure, which minimizes the impact of slight misalignments of successive mask levels. In the future, significant improvements in the SOS material system can be expected (e.g., improved substrate polishing and epitaxial layer deposition), which should reduce the defect level in the active silicon layer.

Packing density is a function of the design rules acceptable in a production environment.

For all the candidate technologies in a modern production facility, the critical dimensions are typically 0.3-mil metal line widths, 0.3-mil metal line spacing and 0.2- to 0.3-mil polysilicon line widths. I^2L technology has the advantage of the smallest basic logic element (a single emitter/collector region adjacent to an injector rail), giving it a significant area advantage in simple logic functions. This is the "micro" packing density referred to in Table I.

Interconnection can be a limiting factor.

In designing an entire chip of logic, I^2L has the disadvantage of very limited interconnection capability, since only a single level of metal interconnect is generally available. I^2L chips are, therefore, dominated by metal interconnect area and are larger than would be expected from the very small elementary cell area. This is the "macro" packing density of Table I. Technologies such as CMOS/C^2L have 2.5 levels of interconnection. These levels consist of aluminum metallization, polysilicon gates, and diffused tunnels. Since the diffused tunnels and polysilicon regions must be limited in length to prevent excessive voltage drop, they give less than a full level of interconnection. While crossunders are also available in the I^2L technology, the high current flow on I^2L chips and the limited noise immunity make the use of such conducting paths very risky. As a result, only 1/4 of a level of interconnection is allowed in Table I. Some I^2L vendors use two levels of metallization to provide interconnection, but this process is generally regarded as a potential reliability hazard and significantly increases the process complexity. MOS technologies can use diffused "tunnel" regions and polysilicon layers for interconnection because the small current flow in the devices results in

Table I
Success criteria—how the technologies fare.

	CMOS Al gate	*CMOS C^2L***	*CMOS SOS*	*SiG NMOS*	*I^2L**
Process simplicity (10 = simplest)	4	7	6	8	3
Number of masks	6	5	7	5	7
Speed (propagation delay on chip)	30 ns	10 ns	3 ns	15 ns	15 ns
Packing density					
Micro (10 = densest)	1	3	5	6	8
Macro (10 = densest)	1	2.5	4	4	3
Levels of interconnection	2	2.5	2.5	2.5	1.25
Yield potential (10 = best)	4	5	8	6	3
Cost/wafer (10 = lowest cost)	8	10	4***	10	7

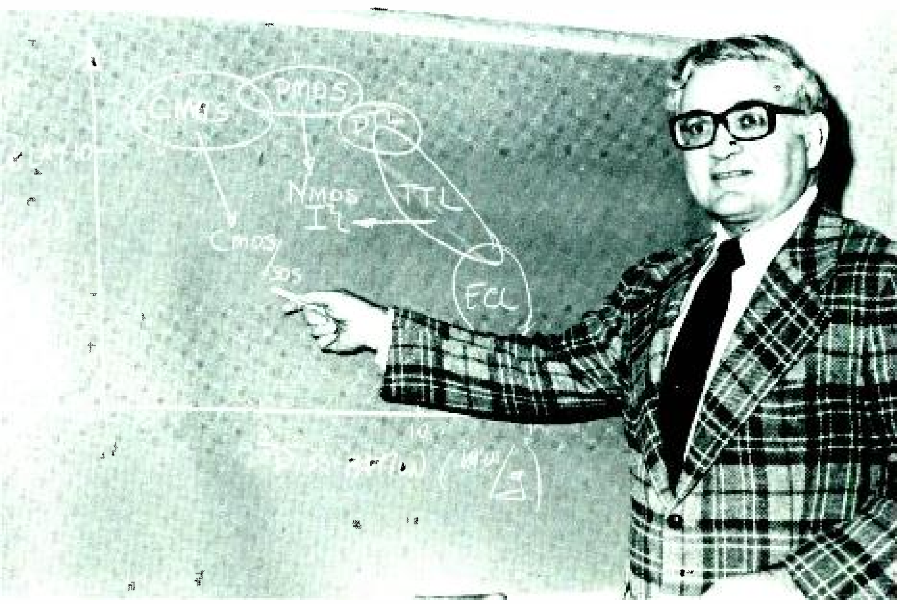
*Three generations of I^2L technology exist, ranging from the original simple four-mask process to a complex, multilevel-metallized dielectrically-isolated process. The numbers in this chart reflect moderately complex "second generation" I^2L with T^2L buffer circuits at the outputs.

**See insert on C^2L technology.

***Intensive efforts at RCA to reduce CMOS/SOS cost per wafer are likely to result in improvements leading to a 10 rating in the early 1980s.

Jack Hilibrand joined RCA Laboratories in 1956 and was involved with the development of various semiconductor devices until 1961, when he joined what is now the Solid State Division and played a key role in developing the RCA COS/MOS integrated circuit line. Since 1971, he has been responsible for planning and coordinating monolithic LSI development and hybrid circuit activities for the business activities of the RCA Government Systems Division and Commercial Communications Systems Division.

Contact him at:
Government Engineering Staff
Government Systems Division
Moorestown, N.J.
Ext. PM-2696



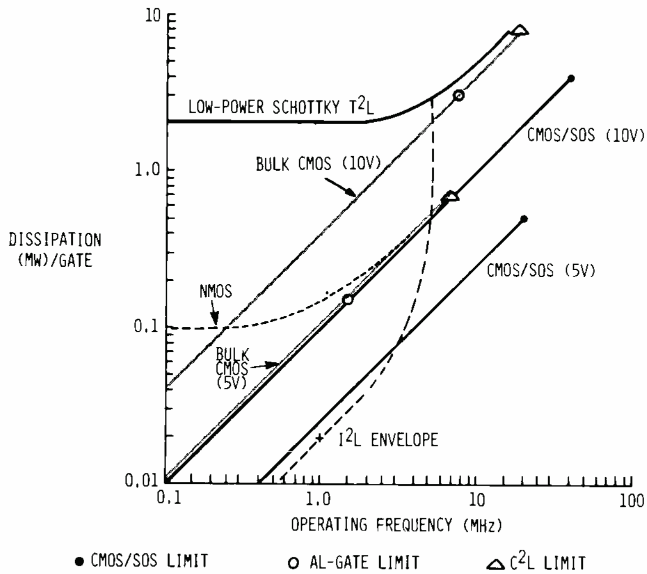


Fig. 1

Power-speed tradeoff differs among technologies. NMOS and low-power Schottky circuits have a quiescent power dissipation plus an incremental dissipation proportional to frequency at higher frequencies. Complementary technologies, such as CMOS, have essentially no quiescent power dissipation, so power is directly proportional to operating frequency.

negligible voltage drops. Some currently-used 4k RAMs and almost all 16k RAMs have two polysilicon layers and one metal level.

Power dissipation is the ultimate limitation on the number of logic functions that can be performed on a single chip.

For the various LSI technologies, this limitation occurs at different levels of complexity. Fig. 1 shows operating power dissipation per gate as a function of frequency for several technologies. The critical parameters are the voltage swing and the current drive required to charge capacitors at the desired speeds. I^2L benefits from its small voltage swing and slow speeds, although the p-n junction depletion and diffusion capacitances to be driven are relatively high.

In most technologies (see Fig. 1) the power dissipation consists of a significant quiescent value plus, at high frequencies, an incremental value proportional to frequency. In low-power Schottky T^2L circuits, for example, the quiescent power dissipation dominates below 1 MHz. Complementary ICs (as in CMOS), on the other hand, have virtually no quiescent power dissipation (except for nanowatts from junction leakage). Fig. 1 clarifies some confusing aspects of the power-speed tradeoff as it occurs in the various technologies. The curve for CMOS/SOS operated at 5 V shows that the power dissipation per gate on a chip is directly proportional to the frequency of operation. Gates that are not switched do not dissipate power because of the complementary configuration basic to CMOS logic. In a memory, only a very small percentage of the circuits on the chip function at any one time, while at the opposite end of the spectrum, all of the logic in a shift register switches at the clocking speed. In a typical digital system, between one and ten percent of the gates are operating at any one time. As a result, the power dissipation shown for CMOS must be adjusted by an application-sensitive factor of between 0.01 and 1.0.

The other curves for CMOS are interpreted similarly, with the end point on the curve reflecting the maximum operating frequency for the designated logic technology. The NMOS and Schottky T^2L curves reflect the fact that there is a steady-state current flow in each logic gate, so significant power is dissipated even when the gate is not switching. This appreciable quiescent power dissipation limits the level of LSI that can be achieved with these technologies.

In I^2L circuits, power dissipation can be traded for speed by decreasing the current in the injector rail and accepting a slower charging time for the junction capacitances. The I^2L curve shown is an *envelope* of the end points of curves of the T^2L form. To operate at 1 MHz, for example, the power dissipation is set to 20 microwatts/gate and all the gates in the circuit operate at this dissipation, independently of how active they are or at what speed they are actually operating.

In complementary circuits, the low quiescent power dissipation results from the complementary device structure. In T^2L, I^2L, and NMOS circuits, low quiescent power must be paid for in terms of slower speed capability, or by elaborate power-supply clocking schemes to turn off sections of the system that are not in use. In most large systems, therefore, CMOS technology offers major power dissipation advantages at the LSI and VLSI levels.

Future trends

The most significant new technological factors will be electron-beam exposure systems and reoxidation techniques.

Finer resolution capability favors MOS device technologies, since they can be scaled down in both voltage and current. For lower-voltage operation, the oxide layer insulating the gate from the conducting channel in the semiconductor body can be thinner. Thinner oxide layers permit higher speed operation. This finer-geometry benefit is not as applicable to bipolar devices because a forward-biased p-n junction requires a fixed voltage swing at the level presently used in I^2L circuits.

Oxide-isolation techniques will enhance all the technologies, since the planar surface will permit the narrower lines and spaces achieveable with electron-beam exposure to be used without introducing reliability hazards at oxide steps. These techniques offer a substantial advantage in device capacitance (and device speed) for SOS, wherein the sides of the device island, as well as its bottom, will be isolated.

Electron-beam techniques are likely to be applied first to improved masking (fewer defects and better registration will permit larger chips) and later to wafer processing. By combining ion implantation and low-temperature annealing steps with very small electron-beam-defined structures, it should be possible to gain a factor of three to ten in dimensional control. This major step toward reduced device size is likely to be the key technological item exploited in the VLSI technologies of the 1980s.

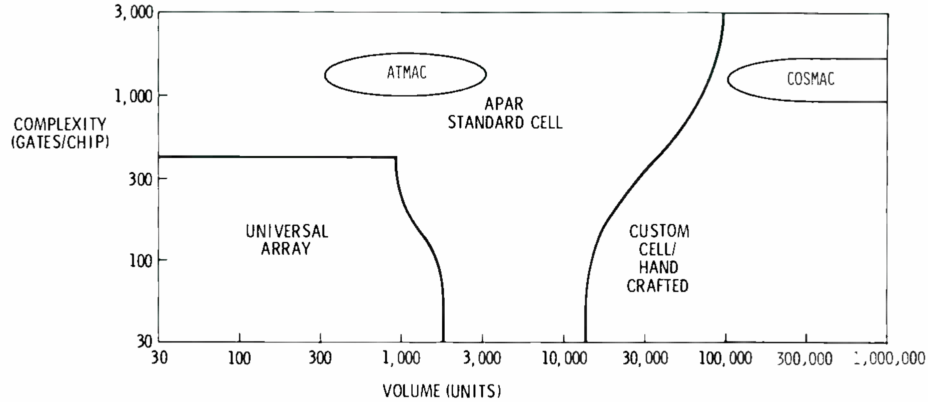


Fig. 2
The best design tool depends on manufacturing volume and chip complexity.

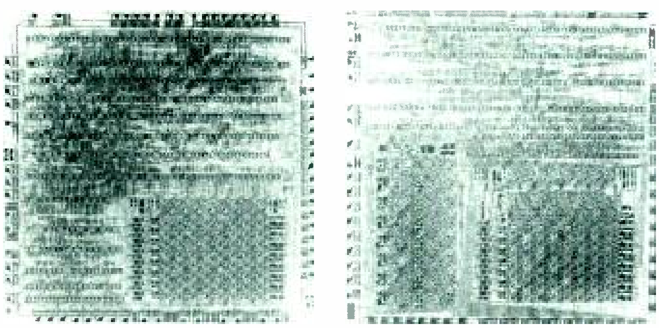


Fig. 3
ATMAC microprocessor is typical of the VLSI chips possible with design automation techniques.

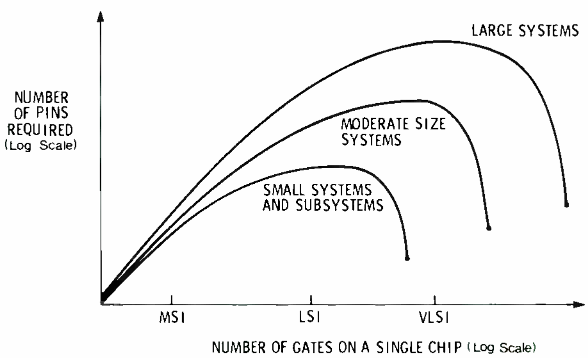


Fig. 4
Pin count per chip is often a limitation for large systems. With dense packing, an entire system fits on one chip, so only I/O pins are needed and it is possible to keep the pin count low.

Design tools for LSI systems

In applying LSI technologies to military systems of modest unit volume, the engineer needs design tools to enable him to lay out, build, and test his circuits. Such design tools exist for the CMOS technologies.[1,2,3] They include universal arrays, the standard-cell automatic placement and routing (APAR) system, and interactive graphic design systems to permit "manual" optimization of computer-generated chip layouts. Simulation tools are available to bypass the time and cost of breadboarding.

Designs that involve less than 500 gates and low manufacturing volumes (1000 units or less) are best implemented using universal arrays (Fig. 2). Volume requirements between 1000 and 20,000 units ranging over a wide spectrum of complexity can be handled efficiently by the APAR standard cell system. Designs that will be produced in higher volumes are done manually because handcrafting with custom cells can achieve minimum chip size, an important factor for high production quantities because of the substantial impact of chip size on recurring part costs. In highly complex circuits, it is often beneficial to use automatic placement and routing followed by extensive handcrafted optimization.

For most military systems, where the volumes are in the 1000- to 100,000-unit region and chip complexity is greater than 300 gates, APAR is the optimum design technology. This system uses a library of proven logic cells and an efficient layout scheme, MP2D (Multiport Placement, 2 Dimensional), to achieve an optimum tradeoff between small chip size and the nonrecurring design costs involved in achieving a tightly-packed layout. Software supplementing this automatic layout system enables modifications to be made via interactive graphic terminals to optimize layouts or to insert regularly-patterned RAM or ROM supercells into the arrays. Using these techniques, it is possible to build VLSI chips like the two SOS arrays used in the ATMAC microprocessor.[4] Each of these VLSI arrays, 1/4 inch on a side, incorporates over 5000 devices (Fig. 3).

Packaging LSI systems

First-level packaging technology is evolving rapidly under the impact of LSI and VLSI components. The evolution is aimed at providing dense, reliable, and cost-effective interconnection techniques.

The key problem in packaging is the proliferating pin count.

As the total gate count on each chip increases, the number of pins required (Fig. 4) increases almost proportionately. This increase continues up to a chip size that can accommodate a complete system or subsystem. A short time ago, with 100-gate per chip limitations, even very small systems could not be fitted completely on a single chip—they had to be partitioned and a large number of pins were required for logic interconnections. With functional partitioning, only I/O pins are required and the pin count can be kept in the 20-40 range. VLSI technology permits single-chip accommodation of a range of small- and moderate-sized systems. High pin count remains a limitation, however, for large systems.

Leadless hermetic packages allow large systems to be placed on a single ceramic substrate.

The fan-out of leads from chip bond pads on ten-mil centers to the 100-mil spacing of the dual-in-line packages constitutes an increasingly unsatisfactory solution for the package with forty pins and more. The poor area efficiency of such dual-in-line packages is shown in Table II (there is a 36:1 ratio between the chip area and the package area). Because of this inefficiency, the use of leadless hermetic packages (Fig. 5) attached to multilayer ceramic substrates is increasing. With this packaging approach, moderate- to large-size systems (5000 - 20,000 gates) can be put on a single ceramic substrate. The individual leadless hermetic packages provide screenable, testable, hermetic housings for chips with up to 64 pins. They are reflow soldered to the thermal-expansion-matched ceramic substrate. The footprint area of this package (the area it occupies on the interconnecting substrate) is typically four times the chip footprint (see Table II). The complex multilevel interconnection matrix for the ceramic substrate can be designed using automatic routing techniques.

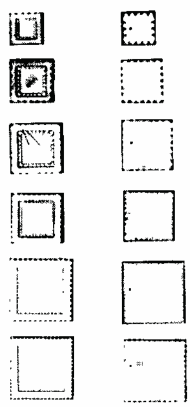
Going beyond the high-density leadless package approach, an active effort is now underway to make hermetic chips available in each of the VLSI technologies. Hermetic chips (which have been used for many years by both IBM and Western Electric) can be mounted on a ceramic substrate and given mechanical and moisture protection. Their use will achieve an overall packing density that will permit large systems (up to 100,000 gates) to be placed on a single ceramic substrate.

Technology obsolescence

One of the critical considerations in selecting a technology for military systems is the rapid rate of technological change in the semiconductor industry. (See "Future shock in electronics," by D. Shore, this issue.) Although military systems are generally designed on a two- to five-year time scale and produced over a five-to- twenty-year period, the evolution of semiconductor technology is driven by the economics of the commercial marketplace and moves much faster. Bipolar technologies such as RTL and DTL have vanished in the past five years, and T^2L is rapidly being replaced by Schottky T^2L. PMOS, in aluminum-gate and silicon-gate versions, is disappearing. Since military-system designs are based on current semiconductor technologies, it is necessary to select, for the design phase, a young technology that may not yet be in the mainstream, but will get there when production quantity parts are needed. The production-semiconductor procurement will be most successful if it coincides with the commercial success of the chosen technology. Even if small quantities of high-rel parts are being bought, the discipline of commercial mass production at the wafer level is critical to cost effectiveness and to a heritage of reliability.

Table II
Packaging variations—putting the same chip in different packages produces substantial variations in size. Comparison is based on an assumed 0.250" x 0.250" chip (0.06 sq. in. area) with 16 pads on each edge (64 pins total).

Format	*Package area (sq. inches)*	*Package/ chip area ratio*	*Lead spacing (inches)*	*Medium*
Dual-in-line pkg. (3/4" x 3")	2.25	36	0.100	PC board
Flat pack (1" X 1")	1.00	16	0.050	PC board
Leadless hermetic carrier	0.25	4	0.030	Hybrid substrate
Chip-and-wire	0.12		0.020	Hybrid substrate
Beam-lead chip	0.07		0.010	Hybrid substrate
Beam-tape chip	0.15		0.020	Hybrid substrate



Package	*Number of leads*	*External size (in.)*	*Cavity size (in.)*
	18	0.250 x 0.250	0.120 x 0.120
	24	0.335 x 0.335	0.185 x 0.185
	28	0.400 x 0.400	0.235 x 0.235
	36	0.400 x 0.400	0.235 x 0.235
	48	0.500 x 0.500	0.300 x 0.300
	64	0.500 x 0.500	0.300 x 0.300

Fig. 5
Leadless hermetic packages make it possible to put 20,000 gates on a single multilayer ceramic substrate.

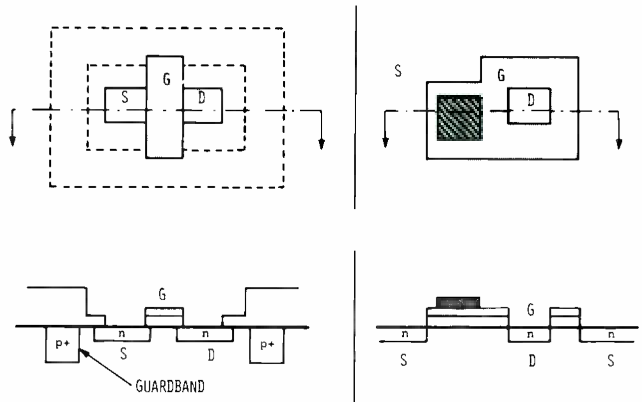
As a chosen technology phases out, a choice is available. If a successor technology with a similar logic structure exists, as with Schottky T^2L or SOS as a replacement for bulk CMOS, a decision can be made to replace parts with equivalent ones in the new technology, or to redesign at the chip level using the low-nonrecurring-cost design vehicles discussed earlier. Alternatively, users can stock both spares and the parts needed for future systems. Given the high reliability of LSI, it is feasible to plan on a limited spares quantity. Specific devices found to be unreliable in system use can be redesigned into current technologies when they are needed.

Multiple sources for new technologies

It is important to have multiple sources available when a system goes into production. However, the availability of multiple sources at the time that initial design decisions are being made is much less important. New technologies are

A quick look at C²L

C²L, or Closed COS/MOS Logic, is an RCA development for improving the packing density and speed of bulk CMOS technology. Topologically, the normal COS/MOS layout has a guard band to prevent sneak conduction paths from source to drain. In the C²L structure, the guard band is replaced by a completely gate-enclosed drain region where no sneak path can exist. Technologically, the metal gate structure is replaced by a self-aligned silicon gate structure. Eliminating the guard band improves packing density by a factor of two. There is also a factor-of-three improvement in speed from the increased active drain periphery (which increases the effective gm/C ratio for the structure) and from the reduced gate/drain overlap in the self-aligned gate structure (which decreases Miller-effect capacitance). While C²L is neither as dense nor as fast as SOS, it significantly bridges the gap from aluminum-gate bulk CMOS to SOS performance.



AL-GATE COS/MOS (WITH GUARDBANDS) | CLOSED COS/MOS LOGIC (C²L)

effectively single-sourced at the point where a military system designer would want to choose them. The multiple-sourcing drive in the RAM and microprocessor marketplaces is oriented more to pin compatibility and functional equivalence than to technology selection. In fact, high-speed static 1k RAMs are now being built (with pin and functional compatibility) using NMOS, SOS, and bipolar technologies.

What is important to the military system designer is that the technology selected must be pervasive, with significant volume in the commercial marketplace. The crux of his problem is the early identification of, and commitment to, that technology. Penetration of the commercial marketplace will both require and result in the yield improvement and accumulated reliability heritage that will lead other companies to enter the field and provide a competitive pricing structure. When production quotations are needed for military systems procurements, this competitive pricing will assure cost effectiveness as long as a mainstream technology has been chosen.

Today's bulk CMOS will be superseded in the next five years. Whether the successor technology will be C²L or SOS, or dielectrically-isolated bulk CMOS *a la* Harris, will be decided in the commercial marketplace based on capability for process and yield optimization. C²L has the advantage of being a simplification of the present bulk CMOS process. The dielectric-isolation approach is a more *complex* way to go and the decision will almost certainly go to C²L. SOS has made significant progress in the past two years toward high-yield processing with ion implantation and silicon gate structures. The key element for SOS will be sapphire-substrate quality improvement and cost reduction. Whether C²L or SOS is favored, there will be second sources within a year after that technology penetrates the commercial marketplace significantly. The two technologies are mask-compatible so that whichever is successful, it can be used in a previously-designed military system.

RCA has dealt internally with the sole-source problem by using both the Solid State Technology Center, where new technologies are made available early for use in military system designs, and the Solid State Division, where these technologies are exploited in the commercial marketplace. Military LSI arrays can be brought to cost-effective high-production levels since there is technological continuity across this SSTC/SSD interface. This system also assures the continued availability of parts from SSTC, even after SSD phases out commercial production in an obsolete technology.

Conclusion

RCA has made a commitment to CMOS technology for the implementation of random-logic LSI. The C²L and SOS structures in CMOS are characterized by optimum capability for extension from LSI to VLSI. Their low power dissipation, high packing density, good interconnectability and, most important, their potential for continued yield improvement make them the leading contenders for large digital systems. Design tools for putting complex systems on chips exist for both C²L and SOS processing, and packaging approaches for maximizing density are being explored.

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Supplying microcircuits for government end-use: risks and benefits

The government microcircuit market involves myriad rules and regulations, complex specifications, and unique operating parameters. The rewards are technology enhancement, product upgrading, an economic buffer, and, if one can put it all together, profit.

J. Handen

In 1977, the DOD and NASA will spend in excess of $100 billion, of which nearly $40 billion will be allocated for procurement and R&D. Out of this $40 billion, between $200 million and $250 million will be spent for high-reliability microcircuits used in a wide variety of equipments and programs, ranging from electronic fuzes for the Army to very sophisticated satellites for NASA and the Air Force. This figure represents 11% to 15% of total domestic microcircuit sales, which are projected at $1.7 billion.

While the annual budget of the DOD and NASA has remained relatively stable during the 70s, with increases barely keeping up with inflation, the expenditures for advanced hardware using microcircuits have increased dramatically. The impact of the microcircuit or IC is just as significant on military and aerospace systems as it is on consumer and industrial products. The transition from electronic tubes to discrete transistors to simple ICs and now to very complex LSI circuits has broadened the horizons of design and product capability enormously. Since the introduction of the IC in the early 1960s, many generations of microcircuit technology have evolved, providing a vast number of diverse miniature subsystems to stimulate the imagination of the military product designer.

Table I
Life cycle for a typical military program may involve five years of work before production begins. This hypothetical example assumes that high-reliability microcircuits are supplied throughout the program, from engineering prototypes to full production. Other programs may take more or less time in each of the stages.

Phase	*Cumulative time (months)*	*Description*
Recognizing need	0	The sponsoring agency determines that a need exists and solicits proposals.
Proposal for development	6	Several contractors develop proposals for the system.
Engineering development	12	The winning contractor receives the development contract.
Engineering prototype	24	If the design appears sound, a prototype is constructed.
Bids for limited production	30	If the prototype meets requirements, the agency may decide to start limited production and solicit bids for this phase.
Limited production	42	The winning contractor tools up for limited production. Various subcontractors may participate.
Bids for full production	48	If the need still exists and funding is obtained for the program, the agency solicits bids for full production for a specified period.
Full production	60	The winning contractor tools up for full production. He will subcontract various subsystems.

As microcircuit technology has advanced, the role of the supplier has changed from that of a simple component vendor to that of a design partner. The LSI chips now available are complete subsystems. As a result, the component supplier has become the subsystem designer, and the role of the system designer is to evolve new concepts and products making use of the sophisticated microcircuits available.

Overview of the environment

Government agencies procure hardware and services through a number of prime contractors who, in turn, ripple funds down to a vast number of second-, third-, and lower-tier subcontractors. A semiconductor supplier sells products to all levels in this hierarchy, since semiconductors (and microcircuits in particular) are the foundation for all advanced electronic equipments.

The life cycle of a typical military program can be compared to the journey of Ulysses, a long and tedious escapade fraught with many risks, dangers, and uncertainties.

A typical program (Table I) starts when a government agency decides there is a need. The first phase is to solicit engineering development proposals from several contractors, one of which will win the award. The winning contractor designs the system and generally issues specifications for the subsystems and components required, using the guidelines established by the agency. The engineering development phase ends when the engineering prototype is delivered and meets the requirements for function and reliability.

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In-house documentation required	In-house records required	Program plan required
Conversion of customer's requirements into manufacturer's internal instructions	Personnel training and testing	Functional block organization chart
Personnel training and testing	Inspection operations	Manufacturing flow chart
Inspection of incoming materials, utilities, and work in process	Failure reports and analyses	Proprietary-document listing
Quality-control operations	Changes in design, materials, or processing	Examples of design, material, equipment, and processing instructions
Quality-assurance operations	Equipment calibrations	Examples of records
Design, processing, tool, and materials standards and instructions	Process utility and material controls	Examples of design, material, and process change control documents
Cleanliness and atmospheres in work areas	Product lot identification	Examples of failure and defect analysis and feedback documents
Design, material, and process change control		Examples of corrective action and evaluation documents
Tool and test equipment maintenance and calibration		
Failure and defect analysis and data feedback		
Corrective action and evaluation		
Incoming, in-process, and outgoing inventory control		

Table II
Plant certification under MIL-M-38510 is stringent; table lists requirements that must be met before certification is given. Compliance with these provisions involves considerable effort and expense. RCA's Solid State Division plant in Findlay, Ohio has been certified since 1973.

At this point the program may be aborted or may continue to the limited-production phase, depending upon the vicissitudes of the decision-makers. If the program is to continue, bids are solicited for this phase. While the contractor who did the engineering development frequently wins the limited-production contract, this is not always the case.

The full-production phase is subject to the most risk because of the high funding level it may require. At this point, political as well as practical variables exert influence. If funding is appropriated, production bids are solicited as with the limited-production phase. However, the stakes are much higher, and so is the intense competition among bidders. The winning contractor must outbid his adversaries and still see a way to realize a profit. The company that designed the system and supplied the limited production hardware frequently loses out at this point because of the competitiveness among contractors fighting for the high-dollar production phase.

During the entire life cycle, the semiconductor supplier provides support to both the winners and the losers. Many successful contractors rely on the component suppliers for the technical guidance, component availability, and component pricing needed to develop winning bids.

Everyone realizes that reliability of components is absolutely essential for the successful functioning of critical electronic systems.

The government has sponsored much of the work in the field of reliability, both in terms of the mathematical theory and in the empirical work leading to the development of microelectronic screening procedures that weed out unreliable devices. Such effort led to development and issuance of standard procurement specifications. The value of these specifications and the benefits derived from them are no longer questioned. It will suffice to say that without them the success of the U.S. space programs and the leadership the U.S. enjoys in sophisticated defense weaponry would not be a reality today.

The basic specifications controlling governmental microcircuit procurements are MIL-STD-883 and MIL-M-38510. Both were developed by the Rome Air Development Center (RADC), and represent a remarkable achievement, considering the large number of diverse opinions and attitudes among the agencies, users, and suppliers. While many consider these specifications as alternatives, they really complement each other.

MIL-STD-883 is a test methods and procedure specification. It defines:

- three reliability classes (A, B, and C)
- screening requirements for each reliability class
- screening methods and procedures
- product performance tests, called *Conformance Tests*

MIL-M-38510 is a complete standard for microelectronic devices. It incorporates MIL-STD-883 where applicable; but, in addition:

- requires plant certifications
- incorporates specific electrical test specifications called "slash sheets"
- provides for standard device nomenclature
- requires device qualifications
- incorporates a QPL (Qualified Parts List) for qualified devices (identified as JAN38510 types)

Table II lists the extra documentation that MIL-M-38510 imposes on the microcircuit manufacturer. This standard represented a key milestone in the government microcircuit specification system. When a user orders JAN38510 devices from a qualified source, he can be sure that the electrical performance and high-reliability processing of these circuits fully meet the rigid requirements of a standardized specification. In addition, the government, through the Defense Electronic Supply Center (DESC), has the responsibility to police the system and maintain the Qualified Parts List (QPL). If a supplier fails to meet the demanding requirements for a particular circuit type, the device type will not be listed on the QPL. If a supplier is on the QPL but subsequently cannot meet the requirements for continuation, the particular circuits will be "delisted."

A further advantage to the user who procures qualifed JAN circuits is that he does not have to prepare unique specification control drawings otherwise required by his customer. Also, when he procures JAN38510 qualified parts, the government shares the responsibility for the performance and reliability of components procured under its particular documents. Another important advantage of the JAN38510 approach is that the user can be almost certain of having a source of well qualified types to choose from and need not be concerned that he will be unable to find suppliers willing to bid to his proprietary specifications.

Neither of the MIL specifications is fixed; both are constantly being reviewed and modified to reflect the latest experiences and attitudes of the users. For example, MIL-STD-883 has been modified by four revisions, called "Notices," and subsequently completely revised to MIL-STD-883A, which was further changed by two additional "Notices." All these changes have occurred since the introduction of the specification in 1968.

Both specifications are complex documents that require trained personnel and specialized facilities for their proper implementation. For example, MIL-STD-883 requires the supplier to facilitate for and perform the following screening tests:

- Scanning electron microscopy (SEM) inspections
- Critical visual inspections
- Temperature cycling
- Fine and gross leak checks
- Centrifuge
- Burn-in at elevated temperature
- X-ray analysis
- Electrical parameter print-out with parameter shift control
- High- and low-temperature testing

This screening adds significant time to the manufacturing process (see Fig. 1). In addition to the above screening, procurement specifications frequently demand both government (DCAS) source inspections and customer source inspections at the manufacturing location. On key procurements, program managers must be assigned to monitor production progress. It can be seen that an extensive investment is required in facilities and trained personnel to participate in this marketplace.

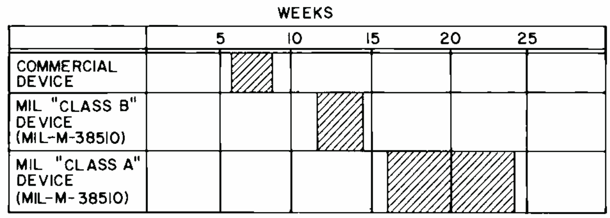


Fig. 1
Manufacturing microcircuits to high-rel specs takes extra time because of the number of screening operations required.

Interfacing with government agencies

Another unique aspect of doing business in the government market is the need for very close relationships between the microcircuit supplier and the agencies who develop the specifications.

A successful supplier must earn the respect and confidence of these government groups by contributing technical support and other inputs needed to develop specifications that everyone will accept. The supplier must attend frequent agency-user-supplier technical and coordination meetings, where issues are highlighted and solutions discussed. If a supplier is cooperative and earnestly aids the agencies and users in meeting their needs and goals, his inputs regarding specifications will be sought and accepted. He then can exert considerable influence to help generate specifications that accurately reflect the capability of the product and optimize reliability, availability, and price. Of course, the key to a supplier's acceptance is still how well he has performed in the past: if he has delivered products to the required specifications in a timely manner his stature among users and agencies is greatly enhanced.

In addition to complex technical and product specifications, the government supplier must understand and adhere to volumes of procurement procedures and regulations.

The primary set of documents is the Armed Services Procurement Regulations, or ASPR (Fig. 2). These documents cover a wide variety of ground from labor practices to accounting and pricing procedures. One of the most significant aspects of these regulations is the requirement that sole-source procurements over $100,000 must be cost/price justified. To comply with this provision of the ASPR, the supplier must make all cost information available to the Defense Contract Audit Agency (DCAA) for thorough review and analysis. For example, the DCAA auditor has the legal right to investigate accounting procedures, expenditures, labor costs, material costs, and processing yields. A supplier must maintain voluminous records in all these areas.

While it is recognized that the ASPR and other regulations are necessary to control procurements and protect the taxpayer from unscrupulous practices and resulting waste, understanding and implementing these regulations can be a costly and taxing effort for microcircuit suppliers that compete primarily in the commercial marketplace, where competition dictates the *modus operandi.*

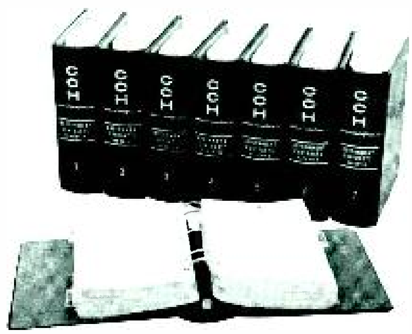


Fig. 2
Government documentation is extensive and complex. This photo of the procurement regulations gives some idea of the volume of material.

The risks

Which government specifications should you implement?

Since specifications are under continuous review, with new and revised documents issued continually, the microelectronic supplier must decide which of them to implement to maximize return. Implementing government specifications can be costly. Capital is needed for specialized processing hardware, and expense dollars are needed to establish systems to comply with the myriad resolutions and procedures. In addition, skilled personnel must be assigned to the effort.

Government specifications are subject to many variables and pressures. As might be expected in such a complex environment, there are many views and approaches on technical issues that are further compounded by political considerations. The supplier must ask himself the following questions:

1) Will customers order to the specifications if implemented? How well are the specs accepted by the industry?

2) How firm are the specifications? Will they be changed or modified before the supplier realizes a satisfactory return on his investment?

3) Will customers be willing to pay the price necessary for the supplier to realize a satisfactory return on his investment?

If a supplier does not gauge the acceptance of the specifications in the marketplace properly, he will commit his resources in the wrong area and will be unable to respond to the actual need.

As the technology evolves and specifications change, the microcircuit supplier faces the serious problem of obsolete inventory.

Inventory that cannot be sold represents a heavy financial burden. Yet, if inventories are not maintained, the supplier cannot be responsive to his customer's needs. The amount of obsolete inventory relates directly to how well the supplier can gauge or influence specification revisions and how well he can forecast actual demand for particular specifications. Even with excellent vision in these two areas, the supplier may still be caught by fundamental changes in technology or the introduction of new microcircuits that obsolete the previous-generation devices.

Good market forecasting is the key to any successful business.

When forecasting is accurate, a supplier will have the proper product at the proper time to meet demand. Conversely, poor forecasting means that a supplier will either not be able to react to needs in a timely fashion or will overspend on unused facilities. In the government area, forecasting can be a challenge. Since the entire business is program-oriented, the supplier must follow discrete programs as they evolve in time and from contractor to contractor. This practice differs from traditional businesses, where certain customers can be expected to order microcircuits on a continual basis. A tv manufacturer continually manufactures tv sets; the only variable is how many. A government contractor orders to his program needs, a rather digital situation in contrast to the linear one typical in the other market areas. Today's key government customer will purchase nothing tomorrow if he does not have a contract.

Thus, the microelectronic supplier must weigh the following variables in projecting product needs:

1) Which programs are likely to be successful?

2) Which contractors are most likely to place the actual orders? When?

3) What specifications are most likely to be used in the procurements?

Often the microelectronic supplier must make decisions without benefit of accurate inputs because neither the government agency nor the actual customer can provide definite information regarding the probability of a program's continuance or the timing of an actual microcircuit buy. Again, a successful supplier must have a "sixth sense" to forecast correctly. In effect, he must second-guess his potential customer, the customer's customer (the agency), and the Congress, which appropriates funds.

Which custom microcircuit programs should get support?

A number of government programs use custom microelectronic circuits to reduce system size or weight or to achieve other advantages. Designing a custom circuit takes considerable technical effort. Most microelectronic suppliers do not have excess technical resources for custom design and must choose wisely among the opportunities. Available resources can be expanded to develop more standard circuits, such as additions to the industry-standard CD4000 CMOS series, or they can be employed in key commercial areas such as television, automotive electronics, or timekeeping. A successful circuit supplier must use his resources to generate product sales; he cannot afford to use them in areas that will not provide such revenue because they are too valuable an asset.

No microcircuit supplier is content simply to recover engineering costs with the modest profit allowed by Government regulations. A circuit designer may spend eight months designing a new standard part that can be added to the company catalog. If the part is selected wisely, continuous sales from this effort will materialize for a decade. Conversely, a custom development for a military program that is aborted early in its life-cycle means that sales will not materialize. The engineering effort expended was, in a commercial sense, poorly used.

The most difficult question a microcircuit supplier must answer is, "Which programs should we support?" To make this decision, he must integrate available information, intelligence, and judgment to pick the right programs. Even when a program is a success, however, it may take several years before full production is reached and the supplier is able to capitalize on years of support and waiting.

The supplier also runs the risk that the program may not be a success. Following the delivery of custom microcircuit prototypes for a government-sponsored system, the supplier may receive any one of the following responses:

1) Design not sound—system aborted or redesigned.
2) Program lacks funding—program delayed or terminated.
3) New contractor on scene—may redesign system.
4) Technological obsolescense—design aborted or modifications required.

Even with successful programs, the time between initial design and production can be so long that the supplier can no longer manufacture devices because the manufacturing processes have changed to keep up with advances in the state-of-the-art. In this case, costly upgrading may be required, which again affects the allocation of the supplier's resources.

A corollary to the previous situation is that government programs frequently need complex custom LSI microcircuits in low volume. In such cases, it is recognized from the start that large-volume production will never materialize. The contractor often has great difficulty getting microelectronic suppliers interested in such business, which can consume considerable technical resources without much product revenue. A few suppliers, such as RCA, provide practical solutions to this problem by offering universal microcircuits (universal gate arrays) that can be tailored to a unique application by minor metallization modifications, and by using computer-generated circuit layout designs (APAR, for example). Both of these techniques are designed to limit the "front-end" engineering cost and reduce lead time. The resulting circuits, while not as cost-effective as high-volume designs on a unit basis, prove to be very cost-effective for low-volume requirements in which the engineering design expense is a significant portion of the total cost. At RCA this effort is performed by a special short-run engineering-oriented facility, the RCA Solid State Technology Center, at Somerville, N.J.

The benefits

The preceding sections may lead one to believe that selling microcircuits to the government end-use market supply does not pay—that the effort required to realize a return on investment is not justified in view of the expense and risks encountered. A number of suppliers have concluded just that and do not participate in the government market. However, many broad-based semiconductor suppliers have chosen to participate because they realize that, if they organize effectively to service this market, they can achieve a reasonable financial return and obtain several second-order benefits, which can be significant. Let's examine these benefits.

Technology advancement—the high performance requirements of many government electronic systems dictate the need for state-of-the-art microcircuits, or circuits with special attributes.

An example of such a need is in the aerospace and missile industry, where components must operate in high-radiation environments. Through government support, special processes were developed to manufacture these devices. Because extensive funding and support frequently are required to develop such products, they would not be possible otherwise, as few, if any, private firms have resources to undertake extensive R&D effort. Once developed, however, many of these special products find application outside the government market. For example, the radiation-hardened microcircuits mentioned above can also be used in commercial satellite programs.

Product upgrading—products meeting the stringent governmental requirements must have high inherent capability and reliability.

Any weakness in the basic design or process will show up immediately in failures to the screening or electrical tests. The successful government supplier must resolve any product deficiencies expeditiously and optimize the design, processing, and packaging for maximum performance and reliability. As a consequence of such discipline, the reliability and performance of the entire product base are upgraded, with the result that commercial-grade devices derive the benefits from these improvements.

For example, scanning electron microscopic (SEM) inspection of microcircuit topography was instituted to detect microcracks in the very thin metal conductor runs. This technique was initiated by government specifications (NASA) and became part of MIL-STD-883 and MIL-M-38510. As the result of this requirement, process improvements were made to existing designs to eliminate such anomalies in the metal. Now all circuits are manufactured with the improved process.

In addition to product upgrading, working with and mastering government specifications gives a supplier expertise in such important disciplines as statistical methods, reliability theory and practice, product evaluation, and failure analysis. All are important skills that contribute to a sound, efficient operation and have a positive impact on all the company's products.

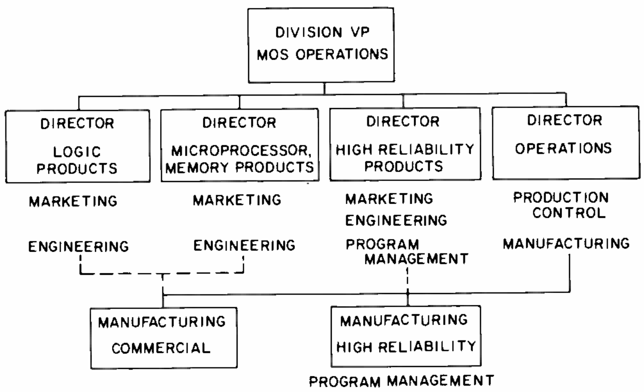
Government sales are a buffer to economic cycles.

Economically, the period from mid-1974 to mid-1975 was quite grim, with most semiconductor suppliers experiencing sudden and dramatic drops in sales and profits. During this period, government-funded programs were relatively immune to the downturn. The very nature of how government budgets are established and approved introduces considerable inertia in the system. Although the approval cycles are lengthy, the monies are spent as planned once funding is approved. In such an environment, government business can be a buffer to the fluctuating sales and profits in the commercial segment, a very significant advantage in the extremely cyclic and volatile semiconductor industry. There is no question that government business adds to the financial stability of any supplier, provided that government business is not the dominant source of revenue.

Organizing to succeed

To participate in the government end-use market successfully, one must organize for success. While there are many ways to organize, depending upon the unique conditions and personality of a particular company, most successful microcircuit suppliers would agree that a separate high-rel organization is essential; the charters of the commercial and government operations are simply too different to combine effectively at the operating level.

The organization of the RCA Solid State Division's MOS Operations, shown below, is an example of one effective approach.



The high-rel group has both marketing and engineering specialists totally dedicated to supporting this market. They are thoroughly familiar with the government specifications and are organized to offer the extensive customer support required. The standard logic and microprocessor/memory product departments have the charter to define and design the basic products. The high-rel line defines and controls the added processing and testing needed to meet the government specifications. In addition, the high-rel activity works on contract efforts to provide circuits with special attributes, such as radiation-resistant CMOS, as well as product evaluations and specification development.

In addition to marketing and engineering, there is also a separate high-rel manufacturing operation directed by a manufacturing manager. Two key support functions, quality and production control, also have personnel specifically assigned to support the high-rel function.

A very important function for major, complex procurements is program management. Program managers coordinate the various elements needed to assure timely manufacture and delivery.

Jack Handen has been Marketing Manager for High Reliability MOS ICs since the inception of that product line in 1972. He draws his experience from a variety of planning, manufacturing, operations, engineering, and marketing management positions he has held with RCA since 1957.

Contact him at:
High-Reliability MOS ICs
Solid State Division
Somerville, N.J.
Ext. 6643

Into the future

What does the future hold for the government end-use microcircuit supplier? While no one can prophesy with total accuracy, several judgments can be made. Sales for government microcircuits will continue to increase at a faster rate than the total government procurement budget; this represents a major growth opportunity for the supplier. Advanced electronic systems require larger quantities of more complex ICs.

Military and other government designers are accepting new technologies more rapidly. Consequently, they are exerting pressure on microcircuit suppliers to make state-of-the-art devices available to government specifications soon after these products are announced. The interest in using microprocessors is an example of this trend. In the past, government engineers tended to be more conservative and use only well-proven components. The current trend is to use the latest devices and not be caught with a technically obsolete noncompetitive design. The microcircuit supplier has helped accelerate this trend by giving the designer confidence that reliable state-of-the-art circuits will be available to military specifications. This confidence was earned by performance over the last decade.

Acknowledgments

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Microcomputer control for the car of the future

E.F. Belohoubek
J.M. Cusack
J.J. Risko
J.R. Rosen

Several years from now, $200 may buy a radar/display system that will make your driving safer.

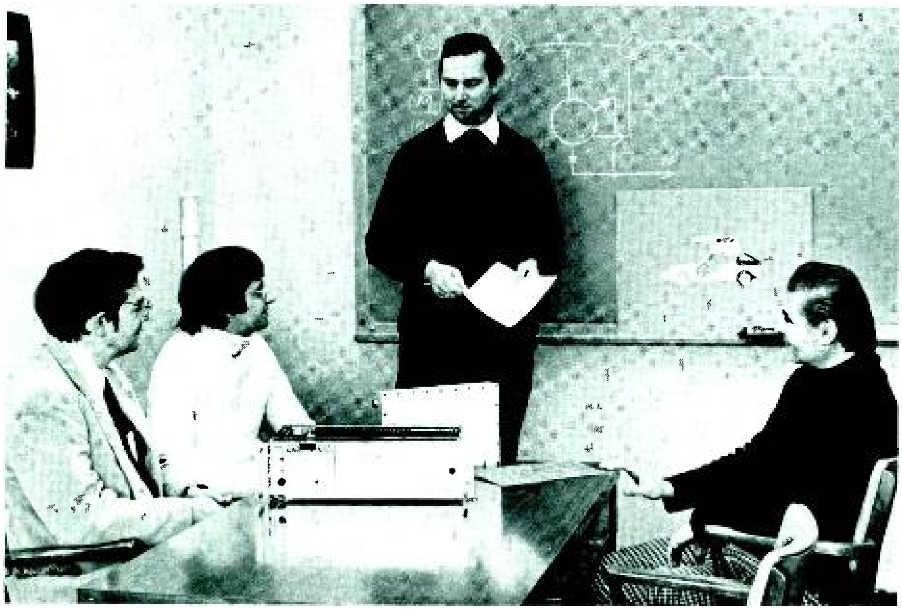
Erwin Belohoubek is Head of the Microwave Circuits Technology Group at RCA Laboratories, a group working on microwave hybrid integrated circuits. In this capacity, he is responsible for the development of passive and active MIC circuits, including high-power transistor amplifiers, multipliers, linear bipolar and FET amplifiers, electron-beam semiconductor amplifiers, circulators and limiters, and small microwave subsystems.

Jerome Rosen has been engaged in the research and development of microwave devices and subsystems in the frequency range of 30 MHz to 40 GHz since 1957. His current automotive-related assignments include a self-mixing X-band Doppler radar, the electronic-signpost Automatic Vehicle Monitoring system, and the electronic tag of the microwave Automatic Vehicle Identification system.

Joseph Cusack has principally worked in the area of minicomputer automation of microwave and thermal measurements since he joined RCA in 1972. In 1974-1975, he participated in the development of a computerized satellite-checkout station for the RCA Satcom satellites. Recently, he has been investigating the potential of microprocessors in microwave applications.

John Risko joined the Microwave Research Laboratory in 1962, working on GaAs and GaSb tunnel diodes and varactor diodes. He has since worked on silicon devices, including IMPATTS, TRAPATTS, and more recently BARITT structures. Mr. Risko received a 1972 David Sarnoff Research Laboratories Achievement Award for "team effort leading to the development of S-band Trapatt Amplifiers."

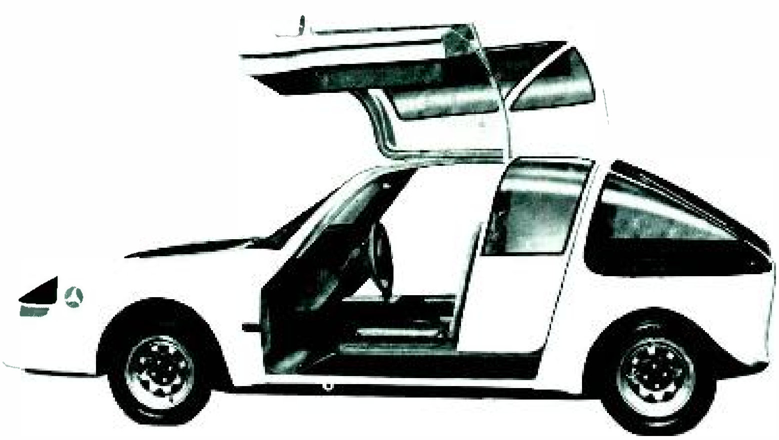
Authors (left to right) **Risko, Cusack, Belohoubek,** and **Rosen**
Contact them at:
Microwave Circuits Technology, RCA Laboratories, Princeton, N.J., Ext. 2629



Until recently, car manufacturers have generally been slow to introduce electronic advances to the automobile. However, this situation is changing, and a definite trend toward using automotive electronic systems is becoming evident. This is especially true with the advent of the microprocessor, which has opened up a wide range of possibilities for controlling relatively complex electronic systems in a cost-effective manner. Two examples of automotive microprocessors already in use, or shortly to reach the market, are anti-skid systems[1] and the various forms of electronic fuel control[2] used for improved economy and low exhaust emission. Looking toward additional applications in the future, the Microwave Technology Center at RCA Laboratories is presently developing a microprocessor-controlled information and safety system for a Research Safety Vehicle (RSV), sponsored by the U.S. Department of Transportation.*

The major objective of this program is to develop a safety car in the 2000-lb class for the mid-1980s. Fig. 1 shows a preliminary mechanical mock-up of the car, which will include many innovations such as a lightweight, foam-filled frame with plastic body-glove covering, an air-bag restraint system designed to provide protection to passengers in frontal crashes up to 80 km/h, an anti-skid braking system, pedestrian impact protection, a special front-end and side-frame structure designed to absorb energy in high-speed crashes, etc. RCA's contributions to the program are a microprocessor-controlled noncooperative radar and an electronic dashboard display. The radar and the display are interfaced with a number of safety-related sensors throughout the car

*The RSV is being developed by Minicars, Inc. of Goleta, Cal., with RCA as the electronics subcontractor.



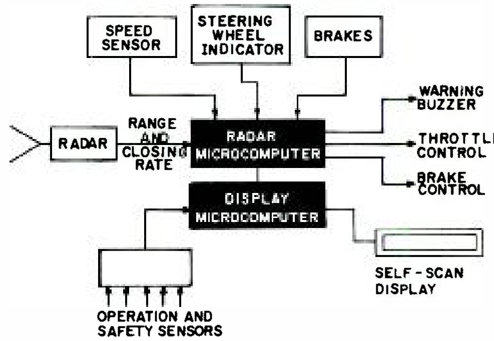


Fig. 1
Research Safety Vehicle, shown in mock-up form here, will have a number of safety features besides the electronics system that RCA is providing.

Fig. 2
Electronics system is divided into two separate microcomputer systems for ease in testing and changing algorithms.

that determine unsafe operating conditions, provide warnings, and can control the RSV's braking and acceleration via the microprocessor.

Work on the RSV began in the middle of 1975; the present development period is aimed at demonstrating the feasibility of the various concepts in an experimental vehicle. The Dept. of Transportation expects prototype cars to be fabricated in 1977-78, with extensive road-testing to follow. Since the present electronic subsystem is designed mainly to show the feasibility of its various functions, a substantial effort will still be required, especially in the radar area, to refine the individual components for actual use in cars.

Outline of the two systems

Fig. 2 is a block diagram of the electronic subsystem for the RSV. There are two separate microcomputer systems in the developmental car—one for the radar, and one for the central display and its associated sensors. This arrangement provides maximum flexibility in testing and changing algorithms. However, in the final version, most of the computer functions will be designed into a few LSI chips, leading to greatly reduced size and cost. Such a central microprocessor interfacing with a number of sensors and an electronic display opens a nearly unlimited number of special convenience- and safety-related functions; we explore only a moderate number in the present RSV.

The dashboard display is clutter-free and easy to read.

The electronic dashboard display is the information center of the car, displaying speed, fuel level, trip mileage, rpm, and other relevant information in easy-to-read, luminescent-orange alphanumerics. Clutter is greatly reduced, since the display provides only the most important driving-related information. All warnings about car-component malfunctions—low oil pressure, high water temperature, or anti-skid system inoperative, for example—appear as three-second override messages on the display and are repeated in thirty-second intervals until the malfunctions are corrected. The regular driving information remains on display between the warning messages. Since the single-line display is located right in front of the driver, directly below the normal line of sight onto the road, it is nearly impossible to overlook the flashing of an emergency or warning message. At the same time, the display greatly simplifies the dashboard, so the available space can be used for other convenience features, such as CB radio, tape cartridge player, etc.

The noncooperative radar system does not use "tags" or reflectors on other cars.

The other important microprocessor-controlled system in the RSV is a forward-looking noncooperative fm/cw radar. Earlier work at RCA Laboratories had been devoted to a second-harmonic, cooperative radar system[3] that provided much of the background for the present noncooperative system development. The new radar unit has several functions that it can perform simultaneously, thanks to the programming and decision-making capabilities of the microcomputer. During highway driving under cruise control, the radar monitors the space ahead, and if the RSV approaches another car too closely the microcomputer deactivates the cruise control and automatically maintains safe headway. This is done by monitoring the range and closing rate with respect to the vehicle in front. As soon as the path ahead is clear, the cruise control goes back into operation. The radar also provides audible warnings for obstacles and other cars up to 30 meters ahead, which is especially important when driving in fog or with impaired visibility.

The last and possibly most important function of the radar system is to apply the brakes automatically in situations where a serious collision appears to be unavoidable. This braking function is automatically disabled if the driver takes evasive action or applies the brakes himself. The system design gives high priority to avoiding false alarms that could trigger accidents or cause the driver to lose faith in the system. Therefore, the automatic braking will be activated rarely—only after a series of measurements and sensor indications clearly determine that a collision is indeed unavoidable.

Radar system

A standard fm-modulated cw radar (Fig. 3) operating at X-band provides the desired range and closing-rate information with respect to vehicles or obstacles directly ahead of the RSV. The varactor-tuned transferred-electron oscillator is frequency-modulated at a sweep rate of f_m = 1 kHz and a frequency deviation of Δf = ± 25 MHz. The signal radiates from a printed-circuit antenna mounted under a radome in the hood. A balanced mixer is used for homodyne detection, followed by an amplifier chain with a shaped-gain characteristic.

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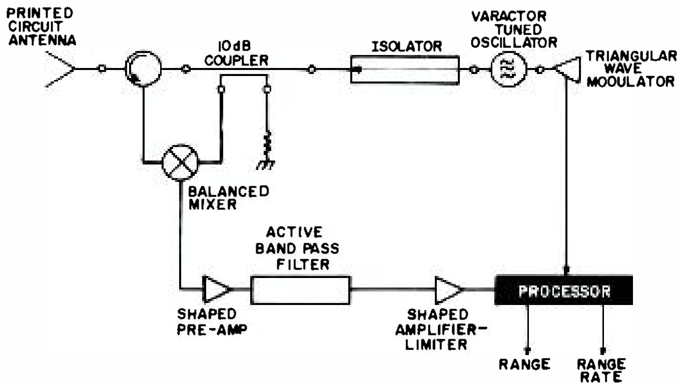


Fig. 3
Fundamental-frequency radar produces range and range-rate outputs that are used for making warning/braking and headway decisions.

The antenna consists of 128 fan-shaped dipoles and a feed structure printed on both sides of a Duroid circuit board. To reduce the number of possible false alarms that otherwise would arise from parked cars, overpasses, and road signs, the antenna beamwidth and both the vertical and horizontal side-lobes must be very small. Consequently, the beamwidth of the printed antenna is approximately 5° in azimuth and 10° in elevation, and a Chebyshev current-taper[4] is used to excite the individual antenna elements to reduce the side-lobes. The side-lobe levels listed in Table I represent the performance of the antenna with such a taper. Adding shielding and damping material a few inches ahead of the antenna reduced both horizontal and vertical side-lobes to below −20 dB, which proved to be sufficient for eliminating false alarms caused by the antenna side-lobe responses. Since the damping material is located under the radome structure, it does not interfere with the aerodynamics or the aesthetics of the RSV.

Range and range-rate information is derived by processing the i.f. signal that appears at the mixer output. For an fm/cw radar with a triangular fm modulation the beat frequency is of the form:[5]

$$f_B = |8(R/c)\Delta f f_m \pm (2\dot{R}/c)f_o| = |f_R \pm f_D| \quad (1)$$

where R is the range, $\dot{R}$ the range rate, f_o the carrier frequency, and c the velocity of light. For $\dot{R}>0$, the plus sign in Eq. 1 gives the beat frequency during the up-swing of the modulation, while the minus sign corresponds to the down-swing. In Eq. 1, f_R is often called the range frequency, and f_D the doppler frequency. For the parameters chosen in our system a range of 1 m corresponds to $f_R = 667$ Hz and a range rate of 1 m/s to $f_D = 70$ Hz. By measuring the beat frequency during both the up- and down-swings of the modulation, range and closing rate can be determined separately:

$$R = (c/16\,\Delta f f_m)(f_{Bup} + f_{Bdown}) \quad (2)$$

$$\dot{R} = (c/4f_o)(f_{Bup} - f_{Bdown}) \quad (3)$$

Table I
Performance specifications for radar system show small size, accurate range and range rate, and low gain at the side-lobes to reduce potential false alarms.

Frequency:	10.575 GHz
Stability:	within 1% from −50° to +60°C
Power output:	27 mW
Frequency deviation:	±25 MHz
Modulation rate:	1 kHz
Size:	32 × 19 × 5 cm
Power consumption:	6 W
Range:	6 to 30 m ± 0.2 m
Range rate:	0 to 160 km/h ± 10 km/h
Antenna gain:	25 dB
Side-lobes horizontal:	−18 dB
Side-lobes vertical:	−15 dB

The microprocessor calculates the beat frequency, f_B, by using a 1.95-MHz clock to count the time between successive zero-crossings. The calculation is performed over several modulation periods and averaged; this procedure guarantees a much higher accuracy and lower granularity than the conventional method of counting zero-crossings.

During our early experiments, we used the range information obtained in this form and differentiated it with respect to time to determine the closing rate. Provided sufficient time, on the order of a few tenths of a second, is available, this computation is fairly accurate and can be used for the headway-control algorithm. To initiate emergency braking, however, the response-time must be much shorter, so the doppler frequency must be extracted directly from the beat frequency. Since the doppler frequency is the result of subtracting two relatively large numbers from each other, the accuracy requirements for the beat-frequency measurements are more severe than for range-measurement alone. The present system therefore measures f_D to an accuracy of 12 bits, which requires approximately 80 ms for one averaged range and range-rate reading with the 8-bit microprocessor. If a special-hardware multiplier were used, this time could be reduced to about 30 ms.

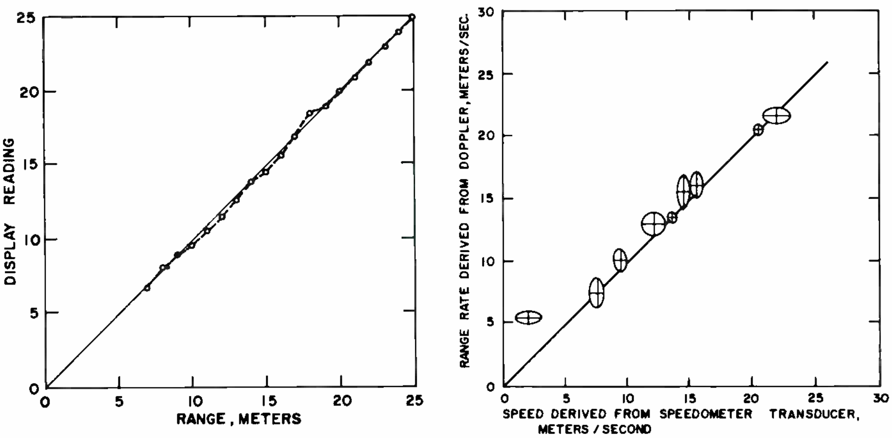
Microprocessor radar algorithm

An RCA COSMAC development system (Microkit) using the CDP1801 microprocessor performs the calculations and decision-making for the radar in two basic areas—warning/braking and maintaining a safe headway distance. The system converts radar data from a digital interface into range and range rate (closing velocity). It then takes this information and combines it with other sensor inputs and decision criteria to generate an audible warning or an output that will operate the car's brakes when necessary. The system determines a safe headway distance with respect to vehicles ahead by using the range and range-rate information together with car speed.

Range is derived from the radar interface input according to the equation

$$R = K_R N\,(1/COUNT_{up} + 1/COUNT_{down}) \quad (4)$$

where K_R is a lumped constant depending on the radar parameters f_m, Δf, and samp-



Figs. 4a (left) and 4b
System is accurate to ±0.2 m in range (left) and ±10 km/h in range rate. Transducer inaccuracy at very low speed produced the off-line data point in the range-rate graph.

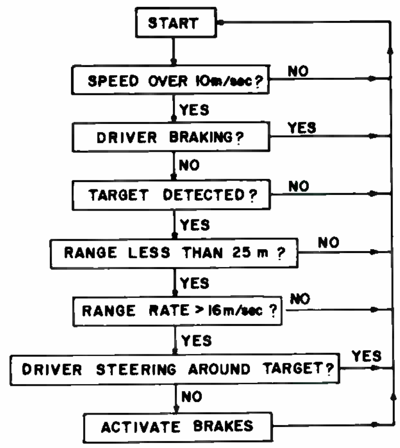


Fig. 5
Braking system avoids false alarms by checking six conditions before activating brakes. This avoids false targets that take place during slow-speed maneuvering and also gives driver control of the car if he is trying to avoid an accident.

ling frequency f_s. N is the (programmable) number of beat-frequency periods over which the measurement is taken. $COUNT_{up}$ is the number of periods of the sample frequency f_s that occur over N periods of the beat frequency during the first half of the modulation cycle, and $COUNT_{down}$ is similarly defined for the second half of the modulation cycle. Range rate is determined by measuring the difference between $1/COUNT_{up}$ and $1/COUNT_{down}$ and using another calibration constant, K_D, in place of K_R. Special threshold circuits provided in the hardware interface between the radar and the Microkit inhibit the range measurement when the signal drops below a given level any time during the measurement cycle.

Checking the radar's accuracy

The accuracy of the measurement system was checked by measuring the range to a stationary corner reflector having dimensions equivalent to a 10-m^2 radar cross-section, corresponding to that of a medium-sized car. Fig. 4a shows stationary range measurement data obtained from such a well-defined target; the range accuracy is typically within ± 0.2 m. Range-rate measurements were performed by driving the car at constant speed towards a tape-supported corner reflector that was pushed out of the way at impact. This relatively simple test permitted taking data up to speeds of 80 km/h, as shown in Fig. 4b. Under actual driving conditions, the accuracy of range and range-rate information could be substantially lower because of changes in the effective reflection point on the target vehicle that are caused by slight steering-angle variations, up-and-down movements of the car, etc.

As the range and range rate are continually updated, they are used together with other sensor inputs to perform a number of control functions. The present system provides the necessary signal outputs for warning the driver about obstacles ahead and for automatic braking in case of an unavoidable collision.

Avoiding false alarms

In most cases, an alert driver will be able to avoid a collision by evasive action or braking. For this reason, the system will not generate a braking output if the driver is already braking or if he is turning the steering wheel hard enough to avoid an accident. This is done by having the microprocessor act as a filter that sharply limits the conditions under which the braking output will be generated. Although this reduces the benefits of the system somewhat, it does prevent unnecessary braking.

Also, in a normal driving situation, a great number of nondangerous targets may appear in the line of sight of the radar. The system can reject many of these targets by ignoring all the ones farther away than some maximum range, nominally 25 m. In addition, a minimum speed threshold inhibits the processor from initiating braking if the vehicle speed drops below some lower limit, nominally 36 km/h. This restriction again reduces the system benefits somewhat by disallowing operation for very-low-speed collisions, but it also rejects a number of false targets that could occur during slow-speed maneuvering, as in a parking lot.

Fig. 5 shows a sample flowchart for the braking-algorithm software. Since using a microprocessor permits radical changes in system performance characteristics by changing software, the microprocessor acts as a useful development tool as well as a sound way to implement the final logic design. To date we have experimented with linear expressions of the form

$$K_1 v + K_2 \dot{R} + K_3 R > 0 \qquad (5)$$

in order to generate outputs for an audible warning and collision-mitigation braking. Such linear equations have traditionally been used in this field because they are easily implemented with analog hardware. The microprocessor, however, can also handle nonlinear control equations where it becomes necessary.

The radar system also maintains a safe headway with respect to vehicles ahead of the RSV. For this purpose, range rate is derived by differentiating range with respect to time, because adjustments in headway have a relatively long time constant (roughly a second) and require a higher accuracy in range rate than the emergency braking algorithm does. This more accurate range is important to keep the feedback control loop for the car-following algorithm[7] stable and free from short-term braking or acceleration impulses. In the present system, the outputs from the microprocessor to the car's throttle and brakes are not yet interfaced, but are shown as display messages—"speed up" or "slow down." The actual interface with the car is part of the next phase of the RSV program.

Testing performance on the highway

A series of road tests on both regular highways and winding country roads was performed to check the operational capabilities of the radar system. In the cruise-control mode, modified for safe headway keeping, the radar demonstrated excellent tracking capabilities with respect to cars ahead. The system normally tries to keep a predetermined cruising speed (presently, by showing the proper "speed up" or "slow down" commands), and if the car approaches another vehicle within 25 m it keeps a speed-dependent safe headway with respect to this vehicle. The radar in these tests was not disturbed by any false readings from oncoming traffic, passing bridges, road signs, etc. One of the major difficulties encountered was that although most vehicles have fairly large radar cross-sections, some cars, especially those with strongly slanted backs, provide only little reflected power, which leads to temporary signal dropouts.

The algorithm for automatic brake application was tested by driving the car at high speed through a stationary expendable corner reflector and monitoring distance from the target at which the brake signal was initiated. For speeds up to 100 km/h, the maximum that could be achieved on our test range, the brake signal occurred correctly within the expected range—10 to 25 m before the target. Using the same algorithm, threshold settings, and sensitivity, the radar did not produce any brake signal outputs during regular highway driving, indicating essential freedom from "false alarms." Such tests will have to be performed, however, on a much better controlled basis and for prolonged periods of time to truly optimize the braking algorithm for the wide variety of possible road and accident situations it may encounter.

Performance and safety sensors

A second COSMAC development system monitors vehicle performance and various safety-related sensors. The sensor status is shown on a Burroughs 32-character, single-line, self-scan display. Fig. 6 is a block diagram of the display-microprocessor system with its associated ROM and RAM memories.

The binary data interface has 24 switch closure inputs to buffers or inverters that are either "on" or "off" (12V or 0V). The status of the group-selected buffers or inverters is read by turning on a transmission gate. The switch-closure sensors monitor hand-brake status, brake-fluid level, whether the doors are closed, and other similar, simple functions. The steering-wheel interface is a one-shot oscillator whose period of oscillation is controlled by the resistance of a potentiometer that senses the movement of the steering-wheel shaft. An analog/digital converter with a multiplexer digitizes analog inputs such as water temperature, fuel level, and oil pressure.

Two other sensors provide pulse trains whose frequency is proportional to fuel flow and engine rpm, respectively. The pulse trains clock counters, which are read at intervals determined by the software; the data is then converted into a form suitable for display.

The velocity-monitoring circuitry is an example of typical sensor interface card. It determines the car velocity by means of a generator attached to the RSV's speedometer cable. The generator's output frequency is proportional to the angular velocity of the speedometer cable, and when it is applied to an op-amp (CA3401) that is driven into saturation, it provides a squarewave input to an inverter. The resulting signal clocks a counter that in turn is read by activating a bilateral switch. The system software interprets the counter reading and displays the speed in km/h.

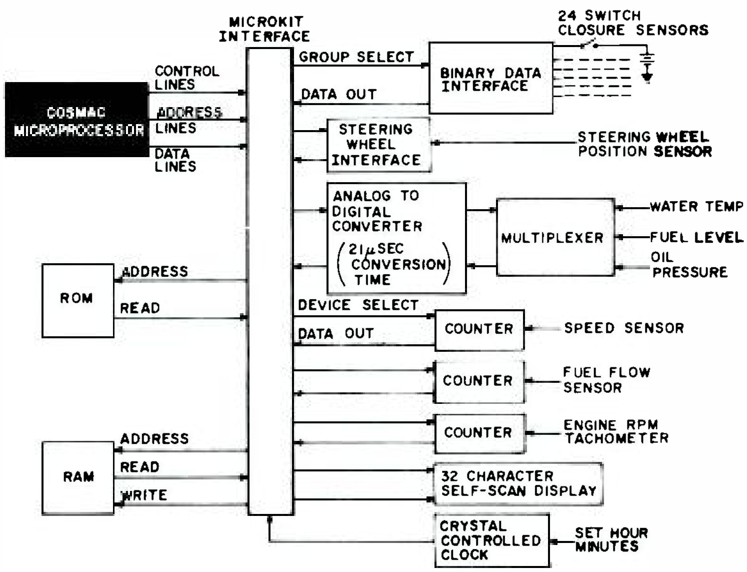


Fig. 6
Improved display system unifies the numerous bits of safety and performance information that are spread across today's dashboard.

Central information display

An electronic display system presents the information pertaining to vehicle performance and safety devices to the driver. A Burroughs gas-plasma, single-line, 32-character "self-scan" display was selected as the best commercially available system for automotive applications at this time; Fig. 7 shows how the display appears to the driver. The "self-scan" unit uses x-y addressing and a 3-phase driver system to propagate a gas plasma the length of the display. The unit comes complete with memory for refresh and a character generator with a repertoire of 128 different characters. A dc-dc converter boosts the car's 12 V to 250 V to provide the operating voltage for the display.

The driver of the RSV can choose between two normal modes of information display, as Fig. 7 illustrates. One mode shows fuel level, rpm, and an analog representation of speed in the form of a horizontal bar graph. The other display mode indicates trip mileage, time, fuel economy, water

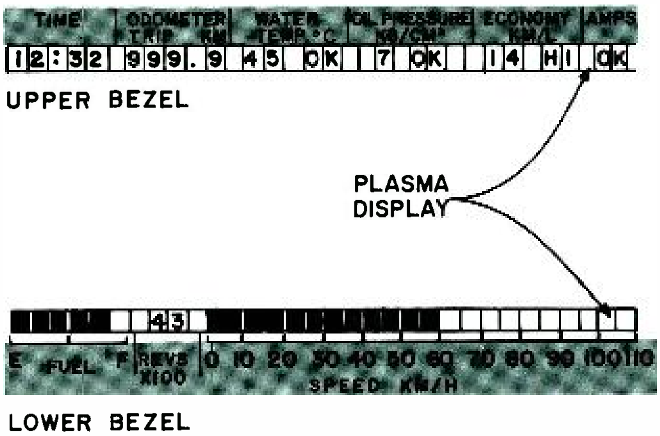


Fig. 7
Driver's view of the self-scanning display shows how above-the-dash location keeps driver's eyes close to the road while checking display information. Driver has choice of two display modes, with emergency messages overriding in case of a malfunction. Display is both digital and bar-graph in form.

temperature, oil pressure, and battery status.

In case one of the sensors detects a malfunction, an emergency message interrupts the normal display. This message appears for several seconds and then is turned off for a short period of time before recycling; it recycles continuously until the malfunction is corrected. The nine presently used emergency messages are:

- SERVICE BRAKE ON
- DOORS OPEN
- RADAR WARN—SLOW DOWN
- RESTRAINT SYSTEM OUT
- ANTI-SKID OUT
- BRAKE FLUID LOW
- OIL PRESSURE LOW
- WATER TEMP HIGH
- HAZARD

The system software determines the time for which the messages are displayed and then repeated, in addition to the priorities assigned to the individual messages in case there is more than one malfunction.

Conclusions

The introduction of microprocessors to the automobile opens many new exciting possibilities for improved performance, safety, and convenience in future cars. In this program we investigated the possibility of using microprocessors in two specific applications. One is the monitoring and display of a variety of performance- and safety-related sensors in the car—a fairly straightforward engineering task. The other, much more challenging, task involves adapting a noncooperative cw/fm radar to automotive needs. The radar described here has successfully demonstrated the feasibility of the following functions: headway control with respect to other vehicles on the road; collision-mitigation braking when a collision is clearly imminent; and warning the driver of obstacles and cars ahead.

In developing suitable algorithms for these functions, heavy emphasis was placed on ensuring that the radar system would be free from false alarms. This means the system must not respond to targets that are not in the direct path of the vehicle, such as parked cars on the shoulder, bridge abutments, overpasses, road signs, etc., or even to cars ahead, if there is still enough time for the driver to avoid them by evasive action. Thus, before radar-controlled braking is initiated, a number of special conditions have to be fulfilled—for example, car speed above 36 km/h, target within 25 m, and steering angle within certain limits dependent on car speed. This ensures that false targets do not lead to unnecessary braking, which in itself could lead to accidents that would cause the driver to lose faith in the system.

It is a major and very difficult task to determine an algorithm that can satisfy these safety considerations, yet still lessen the severity of accidents. Here, the microprocessor, when properly interfaced with a number of sensors, can perform a unique function, making radar-controlled braking a realistic possibility. With the limited amount of road-testing performed so far it appears that a radar system fulfilling the above requirements is indeed possible, although using much more refined algorithms and after more carefully controlled road tests relating to the wide variety of possible accident situations.

Aside from the purely technical feasibility and public acceptance of such a system, there is one more very important factor to consider—cost. Initial estimates using the PRICE[8] analysis indicate probable manufacturing costs of $50 for the radar, $90 for the microcomputer, and $30 for the display. These numbers, although somewhat high, still show that such a system, with some further refinements, may become economically feasible in the next ten years.

Acknowledgments

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CVM—a microprocessor-based intelligent instrument

C.T. Wu

Capacitance-voltage plots tell a great deal about the physical characteristics of MOS wafers. The microprocessor-based CVM provides this information for on-the-spot use during manufacture and for long-term data analysis.

During the manufacturing of integrated circuits, various instruments are needed to monitor critical process parameters. In some cases, calculations must be performed on the measured quantities, and data must be logged for further statistical analysis. Since a real-time minicomputer-based system capable of handling these tasks throughout a large physical area involves a relatively large investment, an attractive alternative is to use "intelligent" instruments. Such instruments perform local calculations and then, at specified intervals, ship the formatted results to an existing main-frame computer. Microprocessors can provide intelligence to the instruments and also allow ordinary phone lines to be used as the communications link to the central computer. Simple and flexible distributed-intelligence systems can be realized this way rather effortlessly.

One such intelligent instrument is the Capacitance Voltage Monitor (CVM), based on the COSMAC microprocessor. The CVM was developed as part of an overall program in the Solid State Technology Center to achieve better understanding and control of the IC manufacturing process.

Capacitance-voltage measurements

Capacitance-vs-voltage plots are often used in the semiconductor manufacturing process to measure physical characteristics of MOS (Metal-Oxide-Semiconductor) devices.[1] For this purpose, test wafers with capacitors of known geometry are placed in a furnace together with production wafers during a run. By studying the CV plots of the resultant test samples, it is possible to determine flatband voltages, mobile ion concentrations, bulk minority carrier lifetimes, surface recombination velocities, etc. Because the measurements are relatively simple to make, CV plots have become standard practice in RCA's MOS wafer-fabrication process for both SSTC and SSD.

CV plots show the capacitance of a sample against its dc bias. To make one, a small ac signal of fixed amplitude (millivolts) and frequency (typically 1 MHz) is usually added to a slowly-varying ramp voltage and applied to the sample. The measured reactance is then plotted as a function of the input ramp voltage. This operation can be done on CV-plotting equipments that have adjustable ramp speed and amplitude; these are available from several equipment vendors.[2,3]

In practice, two superimposed plots are made with the same sample, one at normal temperature and one done after heating the sample under a fixed bias. The shapes of these curves and their relative displacement contain the desired information. Quantitative interpretation of these plots involves picking off points from several precomputed charts.[4] Specifically, in order to obtain the flatband voltage (V_{fb}), the normalized flatband capacitance (C_{fb}), and the shift after heating, three charts are needed. These results are recorded and filed if they fall within expected process limits.

Purpose of CVM

To automate this measurement-making, the microprocessor-based CVM system has been designed to monitor CV plots and compute the required results. Test results accumulated over a day are sent to a data file in TSO (Time-Sharing Option on the IBM 370 system) via an ordinary telephone line. Statistical analysis and reporting based on these data can then be performed using the full resources available in a large system.

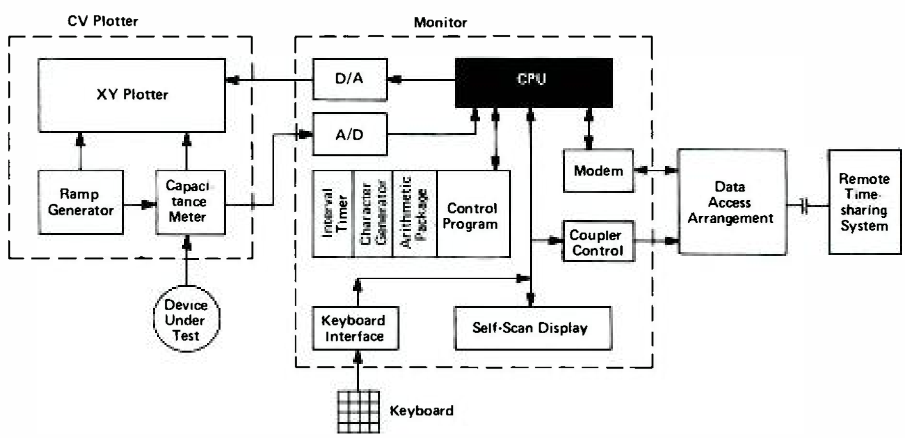

Fig. 1
Capacitance voltage monitor (CVM) system measures physical characteristics of MOS wafers. System monitors CV plots (left side of block diagram), then transmits results of a day's testing to a time-shared computer.

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CVM design procedure

CVM is built up from a microcomputer nest—the COSMAC Development System (CDS)—by adding functional modules.[5] Since the CDS has extra connectors specifically provided for user-developed boards, systems directed toward particular applications can be constructed easily. To do this, each board is breadboarded and then debugged in CDS with the aid of an interactive debugger, provided with CDS. By ensuring that each hardware component operates properly in real time, final debugging becomes simpler.

Applications software for the system was developed in parallel with the aid of the COSMAC System Development Program (CSDP),[6] and most of the functional flow and computations were simulated with CSDP. Routines dealing with peripheral control and real-time responses, however, were handled with the debugger in CDS.

System components

CVM consists of two parts, a Boonton CV Plotter and a COSMAC-based monitor. Fig. 1 shows the monitor's functional components; each block in the diagram represents a single PC board (except the one marked "CPU," which is the CDS microcomputer itself).

The following I/O modules, when added to the CDS, form the CVM:

- A/D converter—used to sample a pair of voltages corresponding to the x-y plot
- D/A converter—used to drive the x-y plotter
- Self-scan display—used for displaying computed results
- Keyboard interface—used for operator entry of parameters
- Interval timer—used for updating time-of-day clock
- Data coupler control—used for data access and dial-up of computer system
- Modem—used to modulate and demodulate signals to the telephone line

In addition to the I/O modules, two ROMs are needed for computational purposes. Each resides in a PC card; they are:

- Arithmetic Subroutine ROM—16-bit arithmetic subroutines for multiply, divide, and conversions
- Character Generator ROM—5×7 dot-matrix representation of ASCII-coded characters

Control signals for most of these I/O modules are derived from the CDS I/O decoder. Here, eight output ports and eight input ports can be supported in a one-level I/O structure. Apart from these, I/O can also be mapped as memory data, as in the interval timer. In this module, controls are derived from memory read/write signals and "time" appears as two bytes of RAM. Depending on the particular I/O device, one of these methods may prove more convenient for the programmer.

System operation

Fig. 2 is a simplified flowchart of the CVM system. As indicated, the two main tasks that the monitor performs are local computation of CV measurements and data-logging to a remote computer. To start, an operator initializes the CVM at the beginning of the day by data and time entries. Then the CVM makes a series of measurements until the end of the day, when it transmits the collected data automatically.

Operation of the system is as follows. For each test, CVM asks the operator to enter two identification numbers associated with it. First, the display shows:

SAMPLE #=

After entering the number through the keyboard, the display shows

TCC #=

A second number can then be entered. The display will now show:

ENTER COMMAND

There are four options in responding to this message. To get a continuous display of time (updated every second), the user

Chin Tao Wu has worked on various aspects of computer systems design since joining RCA in 1965. He has been interested in microprocessors since 1971 and was active in the earlier support work for RCA's COSMAC microprocessor. Mr. Wu has received three RCA Laboratories Outstanding Achievement Awards, has published a number of technical papers, and holds several U.S. patents.

Contact him at:
LSI Systems Design
Solid State Technology Center
Somerville, N.J.
Ext. 6061

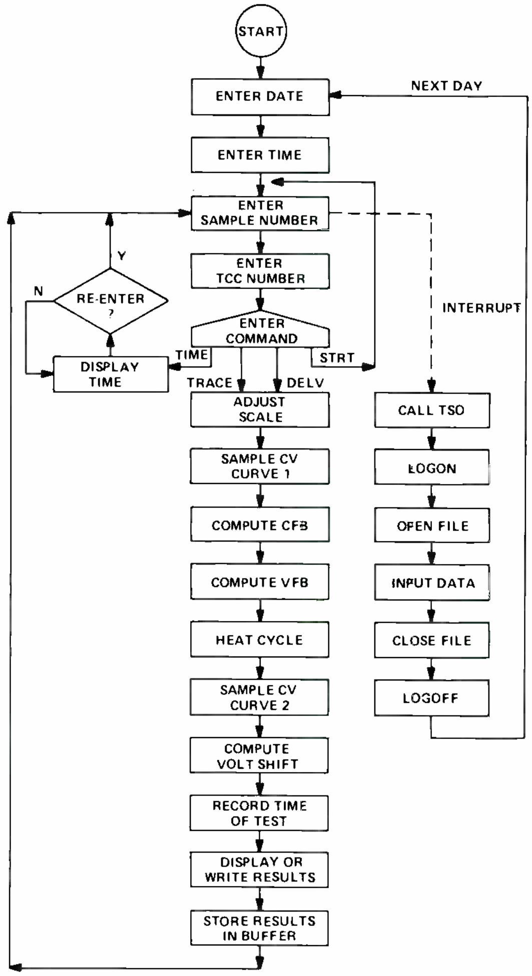
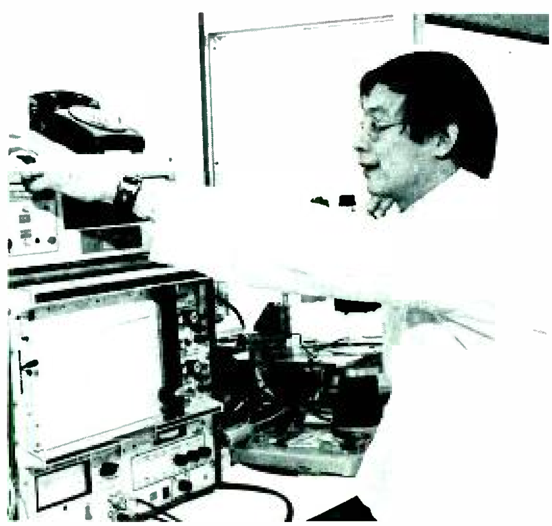


Fig. 2
CVM takes two curves for devices, one at normal temperature and one after heating, then compares them. Data is logged out to time-shared computers (TSO) for analysis upon interrupt at end of a day's testing.



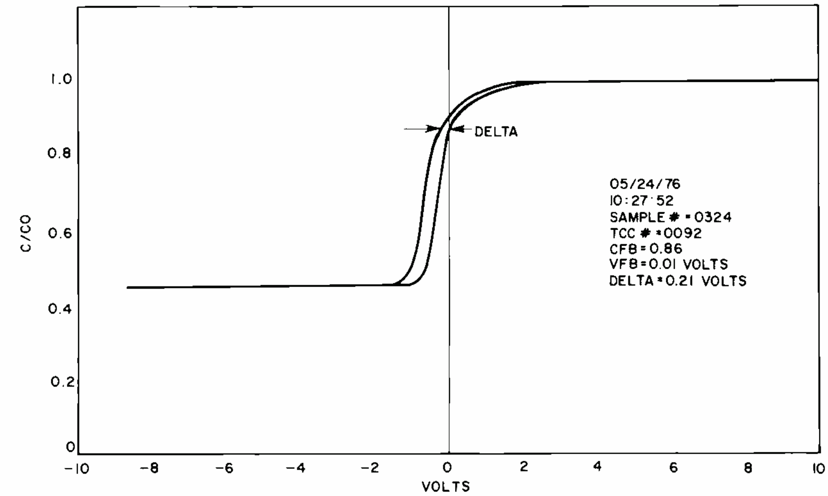


Fig. 3
Sample output shows three directly-computed data points. CFB is the normalized flatband capacitance, VFB is the flatband voltage, and DELTA is the voltage shift after heating. Old system required picking off values from precomputed charts.

depresses the key marked 'TIME'; to perform a measurement and have the results shown on display, he hits the key marked DELV; to perform a measurement and have the results written with the plot, he hits the key marked TRACE; and, to enter a new set of test identifications because of entry error, he hits the key marked STRT.

During an actual measurement, the scales in the x-y plotter and the capacitance meter usually have to be adjusted in order to obtain a plot with proper y-deflections. To allow for this, CVM shows:

ADJ SCALE & STRT

After adjusting the scales, the operator then hits STRT to begin analog sampling of the x-y plot by the monitor. During this process, CVM shows:

PLOTTING

to indicate that the x-y voltages are being sampled.

Computations

When CVM obtains all the coordinate pairs in the first trace, computations begin. They are based on piecewise linear approximations of the CV equations, using a fixed oxide thickness and sheet resistivity. A fixed-point, 16-bit arithmetic package in ROM is used for these calculations.

In the computation, the flatband capacticance, C_{fb}, is first computed as a function of the minimum measured capacitance, C_{min}. Then, from C_{fb}, the corresponding voltage from the CV trace is picked off as V_{fb}. Both C_{fb} and V_{fb} are obtained from the first trace. After this, the sample is heated under a fixed bias and then cooled.

Sampling of the second CV trace begins after the heat cycle. Here, the voltage corresponding to the C_{fb} of the previous trace is found from the curve. This result is subtracted from the previous V_{fb} to obtain the voltage shift Δ between the two traces. C_{fb}, V_{fb} and Δ are then stored in memory together with test identification and time of test for later logging.

Fig. 3 is a sample of a CV trace with the accompanying data calculated and plotted by the CVM.

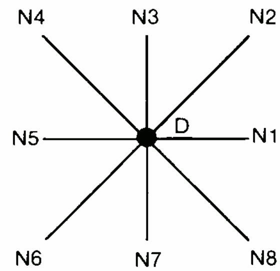
Character plotting

The way in which CVM writes alphanumeric characters on the x-y plotter illustrates an interesting capability of a microprocessor-based system. It is an example of performing a required function by combining relatively complex software with simple-minded I/O hardware. Fig. 4 shows the flowchart of the character-plotting routine.

The plotting operation requires a D/A converter to generate a pair of deflection voltages. Fig. 5 shows the functional block diagram for the converter and its interface to CDS.

From an OUTPUT instruction, the 8-bit data is split into two 4-bit fields in the converter interface. One of these 4-bit fields is decoded to generate commands for multiplexing control and pen up/down motions; the other 4-bit field contains the data for the D/A converter. Two analog "sample-and-hold" gates hold the x- and y-voltages between conversions.

Pen plotting movement consists of tours through the connecting dots forming the dot-matrix of an alphanumeric character. Travel preference is arbitrarily assigned to the first-encountered dot in a counter-clockwise sweep starting from the x-axis.



For the example above, if a dot D has two neighbors, N2 and N3, the pen movement will be from D to N2.

To start a tour, the pen begins to scan from the lower left corner of a 5×7-dot character image. As the dot-matrix image is traversed, dots in the path are erased one by one so that the remaining dots are unexplored parts of a character. At the termination of a linear segment, the last dot will have no immediate neighbors. Scanning then begins again from the lower left corner; this procedure is repeated until all dots have vanished.

To obtain various character sizes, scaling can be done by changing the constants assigned to the x- and y-deflections.

Data logging

An interrupt occurring at a fixed time daily starts data logging. First, the TSO system phone number is dialed automatically and DVM logs itself on as an interactive user. Then, a data file is opened and the collected data is entered. Afterwards, CVM closes the file and logs off the system. These actions are performed in an interval of several minutes by software that mimics a normal TSO user.

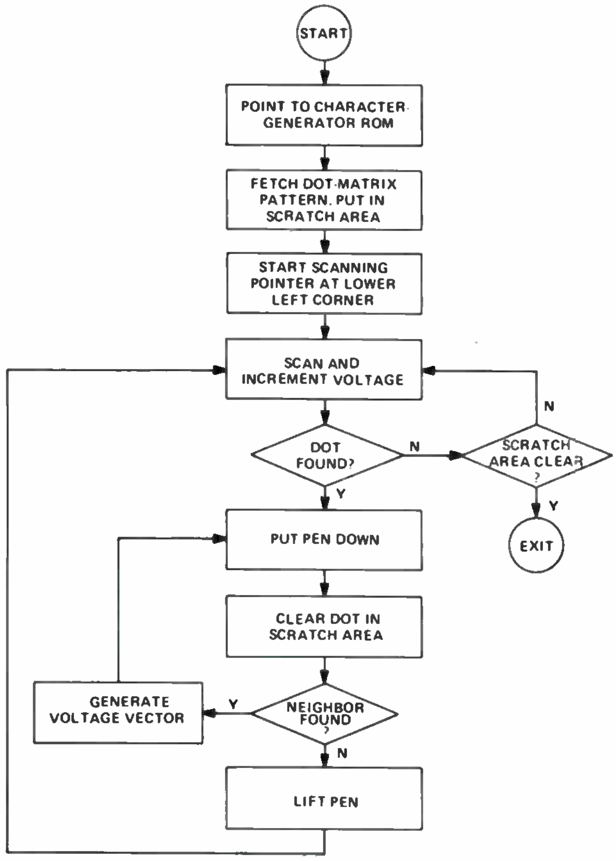


Fig. 4
Connect-the-dot character plotting is done with simple hardware and relatively complex software. Pen scans 5x7 character image to find the linear segments.

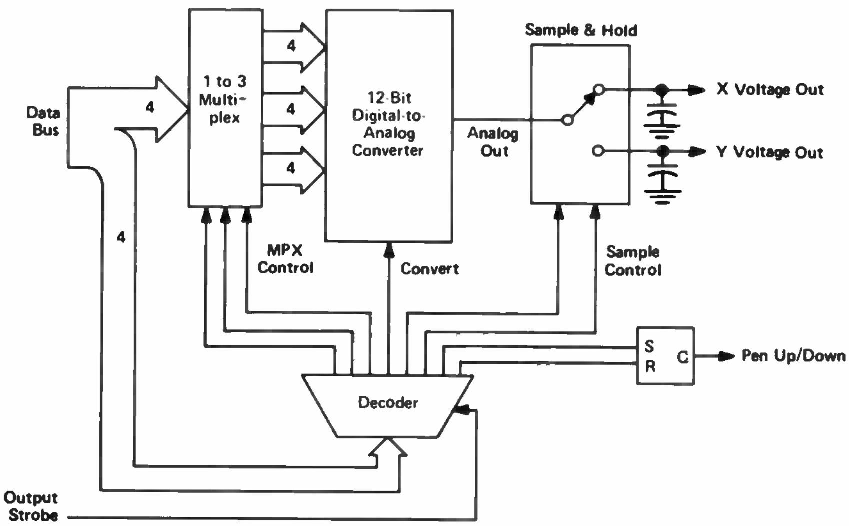


Fig. 5
Plotting system generates x-y deflection voltages through D/A converter.

Communications with TSO are carried out in asynchronous ASCII code. Since ASCII code cannot accommodate eight data bits per character, binary data are coded so that each character carries only four bits of information. Therefore, hexadecimal numbers are simply coded as the corresponding ASCII characters 0, 1, .. E, F. Conversion to recover the four bits is relatively straightforward in this coding scheme.

The logged data constitutes a basis from which statistical analysis and quality control can be realized. For this, large computers are usually better than microcomputers because of the need for crunching large quantities of numbers. Moreover, the file-storage capability of a large mainframe computer is necessary for keeping a large data archive.

Since process degradations must be detected and corrected as soon as possible, process data collected on the factory floor are crucial. For a complex process such as manufacturing integrated circuits, continuous distributed monitoring of various parameters is necessary for fast corrective actions.

Conclusions

The CVM system shows that microprocessors can provide intelligence to process-monitoring and control instruments. This intelligence frees the operators from manual tasks and also allows the collected data to be communicated to a remote central computer, where it can be processed and filed. Simple and flexible distributed intelligence systems can be realized with relative ease for the control of complex processes.

Acknowledgment

The author wishes to thank K.H. Lee, J. Kau and D. Fraipont for their contributions in the design, construction and debugging of the CVM.

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The ATMAC microprocessor

A.D. Feigenbaum
W.A. Helbig
S.E. Ozga

ATMAC is a low-cost, low-power high-speed microprocessor designed specifically for array-type computations.

Conventional microprocessors are impractical for real-time signal-processing applications that require very high-speed processing and accessing of very large arrays of data. Recently, Advanced Technology Laboratories (ATL) has developed a bit-slice microprocessor called ATMAC specifically as a low-power, low-cost, high-speed means of solving matrix-algebra algorithms, implementing digital filters, and performing other computations requiring high-speed signal processing.

What is ATMAC?

The ATMAC microprocessor (Fig. 1) is composed of two VLSI (Very Large-Scale Integrated) chip types: a "data execution unit" for data manipulation and an "instruction and operand fetch unit" for memory addressing and program control. These chips are partitioned into eight-bit slices; however multiple chips can be assembled to construct a microprocessor with word lengths greater than eight-bits. A typical 16-bit microprocessor (see Table I) would require two of each chip type. In other cases, because of the flexibility of the design and the inclusion of several "byte transfer" instructions, systems may be configured where more than one of either chip type may be used. For example, two instruction and operand fetch unit chips may be used for addressing up to 65,536 words of data memory and program memory, and three data execution unit chips may be used to permit handling single-word data with precisions of up to 24 bits.

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Alan Feigenbaum recently joined the Engineering Communications section of RCA's Advanced Technology Laboratories, where he is involved with writing reports and proposals for various projects undertaken by the ATL group.

Contact him at: **Engineering Communications, Advanced Technology Laboratories, Camden, N.J., Ext. PC 2853**

Walt Helbig has been working in computer technology since he joined RCA in 1952. For the past two years, he has been Engineering Leader of the Architecture and Applications Group directing work in the areas of system design for LSI microprocessors, multiprocessors, fault tolerant processors, array processors, and associative processors. He is currently directing hardware and software design and implementation of the ATMAC microprocessor and CCD mass memory.

Contact him at: **Architecture and Applications, Applied Computer Systems Laboratory, Advanced Technology Laboratories, Camden, N.J., Ext. PC 5071**

Stan Ozga has been a major contributor in the design of several LSI computer systems since he joined RCA's Advanced Technology Laboratories in 1970. He is currently project engineer of the ATMAC micrprocessor, with prime responsibilities in architecture design, detailed logic implementation and system integration.

Contact him at: **Architecture and Applications, Applied Computer Systems Laboratory, Advanced Technology Laboratories, Camden, N.J., Ext. PC 3094**

Authors (left to right) **Feigenbaum, Helbig,** and **Ozga.** The control unit on the table is used for ATMAC program development.

ATMAC is also capable of a full computational repertoire, with throughput of millions of operations per second. The total amount of hardware necessary for a system is minimized, because ATMAC uses an eight-bit-slice partition for the two VLSI chips and bidirectional buses for interconnections with peripheral equipments and subassemblies. The bidirectional bus system (Fig. 2) reduces the number of connections between ATMAC and other units and is cost-effective. It allows ATMAC to communicate asynchronously with program memory, data memory, I/O devices, and special function units (such as a hardware multiplier or accumulator).

Additionally, ATMAC's architecture permits many operations to be performed in parallel. This provides ATMAC with substantial gain in processing throughput over other microprocessors that have equal or faster cycle times. It is organized to provide maximum flexibility in configuring a system for various applications, and can integrate into its operation one or more unique SFUs designed for a particular application.

ATMAC also has the ability to perform fast-fourier transforms (FFTs), which allow information to be extracted from signals in the time domain by transforming them into the frequency domain. The modular sections of an FFT program have been written for the ATMAC

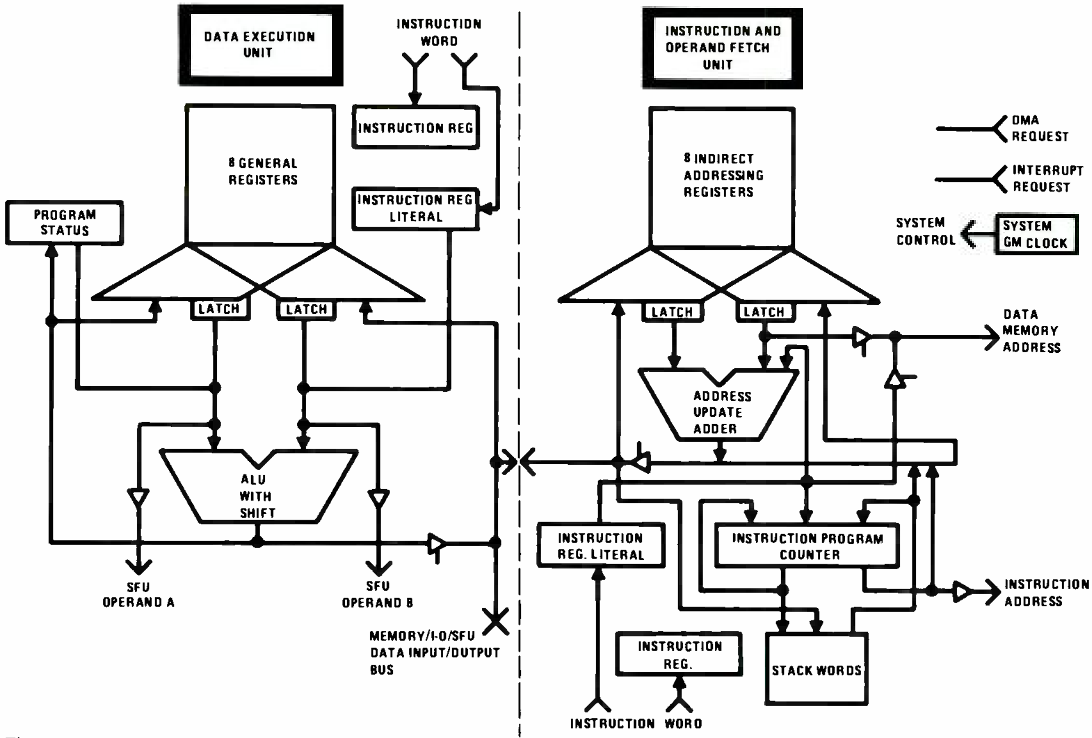


Fig. 1
ATMAC microprocessor consists of two chips: the data execution unit and the instruction and operand fetch unit.

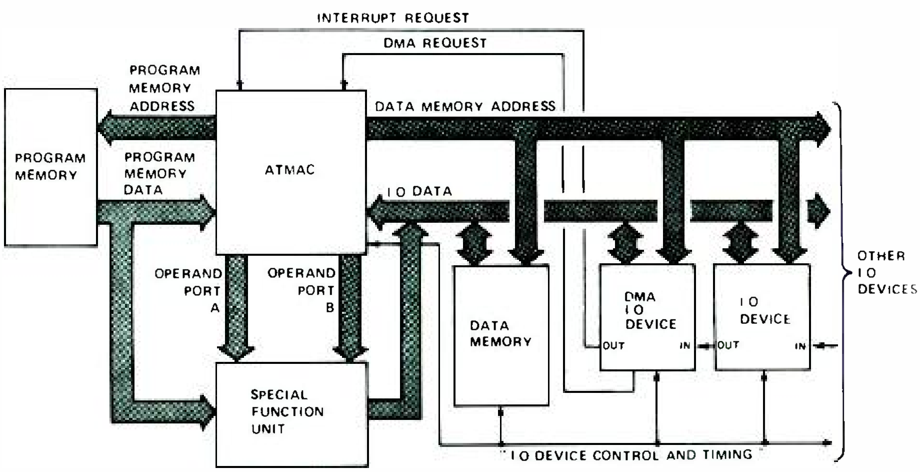


Fig. 2
ATMAC bidirectional bus system allows the microprocessor to communicate asynchronously with memory, I/O, and special function units.

Table I
Typical 16-bit ATMAC system consisting of two data execution units and two instruction and operand fetch units.

Data word length	16 bits (8-bit slices)
Memory address length	16 bits (8-bit slices)
Data memory	65,536 16-bit words
Program memory	65,536 16-bit words
Register complement	eight 16-bit general registers eight 16-bit indirect address registers one 16-bit program sequence counter four 16-bit program counter stack registers
Number of instructions	189
Instruction execution time	short cycle—280 ns Intermediate cycle—350 ns
DMA channel	One word every 700 ns
Support software	Fortran IV cross assembler Fortran IV simulator Scientific subroutines
Power dissipation	$\leqslant \frac{1}{2}$ W at 3×10^6 instructions/s

Table II
Fast-Fourier transform memory requirements and execution times for an ATMAC microprocessor with SFU multiplier.

No. of complex points	*Data memory words*	*Program memory words*	*Execution times (ms)*
4	32	16	0.0167
8	64	40	0.0519
16	128	88	0.1427
32	256	184	0.3638
64	512	376	0.8819
128	1024	760	2.0724
256	2048	1528	4.7598
512	4096	3064	10.7435
1024	8192	6136	23.9315
2048	16384	12280	52.7457

microprocessor so that the execution time, I/O time, scaling time, and memory-size requirements for both the program and data memory can be estimated. For many applications, the execution times are short enough to allow real-time FFT processing (see Table II). Results show that the ATMAC memory requirements for a moderate number of data points is very reasonable.

Data execution unit

The data execution unit performs arithmetic and logic operations defined by ATMAC's instruction repertoire. All the operations performed in this unit have operands derived from either the general register stack, an immediate operand from the instruction word, or a hard-wired literal. The operations are register-to-register oriented; results are stored in one of the selected registers and optionally sent over the I/O data lines to I/O devices, to data memory, or to the instruction and operand fetch unit (see Fig. 1). The main architectural features of the data execution unit include the arithmetic and logic unit, which performs all arithmetic operations specified by the executed instructions, and the general register stack, which is a quad-port, eight-word, scratch-pad memory used for arithmetic operand storage.

Instruction and operand fetch unit

The instruction and operand fetch unit is the control portion of the ATMAC microprocessor. It includes the following:

Indirect address register—a quad-port, eight-word scratch-pad memory used for indirect address storage;

Address update adder— a two's complement arithmetic unit used optionally to update the indirect addresses that are transmitted onto the data memory address lines;

Instruction program counter—a full length, double-rank counter responsible for instruction sequencing control, may be set with branch addresses;

Instruction program counter stack—a four-word last-in-first-out, register stack used for interrupt, subroutine, and iterative loop program linkages,

System clock;

DMA synchronization logic;

Interrupt control.

As in the data execution unit, the instruction and operand fetch unit is byte-expandable. Among its functions, it includes instruction sequencing, operand and instruction accessing, and data memory accessing. Its operations are completely independent and are performed in parallel with those of the data execution unit.

Data processing capabilities

ATMAC can perform, in single-step operations, many of the functions possible on one or two variables, such as:

The arithmetic operations, add and subtract, with options for handling double-precision arithmetic and multiply-and-divide step functions;

The logical operations *and, or, exclusive or*, and *complement* (either ones or twos),

The register-load operations—loading a register with the content of another register (copy), zero, positive one, and one more than, or less than, the content of another register,

Absolute-value operations—placing the absolute value of the content of one register into another, and the addition of the absolute value of the content of one register with the previous content of the register being used, to accumulate the sum.

ATMAC can also perform, with the use of one or two instructions, all of the possible test conditions on zero, one, or two variables and branch to a new point in the program execution if the test is successful. Further, with the use of one type of SFU, ATMAC can multiply two integers at high speed, multiply two fractions, accumulate the sum of successive double-precision products of the multiplication of two integers or fractions, and transfer the results directly into data memory.

Input/output capabilities

ATMAC is capable of transferring data to peripherals by the direct execution of an instruction or as an optional parallel function of many instructions. Direct transfers of data between two peripherals is accomplished by direct execution of an instruction, optional parallel I/O function of many instructions, execution of the direct memory access cycle, or an interrupt-driven I/O.

Memory addressing

Data memory (I/O device) addressing is done by using the content of one of eight indirect address registers, or by using a direct address contained in the immediate operand field of some of the ATMAC type II instructions. When the content of an indirect address register is used as the address, it may (through the use of a parallel operation) be modified so that it will have the proper value needed for its subsequent use.

Program execution control

ATMAC uses three types of hardware elements to control the execution of programs. These are the instruction program counter, the instruction program counter stack, and the iteration counters.

The instruction program counter is a double-rank counter that contains two addresses. The first rank contains the address of the instruction presently being executed and the second rank contains the

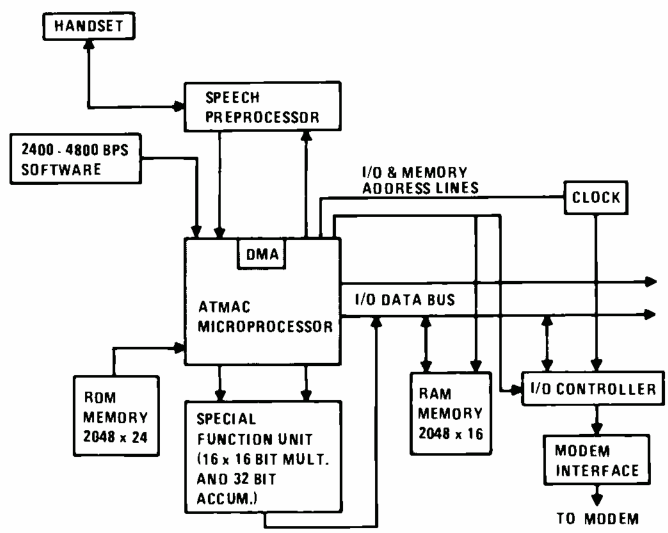


Fig. 3
Narrowband speech processing system uses ATMAC to provide the type of parallel operations and array processing needed.

address of the next sequential location in the program memory. A four-word, last-in-first-out register stack controls the program in nested loops, subroutines, and interrupts. When the present program sequence is broken by a transfer to some other routine, the content of the second rank of the instruction program counter may be "pushed" into the stack, thus moving all of the previous contents of the stack's four words down one location (discarding the previous content of the fourth word). For machine configurations using address lengths of sixteen or more bits, two iteration counters are provided. Separate controls are available for each of these counters so that, under control of the options provided in the instruction format, these counters may be individually tested and decremented.

Software support

In addition to the ATMAC microprocessor hardware, RCA has developed a complete software support package. An off-line cross assembler has been developed and is operational on the Univac Series 70/45 and DEC PDP 11/40 computers. The assembler is written in Fortran IV and is capable of translating user symbolic source code to object code, suitable for loading into the ATMAC program memory. The object code is loaded on 9-track magnetic tape and is also used as an input to the off-line instruction-level simulator, which is also written in Fortran IV. It is capable of testing the assembled software independently of the microprocessor and can determine how long it takes to run a simulated program. The simulator can view the computer state after each instruction or group of instructions and determine the content of each memory and register location. The major features of the simulator are user command language, detailed instruction simulation, I/O device simulation, DMA device simulation, output reports, debugging, and SFU simulation. In addition, a Fortran IV computer language and various mathematic routines are being written.

Applications

One of the first ATMAC applications was in the RCA narrowband digital speech processing system shown in Fig. 3.

This system required a high-performance processor that could perform all the arithmetic and logic functions of a secure terminal operating in a full-duplex mode, including the processing of the linear predictive coding (LPC-10) algorithm. RCA examined the major microprocessors on the market and concluded that none had the architecture or speed to perform the LPC-10 algorithm in real time. In fact, these microprocessors, including the bipolar bit-slice microprocessors, proved to be 2½ to 3 times slower and more expensive than ATMAC in speech-processing applications. ATMAC had the architecture that provided the type of parallel operation and array processing necessary for performing the LPC-10 algorithm in real time.

ATMAC is well adapted to controlling the multiple use of a network of communication channels.

This application enables time sharing (time division multiple access—TDMA) of transmission among a number of users. Control and use of a channel depend primarily on the operational needs of the particular group of users who have access to it. An entire subscriber unit can be controlled by ATMAC, which, by means of an address and data bus, controls other programmable hardware used for signal processing. In the receive mode, ATMAC performs a digital "automatic gain control," which maintains a selected output level. In the transmit mode, ATMAC can adjust the precise carrier frequency to ensure that the transmitted signal is received by satellite equipment with the same frequency as the channel control order wire (CCOW) transmission. CCOW allows operator access to transmission channels and other users to join the transmission net.

An avionics computer for a space-guidance control system is another unique application of the ATMAC microprocessor.

One of the requirements for such a system is that the microprocessor should be able to handle long word lengths—24 bits or more. Most commercial microprocessors (which can only handle 8- to 16-bit word lengths) are not expandable and, therefore, could not meet this particular requirement. ATMAC, on the other hand, can have at least a 24-bit word length by using three 8-bit-slice chips.

Another requirement for this type of system is that the microprocessor should be compatible with a flight-qualified core memory and simultaneously be able to execute elementary instructions. Since most flight-qualified core memories have a cycle time of 800 ns or greater, an efficient architecture with a fair degree of parallelism is required. ATMAC's efficient and high-speed throughput is able to meet this requirement.

ATMAC can provide a guidance control system with notable advantages in accuracy, reliability, vehicle attitude determination, redundancy mechanization, computer throughput and flexibility, and system growth potential. It can also serve as a preprocessor for a guidance-control system and perform thorough on-line self-check diagnostics.

RCA has proposed to use the ATMAC microprocessor in a fingerprint matching system for the FBI.

The FBI's current Automatic Fingerprint Matching Processor, which uses the M-40 fingerprint algorithm, has an average matching time, per pair of prints, of about 20 ms. The FBI would like to have a unit that could use the M-40 algorithm to perform four pairs of comparisons per hand in less than 10 ms. For this application, RCA has taken advantage of ATMAC's multiprocessor capability. While a single ATMAC microprocessor could perform the program execution in about 25 ms, a four-microprocessor system is capable, on the average, of processing the entire fingerprint-matching operation for one search-and-file comparison in 10 ms.

Several other applications have been proposed.

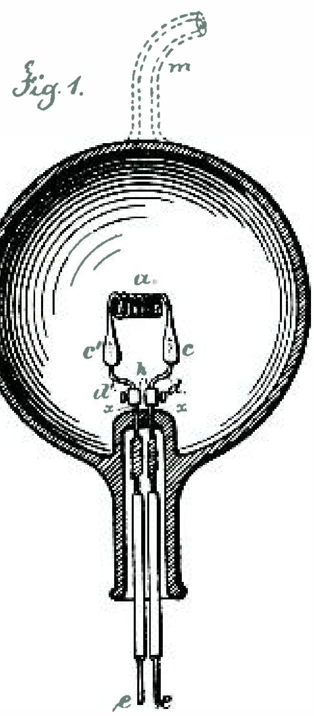
ATMAC can be employed in a Global Position Satellite system, where it would control range tracking loops, select a satellite for a navigation position fix, perform a frequency and time search for a time transmission (FFT), and give range readings for navigation position fixes. In other applications, ATMAC can be the basis for high-speed, low-cost, efficient, and flexible signal-processing systems for such projects as sonar signal processing, image bandwidth compression, and seismic data processing.

Conclusion

Because of its advanced architecture, expandable word length, ability to perform complex array computations, and interface with SFUs and other peripheral equipment, ATMAC can be adapted to almost any type of signal processing system at a very low cost. Incorporating the latest advances in CMOS/SOS VLSI technology and computer-aided design, this exceptional microprocessor may prove to be a trend setter in the field of signal and data processing.

"Congress shall have Power...
To promote the Progress of Science
and the useful Arts,
by securing for limited Times
to Authors and Inventors,
the exclusive Right
to their respective
Writing and Discoveries."

U.S. Constitution Article I, Section 8



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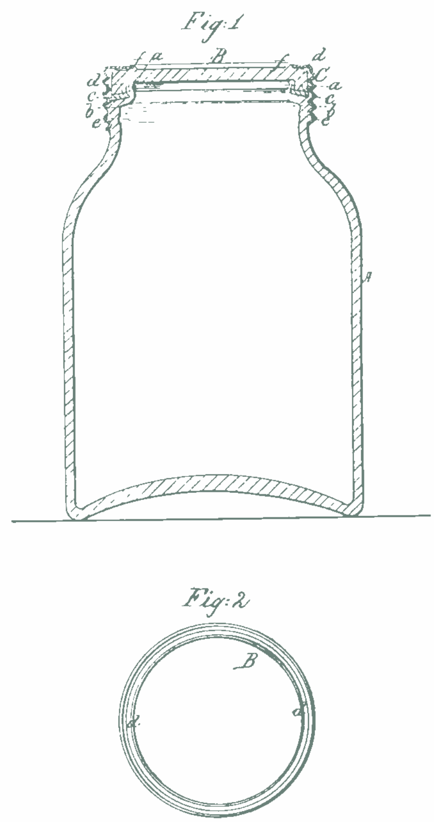

MASON U.S. PATENT 102,913

Development of the American patent system

B.E. Morris

American inventiveness has flourished under our patent system, but the first draft of the constitution didn't even mention patents. Even after the system began, it was beset with problems.

Governments began to grant individuals and businesses exclusive rights to make, sell, or use certain articles of manufacture or processes for making them in the Middle Ages in Europe, when it was necessary for governments to encourage risky ventures and trade with others. For example, Venice had a well developed patent system by the 15th century.

The English system

In England, it was believed the crown had the right to give to an individual an exclusive right to practice a certain trade, provided the public benefited. The earliest known grant of letters of protection was given in 1331 by Edward III to Flemish weavers so they would introduce their art to England. This and succeeding grants to other weavers gave rise to a flourishing cloth industry in England in the 14th century. These weavers did not invent this craft, but practiced it so the public could learn it and all would benefit, which England assuredly did. The earliest instance of a monopoly grant for a new process was given in 1440 to John of Shiedame for a salt-manufacturing process.

By Elizabethan times, quite a few patents were granted by the Crown, some of merit and some not. Patents were granted for various periods of time, and for the first time some were granted that deprived the public of a right to manufacture certain articles, such as playing cards, which were not new to the realm at all. Meritorious inventions, such as a stocking-knitting machine, were denied patent protection. Any disputes over the validity or enforcement of a patent could not be challenged in court, but were decided by the Crown. This arbitrary state of affairs was enhanced because the Crown could exact a percentage of the profits of a monopoly as the *quid pro quo* of granting it. This proved an ideal way for the Crown to circumvent the necessity of going to Parliament for all its financial needs. It was inevitable that abuses under such a system became rampant.

The House of Commons finally led a decisive protest, and Elizabeth I agreed to allow patent disputes to be heard in the courts. The leading Case of Monopolies, decided in 1603, held that the sovereign could not take anything away from its subjects, except by Act of Parliament, with two exceptions;

> "... that when any man by his own charge and industry, or by his own wit or invention doth bring in any new trade into the realm, or any engine tending to the furtherance of a trade that was never used before; ... the king may grant to him a monopoly-patent for some reasonable time, until the subjects may learn the same, in consideration of the good that he doth bring by his invention to the commonwealth, otherwise not."

The other exception related to grant of monopolies in printing—the forbear of copyright protection.

It should now have been made clear that monopolies were to be granted to inventors only, to protect the fruits of their researches, but abuses continued under the next monarch, James I. Eventually Parliament passed the Statute of Monopolies in 1624, codifying the principles enunciated by the courts in 1603. A fixed term of 14 years was set for a patent grant, which, however, was still granted only by the whim of the sovereign. The law also required that the subject matter of a valid patent had to be novel, at least in England, for the purpose of bringing new commerce into the realm. This Statute continued in full force and effect in England, and is still the foundation of the present British patent system. The laws were somewhat modified in the early 18th century when a requirement was added that a written specification describing the invention accompany the petition for each patent. The monopoly grant was limited to the subject of the specification.

In colonial America

What was happening on this issue, if anything, across the Atlantic? Having in mind the recent turmoil over monopolies in England, the early colonists banned monopolies, except "of such inventions as are profitable to the country," for limited times. Such a law was adopted by the Massachusetts colony in 1641, and in the same year its first patent, for a method of making salt by a new process (sound familiar?) was granted to Samuel Winslow for a ten-year term. But there was one great difference between the British and American systems—in the colonies, grant of a patent was obtained by way of a petition to the legislature, rather than to the governor or the Crown. The fundamental purpose of the patent grant was the same as in England, to stimulate and develop new industries.

Although many patents were granted by colonial legislatures in the succeeding 150 years, no fixed term for the grant of a patent was settled on, and no particular procedural rules for obtaining a patent evolved. Patents

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were granted by the several legislatures only upon petition, and some patents were refused. Since each legislature had powers of enforcement only within its own borders, an inventor would have to apply for a separate patent in each colony in which he hoped to do business. Many new businesses sprang up in the colonies without any patent protection. For example, Pennsylvania, one of the more industrially developed colonies, did not grant any patents before the Revolutionary War, although many industries flourished there. The colonies did recognize British patents, however, which were recorded in Pennsylvania. After the Revolution, Pennsylvania granted more patents than any other of the colonies, the first in 1780 for a currier's oil.

After the revolution

The Articles of Confederation had no provision for either copyright or patent grants. However, James Madison introduced a resolution recommending that the States pass copyright laws:

> "Resolved, that it be recommended to the several States to secure to authors or publishers of any new books not hitherto printed, ... the copyright of such books for a certain time not less than 14 years from the first publication ... such copy or exclusive right of printing, publishing and vending the same, to be secured to the original authors, or publishers, ... by such laws and under such restrictions as to the several States may seem proper."

The resolution was passed on May 2, 1783. Under the Articles, each state had to pass its own laws on the subject, and indeed, most of the States had passed copyright laws at the time of the Constitutional Convention.

The practice of granting patents by way of petition to the legislature did continue in a manner similar to that practiced during colonial times. However, there was no uniformity in either the procedure or rights under a patent among the several states, and jurisdiction was limited to the state of grant. Only one state had passed a patent law at the time of the convention, South Carolina, and this, as we shall see, became significant. In March of 1784, South Carolina enacted a copyright law in accordance with the Resolution of 1783, which further states:

> "The inventors of useful machines shall have a like exclusive privilege of making or vending their machines for the like term of 14 years, under the same privileges and restriction hereby granted to, and imposed on, the authors of books."

Thus, as our patent system evolved from the British system, the governments of the states recognized the value of an economic incentive, by ways of a limited monopoly or exclusivity, to encourage new industries and inventions for the benefit of all.

Patents in the Constitution

The Constitutional Convention, called in May of 1787, sought to create a government with national powers to which the states would be subordinate. After several months of discussions, the first draft of a Consitution was reported out on August 6, 1787. This report did not contain either a patent or a copyright clause. Nor did any of the original plans for a Constitution, submitted by the eminent leaders—Randolph from Virginia, William Paterson of New Jersey, Pinckney from South Carolina, and the five by Hamilton of New York. The proceedings of the Convention were kept secret, and notes of any of the delegates fail to reveal any discussion of a patent or copyright clause. After an additional two weeks of debate, on August 18 both James Madison and Pinckney submitted a draft patent clause to the Commitee on Detail. This was a committee of five delegates—John Rutledge, Edmund Randolph, Nathaniel Gorham, Oliver Ellsworth, and James Wilson—whose task was to reduce the resolutions of the Convention to writing.

Birgit Morris is a Managing Patent Attorney, Solid-State and Electronic Systems, Patent Operations. She joined RCA in 1971 and handles patent matters in the chemicals and materials areas.

Contact her at:
Patent Operations
David Sarnoff Research Center
Princeton, N.J.
Ext. 3249

The clause submitted by Madison read that Congress shall have power

> "To secure to literary authors, their copyright for a limited time. To secure to inventors of useful machines and implements, the benefits therefore, for a limited time."

Pinckney's clause read:

> "To grant patents for useful inventions; to secure to authors exclusive rights for a certain time."

Note one significant difference in the two clauses; whereas both men used the word "secure" with regard to copyright protection, Pinckney still uses the word "grant" with regard to patent protection.

The purpose of the patent clause, according to Madison, was "to encourage by premiums and provisions the advance of useful knowledge and discoveries." As he later reported in the *Federalist*:

> "The utility of this power will scarcely be questioned. The copyright of authors has been solemnly adjudged in Great Britain to be a right at common law. The *right* (emphasis added) to useful inventions seems with equal reason to belong to the inventors. The public good fully coincides in both cases with the claims of individuals. The State cannot separately make effectual provision for either of the cases, and most of them have anticipated the decision of this point by laws passed at the instance of Congress."
> (No. XL III)

The final draft of the Constitution was reported to the Convention by the Committee on Style on September 15, 1787. The patent clause was adopted without any controversy or debate in its present form. How and why the two clauses were combined into one has been lost; however, its basic purpose is certainly known to us.

The Constitution then was the first law, at least in Anglo-American jurisprudence, to recognize a property right in an invention, and indeed, is the only clause in the Constitution that bestows a private property right. The Congress was not to "grant" an inventor a favor, but to "secure" to him a right. The abandonment of words like "grant" and "patent" manifest that intention.

Early U.S. systems and their shortcomings

The first Congress under the new Consititution met in 1789. On April 15, the first petition for a copyright was presented; it was for two books by David Ramsey. Several more followed swiftly. Congress soon realized that it could not handle all these petitions, and that an administrative procedure would have to be set up. Separate copyright and patent bills were brought up in the first and second sessions of Congress, and a patent bill was passed on April 10, 1790. William Murray, a Congressman from Maryland who spoke for the bill, stated that our patent laws had to be different from those in England, where a patent was:

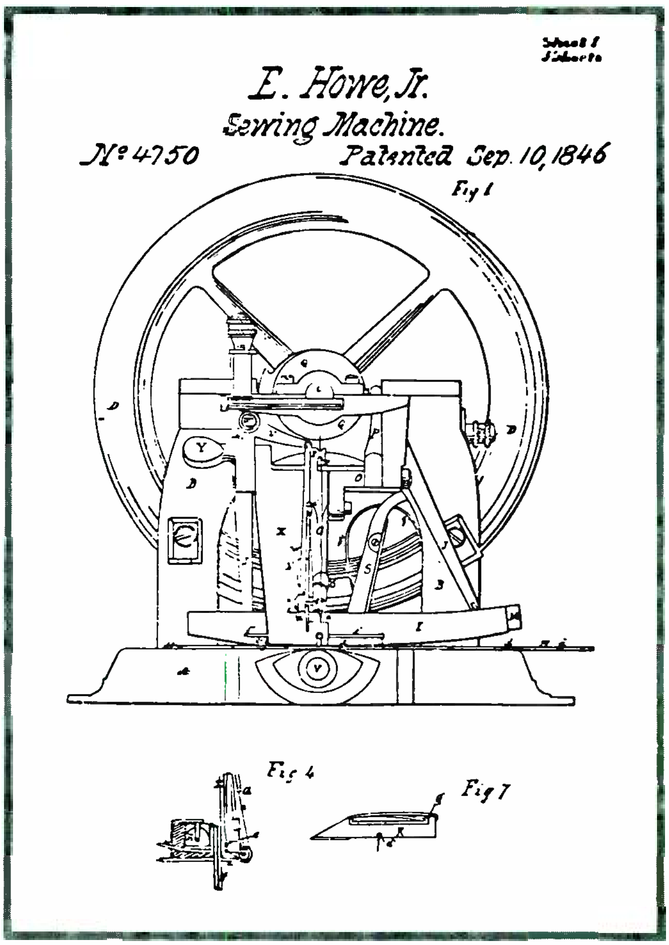
> "derived from the grace of the monarch. . .as a privilege bestowed and an emanation of the prerogative. Here, on the contrary, a citizen has a right in the inventions he may make, and he considers the law but as the mode by which he is to enjoy their fruits."

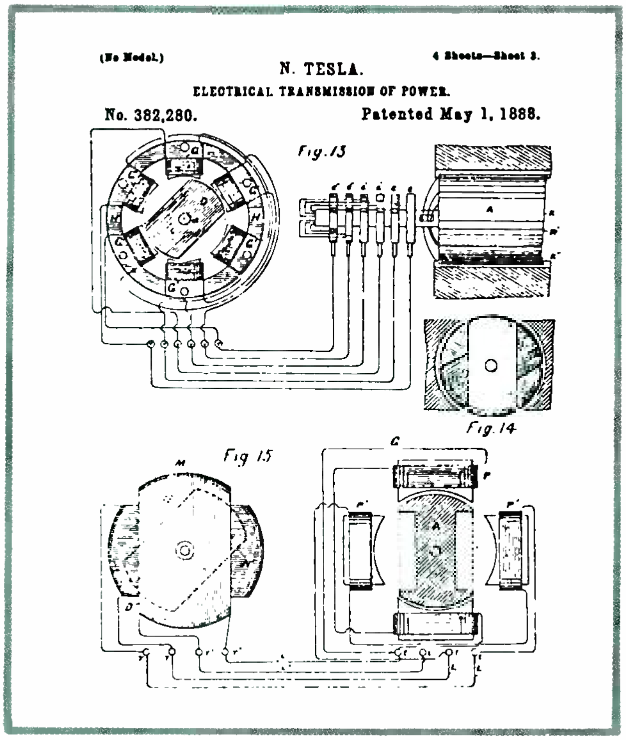
A board consisting of the Secretary of State, Thomas Jefferson, the War Secretary, Henry Knox, and the Attorney General, Edmund Randolph, was to determine whether to grant a patent. An inventor submitted a specification, a drawing, and a model, if possible. The invention had to be new and useful. The term for the patent had a maximum of 14 years, but could be granted for less. Jefferson was very interested in scientific matters and became a champion of the new patent system to encourage ingenuity. It might be mentioned that the first patent law did not preempt the field for the federal government—inventors could and did petition state legislatures for patents also.

Only 57 patents were granted in three years under the first patent act, although many applications were pending. Probably the high office of the original board members prevented them from spending enough time on patents, and in that sense the first Act was unrealistic. Also, the board's standards were high, and many patents were refused. Jefferson, recognizing these limitations, introduced a bill that went to the opposite extreme. The bill passed in 1793 eliminated all examination of patents and was, in effect, a registration bill.

Under the Act of 1793, patents were issued by the Secretary of State's office. In addition to the principal requirements of a specification, drawing, and model, the act also required by the inventor an oath stating that he believed that he was the first inventor.

In 1802 a separate Patent Office was created. The first Superintendent was Dr. William Thornton, who served until 1828. The Patent Office was his passion and he promoted it far and wide. He is credited with single-handedly saving the Patent Office building and its collection of models from destruction by fire during the British attack in 1812. Indeed, it was the only public building in Washington saved from the torch—Thornton pleaded that burning it would be akin to the burning of the library of Alexander, condemned since by all mankind! Sad to say, he only postponed the destruction, for models and records of the office burned accidentally in 1836.





By the 1830s the number of patents granted had greatly increased, and the problems of the registration system had become all too apparent. Many duplicate and overlapping patents were granted; some of them covered subject matter that was not new, and others were on frivolous subjects. By 1835, about 1000 patents a year were being issued and the courts were overwhelmed by lawsuits. The opportunity for obtaining fraudulent patents also vexed the public.

A new system in 1836

A one-term Senator from Maine, John Ruggles, now appeared on the scene. An inventor himself, he took an interest in the patent system and introduced a new patent law to restore the examination of patent application for novelty. This was passed into law in 1836 and forms the basis of our present system.

Under the new law, the patent application was to contain a written specification, a drawing, and a model if practicable, and the invention had to be new. The Patent Office acquired an examining staff and a library. For the first time a register of patents granted was to be maintained; our present system of numbering patents derives from 1836. Patent No. 1, incidentally, was granted to none other than Mr. Ruggles. The term of the patent was 14 years, extendible for an additional 7 years upon approval of the Secretary of State, the Solicitor of the Treasury, and the Commissioner of Patents. For the first time, an applicant had a right of appeal from the denial of a patent by the Patent Office. Many other provisions of this Act have been carried down to our present statute.

The passage of the Patent Act of 1836 coincided with the country's rapid industrialization and expansion westward. Whereas 80% of the U.S. population was engaged in agriculture in 1793, by 1840 the Napoleonic Wars in Europe had cut off our trade abroad and we were forced to manufacture our own machinery and goods. Railroads were being built and the telegraph had been invented; communication could now be maintained within the growing country. The seemingly inexhaustible supply of arable land to the west and the great shortage of labor called for more-efficient agricultural machinery and transportation. It cannot be denied that the new patent system contributed to the unleashing of American ingenuity and inventiveness. As Abraham Lincoln said, "the patent system added the fuel of interest to the spark of genius." Just a glance at the ever-increasing numbers of patents applied for and granted is convincing. The system would have fallen into disuse or been changed radically if it were not responsive to the peoples' needs. In 1790, as we have seen, 3 patents were granted, and that number increased to about 100 per year in 1807 and 200 per year by 1823. Contrasted with the 1000 per year granted after the 1836 Act, the number increased to about 10,000 per year by 1867, and 25,000 per year by 1900. One hundred years after that Act, about 50,000 patents a year were granted; today it is about 100,000 per year. The Patent Office has also grown; in 1836 there was a single examiner in the Patent Office. In 1936, the number had grown to about 670, and today there are about 1200. Back in the 1840s, an examiner in the Patent Office was reported to have resigned because everything important had already been invented. A man of little vision!

Our patent laws have been modified in certain respects since 1836; a major revision was instituted in 1870. It changed the term of a patent to 17 years, its term today, and decreed that, for the first time, patents were to be printed, with copies available to the public. The Commissioner of Patents was also authorized at that time to register trademarks, another recognition of the growth of consumerism. Another revision was passed in 1952, the present statute. One of the principal changes as far as the inventor is concerned was the codification of the requirement that an invention be unobvious to one skilled in the art, as well as novel and useful.

Conclusions

The American patent system has come under increasing attack in recent years, particularly by the courts and the Justice Department, for granting too many patents. The courts have invalidated many patents, most often on the grounds that the invention is obvious. The dange is that many inventions seem simple after they are made, even though the patented solution solved a problem that confounded many. But, it must be remembered that it is the weakly litigated patents that get to the trial stage, rather than the strong ones.

But as we have seen, the American inventor has a right to a patent; he need not come to the Patent Office hat in hand. Our constitution guarantees his right to a patent in the same way it guarantees him the right to free speech, suffrage, or practice of his religion. American inventiveness has flourished under the patent clause, and undoubtedly will continue to do so, so long as we remember its basic purpose and continue to enable inventors to recoup their original investments for the ultimate benefit of us all.

Computer-controlled voice/data switching system

D. Segrue

An order of magnitude faster than manual switching, computer switching allows international businesses to send and receive hundreds of priority data messages per day while still maintaining voice transmission capabilities.

Present-day international telecommunications systems are designed to carry voice or data plus several channels of teletype information. In such systems, speech multiplexers are used to multiplex the telegraph signals with the data or voice and provide an arrangement that allows the system to be switched to a switchboard for voice or to a high-speed modem for data. Fig. 1 illustrates such a system that uses manual switching between data and voice and also has simultaneous teletype operation.

Until recently, system switching has been manual at both the domestic and foreign terminals. This type of operation is suitable for batch or low-priority data transmission to and from a central computer center and satellite computers or remote-job-entry terminals. However, manual switching is unsuitable for those users that have day-to-day business activities requiring the sending and receiving of hundreds of priority messages to distant locations while maintaining voice calling capabilities. This is because the switching set-up time, which is the time needed for coordination purposes between terminals, can range from 3 to 5 minutes, depending upon the type of operation and the efficiency of personnel.

Table I
Comparison of transmission capabilities shows the great advantage that computer-controlled (CCAVD) systems have over manual (MAVD) switching.

Number of transmissions[1]	*Transmission time (seconds)* CCAVD[2]	MAVD[3]
1	8.00	180
2	16.00	360
3	24.00	540
4	32.00	720
5	40.00	900
6	48.00	1080
7	56.00	1260
8	64.00	1440
9	77.00	1520
10	80.00	1800

[1]Message length 2,000 8-level characters at 4800 bps. Combined data set and terminal synchronization time is approximately 70 ms.

[2]Includes warning time.

[3]Estimated coordination time is 3 min.

CCAVD overview

To meet the requirements of large message volumes while maintaining effective voice operation, RCA Global Communications, Inc. has designed and implemented the Computer Controlled Alternate Voice/Data (CCAVD) switching system, which automatically transmits and receives several hundred messages per day with minimal interruption to voice. Table I compares the message transmission capabilities of the CCAVD and manual (MAVD) systems. It is clear that CCAVD is an order of magnitude faster than the MAVD system.

System description

The CCAVD switching system (Fig. 2) consists of a master switch unit that is controlled by signals from the user's central computer, a remote slave switch unit located at the distant end of the communications network, and two manual transmission selectors collocated with both master and slave switches. The manual transmission selectors allow either the overseas or domestic terminals to inhibit computer control for transmitting batch data in cases where large volumes of data are required to be sent without interruption by voice. The master switch unit contains control logic and associated circuitry to provide the following functions:

- Decoding/controlling
- Telemetry signal generation
- Switchboard interfacing
- Telemetry signal detection
- Line switching
- Manual transmission selection

The slave switch unit is functionally the same as the master except that it does not have a decoder/controller.

System operating modes are selected by depressing either "auto" or "manual" pushbuttons on the manual override selector. The automatic mode puts the system under computer-program control. Table II presents a listing of the telemetry signals generated under computer control.

When the decoder/controller receives command *A* it has the master unit transmit a 1000-Hz warning tone for 3.0 seconds. This tone notifies callers that the system will be switched to data for the transmission of a high-priority message. When command *B* is received by the decoder/controller, the system switches from voice to data. Simultaneously, the master unit transmits an inband telemetry tone of 1500 Hz, interrupted at a rate of 100 Hz and lasting for 200 ms, to the slave unit, switching it from voice to data. In addition, upon receipt of this command, the decoder/controller provides a control signal so that if a call is interrupted, it will remain established for up to 20 seconds. At the remote location, the slave unit performs an identical operation on the call signal upon receipt of the telemetry signal.

Command *C* switches the master unit from data to voice and at the same time sends an inband telemetry signal at 2100 Hz, interrupted at a 100-Hz rate and lasting for 200 ms, to the slave unit, switching it from data to voice. The decoder/controller then applies a control signal to the call interface unit, reverting it back to a "call in progress" if the data transmission is less than 20

Table II
Telemetry signals initiate switching automatically.

Signal	*Function*	*Initiator*
A	Warning tone	Master
B	Voice-to-data switch	Master
C	Data-to-voice switch	Master
D	Data-to-voice switch	Slave
E	Computer-inhibit voice and voice-to-data switch	Slave

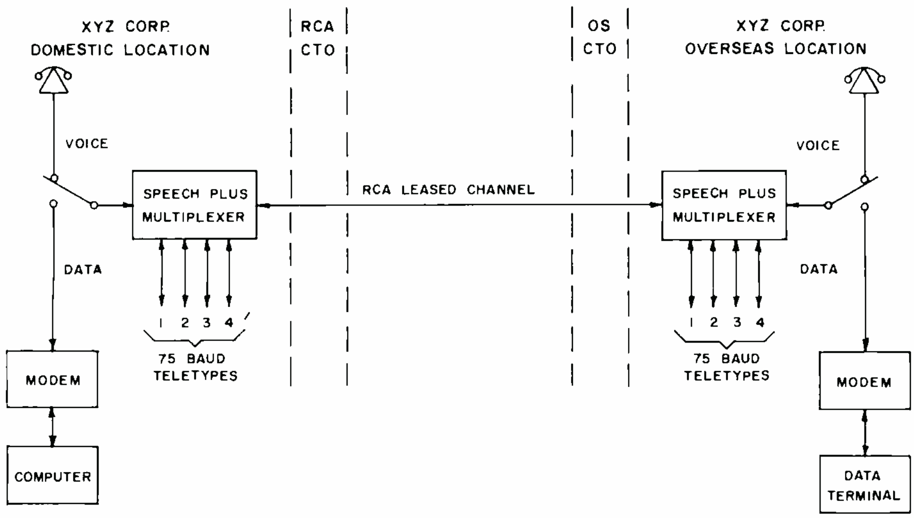


Fig. 1
Typical voice/data and TTY system using manual switching may require up to five minutes for switching between voice and data communications.

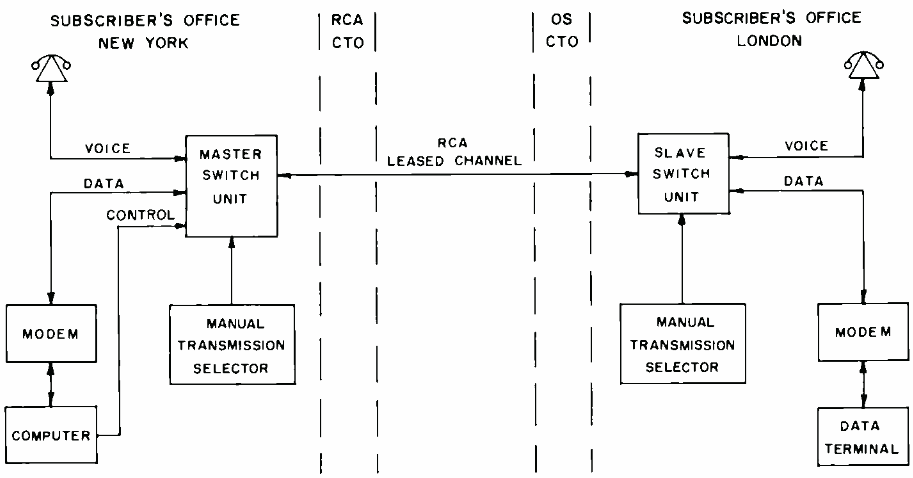


Fig. 2
Computer-controlled alternate voice/data (CCAVD) switching system can send and receive several hundred messages per day with minimal interruption to voice communication.

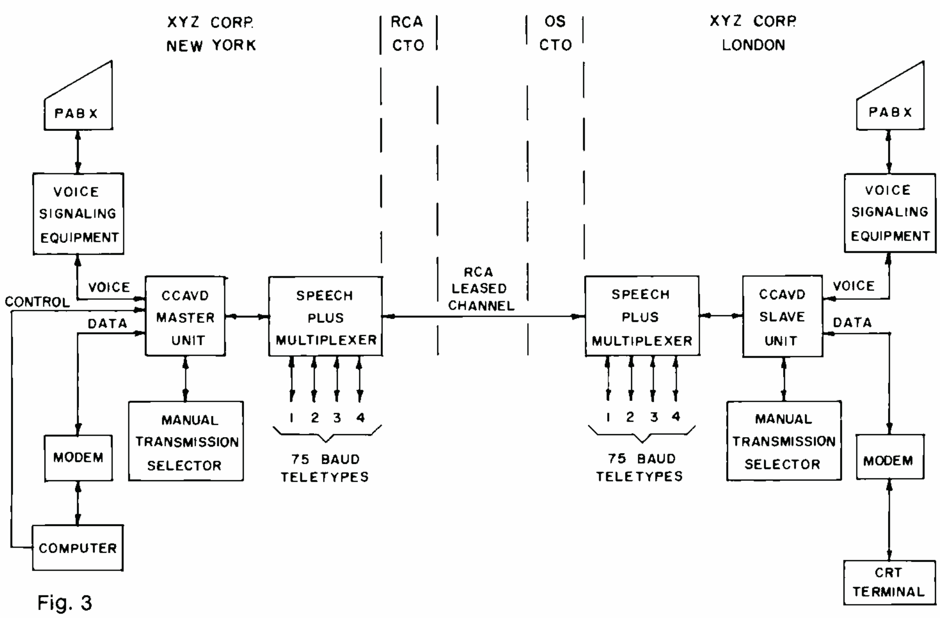


Fig. 3
This CCAVD system was designed for a precious-metals trading company that wanted to transmit market quotations between its New York and London offices.

seconds, or to an idle condition for transmissions over 20 seconds. The slave unit performs an identical function upon receipt of the telemetry signal.

A working CCAVD system

A first-generation CCAVD system has been designed and implemented for one of the largest precious-metals trading companies, which wanted to transmit the current market quotations to its traders' CRT displays in London and New York. Fig. 3 is the system flow diagram for this RCA leased-channel subscriber. The system provides two services: computer-controlled line switching between switchboard and modems; and simultaneous transmission of three telegraph channels with line-selector capabilities.

In the voice mode, the subscriber PABX is interconnected, via the international telecommunications channel to his London phone PABX, allowing calls to be set up between New York and London. Interfacing to the channel is accomplished by speech-plus multiplexers located in New York and London, which, via frequency division multiplexing, enable telegraph signals to be transmitted independently of voice or data to locations not served by the CCAVD system.

The CCAVD is interconnected to the speech multiplexers on a full duplex basis. Both the New York and London telephone systems are interconnected to the CCAVD via voice-signaling equipment. Interfacing to both data modems is done on a 4-wire basis, and computer control signals, in the form of a 1200 bit/s asynchronous serial data stream, are transmitted to the master unit's decoder/controller section.

Assume the system is in the automatic mode and both the New York and London telephone systems are connected. Under computer control, the system is about to be switched to data. The computer will transmit an *A* control signal to the master unit, having it transmit a 3-second warning tone to both the New York and London phone systems, to warn any callers that a switch to data is imminent. After 3.5 seconds, the computer transmits code *B*, switching the master unit to data, thus connecting the New York modem to the international channel. At the same time, the master unit also transmits telemetry tone *B* to the slave switch unit, switching it to data and connecting the London modem to the channel.

At this time, each modem automatically equalizes with the other and raises its "clear-to-send" control signal to the synchronous computer port, allowing CRT data to be transmitted. Upon completion of the data transmission, the source program simultaneously has command *C* transmitted to the master unit, returning it to voice, and telemetry tone *C* to the slave unit. This telemetry tone returns the slave unit to voice and reestablishes a call if one was interrupted for the data burst.

Data transmission can be initiated by the London CRT operator by switching the transmission selector to "manual." This switches the slave unit to data and transmits a telemetry signal to the master unit, producing a switch from voice to data and a computer-control inhibit condition. Upon completion of the data transmission from London, the London CRT operator selects the automatic mode on the manual transmission selector, which switches the slave unit to voice and transmits a telemetry signal to the master unit. This telemetry signal releases the inhibit and also returns the system to voice.

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Multi-link switching

The CCAVD system can also find application in multi-link computer-controlled alternate voice/data line switching systems. The central computer would control the data/voice switching on each independent link. For example, the operation between remote location 1 and the central computer could be in voice, while the link between the central computer and remote location 2 could be in data. To provide the capability of data transmission from remote locations to the central computer, there are manual override capabilities at the remote and central computer locations.

Fig. 4 presents a multi-link CCAVD switching system. As presented, the system is capable of supplying:

1) Voice/data communications between the central location and either remote location, or between remote locations.

2) Independent switch control of each link by the central computer.

3) Manual override capabilities.

In order to transmit data beteen remote locations, an applications program capable of responding to line switching commands from the remote job entry (RJE) terminal, is required.

This is how the system would work.

At remote location 1, selecting the manual mode has the CCAVD switching on that link switch to data and inhibit computer control. Next, the operator at location 1 would input a request to the CPU, via the RJE, to switch the link connecting remote location 2 to the central computer. If this link is available (not busy with data), the CPU switches it to data. During this time, a "not busy" response is displayed on RJE 1. After a few seconds, an acknowledgment signal is sent from location 2 to location 1, and data transmission can take place. Upon completion of the data transmission, the RJE 1 operator inputs an end-of-message code into the central computer, which then switches link 2 to voice and sends an acknowledgment to remote location 1. Upon receipt of this acknowledgment, the operator at remote location 1 switches the system to auto, reverting link 1 to voice and releasing the computer-control inhibit, thus restoring complete system control to the central computer.

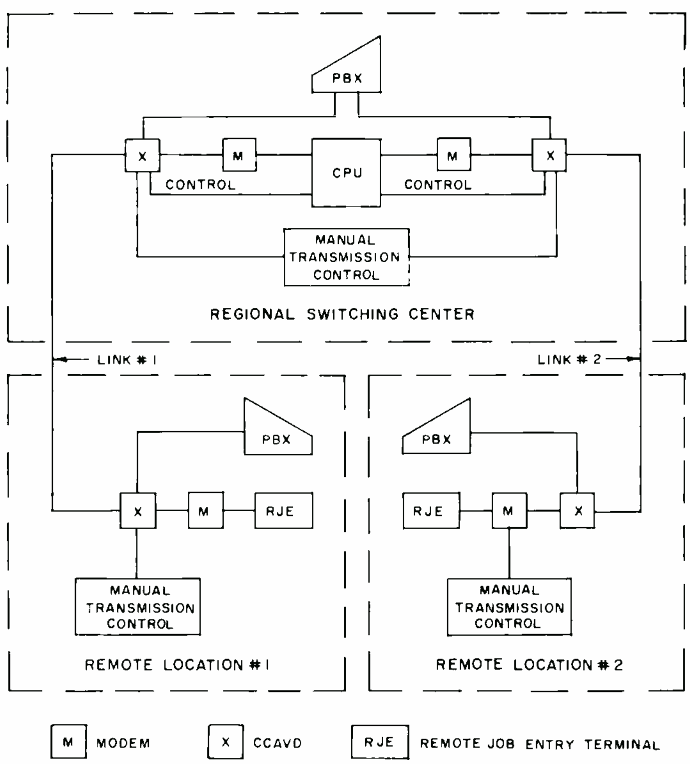

Fig. 4
Multi-link CCAVD system can control voice/data switching at a number of locations.

Dan Segrue joined Globcom in 1970 as a design engineer. His duties have included designing a speech bandwidth reduction system and special-purpose equipment for Leased Channel subscribers. Presently, he is responsible for the planning, design and implementation of international communications systems.

Contact him at:
Leased Service Engineering
RCA Globcom
New York, N.Y.
Ext. 4157

NBC Engineering—a fifty-year history

W.A. Howard

NBC engineers have scored numerous broadcasting "firsts" over the past fifty years in fields ranging from the first "engineered" radio studios to color television.

When NBC was formed in September 1926, the young radio industry was in relative chaos—radio pirates and frequency jumpers were ruling the airwaves. Equipment, including microphones, was primitive; transmitters were only 5 kilowatts, as compared to today's 50 kilowatts; studio facilities were grossly inadequate; acoustics was practically an unknown science; technical standards had not been established; and there was practically no control over frequency allocations.

Radio—from novelty to network

Nonetheless, there was a tremendous increase in the number of radio stations in the early twenties, from 600 in 1922 to 1400 by 1924. Most of these stations were operated as promotional sidelines or as hobbies by businesses such as Westinghouse, General Electric, Wanamaker's, Bamberger's, and the Telephone Company. KDKA, one of the first stations on the air in the United States, was typical—it operated from a cloakroom at the Westinghouse meter factory in Pittsburgh.

The young industry lived temporarily on the novelty factor, but as the novelty wore off, the mortality was high. From 1924 to 1926, the year NBC was formed, the number of stations had declined from 1400 to 620. The improved programming that came with the network had a great deal to do with keeping the entire radio industry from disappearing.

At the time NBC was formed, its ownership was divided among General Electric (50%), Westinghouse, (20%) and RCA (30%). The NBC Engineering Department began in September 1926, when it was formed of engineers from radio stations WEAF and WJZ, in New York, and the American Telephone and Telegraph Co. (AT&T). WEAF and WJZ (NBC's only properties at that time) were pioneer radio stations in New York, and their engineers were the most experienced in the new technology of broadcasting at that time.

On January 1, 1930, as part of a comprehensive unification plan, RCA acquired the General Electric and Westinghouse interests in NBC. Since that date, RCA has been the sole owner of NBC.

The NBC network's first studios were in the AT&T Building on lower Broadway, New York, that was the home of WEAF, originally owned by the Telephone Company. The facilities were inadequate for NBC's operation, and on October 1, 1927 the young network moved into new studios at 711 Fifth Avenue, designed and constructed by the NBC Engineering Department.

The first "engineered" studios

The designing of these studios on Fifth Avenue was the first major project undertaken by the new engineering department, and this resulted in many "firsts" in the industry. For the first time in broadcasting history, studios and control rooms were constructed with sound-isolation materials; each studio had its own individual control room, which was sound-isolated with a triple-glass observation window to its associated studio. The complete studio plant was air-conditioned—another first—temperature and humidity were held constant throughout the year.

In designing these eight studios, the NBC engineers began to experiment with reverberation control in studio space. Many new acoustical treatments were tried; provisions for adjustment were made by including generous amounts of draping. These developments in architectural design, sound isolation, acoustic treatment, air conditioning, and technical facilities became the basis for building all future NBC studios, and many became industry standards.

Radio City

The wide acceptance and rapid expansion of the network put a new demand on NBC; the studios on Fifth Avenue were soon outmoded. In 1930 the NBC Engineering Department was called upon to begin design and construction of a large broadcasting center in the huge Rockefeller Center Complex, with the plant and studios to be constructed according to NBC specifications.

No effort or expense was spared to make this center the finest in the broadcasting world. Sound isolation and acoustical materials were tested to determine the best available at that time, and every new proposed feature was tried in model form before incorporating it into the plan. It was here the "floating studio," or studio-within-a-studio, concept was developed, where the inside walls of each studio were sound-isolated from the outside walls and from the main building structure. This prevented the sensitive microphones from picking up the rumble and noise from subway trains and street traffic. These developments provided the new studios with the best acoustics and sound-proofing in the world.

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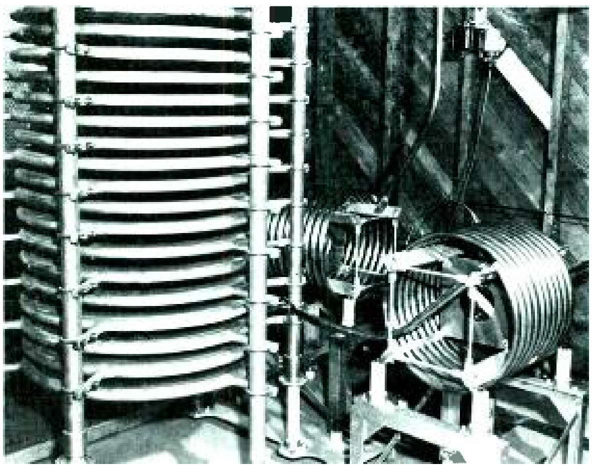
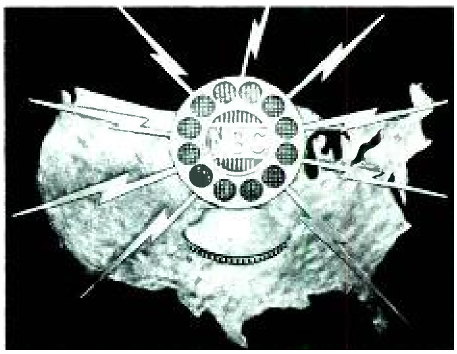
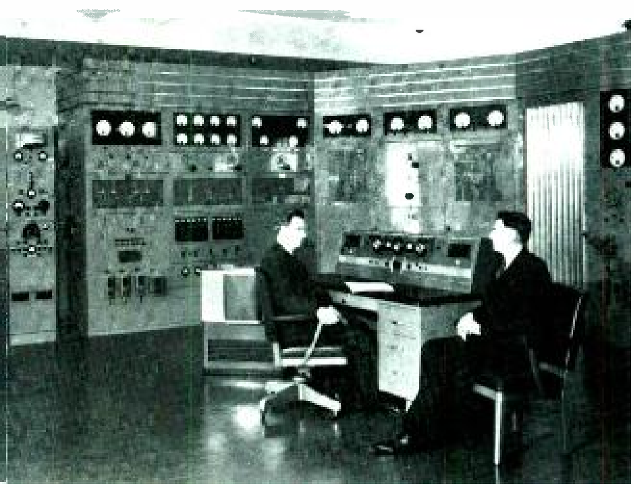
Ed Note: This engineering history of NBC is divided into two parts; this part ends with the early days of commercial television. The second part, to be published in our next issue, deals with the growth of television, color tv, and some specific contributions from NBC engineers.

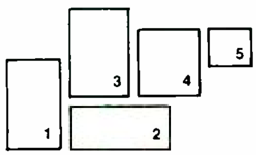
In researching this paper, Bill Howard compiled far more material than we could use in our two-part series. Cutting the number of photographs to what you see here was difficult; it seemed that each one deserved a place. For readers interested in exploring broadcasting history further, the second part of the series has an extensive bibliography.

Also, a note is in order on the perspective taken in this history—an NBC perspective, which naturally excludes the developments that took place in the rest of the industry. In particular, the many contributions of engineers working elsewhere in RCA and at the other networks and manufacturers are acknowledged, but not covered here.









1 100-kW transmitting tube used in the WEAF transmitter output stage during the 1930s; two tubes in push-pull provided the 50-kW output to the antenna. Picture was taken in the entrance lobby of the WEAF transmitting building, which is rather ornate by today's standards. **2** Transmitter console at the WEAF transmitter at Port Washington, L.I. Engineer Lester Looney is at the console. **3** Transmitter engineer at the control console of the WEAF transmitter in the early 30s. Note the microphone for standby announcements. **4** Output transformer on the WEAF transmitter, Port Washington. **5** This logo was evidently the first one for the NBC network at its beginning in 1926. The microphone in the logo is one of the carbon-mike types used at that time.

The first program originated from the studios at the new facility, which was named Radio City, on November 13, 1933. There were 34 studios, a master control, and a transmission facility that could service two independent networks. Radio City's large relay switching system could accommodate 48 separate program-originating points and 14 outgoing channels through an automatic preset system.

The basic principles of this system became the basis for a number of switching systems designed by NBC Engineering for radio and television, with many of these being replaced only recently with the modern solid-state switchers. The big horseshoe master control room was in constant use until 1963, a span of 30 years, and the transmission facility was used until 1973.

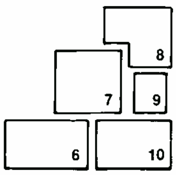
All the Radio City studios were two floors high, with observation rooms on the second floor for visitors, guided tours, and clients. The largest and most famous studio, 8H, could seat 1500 and became the home of the world-renowned NBC Symphony Orchestra conducted by Arturo Toscanini.

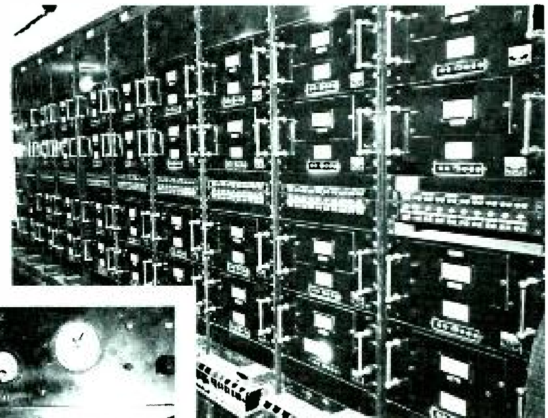
The Red and Blue networks

The first program originated by NBC in 1926 was carried by 21 radio stations, extending as far west as Kansas City. NBC established the first formal, full-fledged network organization supplying regularly scheduled programs, news, and special reports to independent stations across the country that soon became known as "affiliated stations." (There had been a few earlier group hookups of an experimental nature for specific events by independent stations, however.)

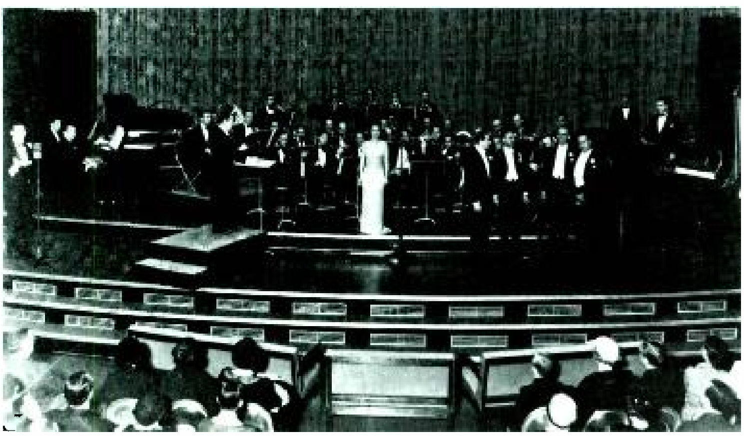
The expansion of the network was rapid, going from 19 stations in 1926 to 180 ten years later. NBC purchased additional stations including WTAM, Cleveland, in 1930, KPO, San Francisco, and WMAQ, Chicago, in 1931 and KOA, Denver, in 1941.

The widespread demand for network service led immediately to the establishment of a second network on January 1,





6 Radio City Studio 8G during a live network performance with audience participation. Frank Black at the piano with the "Ravlers" quartet. **7** Monitoring the Red and Blue Networks, WEAF, and WJZ from the NBC master control room. **8** Racks of NBC/RCA-designed audio amplifiers that went into service at Radio City in 1933 and were not completely phased out of service until 1976. Amplifiers were dc-operated (note dc breakers at bottom). **9** Standard logo used on the condenser microphone. **10** The famous horseshoe master control for NBC's Red and Blue networks. Installed in 1931/32, it was in use until 1964.



1927. NBC engineers named the two networks the Red and Blue, coming from the manner in which the two networks were designated on maps showing network coverage. A special Pacific Coast Network of seven stations was also created in early 1927 to accommodate the time zone difference. By the end of 1941, NBC had 243 stations listed as affiliated stations, including the six NBC-owned stations serviced by the two networks.

In May 1941, after extensive hearings, the FCC decreed that no organization could control more than one broadcasting network. In compliance with this ruling, RCA segregrated the assets and operation of the Blue Network in January 1942 by organizing a separate subsidiary, the Blue Network Company, Inc. In October 1943 this company was sold to Edward J. Noble and under its new ownership the company was renamed the American Broadcasting Company Inc., the third major network in the United States.

International short-wave broadcasting

Another phase of NBC engineering efforts that had a tremendous influence on international relations and news coverage, especially during World War II, was research and experimentation in short-wave broadcasting.

From 1926 to 1929 NBC short-waved programs abroad intermittently with assistance from RCA Communications, Inc. By 1939, when Hitler invaded Poland, NBC had engineered and installed two powerful short-wave radio transmitters at Bound Brook, N.J. Programs and news in Spanish, Portuguese, German, French, Italian, and English were beamed by directional antennas to Latin America, Europe, and the Far East.

During World War II, the U.S. government contracted for full-time use of NBC's international transmitters at Bound Brook. With assistance from NBC Engineering, the government expanded the facilities at Bound Brook and built three additional short-wave transmitters at Dixon, Calif. These facilities at Bound Brook and Dixon were operated and maintained under government contract by NBC engineers.

At the end of World War II, the State Department took over the licenses of the short-wave transmitters at Bound Brook and Dixon and subsequently transferred these facilities to the United States Information Agency for the Voice of America. NBC engineers continued operating these transmitters until 1963 in California and 1964 in New Jersey.

The birth of television

Even before NBC was formed in 1926, RCA was engaged in intensive television research. Immediately after NBC was established as a company, the NBC Engineering Department joined RCA in a joint effort of developing and field-testing a television system for public broadcast.

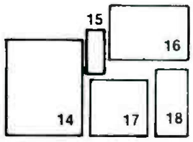
Felix the Cat became the first television performer in 1928.

In 1928, RCA and NBC engineers began operating the first experimental television station, W2XBS, in Van Cortland Park, New York City. Its power output from the transmitter was 250 watts. The system produced a barely recognizable image on a screen about the size of a playing card, but it was television. The camera system was a 48-line mechanical scanning system using a rotating disc and four large photocells for light pickup. The image scanned was Felix the Cat, bathed in high-intensity light and rotating on a windup turntable to provide a moving object.

11 The first television camera used a 48-line mechanical scanning disc with four photocells for light pickup. Experimental station W2XBS was located at Van Cortland Park, New York. **12** The first television star, Felix the Cat. Felix was bathed in high-intensity carbon-arc light and rotated on a turntable to demonstrate tv's motion-capturing ability. The image was barely the size of a playing card. **13** The first NBC television logo.

Aside from being cumbersome, this mechanical system presented a number of severe problems. In order to reconstruct the electronic signal into an image at the receiver, a rotating disc identical to the one at the camera was necessary. Both discs had to rotate in precise synchronization.

On January 16, 1930, an audience in the Proctor Theatre, 58th Street and 3rd Avenue, New York, watched a program projected on a six-foot screen; the program originated at NBC's Fifth Avenue Studios. On July 30 of that year, NBC engineers began operating experimental station W2XBS on a regular basis.



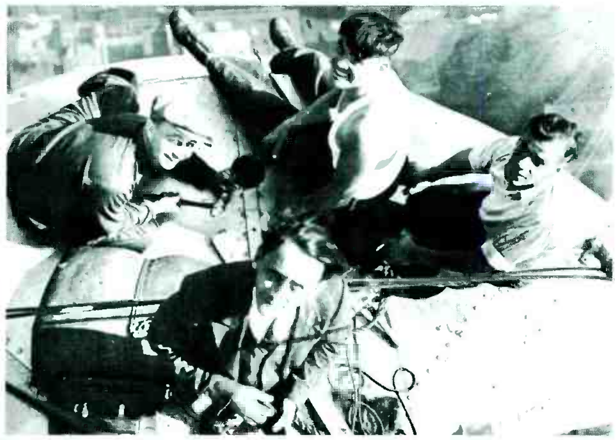
14 The first experimental television antenna, installed on the then-new Empire State Building, broadcast its first signal on October 30, 1931. **15** NBC logo on the induction microphone used during this period. **16** Workmen installing the first television antenna on top of the Empire State Building; NBC engineer supervises. **17** TV antenna of the later 30s on top of the Empire State Building. Design, construction, and installation were supervised by NBC Engineering. **18** New multiple antenna installed in 1950 broadcast five tv and three fm stations. NBC got the top spot because of its long history of tv transmitter development for the Empire State Building.

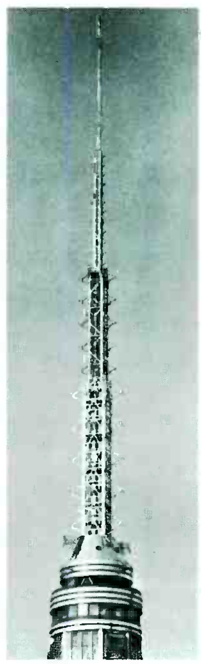
October 30, 1931 saw the establishment of a New York, and television, landmark. Atop the Empire State Building, the world's tallest skyscraper at that time, NBC engineers erected the transmitting antenna for W2XBS as a predecessor to WNBT, America's first television station. The television system now employed 120-line mechanical scanning at the camera, with an all-electronic receiver.

The mechanical tv system gave way to an all-electronic system in 1933.

In 1933 the invention of the iconoscope pick-up tube by Dr. V.K. Zworykin, a distinguished scientist at the RCA Laboratories, eliminated mechanical scanning at the transmitting end of the system. Since the development of the kinescope for the receiver had recently been announced, the RCA television system now became all-electronic. These two developments laid the groundwork for a television system that eventually surpassed all the expectations of the RCA and NBC engineers working at that time.

NBC began broadcasting programs using 240-line pictures from the Empire State Building transmitter on the new all-



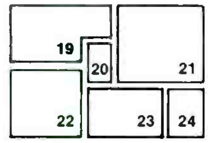


electronic system in 1933. On June 29, 1936, the Empire State Transmitter, reconstructed on the basis of earlier tests, began broadcasting programs with 343-line pictures; in January 1937, the scanning lines per frame were increased to 441. By 1938, experimentation and field tests by NBC and RCA engineers had reached a stage where they determined that television could soon be offered to the public.

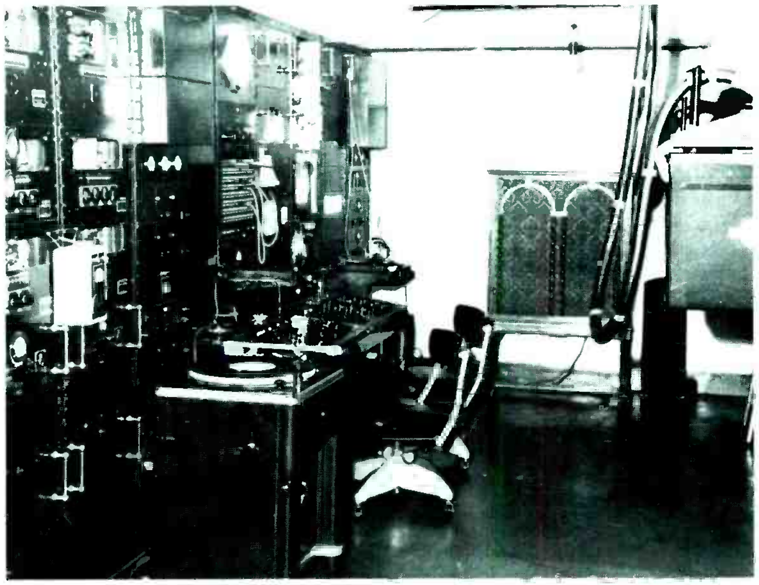
On April 30, 1939, NBC inaugurated America's first television program service to the public at the opening of the New York World's Fair.

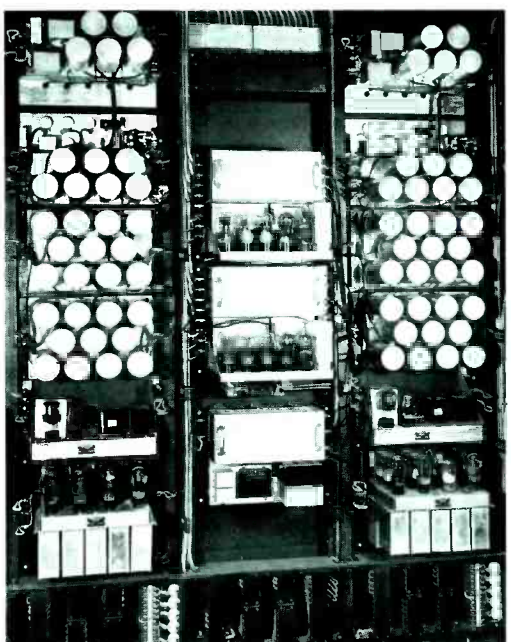
Among the participants in this historic telecast were President Roosevelt, the first Chief Executive ever to be televised, and David Sarnoff, RCA Chief Executive Officer. With the exception of brief interruptions necessitated by changes in frequency assignment and standards, NBC's New York station has telecast regularly scheduled programs continuously since that date.

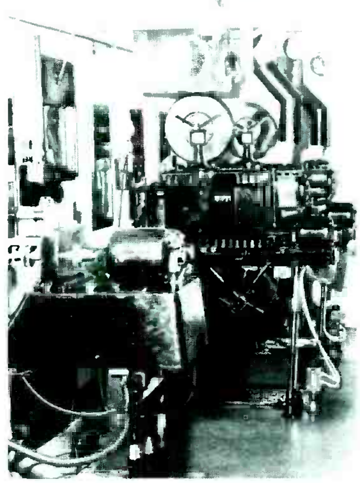
In March of 1940, the FCC announced its unwillingness to approve current technical standards for television and appointed an industry committee, the National Television Systems Committee (NTSC), to recommend new standards. NBC engineers took an active part in this committee and had members on many of its task forces. A majority of the field testing of the new standards was done in NBC's live studio 3H and film studio 3K in Radio City; the NBC transmitting facilities on the Empire State Building were also used. By 1941 the NTSC had issued its report and the new standards were adopted for black-and-white television in the United States using 525 scanning lines. These standards, with minor modifications, are still in force today.



19 Experimental television studio 3H in 1938. Cameraman Al Protzman operates an iconoscope studio camera which required 2400 foot-candles of light for some sets. Betty Goodwin was NBC's first woman announcer. **20** This NBC logo was used from the 1930s until the early 1950s. **21** Early tv film work was done in Studio 5F; camera (at right, with large cable) was mounted on tracks and moved to projector ports as needed. **22** Synch generator panel for experimental television transmission. **23** Experimental Studio 3H, where most of the control procedures for television were worked out. **24** Studio 5F film projection room, which was installed in the 1930s. Projectors used 5-amp carbon-arc light sources.







In June 1941, six months before Pearl Harbor, NBC's television station in New York received the first commercial license in the United States and changed its call letters from W2XBS to WNBT. The first commercial television service was inaugurated on July 1st of that year with four advertising sponsors: Bulova Watch, Lever Brothers, Sun Oil, and Proctor and Gamble.

NBC Engineering and World War II

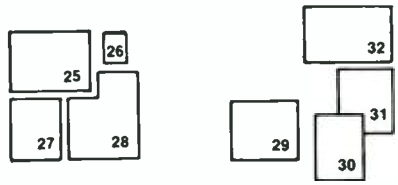
At the beginning of World War II, technical standards and radio development had been well established. NTSC standards for black-and-white television had recently been approved by the FCC and commercial television was only six months old, but the war meant that technical development was drastically cut back. Very few NBC engineers were seen in the broadcasting industry for the next four years—many of them joined the Armed Services as communications experts, and some worked with research institutions, such as the Underwater Laboratories at Harvard University, developing highly specialized communication systems for the Armed Forces.

The NBC Engineering Department, New York, in cooperation with RCA, successfully developed and tested an airborne television system known as the "Block" Project for the Armed Forces. The system consisted of a small television camera in the nose of a military plane with receiving stations on the ground. Before the end of the war, NBC and RCA engineers scored another first by demonstrating a plane-to-plane television system to the Armed Forces.

Members of the engineering staff assisted government agencies on many other wartime projects, most of which were secret. In all, NBC Engineering undertook more than 30 different research projects for government and military services during World War II.

Post-war television

NBC's confidence in television at the end of World War II was summed up by Niles Trammell, President of NBC, as he told the FCC in October 1945, "We are no longer required to predicate plans for television on the winning of the war: Victory has been won; peace is here; television is ready to go." Televison now had the green light.



25 Cameras at New York's Studio 8G, which was converted from radio to television in 1948. **26** NBC logo on velocity microphone used in the 40s, 50s, and early 60s. **27** Studio 8G control room in 1948. Left to right: Robert Shelby, Director of NBC Laboratories; Dudley Goodale, Development Engineer; Vernon Duke, Development Engineer; O.B. Hanson, Vice-President of Engineering and Operations; and Carl Cabison, Video Technician. **28** Flying-spot scanner, designed and built by Vernon Duke, used to get WNBW on the air in Washington, D.C. in 1947. **29** Control room for Studio B at WNBK (Cleveland) in 1948. **30** Studio 8G camera. **31** Author Bill Howard inspecting WNBK film installation in 1949. Equipment includes two clusters of a 35-mm projector (pulse light), 16-mm projector, slide projector, and mirror multiplexer into an RCA TK-20 iconoscope film camera. **32** Bill Resides checking power supplies at WNBK in 1948.

Many technical developments in television made by NBC and RCA engineers resulting from the war effort were now available and could be shown for the first time. The most important of these was the super-sensitive image orthicon television camera tube developed in the RCA Laboratories for the Block Project. This pick-up tube was 100 times more light-sensitive than the iconoscope. The new tube was capable of producing excellent pictures with 250 to 300 foot-candles of light, while the iconoscope used in the now-obsolete studio-3H cameras required as much as 2400 foot-candles.

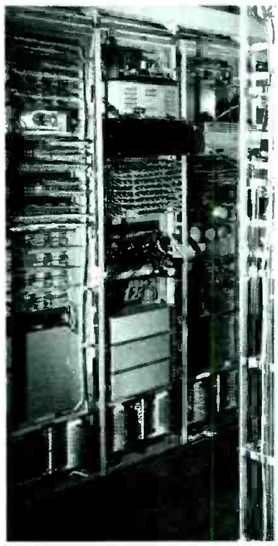
But even though the war was over, NBC faced another crisis in television. Because of the tight security on the new image orthicon and the participation in the war effort, no cameras were available for commercial television expansion using the new techniques. NBC needed to expand its live and film studio facilities in New York, and the Washington station was scheduled to go on the air by mid-1947.

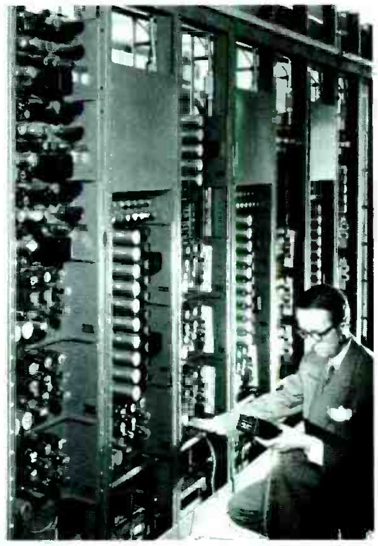
The NBC Engineering Department was called upon to meet this urgent and immediate need. The observation room above the experimental studio 3H was converted into a laboratory to develop and fabricate live cameras using the image orthicon tube and film cameras using the already-proven iconoscope. On June 27, 1947, NBC's television station WNBW in Washington, DC went on the air using the film and live cameras developed by NBC engineers. The studios and transmitters, located in the Wardman Park Hotel, made up the first television installation that NBC had engineered and installed outside Radio City.

Studio 8G was converted from radio to television early in 1948 and went on the air as a commercial studio using the cameras developed by NBC Engineering. This was the first large radio studio in Radio City converted to television. This project demonstrated the excellent foresight of the designers of the original studios, who had made them two floors high. The high ceilings accommodated television lighting and scenery without major architectural changes to the studios.

Commercial tv comes of age

1948 marked the beginning of a period of substantial progress for commercial television in the United States, with 19 stations on the air at the beginning of the year and 47 by the end. The number of home television sets in the country increased from 175,000 to over one million during the same year. This progress directly affected the same NBC Engineering Departments. Four major television plants were scheduled to be engineered and constructed in that year: three live studios and a large film studio and master control in the old RKO movie studios at 106th Street,





New York. Complete television plants, including live and film studios, master controls, and transmitter plants, were to be completed in Cleveland, Chicago, and Hollywood. These studios were to be equipped with RCA's first postwar television cameras, the TK-10 image orthicon live cameras and the TK-20 iconoscope film cameras. The stations were to use the new RCA TT-5 television transmitters and the RCA super turnstile television antenna.

Two engineers were assigned to each location. WNKB Cleveland* and WNBQ Chicago went on the air late in 1948. KNBH followed in early 1949 with studios in Hollywood and transmitter facilities on Mt. Wilson.

With the heavy demand for additional television studios, studio 6B was the second large studio in the Radio City complex to be converted to television. When this studio was completed in 1949, it became the home for the origination of "Mr. TV" himself, Milton Berle, and the Texaco Star Theatre. Even the famous radio studio 8H gave way to television in 1950.

The demand for audience participation shows required expansion outside Radio City. During 1950 several large theater installations were completed and went on the air. These included the 3000-seat Center Theatre in Rockefeller Center, where shows such as the Saturday Night Review starring Sid Caesar and Imogene Coca were originated. International Theatre, the historic Hudson Theatre, and the Balasco Theatre, all in New York, were also completed in that year.

Many other studio conversions followed, including radio studios 6A, 3A, and 3B in 1951 and 1952. In 1954 Century Theatre was converted to televison and a large film facility at 57th Street, New York, was added.

More technical developments from the NBC Laboratories

In these early years of televison, many new developments came out of the NBC Laboratories, which played an important role in the acceptance of television as an advertising medium. Many of these developments are still in use today.

The time differential between the eastern, midwestern, and western states has always been a major problem for network broadcasting. NBC development engineers began experimenting with sound recording in the laboratory for delayed broadcast in the early days of radio. The "Orthacoustic" disc recording system was developed as an outgrowth of this research and the Scully record and playback disc machines were used for many years at NBC New York, Chicago, and Hollywood for delayed broadcasts in the radio network. Audio magnetic tape, a development that came out of World War II, replaced the disc recorders for delayed broadcast in the late 1940s.

Bill Howard joined NBC Engineering Development in 1946. After working on the development of live and film television camera chains, he became involved with the engineering and installation of the original television plant for NBC in Cleveland, Ohio in 1948-49. He managed technical operations for NBC stations in Cleveland and Philadelphia until 1960, when he returned to the NBC Engineering Development group in New York, where he is now serving as a Senior Engineer.

Contact him at:
Engineering Development
NBC
New York, N.Y.
Ext. 4385

On September 13, 1947, in cooperation with Eastman Kodak Company, NBC demonstrated a special camera that had been developed to photograph television images directly from a special kinescope picture tube. This became known as kinescope recording and paved the way for delayed broadcasts for the television network programs, syndicated television programs, and records of television events on 16- and 35-mm motion-picture film. This new development stayed in the laboratory until 1947, when NBC engineers completed a large six-camera kinescope recording studio and placed it into operation on the seventh floor at Radio City. This new facility was in constant use until it was replaced by a smaller and more modern color facility in 1973. Robert Frazier and Edward Bertero in Engineering Development made major contributions in the development of kinescope recording.

In 1948 the "split screen," a video effect developed in the NBC Laboratories, was placed in operation on NBC regular programs. This was the beginning of a large number of video effects developed by NBC engineers that are included in all effect packages in studio switchers today, including chroma key, wipes, lap dissolves, and many others. In 1950, NBC also inititated rear-screen projection capable of integrating and synchronizing filmed backgrounds and live foregrounds.

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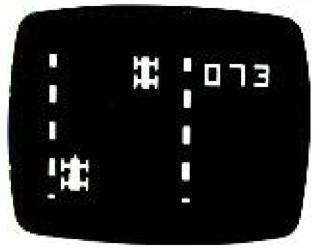
*Ed. Note: Bill Howard, the author of this article, was one of the engineers assigned to put WNBK on the air.

This article consists of two parts; the second part will be in the next issue (Aug/Sep) of the *RCA Engineer*.

Electronic displays

E.O. Johnson

Electronic displays have substantial commercial importance; their development and improvement is a continuing challenge that involves many technical disciplines. Simple physical principles described in this article provide a roadmap through the diverse assortment of display types.

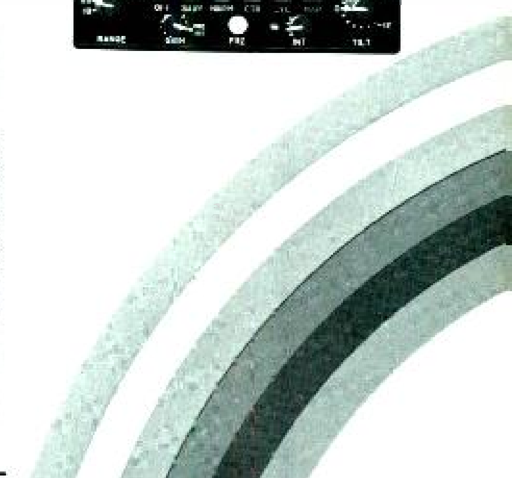


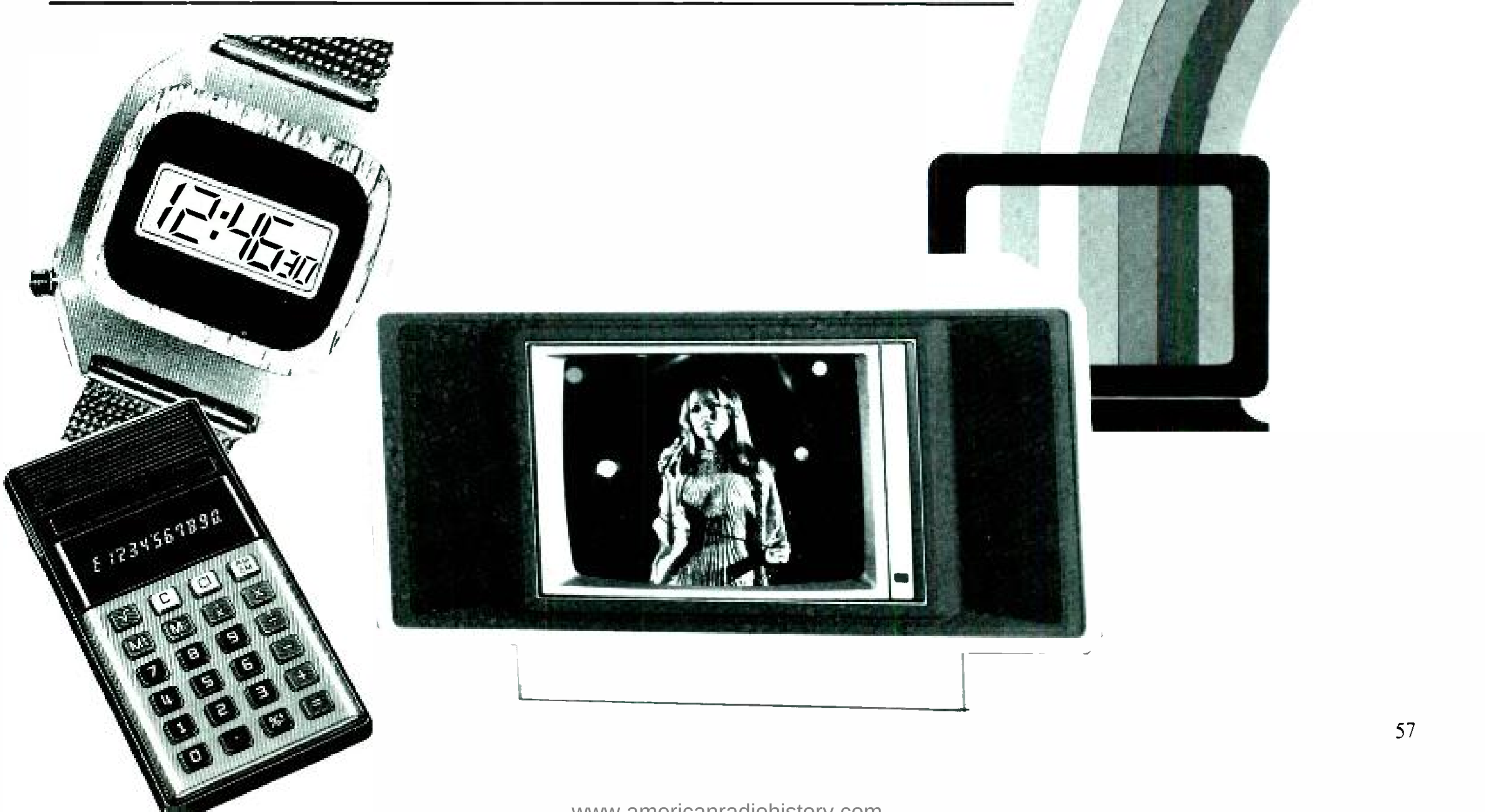
Electronic displays have a world-wide sales volume in excess of $1 billion. This includes displays in tv receivers, calculators, computers, timepieces, and a great assortment of applications of lesser sales volume. Table I shows how the U.S. market is divided among the different display types. The total volume will surely continue to grow as old systems expand and as electronics invades new systems—for example, automobiles. Each application has its own special requirements, and optimizations, that continue to evolve in terms of size, speed, power, color range, brightness, contrast, and all of the other possible parameters. Numerous technical approaches have appeared and will continue to do so. The technical challenge is large and extends across many different disciplines: image perception and biology, optics, physics, chemistry, and electronic circuits and systems.

Table I

U.S. sales of electronic display devices are predicted to increase by almost 40% between 1975 and 1980. Sales levels are given in millions of dollars at the factory level; U.S. sales are estimated as roughly one-half the free-world total. Source: *Electronics*, Jan 6, 1977; pp. 90-91.

	1975	1976	1977	1980
TV picture tubes				
B&W	36	32	29	18
Color	460	530	595	635
CRTs (except tv)	29	29	30	32
Multidigit types				
Gas-discharge	24	28	29	37
Incandescent	2	3	3	4
Fluorescent	2	3	3	5
Electroluminescent	3	4	4	5
LEDs	26	35	40	50
Liquid crystal	4	7	13	27
Plasma panel	6	7	8	13
	67	87	100	141
U.S. total:	592	678	754	826





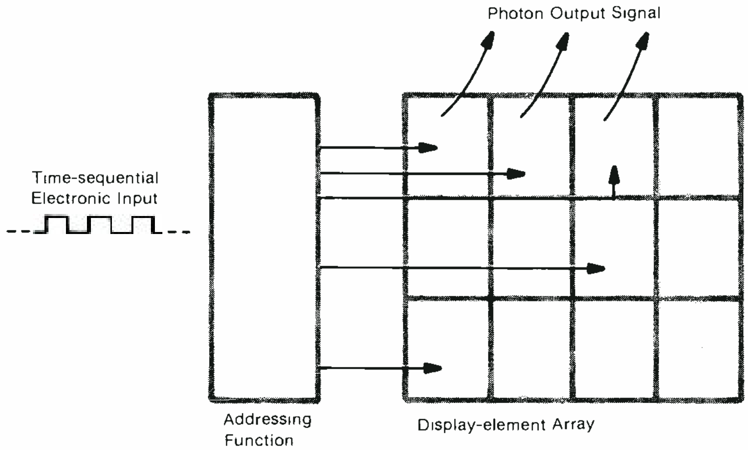


Fig. 1
All electronic displays convert time-sequential electronic signals into spatially configured photon signals. Displays do this in two parts—addressing, which routes signals to the appropriate display elements, and electron-to-photon conversion.

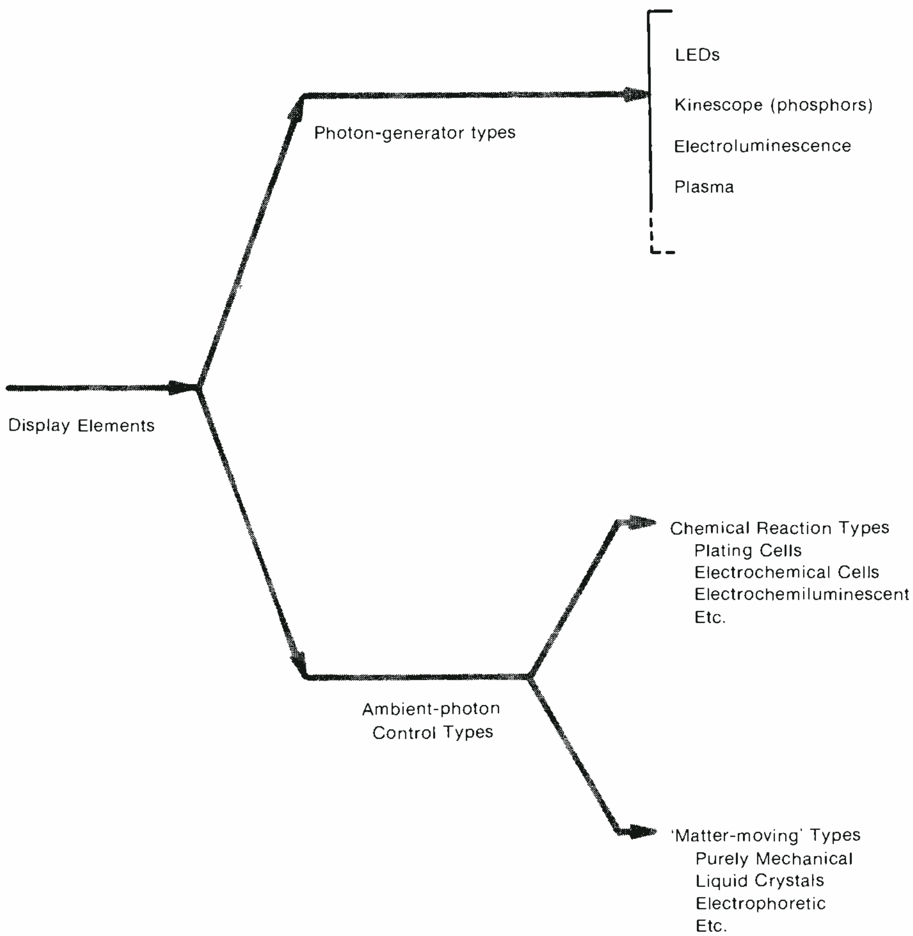


Fig. 2
Most display elements fit into this organizational scheme.

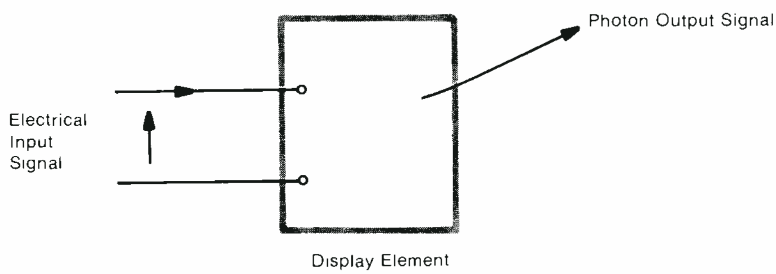


Fig. 3
Photon generator power-conversion efficiency is the ratio of input power to output power. Text shows that this ratio can be expressed as a product of photon/electron energy ratio and photon/electron conversion efficiency ratio.

Basic display functions

As indicated in Fig. 1, an electronic display is a "language translator" that converts time-sequential electronic signals into a spatially configured photon signal useful to a viewer. This function is carried out by two intertwined sub-functions. The first is display-element addressing, in which signal electrons are routed to the appropriate display elements. The second involves converting the signal electrons arriving at each display-element destination into useful signal photons—the inverse of what occurs in a photon detector or imaging device such as a camera tube. As will be shown, the signal electron-photon conversion efficiency in a display element provides a convenient handle for comparing most, if not all, display devices.

The addressing function in displays is virtually identical to addressing in an electron information-storage system and has also been implemented by a great variety of approaches. As will be seen, this function can be discussed in terms of two parameters. One involves the allowable degree of randomness in the coupling between the input signal and the display elements. The other involves the partitioning of routing control between central and local domains, somewhat reminiscent of federal versus state control in governments.

Display element classes

Most, if not all, types of display elements can be conveniently classified according to the general scheme shown in Fig. 2, which illustrates several representative types of elements. The class at the top of the figure is distinguished by the fact that all its elements generate their own photons internally; the bottom class of elements controls ambient photons by modulating such parameters as reflection, absorption, scattering, or optical rotation. These two major classes behave very differently in terms of their photon-conversion efficiencies. The photon-generator class has a theoretical efficiency approaching unity, and some elements, particularly phosphors, are not far removed from this value in practice. The ambient-photon control class of elements has a theoretical and practical ability to greatly exceed unity conversion efficiency, but only at slow switching speeds.

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Photon-generator elements

Fig. 3 helps explain the energy and electron/photon conversion capability of photon generators. In it, the electrical power input P_i to an element is the product of the voltage, V, and the current, I. This can be described in terms of the electron charge, e, and the number of in-flowing electrons, n, per unit of time, t:

$$P_i = VI = (eV)(n/t) \qquad (1)$$

The photon output power, P_o, is expressed in terms of the energy per photon, $h\nu$, and the number of photons, p, being generated per unit of time t:

$$P_o = (h\nu)(p/t) \qquad (2)$$

The ratio P_o/P_i is the power conversion efficiency, η, and this is identical to the energy conversion efficiency if the input and output time periods are conveniently treated as identical:

$$\eta = (h\nu/eV)(p/n)$$
$$= \eta_\nu \cdot \eta_n$$

Thus, the power conversion efficiency is the product of η_V, the photon/electron energy ratio, and η_n, the photon/electron conversion efficiency ratio.

Light-emitting diodes have relatively low power conversion efficiency.

For a solid-state light-emitting diode (LED) element, the input voltage is approximately equal to the semiconductor bandgap energy, and this, in turn, is very nearly equal to the photon energy, so η_V is close to unity in value. The value of η_n, however, is of the order of 10^{-2} or less. It is this low because only about one photon in the 50 to 100 internally-generated photons per electron is able to escape from the diode element because of strong absorption in the semiconductor material. This unfortunate circumstance arises because of two factors. First, the photon energy is close to the bandgap energy. Second, the absorbing path length is lengthened by multiple internal reflection caused by the relatively large index of refraction between the semiconductor material and the outside air.

Phosphor displays are much more efficient.

Phosphor display elements, such as used in a tv kinescope, provide an interestingly different story. These elements are composed of many small crystalline grains that generate photons when electrons are injected, not by a fabricated p-n junction as in the case of the LED, but by a freely-steerable electron beam inside a vacuum space. This beam consists of a relatively few high-energy electrons that are remarkably efficiently transformed into a great many low-energy electrons inside the phosphor grains. These "down-converted" electrons have an average energy comparable with the phosphor bandgap energy and with the usual photon-producing centers, which have a somewhat smaller energy than the bandgap. In commercial phosphors these electrons generate photons with high efficiency and, since it turns out that the photon energy is significantly less than the bandgap energy, and the crystallite size is very small, most of the photons escape for useful purposes. The end result is that $\eta_n \cong$ 0.16 to 0.4. The term $\eta_V \cong 0.6$, a value comparable with unity.

Electroluminescent elements are mostly developmental and incompletely understood at the present time.

Electroluminescent displays use phosphors in a solid-state sandwich structure. Electrons are injected into the phosphor grains by the cathode bounding electrode, but generate photons with far lower efficiency, quite possibly basically so, than an electron beam in a kinescope. This low efficiency seems to arise from the high dissipative losses associated with generating electrons of appropriate numbers and energy by processes totally inside the material, itself. However, the electroluminescent type of element combines the solid-state virtues of an LED with the potentially low-cost-per-unit-area characteristic of a phosphor screen. Thus, we might expect that this type of display element will find use in applications where electric power is not a critical problem, such as in automobiles, and where one needs relatively large and simple low-cost displays having solid-state virtues.

Gas plasmas have a significant potential for large-area displays at relatively low cost.

Plasma-type elements, such as the ones used in plasma panel displays, use the luminescence generated in an electrical discharge in a sealed planar-type vessel filled with a suitable gas such as argon, neon, or a mixture of the two. The simple sandwich-structure cell with bounding electrodes capacitively coupled to the gas discharge exhibits various nonlinearities that simplify addressing. Attempts are being made to enhance their relatively low photon conversion efficiency by using phosphors as in fluorescent lamps, where the photon energy-conversion efficiency reaches about 20% in ordinary commercial products. The photon-conversion process in the plasma cell is somewhat comparable to that in the phosphor of a kinescope. Monoenergetic electrons are injected from the cathode into the gas-discharge plamsa with an energy on the order of a hundred volts. Each injected electron is down-converted to many secondary electrons by ionizing and exciting collisions with gas atoms. These secondaries have a random energy distribution with an average energy of several volts. They excite atoms to produce photons with often good efficiency, but sometimes a large fraction of these are in the uv range and not visible. These uv photons can be converted to visible photons efficiently with a suitable uv/visible phosphor of the type used in the fluorescent lamps.

Ed Johnson has been Director of the RCA Research Laboratories in Tokyo since 1975. Previously, he was Manager of Technical Liaison for International Licensing. He has worked extensively in the fields of semiconductor devices, optoelectronics, and gas-discharge displays, and has received two RCA Outstanding Achievement awards for his research.

Contact him at:
RCA Research Laboratories, Inc.
Tokyo, Japan

Table II
Photon-generating display units have uniform photon/electron energy ratios generally approaching unity, but have widely varying photon/electron conversion efficiency ratios.

Element type	η	η_V	η_n
LED	$\sim 10^{-2}$	~ 1	$\sim 10^{-2}$
Kinescope phosphor	$\sim 10^{-1}$	~ 1	$\sim 2 \times 10^{-1}$
Electroluminescent	$\sim 10^{-3}$(?)	$\sim 10^{-2}$(?)	$\sim 10^{-1}$(?)
Plasma types	$\sim 10^{-1}$	~ 1	$\sim 10^{-1}$
Theoretical limit	~ 1	~ 1	~ 1

The tv kinescope comes closest to the theoretical efficiency limit.

The performance of photon-generating display elements is summarized in Table II. We see that η_V is comparable with unity for all elements if we consider the process after whatever energy down-conversion may exist. The value of η_n is where the big differences exist between various display elements. The theoretical maximum value of η_V and η_n is unity, a value that is most nearly approached in the ubiquitous tv kinescope.

Light-output conversion efficiency, while by no means the only major display parameter, has an importance well beyond simple energy conservation. It affects other parameters, such as the geometrical size and packing density of elements, the driving circuitry and addressing, and the power-supply size and design. These items in turn affect the cost and general acceptability of the system.

Ambient-photon control elements

This class of elements can be described in the same manner as photon-generators if we use Eq. 1 as previously noted, and Eq. 2 with the understanding that ambient photons are being controlled, rather than internally generated. In sunlight, about 2×10^{15} visible photons fall on one square centimeter of display area each tenth of a second, the approximate minimum eye-response time. If we can reflect, absorb, or otherwise completely control all of these ambient photons with 2×10^{15} circuit electrons injected into the display element, η_n would be unity by our definition. The minimum eye-response time of one-tenth second provides the least number of ambient photons that can be usefully controlled for the viewer in a "reference" lighting situation. Obviously, for long exposure time more photons will be involved and this will tend to increase the value of η_n in the types of devices to be described—devices whose photon-control action persists after the electrical input power has been switched off. The minimum eye-response time of one-tenth second is used here because it provides the most conservative value of η_n.

Chemical-reaction elements

These ambient-photon control elements include the types of elements shown in Fig. 2. All of these operate in the same basic manner—in a sandwich cell that has cathode and anode bounding electrodes on each side of a solid or liquid electrolyte. Ionic species in the electrolyte are normally transparent and invisible until they are allowed to pick up or deposit a circuit electronic charge at an electrode. This charge transfer oxidizes or reduces ions and causes them to become more absorbing and/or reflecting of ambient light.

In this process, the number of transformed ions is directly related to the number of inflowing circuit electrons (Faraday's Law). If we combine this result via Lambert's Law, which relates the number of deposited particles with their optical effectiveness, we can directly determine the optical control action of each circuit electron. Performance is found to be surprisingly similar over a wide range of different materials: about 5×10^{17} circuit electrons are needed to block out the 2×10^{15} visible photons falling on a square centimeter in one-tenth second. This gives η_n a value of $(2 \times 10^{15})/(5 \times 10^{17})$, or 0.4×10^{-2}. If the deposited layer remains without requiring additional circuit charge, as is the case with several types of usable cell materials, the useful value of η_n rises indefinitely as we lengthen the viewer observation time.

For all of these chemical-reaction-type cells, the applied element potential is in the order of a volt or two so that, again, η_V is approximately unity.

These types of display elements are promising for a number of reasons. One is that their photon/electron conversion efficiency, $\sim 10^{-2}$ in the worst case, is roughly comparable to that of an LED (see Table II). The value can be much better than that when the above-noted storage effect can be taken advantage of, as when display patterns can be retained for periods longer than the minimum eye-response time. Another reason is that such elements seem intrinsically inexpensive per unit of area compared to single-crystal LEDs. Another reason is that the elements can be made to display various colors, depending upon the chemical species used. Their main disadvantage, not yet completely solved, is that secondary chemical reactions are difficult to control and can greatly shorten operating life.

Matter-moving elements

This type of ambient-photon control element, first analyzed by R. Engelbrecht of RCA's Zurich Laboratories in the general manner sketched below, comprises a wide variety of different approaches as briefly noted in Fig. 2. All involve the same principle. Gross assemblies of atoms or molecules are distorted electrically or moved in or out of position to effect ambient-photon control. A meter needle is perhaps the simplest example. Liquid-crystal display elements are also in the same category, since they operate either by a molecular twisting effect (field-effect mode) or by fluid-turbulence effects (dynamic-scattering mode).

In all cases, frictional and inertial forces and energies determine the necessary electrical input parameters. The optical controlling action is determined by the gross size and shape of the elements that act upon the incident light. Simple physics (energy = force × distance) determines the mechanical inertial energy E_i involved in moving a reflecting or absorbing body of density σ (g/cm^3) and dimensions $l \times l \times l$ through a distance l (cm) in time τ (s):

$$E_i = (l^5 \sigma / \tau^2)\ 10^{-7} \text{ (joules)} \quad (3)$$

Simple physics also determines the frictional or viscous energy E_v involved when the same body is moved in a viscous fluid of vicsocity ϕ (g/cm-sec^2):

$$E_V = (l^3 \phi / \tau) 10^{-7} \text{ (joules)} \quad (4)$$

The energies per cm^2 of display area are obtained by multiplying Eqs. 3 and 4 by l^{-2}. Also note that the kinetic energy acquired at the termination of the translation l is dumped. This is analogous to what is normally done to capacitively stored energy in a logic switching circuit.

The main points to note in Eqs. 3 and 4 are that both energies are inverse functions of time. This means that one pays an increasing energy penalty as the switching time τ is decreased, particularly when inertial effects dominate. However, if τ is of

Table III

Low energies and powers are an attractive feature of matter-moving display elements. Table gives values for ideal elements, which could achieve power requirements under 10^{-7} watts/cm² of display surface. Actual devices use more power, but are still very energy-efficient.

	Inertial	*Viscous*
Energy per element (joules)	10^{-10}	10^{-11}
Energy per cm² of array (joules)	10^{-8}	10^{-9}
At 10 Hz per cm²		
Power (watts)	10^{-7}	10^{-8}
V (volts)	1 (nominal)	1 (nominal)
I (amperes)	10^{-7}	10^{-8}

Conditions

$\tau = 10^{-1}$s	switching time
$\sigma = 1$ g/cm³	water density
$\phi = 10^{-2}$g/cm-sec²	water viscosity
$l = 10^{-1}$ cm	element size and displacement

Table IV

Display-element performance summary shows the different realms of optimum applicability for the various element types.

Type of element	*Photon/electron Energy ratio* η_V	*Photon/electron Conversion ratio* η_n	*Cost per unit area*
Photon-generating			
LED (single xtal)	~1	~10^{-2}	high
Kinescope phosphor	~1	~2×10^{-1}	low
Electroluminescent	~10^{-2}(?)	~10^{-1}(?)	low
Plasma types	~1	~10^{-1}	low
Theoretical limit	~1	~1	—
Ambient-controlling			
Chemical-reaction type	~1	~$10^{-2}\rightarrow\infty$*	low
Ideal matter-moving	~1 ***	~$10^4 - 10^5$**	—
Liquid crystal	~1	~10^3**	low
Various others	~1	~10^3**	—

Notes:
*Lower value at minimum eye response time of 10^{-1} second.
**For values noted in Table III, and no storage effects.
***Controllable by cell design.

the order of 0.1 second, and reasonable values are used for the other quantities, such as shown in Table III, then the energies and related powers for ideal devices are very small indeed: 10^{-7} watts or less per cm² of display surface. Actual devices will require somewhat more energy and power because of parasitic circuit losses, electrical coupling problems, and the parasitic mass of the supporting structure. However, in practice, the overall energy and power demands are so low that such types of elements are particularly attractive for very-low-power applications such as electronic-display wrist watches.

Display-element performance summary

Table IV gives a summary of display-element performance. We see that the values of η_V are all comparable with unity, as one might expect where the injected electrons play a direct role in the photoelectronic transition. The electron/photon conversion efficiency, however, varies greatly in the various types and classes of elements. In the photon-generator class, the conversion efficiency of the ideal element is unity, which is most nearly approached by the ubiquitous kinescope phosphor. The chemical-reaction types operate in most cases with conversion efficiencies (at 0.1-second switching) comparable to the normal efficiencies of the photon-generating types. However, information-storage capability makes very much better efficiency possible when display patterns can be retained for long times. The matter-moving display elements have a very superior conversion efficiency at slow switching speeds, both ideally and in practice, but this efficiency deteriorates monotonically as switching speed increases. This strongly contrasts with photon-generating elements.

A combination of the above properties and the cost/unit area characteristics for the different elements, also listed in Table IV, make their optimum realms of applicability fairly apparent.

Addressing

This subject is no less important than the elements themselves.

As the number of display elements increases, providing an unambiguous address or selecting a desired combination of elements from among the many other elements becomes increasingly difficult: the required degree of addressing "marksmanship" increases. Over the years this difficult problem has spawned a great variety of solutions. Some degree of order among this diversity can be seen if addressing is discussed in terms of two characteristics—the allowable degree of randomness in the coupling between the input signal and the addressing hardware and, also, the partitioning of routing control between a central location and locations in or near the elements themselves. These two characteristics are the coordinates of the diagram in Fig. 4, which seems capable of encompassing almost any conceivable addressing scheme, including those used in information-storage systems.

Addressing can be divided between centrally and locally controlled systems.

Regions CN and CR, above the horizontal axis, encompass addressing systems, actual or conceivable ones, in which all addressing is centrally controlled as in a black-and-white tv kinescope. Regions LN and LR, located below the horizontal axis, encompass systems that have some degree of local routing in or at the elements themselves, as in a shadowmask color kinescope or an LED display using diode nonlinearity for x-y-type selection. The farther a system is depicted below the horizontal axis in the figure, the greater the degree to which routing is carried out locally. The extreme case of local routing control exists in the box labelled "cell identity system," a display-addressing arrangement not presently used, but nevertheless possible. In such a system, each element has its own identity and responds only when its "name" is called during a general information broadcast from the input signal.

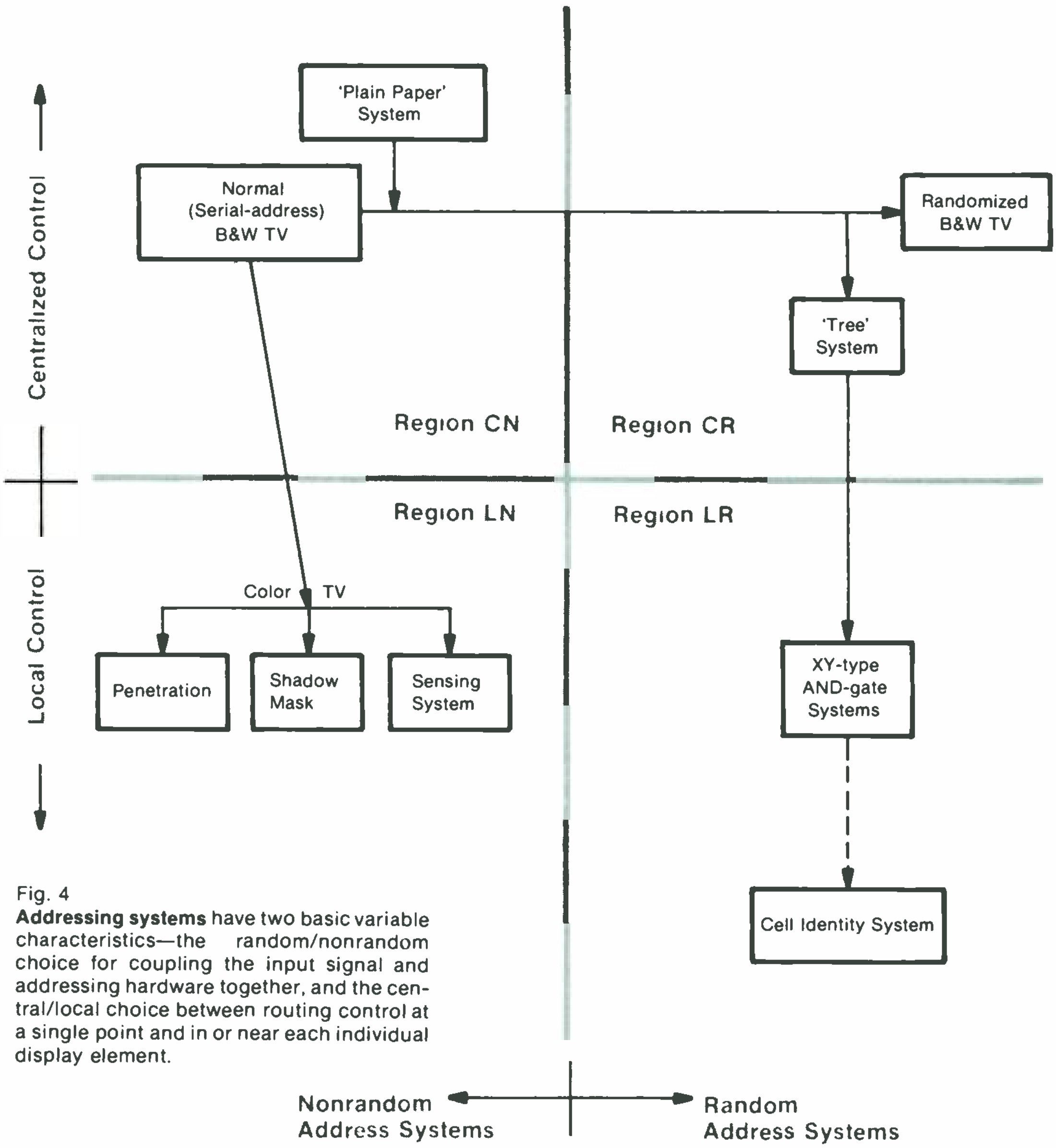


Fig. 4
Addressing systems have two basic variable characteristics—the random/nonrandom choice for coupling the input signal and addressing hardware together, and the central/local choice between routing control at a single point and in or near each individual display element.

Another division is between random and nonrandom addressing.

Regions CN and LN, to the left of the vertical axis, represent systems that are of the nonrandom or series-selection type. That is, the temporal order of incoming signal information to the display is maintained throughout the addressing operation and is applied to the elements in a serial or linear geometrical order, as in a tv raster scan. This is in marked contrast to what happens in systems located in regions CR and LR, which lie to the right of the vertical axis. In these systems, the incoming signal information can be routed to the elements in any desired geometrical order or combination, as in the x-y address system of the LED displays used in hand calculators. Alternatively, the incoming signal information could be stored in a memory, randomly pulled out in time, and applied in any random geometrical order to the display elements.

The simplest addressing systems are located in region CN—the black-and-white tv kinescope, for example. All of the addressing is centrally controlled by circuitry that sweeps the steerable electron beam across the unstructured phosphor layer that constitutes the display elements of the viewing screen. The display elements themselves exercise no routing control of the incoming signal information. The rigid time sequence and relative spatial location of the electron signal fed to the phosphor elements is generated in the tv camera and transmitter and is reproduced as faithfully as possible into the display elements. There is no freedom to shift bits of signal information from this disciplined time/geometry sequence, and none is normally needed.

In such a situation we can conceive of each piece of signal information as existing in a time cell. The series string of these time cells, and the information they contain, is delivered to the display elements one-by-one in a corresponding geometrical order by virtue of the rhythmic raster scan. Time and geometrical order are thus effectively made to coincide with each other and no additional ordering of information is necessary. Each piece of signal information, and each display element, is located to a precision of one part in N, where N is the total number of time cells.

Additional ordering is necessary, however, if the black-and-white tv display action is implemented in a random manner. In such a case the system is located in region CR. Of the several different possible modes of implementation, let us consider the one in which the time order in the above-described series string of incoming information is preserved and the addressing system samples this string randomly and routes each sample to the appropriate display element. In such an approach, the dimensional aiming precision required of the electron beam as it randomly seeks out a particular display element is one part in N, where N is the number of elements to be addressed. In the typical black-and-white tv case, N is approximately 5×10^5, and this level of precision, or geometric ordering, must be used each time a display element is selected. This geometrical ordering is an additional systems requirement, beyond that required in the previous case. It must somehow be built into the beam-deflection devices and circuitry.

But that is not all of the ordering that must be added for this particular mode of random implementation. An additional amount must be built into the system to recognize the geometrical address of each random information sample, and also to provide for some degree of information storage—the information in the incoming time string must survive at least until it is sampled. Although there are other modes of random implementation that may lessen the need for some of this additional ordering, in general it appears that additional geometrical ordering is required in all cases, compared to the serially-addressed black-and-white tv system located in region CN. There are other problems associated with the random approach, notably beam deflection speed and increased energy requirements, but the main point of the discussion here is that the price for randomization is an additional degree of geometrical ordering that must be built into the hardware.

We can view the comparison in another way that leads to the same conclusion. In the serial system, the location of the beam on one display element acts as a reference for the beam in locating the adjacent element. This is quite similar to what is done when one writes a sentence by hand on a piece of paper. The location of the pen or pencil at any point in this system is the reference point for the next-bit maneuver. This situation is depicted in Fig. 4 by the box labelled "Plain Paper" system. Imagine the marksmanship required of your hand if the ink or pencil points were to be set down in a purely random manner!

In the case of the familiar x-y-type AND-gate systems, depicted in region LR, the geometric aiming accuracy for element address is established by the conduction matrix constructed during manufacture. In effect, the geometrical location at each element is established to one part in N, where N is the total number of elements.

The above brief discussion is not intended to deprecate random-address systems. As is well known, random addressing in display and in information-storage systems has great virtue. There is, though, a hardware price to be paid when one disturbs the temporal/spatial order of the signal information. The practical moral of this discussion is that random address should not be used unless there is a compelling reason to do so.

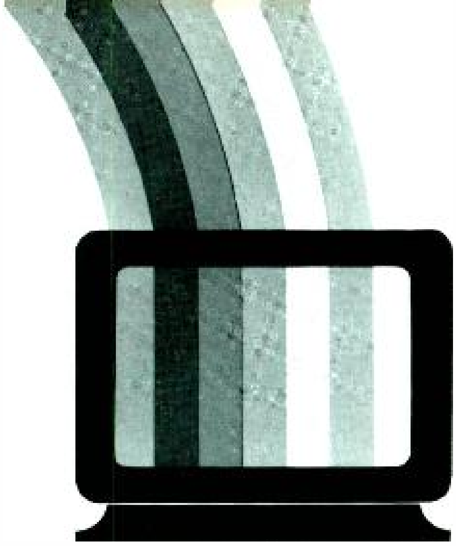
As for the second addressing characteristic, the partitioning of routing control, the transition from the black-and-white-to color-tv kinescope addressing system is a good example. To handle the added addressing burden imposed by the addition of color to the black-and-white system, it has been found much easier in practice to shift some of the routing burden locally to the region of the elements themselves. The shadow-mask tube, the penetration phosphor tube, and the sensing tube, all depicted in region LN, are examples of this approach. In all cases, additional local structure was introduced in or near the display elements. Accomplishing the complete addressing function centrally would require an impracticably high order of electron-beam aiming precision. The slanted line in the diagram indicates that this local control also involves random selection of color.

The same general situation prevails in the random regions CR and LR. Display elements can be randomly addressed centrally via an addressing tree (region CR), but this becomes cumbersome if the number of elements is large. A more practical approach, well known in practice, is to use AND-gate action, mostly of the two-input, or x-y type, at each element. This method greatly reduces the central routing burden without increasing element complexity greatly, at least when the elements themselves can provide the AND-gate action by means of intrinsic non-linearities in their electrical characteristics.

This general addressing approach can be carried to higher levels of local routing control, such as using a larger number of AND-gate inputs. A typical example of this occurs in magnetic-core information-storage systems, in which the cores can be threaded with several control wires. However, a higher degree of local control than exercised in the widely-used x-y system is not usually easily implemented, because it demands too much from the elements of their local surrounding structure. A very slight increase in the complexity of each element of an N-element system increases overall display complexity enormously when N is a large number. This would be the case, for example, of the cell-identity system mentioned earlier and depicted in the lower part of region LR. This is an extreme case in which local control is a maximum.

One suspects that there is an optimum allocation between central and local routing control that depends both on the state of available technology and the utilization factor of the local-control mechanism. For example, there is a high utilization factor for the centralized addressing control in a kinescope system—the central system serves all elements continuously. In contrast, in the cell-identity system, each local routing apparatus is largely idle until that particular element cell is addressed. One might intuitively expect that for displays the optimum allocation of routing control is not far removed, if at all, from the sort of level found in the semiconductor-type x-y system or in the color kinescope system. The variations on the theme may be a bit more subtle for information-storage systems. In them, various subdivisions between central and local control may evolve, such as possibly happened in biological systems.

The same sort of approach used here for display addressing is equally applicable to information-storage systems. Indeed, they can easily be fitted in Fig. 4. For example, audio or video tape or disk systems are of the serial-address type and would thus fit into region CN, as would a delay-line information system. On the other hand, a CCD delay-line information-storage system would fit into region LN, since some degree of local addressing control is used. A variety of conceivable random-type information-storage systems would fit into region LR.



US color television fundamentals—a review

The US Color Television Standards represent masterful "tradeoffs" among psychophysical effects and electronic implementation techniques.

D.H. Pritchard

Color is not a characteristic of an object but, rather, a characteristic of light. This realization provides the answer to the question, "What is color?". *Color** may be defined as a psychophysical property of light—specifically, the combination of those characteristics of light that produces the sensations of hue, saturation, and brightness in a normal human observer. *Brightness* refers to the relative intensity of a color; *hue* refers to that attribute of color that allows separation into groups by terms such as red, green, yellow, etc. (in scientific terms, the dominant wavelength); *saturation* refers to the degree to which a color deviates from a neutral gray of the same brightness—called purity, pastel, vividness, etc.

These three characteristics—brightness, hue, and saturation—represent the total information necessary to define and/or re-create a specific color stimulus. Conceptually, this definition of color is highly convenient and appropriate for an electronic color television communications system, as pointed out later.

To determine specific parameters that describe a color, three highly interrelated factors must be taken into account:

1) Spectral reflectivity of the surface being observed;

2) Spectral distribution of the ambient light illuminating the object; and

3) Spectral sensitivity of the detector.

In consumer television, the detector response (except for scientific measurement purposes) consists of the spectral sensitivity of the "standard" human eye.

*Throughout the paper, terms being defined are italicized.

Thus, the product of the spectral reflectivity of the object, the spectral distribution of the ambient, and the spectral sensitivity of the detector defines those characteristics of light, called color, that generate the sensations of brightness, hue, and saturation in a human observer. The task of a television transmission system is, therefore, to interface suitable apparatus between the detector (human eye) and the source of light energy. This apparatus must transform the light electronically into a form suitable for transmission through a specified communications channel, and then actuate a light-reproducing device that will stimulate the human eye to produce a similar subjective response in the form of *perceived* color as would have occurred if the observer had been present at the scene.

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Grassman's laws

A suitable method of colorimetric measurement and specification must be available to develop a satisfactory color television system. The application of the *principles of mathematical equivalence* to the science of color-matching by a German, Herman Grassman, in 1854 formed the background for modern tristimulus colorimetry. In essence, *Grassman's laws*** state:

1) The eye distinguishes dominant wavelength (hue), purity (saturation), and luminance (brightness).

**These laws represent one of the few verified facts concerning human vision from which various theories relating to the visual process are derived. The trireceptor theory of vision is one classical method used today to explain why the human eye follows Grassman's laws.

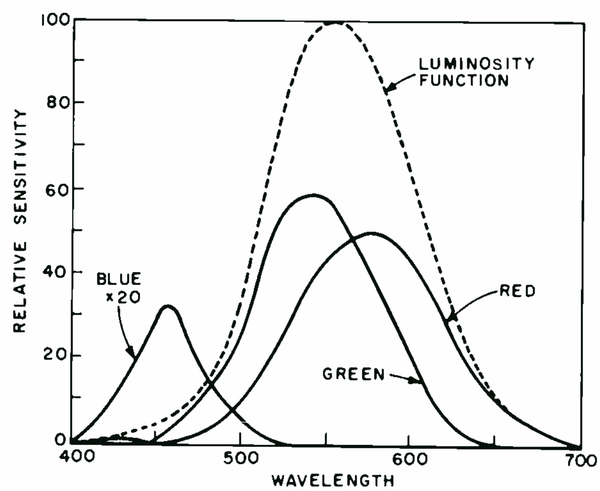


Fig. 1
Trireceptor eye response. The sum of these response characteristics constitutes the total sensitivity, or luminosity, response curve as indicated by the dotted line (reproduced for clarity in Fig. 2). Note that the blue response curve is magnified in Fig. 1 by a factor of twenty.

2) The luminance (Y) of a color mixture equals the sum of the individual color luminance values: $Y_T = Y_1 + Y_2 + Y_3 \cdots$

3) If color A = color B; and color C = color D; then A + C = B + D.

4) If color A = color B plus color C; then B = A − C.

5) If color A = color B; and color B = color C; then A = C.

Stated simply, when equivalent lights are linearly added to equivalent lights, as viewed by the eye as a detector, the sums are equivalent.

Trireceptor theory of vision

To understand colorimetric specification systems we must know the pertinent factors about the human eye: the primary detector for television purposes. It is sufficient for this purpose to accept the trireceptor theory of vision, which contends that the translation of radiant energy to visual stimuli is accomplished by three sets of cones and rods having individual response curves in the red, green, and blue portions of the visible spectrum such as shown in Figs. 1 and 2.

The relative luminosity function response curve is extremely important in developing color specification and reproduction evaluation techniques; thus, it has an important role in the development of a color television transmission system. The expression, "We sometimes tend to look at the

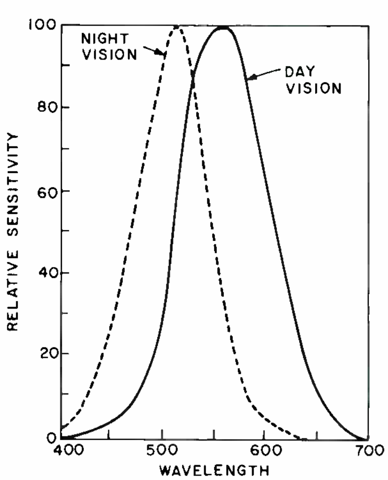


Fig. 2
Luminosity response. The responses relevant to brightness levels represented by television (daylight) viewing is determined by the cones (photopic response) as opposed to low-light response of the rods (scotopic response).

Dalton Pritchard has been involved with communications and information display systems since he joined RCA in 1946. At present, he is engaged in the development and evaluation of video processing circuitry for color tv receivers, particularly in the areas of colorimetry and decoder matrix techniques.

Contact him at:
Television Research Laboratory
RCA Laboratories
Princeton, N.J.
Ext. 2205

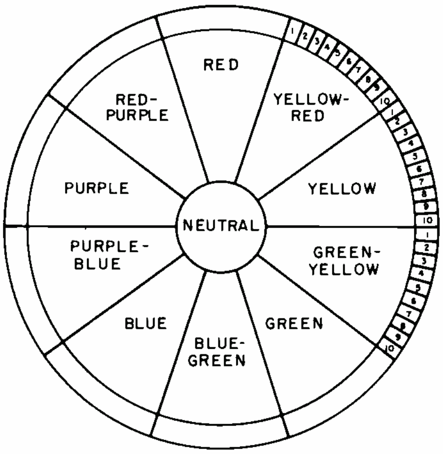
Television system background

On December 17, 1953, the FCC approved transmission standards for compatible color television and authorized broadcasters, as of January 23, 1954, to provide regular service to the public under these standards. This decision was the culmination of the work of the National Television System Committee (NTSC) upon whose recommendation the FCC action was based.

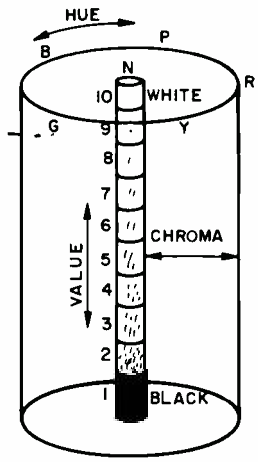
Over twenty years later, in 1977, these standards are still providing color television service of good quality that testifies to the validity and applicability of the fundamental principles underlying the choice of specific numerical standards. It is not the object of this discussion merely to recite the standards themselves, but rather to review the basic concepts along with some of the more interesing features that make the total system truly a masterpiece of "tradeoffs" among the pertinent psychophysical properties and electronic system techniques. Neither is it possible to explore in depth all the subtle details of the complete NTSC color television system in a single article. Thorough treatment of the details is available as indicated in the references cited. However, a compact summary organized for purposes of concise understanding and review of the critical concepts, as opposed to a historical development, is perhaps both interesting and useful.

The previous existence of black-and-white television standards provided a foundation upon which to build the necessary innovative techniques while simultaneously imposing the requirement of compatibility. Within this framework, an underlying theme—that which the eye does not see does not need to be transmitted or reproduced—set the stage for a variety of truly fascinating developments in what has been termed an "economy of representation."

—Dalton Pritchard



a. **Munsell hue circle.**



b. **Munsell color solid.**

Fig. 3
Munsell color specification system. In the cylindrical Munsell color solid, various spectral hues are arranged in an equally divided circle. Saturation in this system is indicated by radial distance from the center; brightness is denoted by the height of the cylindrical solid with black at the bottom and unit, or normalized, white at the top of a ten-level cylinder.

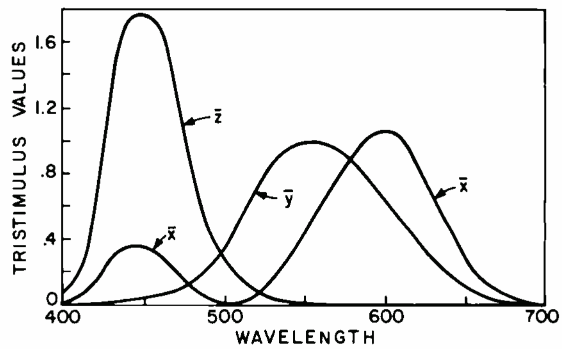


Fig. 4
CIE tristimulus curves. Note that the Y curve is the same as the standard luminosity function.

world through rose-colored glasses," perhaps should be re-stated as, "We view our surroundings through a green-yellow transmission filter." Keep this in mind as we proceed to develop the electronic color television reproduction system.

The human detector evaluates the brightness, or luminosity, of an image by summing the stimuli from the three receptors, while the chromatic attributes, hue and saturation, are determined by the ratios of the stimuli. Thus, light sources having widely different spectral distribution may give exactly the same visual color sensation as long as the amount and ratios of the total stimulation are the same.

The Munsell system

At this point, an early system of color specification that is still used for television camera performance evaluation, referred to as the *Munsell color specification system* (Fig. 3), is worthy of note. This method is used to evaluate surface reflectivity colors. Specifically calibrated paper Munsell color "chips" are available over a wide variety of colorimetric and brightness values and are still used for color television camera performance measurement and evaluation purposes. For rigorous accuracy, the spectral distribution of the ambient light, and the spectral sensitivity of the camera (detector), must be taken into account to obtain the desired colorimetric performance match.

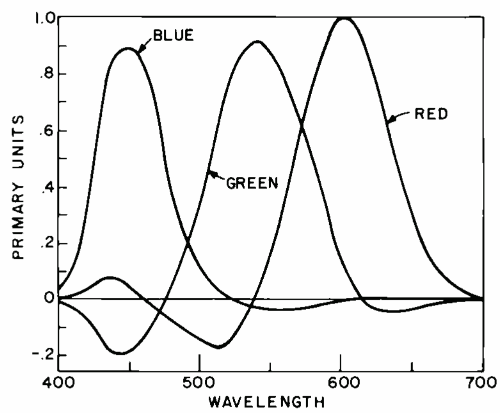


Fig. 5
NTSC color mixture primaries used in the present color television system.

CIE tristimulus colorimetric specification system

The contributions of Grassman, Maxwell, Ives, Munsell, Judd, and others led to the adoption, in 1931, of international color definition and measurement standards by the *Commission Internationale de L'Eclairage* (CIE). This technique, developed for color-matching purposes, does not provide the information for color television systems in an ideal manner, but does serve sufficiently as a means for setting colorimetric standards and providing objective measurement of performance.

The detailed mathematical development of the CIE tristimulus colorimetric specification system is beyond the scope and intent of this paper; References 1, 2, 3, 5, 6, 7 treat the subject in depth. A brief overview of the concepts involved are given here.

Grassman's laws state that only three independent quantities are required to specify a color and that color intensities add linearly. Therefore, a color specifica-

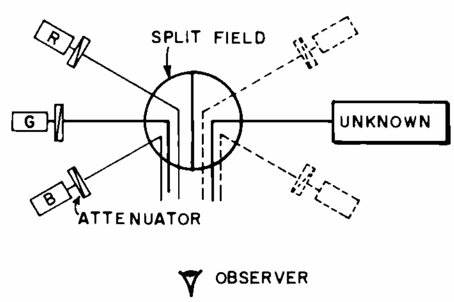


Fig. 6
Tristimulus colorimeter technique. The split-field viewer displays the light to be specified in one half of the screen, while the other half is illuminated with a mixture of the three primary light sources. Since the unknown is to be specified in terms of the three primary sources, their relative intensities are adjusted to obtain a visual match. The relative values of the three primaries are recorded and the process is repeated for all colors in the visible spectrum. Negative values for non-spectral colors are determined by adding the required amount of the appropriate primary to the unknown light to achieve a match, and is thereby recorded as a negative value.

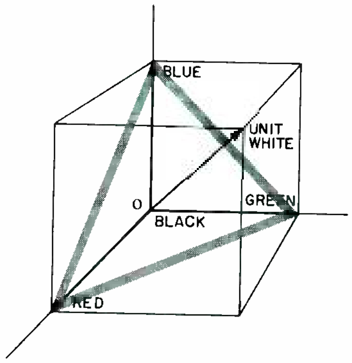


Fig. 7
Color space unit cube. Any color capable of being formed by a mixture of these three primaries may be described by coordinates located within the normalized unit cube.

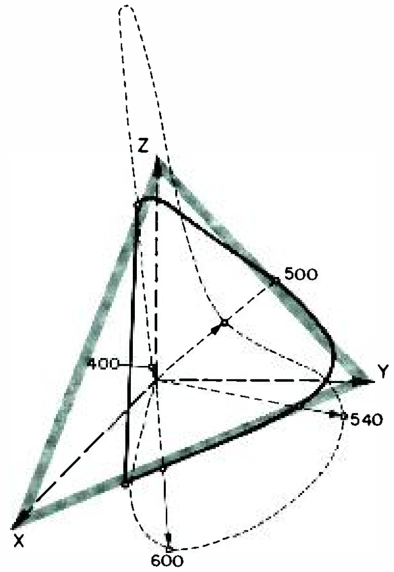


Fig. 8
Color space unit plane and spectrum locus; the unit plane (tone outline) represents constant brightness.

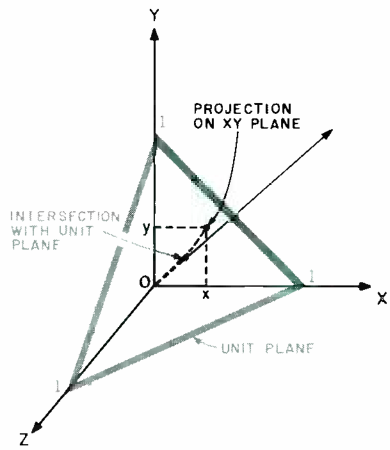


Fig. 9
Color space transformation to the X,Y plane. The intersection of the color vector and the unit plane (tone outline) can be projected into two-dimensional x,y coordinates to represent hue and saturation.

tion system can be envisioned as involving a three-dimensional color space with any set of convenient coordinates, and these coordinates may be transformed mathematically into any other set for convenient measurement or analysis. This concept of a three-dimensional color space* forms a basis for the color television colorimetric design and performance evaluation. The projection of the visible color locus, which is determined on a unit plane by a standard colorimeter technique and then transformed to the two-dimensional x, y plane, provides a method of describing the attributes of chromaticity (hue and relative saturation) independent of brightness. As will presently be seen, this concept is directly applicable to the electrical process of encoding and decoding the video signals that represent the red, green, and blue primary light energies.

A *primary light source* may be defined as one which cannot be reproduced by the summation of two other primary light sources. The reproducer in a color television system must produce light energy in the form of three primary light sources in the red, green, and blue portions of the visible spectrum, respectively. This constitutes an additive process of color mixing as opposed to the subtractive process normally encountered in paint, pigment, and dye processes where surfaces are illuminated by white light and reflect only certain portions of the spectrum of the incident energy to the eye.

Any standard system of color specification should use a set of primaries such that positive amounts of each primary could be mixed to produce any color. However, experiments have shown that certain nonspectral colors cannot be reproduced by any one choice of three real light sources. Thus, a choice of three imaginary, or "nonphysical," primaries was made by the CIE in setting up an international standard; specifically, red at 700 nanometers, green at 543.1 nanometers, and blue at 435.8 nanometers. This results in the 1931 CIE tristimulus value curves shown in Fig. 4 and designated as $\overline{X}$, $\overline{Y}$, and $\overline{Z}$. *Tristimulus values* are defined as the relative amounts of the primaries that must be combined to achieve a color match with all the colors in the visible spectrum. Experiments extending over more than 200 years have shown the validity of this principle and the practicality of the "standard observer." Thus, any set of real primaries in a practical reproduction system may be expressed in standardized tristimulus value form for measurement and evaluation purposes. The set of tristimulus curves for the red, green, and blue primaries as specified by the NTSC for the present color television system is shown in Fig. 5 (note the negative lobes).

The process of determining the relative tristimulus values involves a device termed a *colorimeter* (Fig. 6), which can be used to specify a light source in terms of the three primary light sources.

Thus, the tristimulus values (X, Y, Z) for any color may be determined by integrating its spectral energy distribution, $E(\lambda)$, with the standardized tristimulus values determined by a standard observer for spectrum colors using the colorimeter technique.

$$X = \int_0^\infty E(\lambda)X(\lambda)d\lambda$$

$$Y = \int_0^\infty E(\lambda)Y(\lambda)d\lambda$$

$$Z = \int_0^\infty E(\lambda)Z(\lambda)d\lambda$$

The three-dimensional color unit cube shown in Fig. 7 is visual representation of the mathematics—with the R, G, and B values representing the orthogonal primary color axes. Fig. 8 shows how the locus of visual colors is plotted within this space and how the unit plane is formed perpendicular to the diagonal axis of the cube, thereby representing a plane of constant brightness. If one then rotates the cube and looks directly down the Z axis, a visualization of the projection of the unit plane upon the Y, X wall of the cube is possible. (See Fig. 9.) Thus, the tristimulus values can be transformed to a two-dimensional set of values describing the chromaticity values (hue and saturation) independent of brightness.

*With three orthogonal axes representing specific red, green, and blue primary light sources that may be mathematically transformed into the standardized CIE color mixture values.

The visual locus of spectrum colors, thus transformed, provides the familiar "horseshoe" shaped CIE chromaticity diagram used extensively to describe colorimetric performance of the television system. Fig. 10 is an example of such a diagram indicating the locus of the colors reproducible by the three primaries specified by the NTSC for color television purposes (dashed triangle). For comparison, the irregular gamut of all paints, pigment and dye processes is included.

The mathematical process of accomplishing the above transformation from tristimulus values to x, y chromaticity coordinates is as follows:

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

$$z = \frac{Z}{X + Y + Z}$$

while $x + y + z = 1$.

What are the special features of the two-dimensional (x,y) CIE chromaticity color diagram?

In such diagrams (Figs. 11 and 12), points around the periphery of the visible locus indicate different hue values, while coordinates that move radially outward from the central portion of the diagram indicate increasing color saturation. Color-mixture coordinates may be determined graphically by a simple straight-line geometrical technique known as the "center-of-gravity" weighting method.

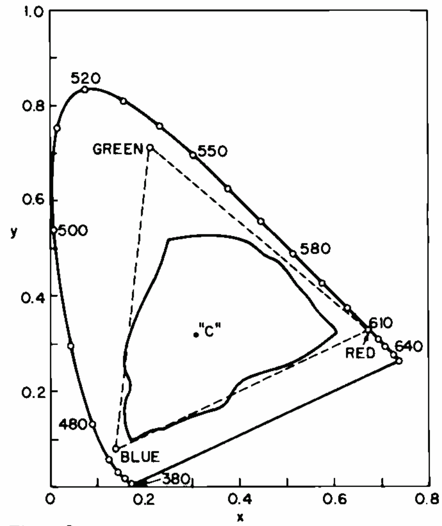


Fig. 10
CIE chromaticity diagram; NTSC color gamut (dashed triangle); and paints, pigments, and dye gamut. "C" marks the center-of-gravity of the chromaticity diagram.

An important deficiency of this representation of chromatic attributes is that equal distances in various portions of the diagram in x, y coordinates do not produce equally perceptible color differences. In fact, this type of nonlinearity varies by an amount of twenty or thirty to one. Fig. 11 is a plot of the classical Munsell colors in CIE coordinates while Fig. 12 is an indication of ellipses of equal color acuity for various portions of the diagram that points up the

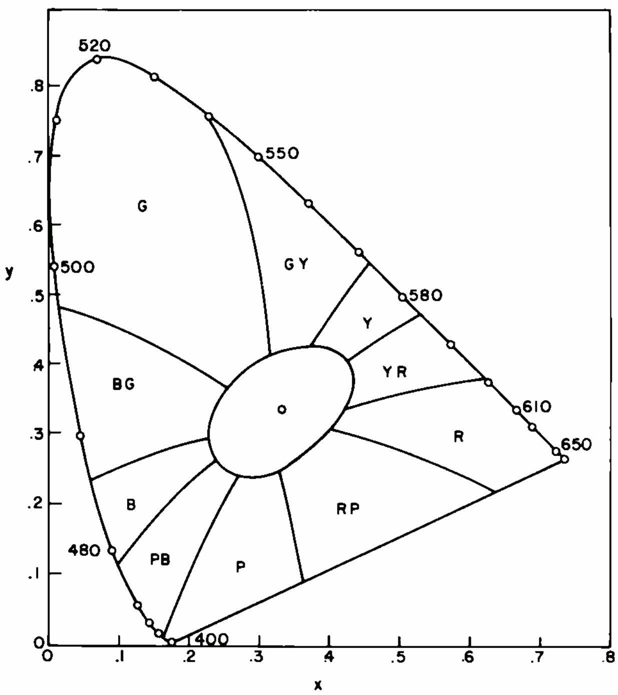


Fig. 11
Munsell colors plotted on CIE plane to represent chromatic attributes.

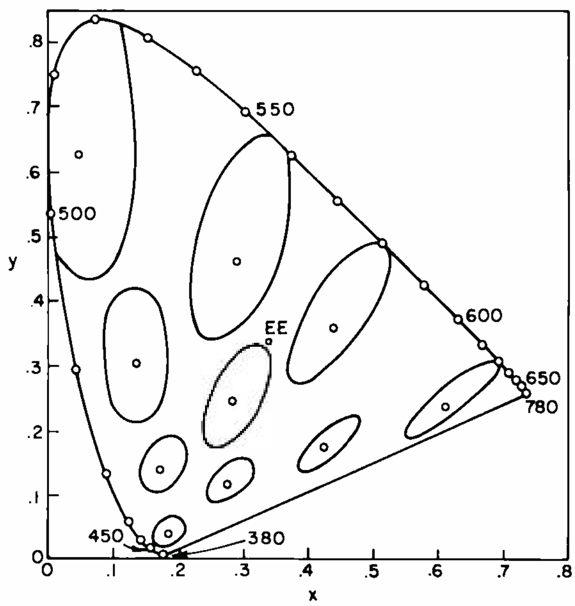


Fig. 12
Color acuity ellipses for various portions of the CIE chromaticity diagram (expanded by 100 to 1 for clarity).

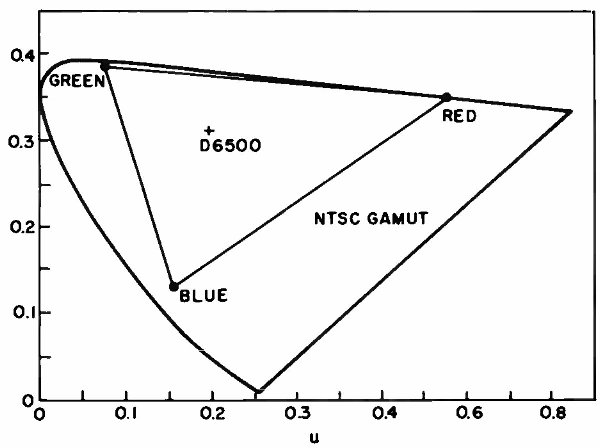


Fig. 13
Transformation of CIE diagram to u, v coordinates.

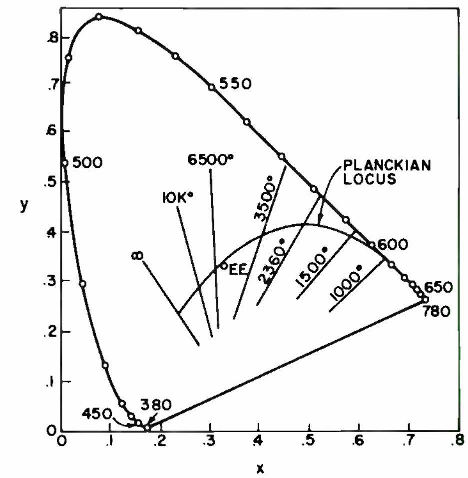


Fig. 14
Black-body locus, or Planckian locus, representation of color temperature.

high order of nonlinearity of perceptual color differences relative to equal geometrical coordinates.

Different mathematical transformations have been developed, the most notable being the Eastwood modification in 1964, in attempts to provide a closer match between subjective color-difference perception and equal distances on the chromaticity diagram. Fig. 13 is an example of this transformation in terms of u, v coordinates where the relative nonlinearity is reduced to about four to one. Further transformations restore the three-dimensional factor of brightness in which the coordinates are designated as U^*, V^*, W^*. A three-dimensional vector whose absolute value represents a total color-difference sensation is often referred to as color error (C_E) and is mathematically determined by the expression:

$$C_E = \sqrt{(U_1^* - U_2^*)^2 + (V_1^* - V_2^*)^2 + (W_1^* - W_2^*)^2}$$

Various investigators have reported somewhat different variations in the perceptibility of color differences, and research in this area is continuing with the aid of computer optimization techniques.

What is "white?"

After realizing that, by definition, color depends upon the characteristics of light that create the sensations of hue, saturation, and brightness, a legitimate question might be, "*What is white*?"—defined in colorimetric terms. In normal human experience, the most nearly uniform ambient light is provided by sunlight and, in modern times, artificial sources such as incandescent and fluorescent lights. Remembering that the three interrelated factors of surface reflectivity, ambient spectral distribution, and detector response determine the perceived color of an object, one might assume that a surface that reflects all portions of a daylight ambient equally to a standard "eye" detector would represent a reference white or gray colorimetric value. In 1931, the CIE recommended three standard reference-white illuminants:

Illuminant A—incandescent lamp, 2854° K
Illuminant B—noon sunlight, 4870° K (correlated)
Illuminant C—average daylight, 6770° K (correlated)

Illuminant E is a hypothetical equal-energy light source whose CIE coordinates are: $x = 0.33$, $y = 0.33$.

In 1965, a correction for Illuminant C was adopted that is referred to as Illuminant D6500; 6504° K (correlated). D6500 is now accepted as the reference white for color television standards, but the difference between Illuminant C, upon which the standards were based, and D6500 is negligible for all practical purposes and must be considered only when specific computation numerical cross-checks are required.

"White" light sources may be referenced to the radiant energy emanating from a black-body radiator at any given temperature. This light follows Planck's radiation law, having a certain color characteristic according to the radiator temperature expressed in degrees Kelvin. Thus, *color temperature* is a term used to describe a radiant energy source whose color matches that of a black body radiator at that temperature. Fig. 14 shows the black-body locus, or Planckian locus, plotted on the CIE (x, y) chromaticity diagram. A source of radiant energy that does not fall exactly on the black-body line can be described by the term, "*correlated color temperature*," which is the temperature of a black-body radiator that most closely matches the color coordinates of the source. The deviation of a correlated color temperature from the black-body curve is described in terms of minimum perceptible color difference (MPCD) units.

The color television system was based upon a white reference of Illuminant C (now D6500), and the transmission signals in the U. S. adhere to this standard. Receiver kinescope white reference practice over the years has changed in the direction of higher color temperature (typically 9300K + 17 MPCD). However, in recent years the trend is to return to D6500, which results in better color quality and less subjective colorimetric reproduction errors.

Thus, a color television display, usually a cathode ray tube, provides red, green, and blue primary light sources controlled by three electrical quantities in the form of appropriately formed electrical signals. The chromaticity coordinates of the R, G, and B primaries can be defined, and the tristimulus standardized values (X, Y, Z) for the display are the sums of the tristimulus values for each of the primaries.

A rigorous and internationally standardized system of colorimetric performance and evaluation has been established that is applicable to a practical color television system. The parameters of brightness, hue, and saturation may be directly translated into representative electrical signal implementation techniques as will be pointed out shortly.

NTSC system concepts and development

The technical basis of the NTSC color standards lies in the fundamentals of the science of colorimetry. To proceed to develop a color transmission system, we need to have a method of specifying the desired color sensation and to calculate the perceived color corresponding to a given spectral distribution of energy. The concept of hue, saturation, and brightness—coupled with the electronic technological ability to analyze the light emanating from a scene into three primary spectral color distributions—allows the communications systems engineer to recombine the specific color signal values in the proper proportions at the reproducer. Thus, the visual sensation of the color reproduction essentially corresponds to that of the original scene. The NTSC color standards define an electrical process of achieving this result within the limits of a specific communications channel.

Contrary to what might be assumed, the selection of the display (receiver) color primaries occurred first, and the color camera "taking" filter characteristics were then specified. The reasons for this relate simply to the availability at the time of suitable, and intrinsically efficient, cathodoluminescent phosphor materials to be employed in a color kinescope. The spectral distributions and dominant wavelengths of these light-emitting materials were used to determine the three systems primaries whose equivalent characteristics at the camera were obtained by appropriate dichroic filters, trimming filters, and electronic "matrixing" techniques.

The original assumption, for colorimetric reproduction fidelity reasons, was that the camera filters and the reproducer light-emitting characteristics were essentially "matched." However, over the years, the kinescope primaries have been purposely changed such as not to match the camera-standardized primary filters. This has been done primarily to obtain higher picture brightness values even though colorimetric errors are introduced. These errors can be subjectively reduced by appropriate design of the receiver decoder process, whereby subjectively critical colors (e.g., flesh color) are accurately reproduced and the major errors occur in relatively noncritical color values. This tradeoff between overall brightness and colorimetric subjective fidelity comprises a delicate balance of colorimetric design and circuit engineering that has received much attention by receiver system designers over the years.

The *basic camera function* is to convert the spectral distribution of the scene light into tristimulus values in terms of red, green, and blue receiver primaries. The three electrical signals originating at the camera must be transmitted over the communications channel and used to control the three electron beams to make the *perceived* color at the receiver appear essentially the same as the *perceived* color at the scene. The scene to be televised is analyzed in terms of its red, green, and blue components by the three light-sensitive devices in the camera. The camera outputs consist of three signal voltages, proportional to the amounts of red, green, and blue in the scene on a point-by-point basis as determined by the scanning rates and contained within a communications-channel bandwidth of about 0-4 MHz.

The three signals representing the red, green, and blue scene information may then be transmitted over the intervening communications channel between the transmitter and the reproducer by a variety of methods. For example, three parallel and simultaneous channels might be employed, or a common channel might be time-shared at either horizontal line rate or at field rate. Neither of these approaches, however, meets the requirement of compatibility with the existing monochrome system that occupied a single 6-MHz channel allocation.

A preferred signal arrangement had to be developed that resulted in compatible operation within the existing monochrome framework and that made efficient use of the existing channel capacity. Thus, one signal (luminance) was chosen to occupy the major portion (0-4 MHz) of the channel bandwidth and contained the *brightness* information as well as the detail content. A second signal (termed the *chrominance signal*) representative of the chromatic attributes of *hue* and *saturation*, was assigned to less channel width in accordance with the attributes of human vision that do not require full three-color reproduction over its entire range of resolution.

Certain important features of human color vision are exploited to package the combination of the brightness information and the color information within the 0-to-6-MHz channel allocation. First, the color acuity of the eye decreases as the size of the viewed object is decreased and thereby occupies a small part of the field of vision. Second, objects that occupy a very small part of the field of vision produce no color sensation, only that of brightness. Therefore, no color information need be transmitted in this spatial frequency range (corresponding to video frequencies above about 1.5 MHz).

Objects of a size to occupy an intermediate part of the field of view (video frequencies from about 0.5 MHz to about 1.5 MHz) are perceived by a two-color vision process consisting of those colors producible by mixing only two primaries of orange and cyan. Thus, in this spatial frequency region, only orange and cyan information need be transmitted.

Large areas corresponding to video frequencies below about 0.5 MHz are seen by three-primary color vision, and full three-color information is required for satisfactory color reproduction. These system limitations do not necessarily mean that the picture quality has been reduced. Realization of these features simply allows the communications engineer to develop a color television system that does not transmit information that the eye cannot use and thereby permits a degree of compression of the required information into a specified channel.

Thus, the *principles* of "*mixed-highs*" and "*I, Q color-acuity axis*" operation were exploited. One remaining problem was to simultaneously transmit the brightness signal and the chrominance signal within the same channel limits.

Signal encoding and decoding techniques

The importance of the colorimetric concept of brightness, hue, and saturation comprising the three pieces of information necessary to analyze or re-create a specific color value becomes evident in the formation of a suitable composite color television signal format.

To provide compatibility, the total television signal must contain a monochrome signal in the conventional form such that a black-and-white receiver will function normally. For this purpose, the monochrome signal (Y) can be made to represent the desired brightness information and to include the detail signals. The additional hue and saturation information required for color is added in such a way that it is ignored by a black-and-white receiver. A color receiver detects the additional information and is designed to re-create the original red, green, and blue primary color signal values as initially generated in the color camera.

The luminance, or monochrome, signal is formed by addition of specific proportions of the red, green, and blue signals.

The "Y" signal must have voltage values representative of the brightness sensation of the human eye. Therefore, the red, green, and blue components are tailored in proportion to the standard luminosity curve for the particular values of dominant wavelength represented by the three color primaries chosen for color television. Thus, the standard luminance signal values were determined to be as follows:

$$E_Y = 0.30\ E_R + 0.59\ E_G + 0.11\ E_B$$

The voltage outputs from the three camera tubes are adjusted to be *equal* when a scene reference *white* or neutral gray object is being scanned, regardless of the color temperature of the scene ambient. However, the colorimetric values have been determined by assuming that a reference white of D6500 will always be used at the reproducer. Thus, the color values at the reproducer will appear as if the scene had been illuminated with D6500 white light. Serious colorimetric errors result if the reproducer is allowed to vary to any large extent from a value of D6500 even though the studio reference can, and often does, legitimately use values in the order of 3250°K.

Signals representing the chromaticity information (hue and saturation) may be generated by subtracting the luminance signal from the red, green, and blue signals, respectively.

This results in a new set of signals termed *color difference* signals designated as R-Y, G-Y, and B-Y. These signals are encoded in a specific manner at the transmitter, passed through the common communications channel, detected at the receiver, and individually added to the luminance signal to reproduce the original R, G, and B signals to actuate the reproducing device as indicated below:

$$E_Y + E_{(R-Y)} = E_Y + E_R - E_Y = E_R$$
$$E_Y + E_{(G-Y)} = E_Y + E_G - E_Y = E_G$$
$$E_Y + E_{(B-Y)} = E_Y + E_B - E_Y = E_B$$

In NTSC color standards, the chrominance signals (color-difference values) are encoded on a common subcarrier in the high frequency portion of the video domain by simultaneously modulating the phase of the subcarrier to represent the instantaneous hue value, and modulating the amplitude of the subcarrier relative to that of the brightness component to represent color saturation. The hue and saturation information can be carried without loss of identity provided that proper timing in a phase sense is maintained between the encoding and subsequent decoding processes. This is accomplished by transmitting a reference timing signal, or *burst*, consisting of eight or nine cycles following each horizontal synchronizing pulse during the blanking interval. (See Fig. 15.) Quadrature synchronous detection is used to identify the individual color-signal components of the chrominance subcarrier. When individually recombined with the luminance signal in a linear resistive matrix, these color-signal components re-create the desired red, green, and blue signals.

At the transmitter, the color-difference signals are initially formed by linear matrix combinations of the red, green, and blue signals. These signals are band-limited: to about 0.6 MHz in the case of the color-difference signal designated as "Q", containing the green-purple color-axis information; and to about 1.5 MHz in the case of the "I" color-difference signal, representing the orange-cyan color-axis information. These two signals then are used to individually modulate the color subcarrier in two balanced modulators maintained in phase quadrature. The "sum" products are selected and linearly combined to form a composite chromaticity subcarrier whose instantaneous phase represents the hue of the scene at that moment, and whose amplitude—relative to the brightness signal amplitude—is a measure of saturation. This signal is then added to the luminance signal, along with the appropriate horizontal and vertical synchronizing and blanking signals to include the color-synchronizing burst. The result is the total color video signal.

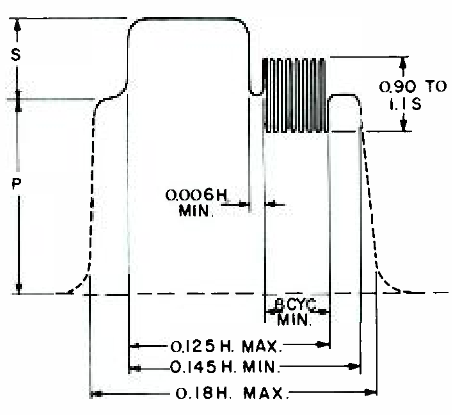


Fig. 15
Horizontal sync and color burst. The eight or nine "burst" cycles following the horizontal sync pulse allow proper relationships to be maintained through the encoding and decoding processes.

Symmetrical system equations

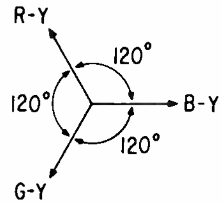
The basic process may be understood in mathematical terms by using a simplified, and historically first, form in which equal values are assigned for the R, G, and B luminance components (0.33 for each when white is normalized to a value of 1.0). Also, a *symmetrical system* of assigning 0°, 120°, and 240° phase to represent the red, blue, and green hue values, respectively, is employed, resulting in equal subcarrier amplitude values for fully saturated primary colors.

From the *symmetrical system equations*, it is easy to see that the color-difference signal values must have a positive amplitude of 0.66 for the desired color, and negative values of −0.33 for the other two primary colors. Thus, in the process of re-creating an individual primary color signal, the color-difference signals are added linearly to the "Y" signal; this reinforces the desired color signal to a value of 1.0 and cancels the luminance signal to zero for the other two colors. The same process is applied to each channel in turn.

The "prime" designation associated with each primary signal voltage value indicates that the signals are nonlinear by a specified amount to compensate for the nonlinear voltage-to-light characteristic of the reproducing kinescope. The overall system philosophy is to linearly reproduce the light input to the camera at the output of the kinescope; however, the signals in the transmission path are nonlinear with an

NTSC System Equations

Symmetrical system equations



$$S_T = \frac{1}{3}R' + \frac{1}{3}G' + \frac{1}{3}B' + \frac{2}{3}R' \cos \omega_c t + \frac{2}{3}G' \cos(\omega_c t + 120°) + \frac{2}{3}B' \cos(\omega_c t + 240°)$$

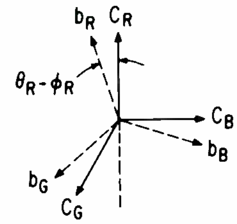
$$R' - Y' = \frac{2}{3}R' - \frac{1}{3}G' - \frac{1}{3}B'$$

$$G' - Y' = -\frac{1}{3}R' + \frac{2}{3}G' - \frac{1}{3}B'$$

$$B' - Y' = -\frac{1}{3}R' - \frac{1}{3}G' + \frac{2}{3}B'$$

$$Y' = \frac{1}{3}R' + \frac{1}{3}G' + \frac{1}{3}B'$$

General case I



b = TRANSMITTER
C = RECEIVER
θ = TRANSMITTER
φ = RECEIVER

$$Y' = a_R R' + a_G G' + a_B B'$$

$$C' = b_R R' \cos(\omega_c t + \theta_R) + b_G G' \cos(\omega_c t + \theta_G) + b_B B' \cos(\omega_c t + \theta_B)$$

FOR NTSC:

$a_R = 0.299$
$a_G = 0.587$
$a_B = 0.114$

General case II

DECODING ANGLES : ϕ_R , ϕ_G , ϕ_B
DECODING GAINS : C_R , C_G , C_B

$$R' - Y' = C_R b_R R' \cos(\theta_R - \phi_R) + C_R b_G G' \cos(\theta_G - \phi_R) + C_R b_B B' \cos(\theta_B - \phi_R)$$

$$G' - Y' = C_G b_R R' \cos(\theta_R - \phi_G) + C_G b_G G' \cos(\theta_G - \phi_G) + C_G b_B B' \cos(\theta_B - \phi_G)$$

$$B' - Y' = C_B b_R R' \cos(\theta_R - \phi_B) + C_B b_G G' \cos(\theta_G - \phi_B) + C_B b_B B' \cos(\theta_B - \phi_B)$$

General case III

ALSO:

$$R' - Y' = (1 - a_R) R' - a_G G' - a_B B'$$

$$G' - Y' = -a_R R' + (1 - a_G) G' - a_B B'$$

$$B' - Y' = -a_R R' - a_G G' + (1 - a_B) B'$$

THE COEFFICIENTS ARE:

$(1 - a_R)$	$-a_G$	$-a_B$
$-a_R$	$(1 - a_G)$	$-a_B$
$-a_R$	$-a_G$	$(1 - a_B)$

NTSC values specified by committee

(1) $a_R = 0.299$
$a_G = 0.587$
$a_B = 0.114$

(2) MAXIMUM "BLACKER THAN BLACK" SWING = $\frac{1}{3}$

$\therefore$ $b_R = a_R + .333$
$= .299 + .333 = .632$

$b_B = a_B + .333$
$= .114 + .333 = .447$

(3) $\theta_B = 0°$

$\phi_B - \phi_R = 90°$

Nine basic equations

$$(1 - a_R) = C_R b_R \cos(\theta_R - \phi_R)$$
$$-a_R = C_G b_R \cos(\theta_R - \phi_G)$$
$$-a_R = C_B b_R \cos(\theta_R - \phi_B)$$

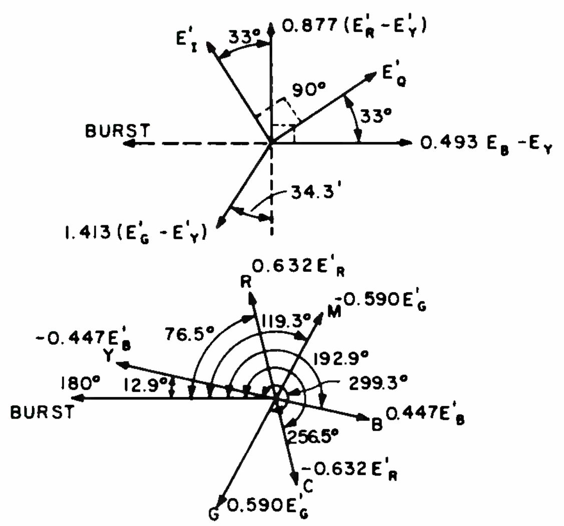
$$-a_G = C_R b_G \cos(\theta_G - \phi_R)$$
$$(1 - a_G) = C_G b_G \cos(\theta_G - \phi_G)$$
$$-a_G = C_B b_G \cos(\theta_G - \phi_B)$$

$$-a_B = C_R b_B \cos(\theta_B - \phi_R)$$
$$-a_B = C_G b_B \cos(\theta_B - \phi_G)$$
$$(1 - a_B) = C_B b_B \cos(\theta_B - \phi_B)$$

Solutions to nine basic equations for NTSC

RED		GREEN		BLUE	
	$a_R = 0.299$		$a_G = 0.587$		$a_B = 0.114$
	$b_R = 0.632$		$b_G = 0.590$		$b_B = 0.447$
	$C_R = 1.1402$		$C_G = 0.7027$		$C_B = 2.0284$
	$\theta_R = 103.47°$		$\theta_G = 240.67°$		$\theta_B = -12.95°$
	$\phi_R = 90°$		$\phi_G = 235.75°$		$\phi_B = 0°$

NTSC color signal specifications



$$E'_I = -0.274 E'_G + 0.596 E'_R - 0.322 E'_B$$

$$E'_Q = -0.522 E'_G + 0.211 E'_R + 0.311 E'_B$$

$$\frac{E'_B - E'_Y}{2.03} = -0.545 E'_I + 0.839 E'_Q$$

$$\frac{E'_R - E'_Y}{1.141} = +0.839 E'_I + 0.545 E'_Q$$

$$\frac{E'_G - E'_Y}{0.703} = -0.399 E'_I - 0.900 E'_Q$$

$$E'_Y = 0.589 E'_G + 0.299 E'_R + 0.114 E'_B$$

exponent, or "gamma", having a specified value of 2.2.

From the symmetrical case, a *generalized case* can be developed with two of the color-difference signals in phase quadrature and precise values for the signal voltages and the encoding and decoding angles as actually proposed by the NTSC and adopted by the FCC. *General Case I* shows that the primary color values comprising the luminance signal are not equal, but are 0.299 for red, 0.587 for green, and 0.114 for blue.

The general expressions for the three primary color-difference signals are given in *General Case II*. These same color-difference signals may also be expressed in terms of R, G, and B as indicated in *General Case III*. From these equations, nine coefficients are produced, for which values must either be assigned or calculated to specify the total system.

These coefficient values have been specified by the NTSC. The luminance primary color values have already been determined, and the receiver decoding angle representing blue was arbitrarily determined as 0° in a Cartesian coordinate system (180° from the phase of the reference burst). A difference of 90° was assigned between the signals representing blue and red. It was also decided that maximum saturation would be represented by a peak-to-peak value of subcarrier signal whose negative value would never swing "blacker-than-black" by more than −0.33 (white normalized to a value of +1.0 and black at zero).

If the coefficients of the color-difference signal values, as indicated in General Case II, are set equal to the color-difference coefficients derived from General Case III, *nine basic equations* are formed that characterize the NTSC system. These equations may be solved for the unknowns if the *NTSC values* are inserted. (The underlined values are those specified by committee.)

Thus, the total NTSC color signal values and encoding and decoding angles are determined to form the desired luminance (brightness) and chrominance (hue and saturation) information carrying signals. A graphical representation of the mathematical process is shown in Fig. 16. Fig. 17 shows the standardized values for a composite color-bar signal. A complete statement of the *specifications of the NTSC color signal values* is included with the equations.

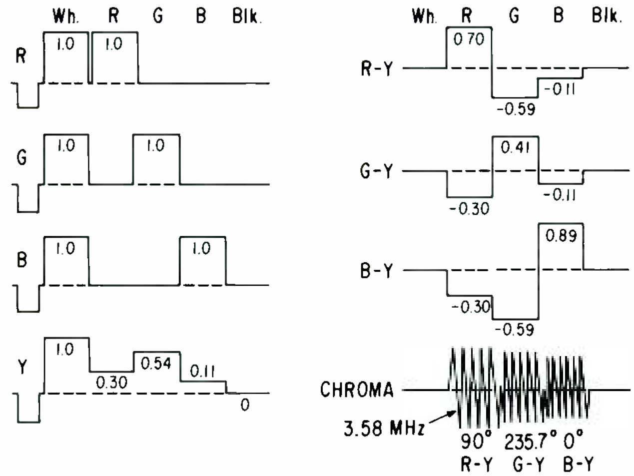


Fig. 16
Basic color signal waveforms. These signal waveform values have been normalized for a scene comprised of a white, red, green, blue, and black bar pattern. The primary color signals are shown along with the color-difference signal values required to add to the luminance signal to re-create the individual color signals. The chrominance signal component is also shown.

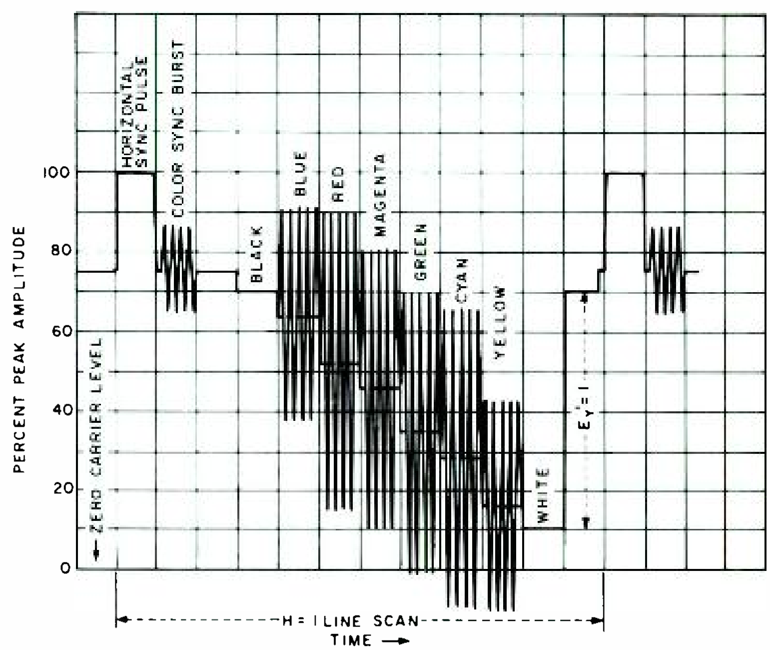


Fig. 17
Color bar standard values formed from the three primary colors and their equal-mixture complementary colors.

Encoding

In summary, the scene to be televised is analyzed in terms of its specified red, green, and blue components by the camera. The resulting three output signals are combined in linear matrices to form a luminance signal (E_Y) containing frequencies in the 0-to-4-MHz range. Two specific color-difference signals are also formed; one designated as "I" and having a bandwidth of about 1.5 MHz, and the other designated as "Q" with a bandwidth of about 0.5 MHz. The "I" signal contains the orange-cyan color hues while the "Q" signal reproduces the green-magenta range of colors. When both the I and Q signals are present (0-to-0.5-MHz range), full three-color reproduction is available. In the frequency range from 0.5 MHz to 1.5 MHz, only the I signal exists and the preferred high-acuity orange-cyan locus of colors is reproduced. In the frequency range above 1.5 MHz, only the Y signal exists; it provides the high frequency monochrome detail informa-

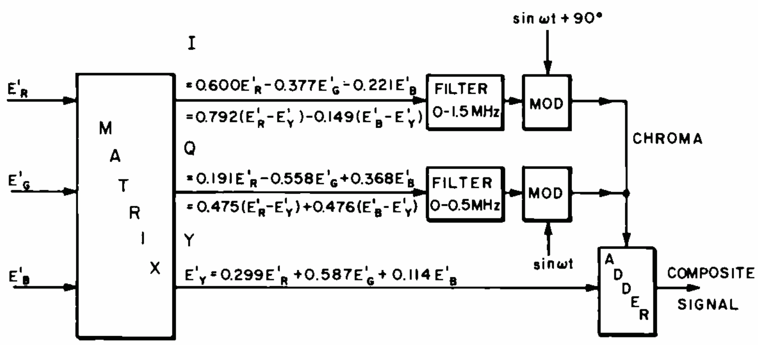


Fig. 18
NTSC encoder functions and signal make-up designations.

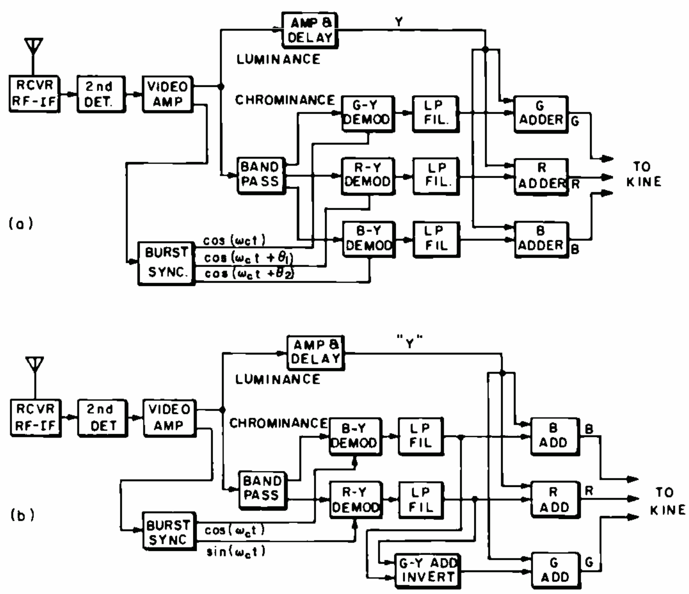


Fig. 19
NTSC receiver decoder functions. Drawing (a) shows the fundamental operation of recovering all three color-difference signals; (b) is a simplification that requires only two decoders with a matrix to form the other (G-Y) color difference signal.

tion. To reproduce the preferred orange-cyan colors, the angles representing I and Q are in phase quadrature, but are rotated 33° from the B-Y and R-Y phase designations. The 33° angle was determined experimentally and specified by committee. Fig. 18 summarizes the transmitter encoding functions and signal-makeup designations.

Decoding

At the receiver, the *decoding process* is essentially the inverse of the encoding function. Fig. 19 shows two typical receiver functional diagrams. The luminance signal, in the video domain, is fed to all three of the reproducing kinescope guns at the appropriate levels to produce a monochrome picture having a D6500 color temperature. The chrominance signal is separated by a bandpass filter and impressed upon the inputs of the synchronous demodulators. These demodulators extract the appropriate color-difference signals at the desired phase angle, as determined by a locally generated sub-carrier reference signal locked to the incoming "burst" signal.

The receiver designer is free to determine the particular decoding process. For example, the I, Q signals available, followed by the appropriate matrix, can be used to form the necessary R-Y, B-Y, and G-Y signals. On the other hand, R-Y and B-Y signals with equal bandwidth (0-to-0.5 MHz) may be decoded directly with a simple matrix to form G-Y. In either case, the detected color-difference signals are individually added to the luminance signal in proper proportions to re-create the specific red, green, and blue signals that actuate the kinescope display device.

The overall gain of the chrominance channel determines the reproduced color saturation (ratio of chrominance to luminance), and the overall phase adjustment of the decoding reference signal provides a control of the average hue of the reproduced scene.

Luminance—chrominance

Another reason for the choice of signal values in the NTSC system is that the eye is more responsive to spatial and temporal variations in luminance than it is to the same variations in chrominance. Therefore, the relative chrominance gain and angle values are proportioned to take advantage of this characteristic in order to reduce the visibility of random noise and interference effects introduced into the transmission path between the transmitter and the receiver. Thus, the principle of *constant luminance* is exploited to an extent that the combined brightness of random-noise variations in the red, green, and blue channels appears constant in relation to the luminosity response of the average human eye. In an idealized linear system, the improvement in *visual* signal-to-noise ratio is in the 8-to-10-dB range. However, even though the system is inherently nonlinear, the brightness-cancellation process is effective at relatively low-level chromaticity signals, and the average improvement is in the order of 4 to 5 dB.

The problem remains of arranging the chrominance and luminance signals within a common channel without excessive mutual interference. Recognition that the scanning process, being equivalent to sampling, produces signal components concentrated in uniformly spaced groups across the channel width introduced the principle of *horizontal frequency interlaced* (dot interlace) operation. The color subcarrier frequency was chosen to be an odd multiple of one-half horizontal line frequency at a value of 3.579545 MHz. Thus, in an interlaced system, the phase of the subcarrier alternates in succeeding lines by 180° and four fields are required for picture completion. In addition, the chrominance subcarrier, by definition, becomes zero when no color exists and only shades of gray are to be reproduced via the luminance channel.

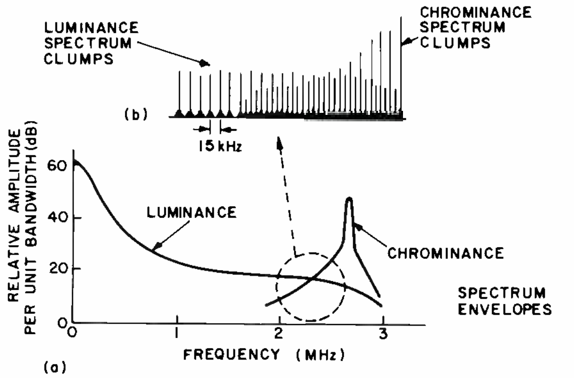


Fig. 20
Frequency-interlaced relationship of chrominance and luminance.

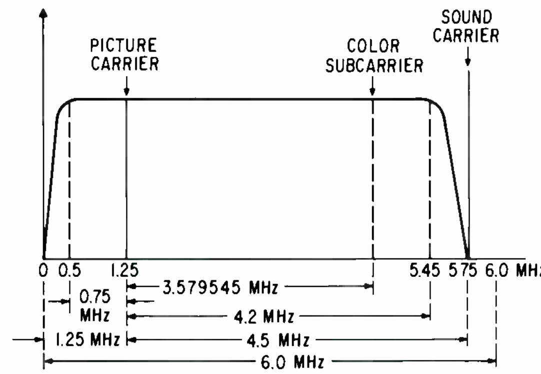


Fig. 21
Transmission channel for the NTSC color system.

By the interleaved nature of the subcarrier frequency relative to the timing of the horizontal scan rate, the visibility of the subcarrier signal is reduced, and if the system were linear, would exactly cancel on alternate lines. This interleaving process, indicated in Fig. 20, makes it possible to transmit the chromaticity information in the form of a phase- and amplitude-modulated subcarrier within the same channel width as that previously occupied by the monochrome transmission alone.

Since the picture-signal-energy-distribution versus frequency is grouped into intervals having 15.734-kHz spacings (horizontal scan rate), various prime numbers can be chosen to produce odd multiples of one-half line rate. The particular choice in the vicinity of 3.6 MHz was made for two reasons. First, the high frequency resulted in a fine interference pattern having low visibility because of small spatial dimensions. Second, this value allows about 0.5 MHz of double-sideband frequency range for the color-signal sideband components allowing for the sound carrier located at 4.5 MHz. The choice of the exact frequencies is

$$f_{LINE} = \frac{4.5 \times 10^6}{286} \text{ Hz}$$
$$= 15{,}734.26 \text{ Hz}$$

$$f_{FIELD} = \frac{f_{LINE}}{525/2} \text{ Hz}$$
$$= 59.94 \text{ Hz}$$

$$f_{SC} = \frac{13 \times 7 \times 5}{2} \times f_{LINE}$$
$$= 3.579545 \text{ MHz}$$

This choice allows the approximate average beat of 920 kHz between the color subcarrier and the sound carrier to also be interlaced to reduce its average visibility. The sound carrier, for reasons of compatibility, remained at 4.5 MHz, and the total number of scanning lines remained at 525 lines in a two-to-one vertical interlaced system. Thus, the color subcarrier, f_{sc}, became 3.579545 MHz with the horizontal scanning rate f_{LINE} = 15.734 kHz, and the vertical rate f_{FIELD} = 59.94 Hz. These rates, although slightly different from the black-and-white standards, fell within the previous tolerance ranges and therefore were acceptable.

The assigned communications-channel frequency relationships are shown in Fig. 21. The picture signal is handled in a vestigial-sideband manner with appropriate amplitude and phase compensation exactly as previously employed in the monochrome system with the sound signal spaced 4.5 MHz from the picture carrier. The color information is carried on a subcarrier located at 3.579545 MHz from the picture carrier. A specific color-signal phase-compensation filter introduced at the transmitter compensates for the typical characteristics of a receiver i.f. response to maintain phase and amplitude symmetry around the color subcarrier at 3.58 MHz.

Thus, the NTSC color standards provide a compatible signal with respect to the previous monochrome standards, and it follows that the numerical values describing the color signal are more precisely specified and therefore fall within previously existing tolerances. The color signal values for the complete system are regulated at ±20% amplitude and ±10° phase. However, the standards of good practice recommend ±10% amplitude and ±5° phase. The relative time delay match between the chrominance and luminance signal components is ±50 ns. The accuracy of the 3.579545 MHz is ±0.0003% (approximately ±10 cycles tolerance) with a rate of drift not to exceed one-tenth of a cycle per second. The horizontal and vertical scanning signals are, of course, derived from the color subcarrier in order to insure the interleaving relationship.

Conclusion

In the early development period of color television, some critics quipped that NTSC might represent, "Never The Same Color." But this ingenious system of standards—an imaginative combination of psychophysical and electronics characteristics—has prevailed for over twenty years and represents one of the more complex yet highly successful technological information display systems ever devised.

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The XL-100 XtendedLife chassis

These new chassis reduce energy consumption to that of a 100-watt light bulb or less and offer improved performance, reliability, safety, and serviceability—without increased cost.

P.C. Wilmarth

In February of this year, RCA introduced the first of a series of chassis destined to replace the present XL-100 and XL-100 ColorTrak chassis. These "XtendedLife" chassis are the result of the most intensive development effort since ColorTrak. The goals of this development program were:

1) To effect a major cost reduction by intrinsic design and by standardization across a broader spectrum of the product line;

2) To maintain or improve the excellent performance established with ColorTrak;

3) To use less power in this energy-conscious world;

4) To significantly enhance long-term reliability;

5) To make the most manufacturable and serviceable chassis in RCA history; and last but not least,

6) To meet even more stringent safety requirements.

Chassis description

The basic "XtendedLife" chassis, designed to achieve maximum standardization, will ultimately evolve into a series of four chassis. The first two are for price-leader models for 19" and 25" sizes, replacing XL-100 instruments and featuring several performance improvements:

DC restoration—optimized to make blacks as they should be and for excellent color rendition.

Greater picture resolution—designed with equal preshoot and overshoot with phase response optimized for minimum ghost effects.

Automatic flesh correction and color level—features introduced with ColorTrak and repackaged into a new single chroma IC that maintains excellent fleshtones without the loss of rich green colors.

Picture stability—virtually impervious to line variations and line surges while maintaining picture size with brightness changes.

The second two chassis are for deluxe models which have all the above features, plus:

ColorTrak—maintains proper color level for various settings of the contrast control; corrects contrast and color automatically for varying room light conditions, virtually eliminating need for customer adjustment. (Same features introduced in initial ColorTrak models.)

High voltage—about 2 kV more than "XtendedLife" price-leader chassis (29.5 kV) for greater picture resolution.

Adjustable peaking control—maintains equal preshoot and overshoot through peaking range.

Tuning systems—models feature a variety of tuning systems for customer preference.

Increased contrast—tinted phosphors in the picture tube increase contrast.

The new chassis family has four major subassemblies: power supply package, signal package, deflection package, and tuning system. This partitioning served two needs: 1) It enabled manufacturing to choose the most cost effective plant for assembly and test for each subassembly; and 2) It integrated most effectively with present techniques for automatic testing. After test, all subassemblies are hard-wired together into a complete chassis requiring little further testing. The chassis is a horizontal type, which enhances reliability by keeping most components in the cooler ambient air at the bottom of the instrument.

The "XtendedLife" chassis are partitioned into eight modules which contain most of the circuitry; the exceptions are the horizontal output stage and some power supply components. Seven of the modules are common to the entire series; the eighth or luminance module has two versions: one for the price-leader series, and the other for the deluxe series which uses the same integrated video processor circuitry as the previous ColorTrak models. The modules are all new with the exception of the IF/AFT module, and were repackaged for two basic reasons:

1) For more cost effectiveness—modules were designed for auto-insertion of resistors and capacitors and to use a more cost effective interconnection system.

2) For improved reliability—copper spacings were doubled from 6V/mil to 3 V/mil.

Developments to meet the objectives

The bulk, weight, and power loss of the familiar power transformer used for isolation have been eliminated.

All supply voltages for the main chassis are derived from the high-voltage transformer secondaries, with the transformer providing isolation. As shown in Fig. 1, the main power supply (full-wave bridge and

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B+ switching regulator) and the horizontal output stage (transistor deflection) are all ac-line connected or "hot". To provide complete chassis isolation, four main components—the horizontal-output transformer, the horizontal-driver transformer, the start-up transformer, and the yoke—must be isolated from the power line. The yoke isolation is between the vertical and horizontal windings as the horizontal windings are "hot" and the vertical windings are isolated, or "cold". A start-up transformer is needed for the horizontal oscillator and driver, since their main source of supply is from the flyback. At turn-on, the surge of current required to charge C1 (the power supply electrolytic) flows through the primary of the start-up transformer T1, thus inducing enough voltage at the T1 secondary to get the oscillator started. Once started, the source from the flyback transformer takes over and the start-up transformer is switched out of the circuit by the switching diode CR1, which is then reverse biased.

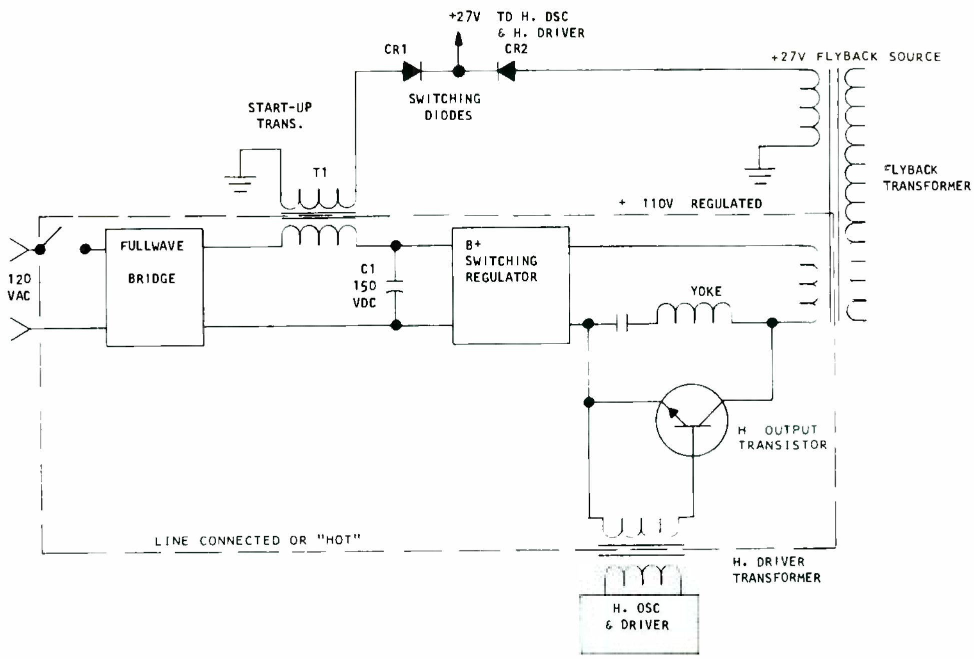


Fig. 1
Main power supply showing components that require power-line isolation. These include the start-up transformer primary, the horizontal-driver transformer primary, the yoke, and the horizontal-output (flyback) transformer primary.

Reduced power consumption was one goal.

One way this was made possible was by using a switching regulator (Fig. 2) to provide a regulated dc supply for the horizontal output transistor. The regulator is switched at the horizontal frequency rate (15,743 Hz) which allows the use of much smaller capacitors for filtering than would be required at 60 Hz.

Think of the regulator as an electronic switch (SCR401) that supplies pulses of current to charge the filter capacitor C401 which stores the energy and allows it to be discharged into the load at a constant rate. The +150V supply voltage in Fig. 2 is supplied by a conventional full-wave bridge from a 120V ac supply. This supply will vary from approximately 130 to 170V dc when the power line varies between 105 to 135V ac. When the switch (SCR401) is closed, +150V is applied across a flyback winding L402 and the horizontal output load. Current flows through L402 into the load and C401, and the time constant of this combination is considerably longer than the horizontal scan time of 50 μs. This can be seen by the shape of the current pulse in Fig. 3, which also shows that the switch is *on* during scan and *off* during retrace.

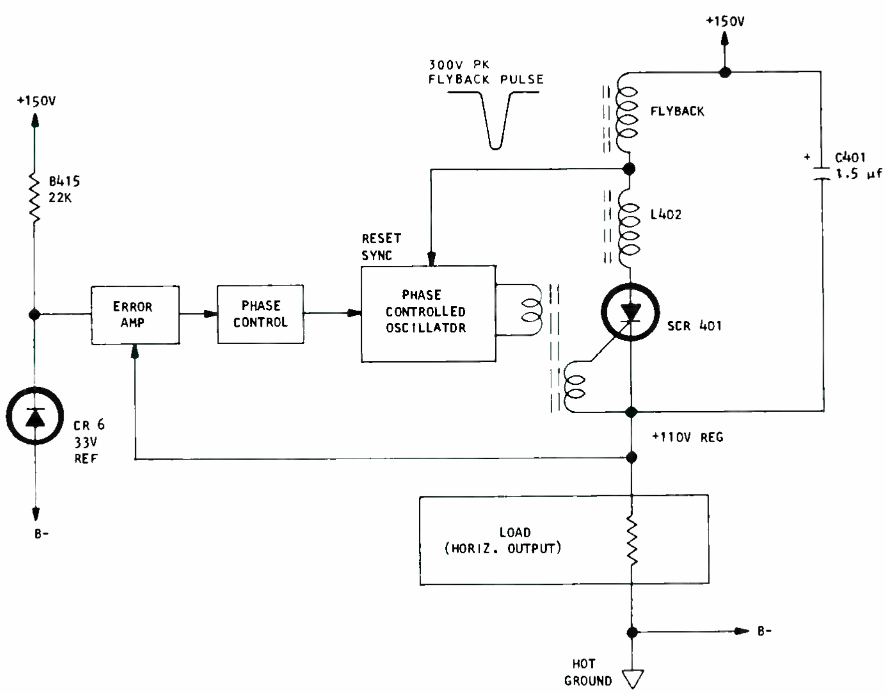


Fig. 2
Switching regulator in which an electronic switch (SCR401) supplies pulses to charge C401 which is then discharged into the load at a constant rate.

Fig. 3 shows that when B+ from the unregulated supply is low, the switch is

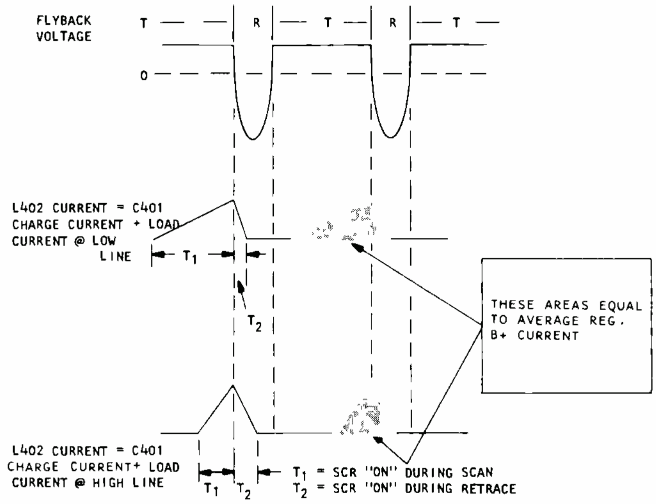


Fig. 3
Switching regulator operation can be observed in this timing diagram, which compares flyback voltage with charge and load current for different power-line inputs.

turned *on* early in the scan cycle to deliver a larger average current to charge C401. Conversely, when unregulated B+ is high, the switch is turned *on* much later in the scan cycle for a smaller average charge current. Thus, by controlling the instant when the switch (SCR401) turns *on*, the required regulated +110V dc is maintained at the load.

As shown in Fig. 2, the phase-controlled oscillator provides a turn-on gating pulse to SCR401 through T1 to control the instant when the SCR swtiches. This turn-on instant is determined by the error amplifier and phase control circuits that drive the phase-controlled oscillator. The error amplifier samples the output of the regulator (+110V) and compares it against a 33V zener diode reference (CR6). Output from the error amplifier feeds the phase-controlled circuitry which either advances or delays the turn-on of SCR401, thus maintaining the +110V for the horizontal output supply. This system also provides regulation against chassis load variations, since an increase in load current would tend to drop the 110V dc that is fed to the error amplifier.

To prevent nuisance service calls, a current shutdown circuit is included with the regulator circuit. This circuit prevents device or component failures in the horizontal output stage, regulator, and power supply circuits when unusual picture tube arcing causes excessively high current drain. If extended arcing does occur, the increased current is sensed and the shutdown circuit shuts off the SCR, which in turn shuts off the chassis. To return to normal operation, the customer simply turns the switch *off*, waits for approximately 30 seconds and turns the set back *on* again.

In summary, power was reduced by use of the switching regulator. Its losses are basically those of the switch itself and are far less than losses in a series-pass regulator or a ferro-resonant transformer. Many other circuits were optimized for lower power such as a larger yoke requiring less power to scan the picture tube, lower supply voltage (dropped from 30V to 22V for most of the chassis), a vertical circuit (derived from a recent black-and-white chassis) which is more than twice as efficient for power, and a 33-ohm speaker for a more efficient power match into the 22V supply. Table I gives an indication of just how efficient the new chassis is. Brightness is compared to input power on the new "XtendedLife" chassis (CTC85) against its predecessor XL-100 and one of the better performing competitors.

Table I
Efficiency of various tv chassis measured in terms of brightness per average power.

Brand	*Brightness (Ft.-Lamberts)*	*Input power (Avg. Watts)*	*Efficiency (Bright/Avg. Power)*
XtendedLife	390	89	4.38
XL-100	380	117	3.24
Competitor	300	134	2.23

Note that the "XtendedLife" chassis is the brightest of the three. High voltage at zero beam current is only 17.6kV but drops only about 1.5kV at 1.5mA of beam current. Most other sets will deregulate about 2.5kV. Special attention was given to keeping horizontal overscan to a minimum, which resulted in higher peak brightness. To further enhance performance, a delta picture tube was used for its small spot size.

Another major goal was to improve serviceability.

Some of the serviceability improvements included:

1) all eight modules are removable while the chassis remains in the cabinet;

2) all active devices are on modules with the exception of the regulator SCR and the horizontal output transistor, and these two devices are plug-in and accessible without chassis removal. (The tuners are an exception as their devices are not plug-in);

3) All components are accessible from the top side of chassis (no components under chassis);

4) Modules are marked with description of inputs and outputs, with voltage and pulse shapes identified, and with test points.

As a result of the attention paid to serviceability, this chassis achieved the highest rating by far of any RCA design. This rating, made by (ISCET) International Society of Certified Electronic Technicians, is derived from a standard form where points are given for such serviceability items as ease of back removal and reinstallation, service control accessibility and identification, accessibility for service and component identification, etc. The total points received are compared against the maximum attainable points for a percentage rating. The "XtendedLife's" 89.94% rating exceeds that of competitors with one isolated exception. It should be noted here that a serviceable set is also a manufacturable set.

Many avenues were pursued to achieve the major goal of cost reduction.

Some of the major cost reductions are as follows:

1) Repackaging was one of the more significant. Chassis metal was reduced to at least one half of the previous XL-100 chassis and designed for minimum scrap in tooling. Chassis weight was reduced by 15 lb, of which about 6 lb was the bulky power transformer. The reduction of chassis metal itself resulted in several dollars' savings. A new interconnect system for modules was very cost effective.

2) An intensive program in which Consumer Electronics' Strategic Sourcing group helped find new components resulted in considerable savings.

3) The chassis was designed with unprecedented interaction with manufacturing experts for considerable savings in assembly and test labor. More components are automatically inserted than ever before.

4) The two 14-pin chroma ICs used in ColorTrak were redesigned by Solid State Division into a new single 24-pin IC for a major cost reduction while still retaining the features of auto-tint correction and color overload regulation introduced in ColorTrak.

5) Cost savings were obtained by the developments in deflection circuitry previously described.

6) The standardization achieved in the new series of four chassis, where the majority of parts are identical, resulted in significant savings.

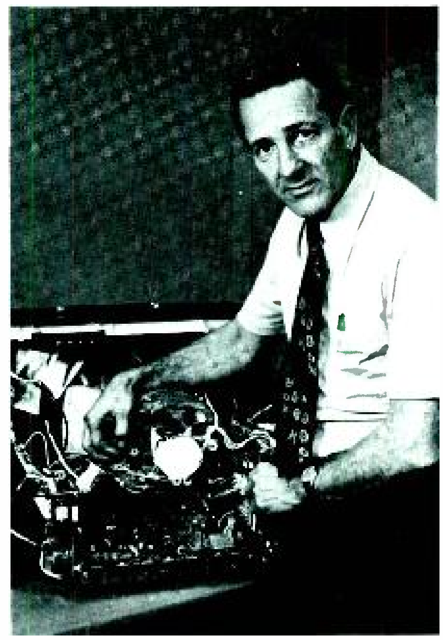
7) Savings were achieved in almost every circuit in the chassis, and the total savings in the instrument represents one of RCA's larger cost reductions while performance was maintained or enhanced.

The "XtendedLife" chassis is about twice as reliabile as the reliable ColorTrak.

This series of chassis has been designed to run cooler and last longer than any previous RCA chassis. The reduced power consumption and the use of a horizontal chassis, where most components are at the bottom of the cabinet, have produced average temperature reductions of about 20% on the Celsius scale compared to its XL-100 predecessor. Cooler operation means greater inherent reliability over the life of the set. Of course temperature is not the only factor. The Safety and Reliability Center contributed greatly by guiding Design Engineering toward components with high reliability. The Quality and Reliability Department supplied valuable research on failure analysis. Their reliability predictions based on past history show that the new chassis is approximately twice as reliable as the initial ColorTrak chassis, which had already made significant strides toward higher reliability.

Rigid safety standards were applied throughout the development cycles.

Reviews were made by the Safety and Reliability Lab to assure conformance to proposed new government standards and to RCA's own stringent safety requirements. These chassis were designed to meet double-isolation requirements, meaning that if one stage of isolation were to fail, the enclosure or cabinet will still retain one stage of isolation against shock hazard. For additional reliability, all high-energy circuits are mounted on materials that are particularly resistant to arc tracking.



Paul Wilmarth has worked in television engineering since he joined RCA in 1963. His most recent assignment was project leader for the "XtendedLife" series of chassis.

Contact him at:
Project Engineering
Consumer Electronics
Indianapolis, Ind.
Ext. 2828

Conclusion

The "XtendedLife" chassis represents a new performance standard for the industry. This is supported by the enthusiastic reception from distributors upon seeing the first of the series (CTC85) demonstrated against its major competitors during its introduction.

In a June 23, 1977, press release, Roy Pollack, Vice President and General Manager of Consumer Electronics, said "complete conversion to the new chassis design will be accomplished by mid-1978." RCA is believed to be the first domestic manufacturer to accomplish such a drastic energy-reducing model changeover.

Improved design and production efficiencies have permitted an optional retail sale price that is essentially the same as previous models. At the same time, the "XtendedLife" set will operate at lower temperatures which, combined with other design features, will increase the set's life expectancy.

RCA's new "XtendedLife" chassis consumes only 89 watts in both the XL-100 19-inch and 25-inch screen sizes; while in the deluxe ColorTrak 25-inch receiver, it uses only 102 watts.

Edison Electric Institute estimates the national average cost of electricity at 3.5 cents per kilowatt-hour. Average family television viewing totals 6.3 hours per day, according to the latest Nielsen study. Thus, over a year's time, the average RCA "XtendedLife" color receiver will cost $7.70 to operate, compared to $28.88 for past tube-type RCA sets.

Acknowledgment

The "XtendedLife" chassis was not solely a Consumer Electronics development. Several organizations, including Solid State Division, Picture Tube Division, and RCA Laboratories contributed to the success.

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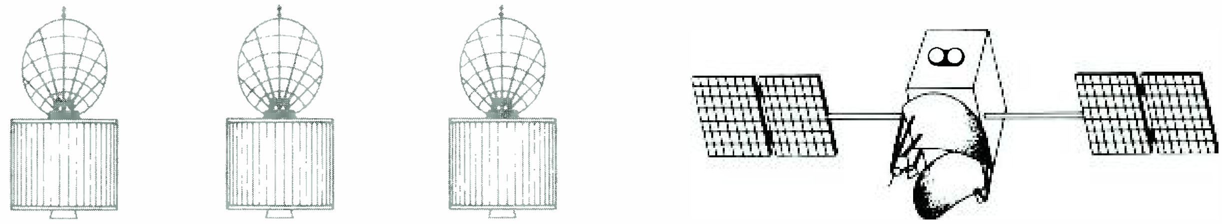

Anik B, the new Canadian domestic satellite

R.W. Hoedemaker
D. G. Thorpe

Scheduled for launching next year, Telesat Canada's fourth spacecraft will handle communications on two frequency bands—6/4 GHz and 14/12 GHz.

RCA Astro-Electronics is now constructing Anik B, the dual-band Canadian domestic communications satellite that follows the first-generation Anik satellite. Its twelve-channel 6/4-GHz transponder will provide continuity with the existing Telesat Canada communications system, and an additional transponder will add a new capability at 14/12 GHz.

The spacecraft will be able to continuously operate ten 6/4-GHz TWTAs and two 14/12-GHz TWTAs throughout a 7-year life, including eclipse periods. This corresponds to a total rf generated power of 140 watts. The 4-GHz downlink provides Canadian coverage with an increased minimum EIRP of 36 dBw. The 12-GHz downlink provides four regional beams, each with a minimum EIRP of 46.5 dBw. The uplink beams provide Canadian coverage with minimum G/Ts of −6 and −1 dB/°K at 6 and 14 GHz, respectively.

The basic spacecraft bus is similar to the RCA Satcom design. The new communications payload is being designed and built by Spar Technology, Ltd., a division of Spar Aerospace Products, Ltd., of Montreal. The spacecraft is scheduled for launch in November 1978 by a Delta 3914 launch vehicle.

General communications characteristics

Anik B will be a dual-band satellite with two independent transponder subsystems: one operating in the 6/4-GHz bands with the other using the 14/12-GHz bands. Tables I and II give a summary of the Anik B spacecraft and its communications system.

The 6/4-GHz communications system on Anik B will be directly compatible with the first-generation Anik satellite.

The channel-allocation and frequency assignments are identical to Anik, using the 5.925-to-6.425-GHz band as an uplink and the 3.7-to-4.2-GHz band as a downlink. There are twelve rf channels spaced 40 MHz apart, with channel 1 at 3.72 GHz (downlink). RF channel transmission characteristics, such as frequency response, group delay, and linearity, will be similar to Anik. Since Anik B will be a body-stabilized satellite, there will be no spin-synchronized multipath components at the channel edges as on Anik. The out-of-band attenuation following the output travelling wave tube amplifiers (TWTAs) has also been improved, permitting more flexibility in frequency-division multiple access (FDMA) services without excessive adjacent-channel interference.

The satellite antenna generates shaped gain contours on both uplink and downlink that provide coverage patterns matching the outline of Canada, as seen from geosynchronous orbit, in a similar fashion to Anik. Antenna polarizations, which are linear, are identical to Anik's, thus providing full compatibility with the some 60 existing earth stations in the Telesat system. Uplink G/T (−6 dB/°K) is nominally 1 dB better than Anik's; the flux density to saturate each TWTA is reduced accordingly to −81 dBw/m^2 to maintain essentially the same uplink C/N.

The saturated output power of each TWTA has been increased from 5 to 10 watts, providing a minimum EIRP within the Canadian coverage area of at least 36 dBw. There are twelve 10-watt 4-GHz TWTAs—

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Communication system parameters

C/N (carrier-to-noise ratio): The ratio of specified measures of the carrier and the noise after specified band limiting and before any nonlinear process such as amplitude limiting and detection.

G/T (figure of merit): This is a very useful indication of the performance of an earth station, defined as:

$$10 \log_{10} \left[\frac{\text{antenna power gain}}{\text{system noise temperature (K)}} \right]$$

Table I
Anik B is scheduled for launch in November 1978, and is designed with enough fuel for seven years of station-keeping.

Mission objective	Provide point-to-point voice, video and data communications traffic to Canada's ten provinces and two territories.
Launch information	
Site	Air Force Eastern Test Range, Cape Canaveral, Florida
Vehicle	Three-stage Delta 3914 with nine castor solid-propellant strap-on motors
Orbital elements	
Circular	Geosynchronous, 19,325 nautical miles above the equator
Period	24 hours
Inclination	Equatorial, zero
Spacecraft	
Height	128.3 inches
Width	79.7 inches
Length	375.6 inches with solar panels extended
Weight	2023 pounds
Stabilization subsystem	Three-axis stabilized; earth oriented
Design lifetime	Seven years
Payload	Dual-band transponder system providing 12 channels in the 6/4-GHz band and 6 channels in the 14/12-GHz band
Tracking	Telesat Tracking, Telemetry and Command, Earth Station at Allan Park, Ontario, and Intelsat stations at Fucino, Italy and Carnarvon, Australia.
Owners and managers	Telesat Canada

Table II
Dual-band satellite will provide communications services at 6/4 GHz and 14/12 GHz.

	6/4 GHz	14/12 GHz
Number of TWTAs	12	4
Number of rf channels	12	6
Usable bandwidth per channel	36 MHz	72 MHz
Receive band	3.700 GHz-4.200 GHz	14.0 GHz-14.5 GHz
Transmit band	5.925 GHz-6.425 GHz	11.7 GHz-12.2 GHz

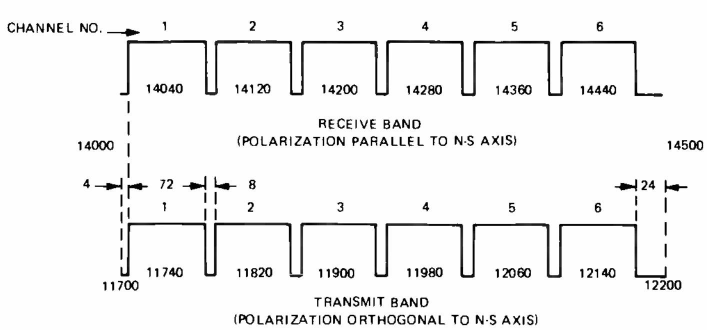

Fig. 1
14/12-GHz frequency plan shows six rf channels with an 80-MHz spacing and 72-MHz useful bandwidth per channel.

Bob Hoedemaker is Systems Engineer for the Telesat Canada Anik B Domestic Communications Satellite. He performed the same function on the RCA Satcom series of domestic communications satellites now in operation. Prior to that, he was involved in the systems engineering of the TOS and ITOS meteorological satellites built by AE for NOAA under the direction of NASA.

Contact him at:
RCA Astro-Electronics
Princeton, N.J.
Ext. 3365

Derek Thorpe (not pictured) is with Telesat Canada in Ottawa.

one assigned to each rf channel—with sufficient spacecraft power at the end of seven years to operate a minimum of 10 channels during sunlight and eclipse conditions.

The 14/12-GHz transponder system will provide a new service capability in the Telesat system and allow experiments currently underway to continue.

The 14/12-GHz frequency plan, as shown in Fig. 1, provides for six rf channels with an 80-MHz spacing, thus occupying most of the available 500-MHz bandwidth. The uplink occupies the frequency range from 14.00 to 14.48 GHz, and the downlink operates between 11.70 and 12.18 GHz. The useful bandwidth of each rf channel is 72 MHz.

The uplink satellite antenna patterns will provide for Canadian coverage with a minimum G/T of -1 dB/°K and a nominal flux density to saturate each TWTA of -86 dBw/m^2. A 0-to-5-dB switchable attenuator, actuated by ground command, will permit improved uplink S/N, with an increased flux density of -81 dBw/m^2 to saturate the TWTA. The downlink provides four regional beams, as shown in Fig. 2. Each beam has an elliptical coverage pattern with a nominal 2° × 1.8° cross section.

There are four 20-watt, 12-GHz TWTAs for the six channels; channels 1, 5, 2, and 6 are permanently assigned to a TWTA. Channel 3 may be switched by ground command to either of the first pair of TWTAs, and channel 4 may be switched to either of the second pair of TWTAs, as shown in Fig. 3. Similar rf switching and multiplexing between the TWTAs and downlink antenna beams allows up to two TWTA failures while still permitting access to any of the four transmit beams through the remaining two TWTAs.

Spacecraft system characteristics

Anik B is designed around the RCA Satcom spacecraft, which has been described elsewhere.[3] This paper, therefore, concentrates on those areas which are new or have been modified from RCA Satcom.

The spacecraft will be launched into a transfer orbit of approximately 19,325 nautical miles by 100 miles.

Through the transfer orbit, apogee-motor firing, and the subsequent drift orbit onto station, the spacecraft will be under the direct control of the Satellite Control division of Telesat Canada, supported by RCA Astro-Electronics personnel. Satellite tracking will be carried out primarily from the Telesat Tracking, Telemetry and Command earth station at Allan Park, Ontario. Tracking services will also be available during transfer-orbit from two Intelsat stations located at Carnarvon, W. Australia and Fucino, Italy.

The spacecraft is spun up prior to the Delta third-stage firing and remains in that mode until after apogee-motor firing. During this phase, spacecraft attitude is determined using onboard sun sensors and horizon (earth) sensors and is controlled by pulsed firing of the monopropellant hydrazine reaction control system. Solar arrays are folded against the "north" and "south" panels of the spacecraft, and as the spacecraft rotates, electrical power is alternately provided by the array and spacecraft battery. An omni antenna provides toroidal beam antenna coverage with orthogonal linear polarization for command and telemetry signals. To assure maximum mission reliabililty, two telemetry beacons operate from lift-off in a high-power mode, relaying attitude sensor and spacecraft performance data to the tracking earth stations.

The apogee motor is an Aerojet model SVM-7, the same as in RCA Satcom. Following the apogee-motor firing, the spacecraft is despun down to 5 r/min using the reaction control subsystems (RCS). A further RCS maneuver then aligns the spin axis parallel to the orbit normal. Following this, a dual-spin turn is carried out—a momentum wheel is energized and the spacecraft body rotates 90°, aligning the

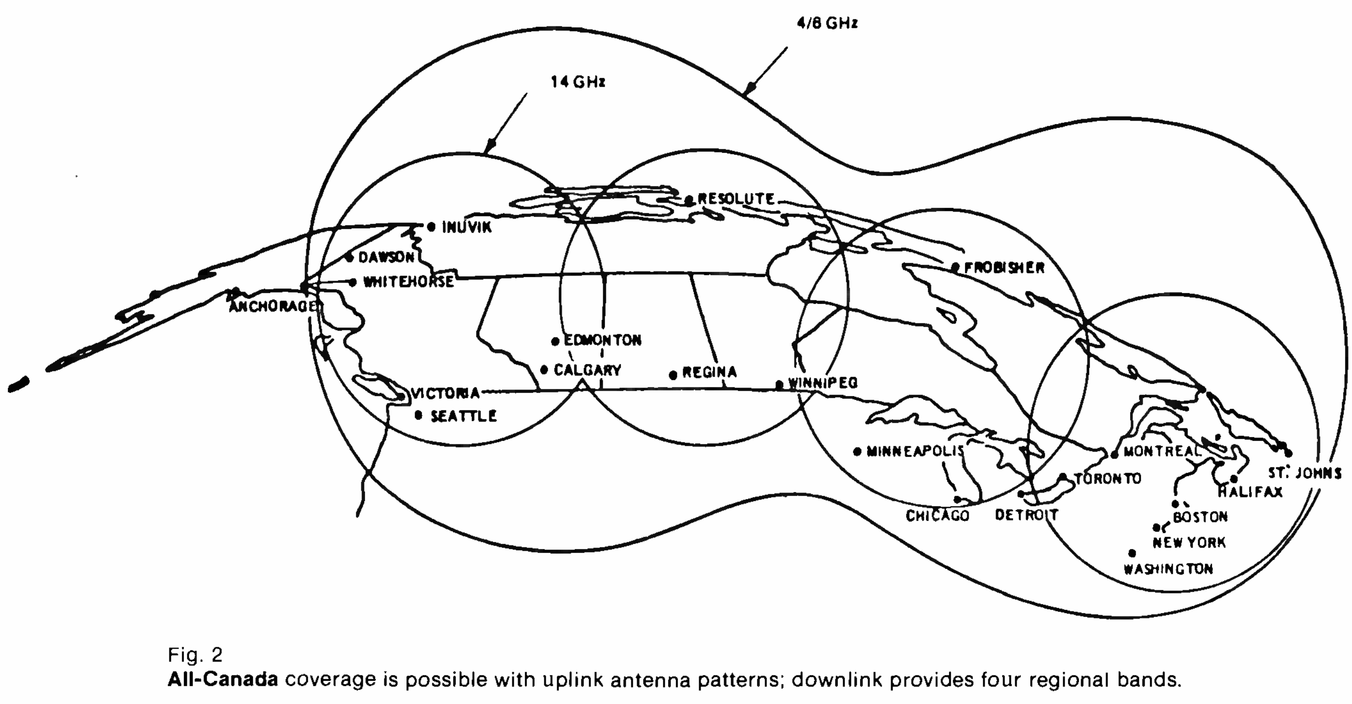

Fig. 2
All-Canada coverage is possible with uplink antenna patterns; downlink provides four regional bands.

wheel axis parallel to the orbit normal. Solar arrays are then deployed, the spacecraft acquires earth capture so the antennas point towards the earth, and the solar-panel rotation is synchronized to track the sun. Station-acquisition drift rates are controlled by the RCS.

The spacecraft antenna on-station pointing performance is designed to be better than 0.12° in pitch, 0.14° in roll, and 0.25° in yaw when controlled by magnetics.

These design requirements are relaxed to 0.25° for pitch and roll and 0.3° for yaw during thruster maneuvers. Fig. 4 shows the spacecraft orientation with respect to earth. Motion in the east/west direction is pitch, the north/south direction is roll, and rotation around the local vertical is yaw.

The attitude-control system has the added feature of providing redundancy checking without disturbing system operations. In all cases except for the momentum wheel, the redundant equipment can also be switched into operation without affecting the communications traffic.

The power system uses an improved solar array and batteries.

The new array uses high-efficiency (12.3%) 2-cm × 4-cm shallow-junction cells with a blue-shifted response. It will initially produce 840 watts of power at equinox and approximately 650 watts during the eclipse season after 7 years in orbit.

The battery capacity has been increased to 51 ampere-hours from RCA Satcom's 36 ampere-hours. There are three 22-cell, 17-ampere-hour, nickel-cadmium batteries that will normally be operated to a depth of discharge of less than 50% during the eclipse season.

Communications subsystem configuration

The 6/4 GHz transponder has three main functional parts: the broadband receiver-driver, the multiplexers, and the TWTAs.

The input multiplexers channel the receiver output for amplification by the TWTAs and the output multiplexers combine the TWTA output for transmission to the antennas.

The receiver-driver converts the 6-GHz received signal to the 4-GHz band and amplifies it to the drive level required for the TWTA. The input to each redundant

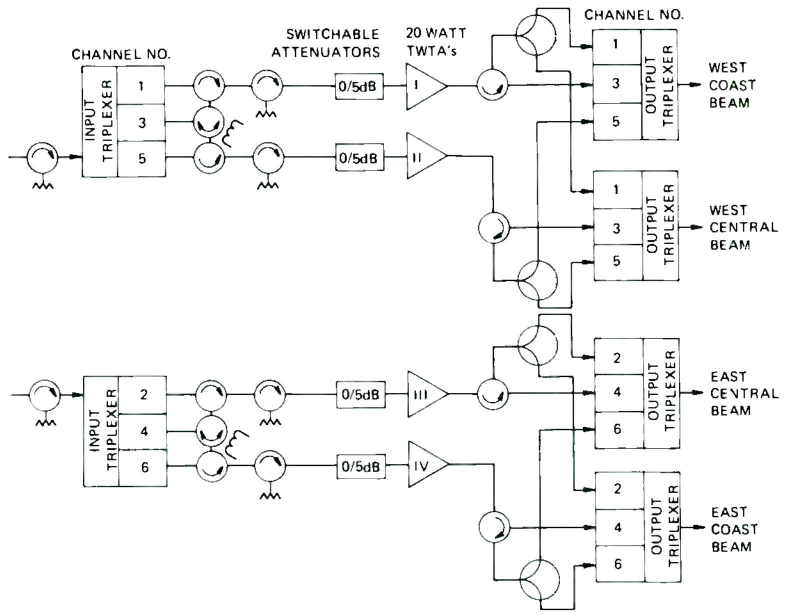

Fig. 3
Switching arrangements in 14/12-GHz system allow up to two TWTA failures while still permitting access to any of the four transmit beams.

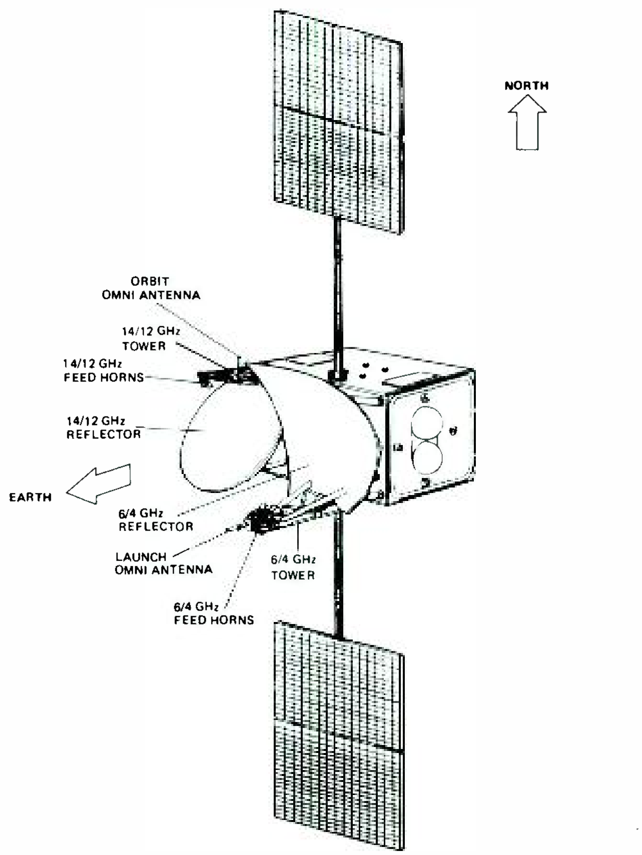

Fig. 4
On-station Anik B. Attitude control system maintains orientation within 0.12° in pitch, 0.14° in roll, and 0.25° in yaw.

receiver has a bandpass filter that provides at least 60 dB of isolation to frequencies in the 4-GHz band. Since Anik B will be a dual-band satellite, it is necessary to add a low-pass input filter to adequately attenuate 12-GHz signals that may radiate from the 14/12-GHz antenna into the 6/4-GHz antenna receive input. (Conventional 6-GHz waveguide bandpass filters tend to have spurious responses at 12 GHz.) The redundant receiver is similar to the one used on RCA Satcom; it consists of a tunnel diode amplifier (TDA) preamplifier, a mixer providing a 2225-MHz frequency translation, and a ten-stage transistor amplifier.

Two input multiplexers separate the amplifier signals into 12 rf channels spaced by 40 MHz. Each input multiplexer consists of two triplexers, each consisting of a waveguide manifold and three quasi-elliptic four-cavity dual-mode filters with center frequencies spaced by 80 MHz. The filters use circular waveguides and are constructed from silver-plated, lightweight graphite fiber epoxy composite (GFEC) material. This fabrication technique reduces the weight of these elements compared to Invar™, which is conventionally used to achieve the required temperature stability.

The TWT is an AEG-Telefunken, 10-watt saturated rf output, high-efficiency, triple-depressed collector design. The high-efficiency electric-power converter used with each TWT provides an overall performance of 10 watts rf output for 30 watts dc input power from the unregulated bus. The TWT has a saturated rf gain of about 57 dB. Each TWTA is protected by a ground-resettable overcurrent/undervoltage detector that can disconnect the individual TWTA from the power bus. The multiple-collector TWT design also provides a TWT dissipation that is essentially independent of rf drive level. When a TWTA is turned off, a heater is turned on to minimize variations in power dissipations for the purpose of controlling temperatures on the transponder panel.

The output of each TWTA is connected to one of two output multiplexers that each combine six TWTA outputs with each channel on 80-MHz centers. The output multiplexers use five-section Chebyschev bandpass filters.

After passing through an eight-section low-pass filter to reject TWTA second- and third-harmonic components, the multiplexer output is connected to one of the two antenna input ports.

Communications operations in the 6/4-GHz band are provided through a single antenna reflector and a triple feedhorn system. This coupling system provides two orthogonal inputs for the two output multiplexers. The power is transmitted to three feedhorns with proper amplitude and phase compensation. In the 6-GHz receive band, the antenna has one output port, which is connected by a power combiner from the three horns.

A lightweight antenna results from fabricating the parabolic reflector from a Kevlar™ fiber epoxy composite (KFEC) sandwich with a honeycomb internal core bonded to external Kevlar™ sheets. A polarization grid, formed by a grid of copper conductors photo-etched on a Kevlar™ scrim cloth, provides the reflecting surface in the sandwich.

A 4-foot-high tripod tower, constructed from tubular KFEC to minimize weight, supports the three feedhorns. The multicoupler is made from aluminum; the rest of the rf equipment, waveguide, and horns are made from GFEC.

The 14/12-GHz transponder is based extensively on the Canadian Technology Satellite technology and flight-qualified hardware.

The transponder has three main functional parts—the broadband receiver, the multiplexers and routing networks, and the TWTAs. The input multiplexers and routing networks channel the output of the receiver for TWTA amplification. The output multiplexers and routing networks combine the TWTA outputs for transmission to one of the regional beams (identified in Fig. 3).

The receiver-driver converts the 14-GHz received signal to the 12-GHz band and amplifies it to the drive level that the TWTAs require. Prior to the receiver, the input signal passes through a 500-MHz bandpass filter. At the input to the receiver, the signal is amplified by a parametric amplifier before being translated 2300 MHz to the 12-GHz band. Further broadband signal amplification is achieved by field-effect-transistor amplifiers (FETAs). The redundant receivers and FETAs can be separately selected by ground command. The FETAs drive the TWTAs via the input multiplexer and routing networks shown in Fig. 3.

The 12-GHz TWTs are AEG-Telefunken double-depressed collector tubes with 20 watts of saturated rf power. The high-efficiency electric-power converter used with each TWT provides an overall performance of 20 watts rf output for 64 watts dc input power from the unregulated bus. The TWT has a saturated rf gain of 57 dB, and the 12-GHz TWTAs have the same protection circuitry described for the 4-GHz design.

Communication in the 14/12-GHz band is provided by an antenna reflector and horn support tower that is separate from the 6/4-GHz system. (See Fig. 4.) The receive beam is formed by combining the vertically-polarized output of all four horns; the four regional horizontally-polarized transmit beams are formed by each of the four horns in turn. The recieve beam is a 7.0° × 1.0° flattened ellipse, and each transmit beam is an elliptical spot beam, 2° × 1.8°, to its assigned coverage region.

Conclusions

The basic Anik B spacecraft bus design is similar to RCA Satcom, but has higher-efficiency solar cells and larger battery capability. These improvements have made possible a spacecraft design that can produce 140 watts of rf power throughout its 7-year design life including the eclipse periods.

The rf power is produced by TWTAs of the latest design. The 4-GHz channels use 10-watt rf output TWTs of a triple-depressed collector design and the 12-GHz channels use 20-watt rf output TWTs of a dual-depressed collector design.

In addition, the advance into the 14/12-GHz band will enable Telesat Canada to commercially apply some of the experiments currently underway in this band on the Canadian Technology Satellite program.

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Economical approaches to updating range instrumentation

RCA is maintaining its long-standing leadership role in range-instrumentation radar by combining solid-state electronics with innovative modification programs to upgrade and modernize instrumentation radars at minimum cost.

R.G. Higbee

Test ranges have been a part of life virtually from the time that military operations moved out of the realm of hand-to-hand combat. As man's capability of flinging projectiles grew, so too did the size and structure of the ranges he needed to test his latest weapons.

The greatest jump in both the technology and test range requirements has come over the past 30 years—in the form of supersonic aircraft, a full range of guided and unguided missiles, and families of new and sophisticated projectiles. The operational capabilities of modern flight systems generated the need for today's test ranges—from the vast, ocean-spanning ICBM ranges to the small areas set up to prove out light, tactical missiles and projectiles.

All of these ranges, both large and small, require instrumentation of great accuracy and precision, with measurement capabilities to match the operational characteristics of the equipment under test. And this implies radar. Although optics, electro-optics, communications channels, and timers are important to these ranges, the workhorse of the test ranges remains radar, with its all-weather capability, reliability, and overall accuracy and flexibility.

Government Systems Division's Missile and Surface Radar organization was one of the first industry suppliers of range instrumentation radars, and today remains a world leader in this area. RCA has been at the forefront of this special instrumentation field since the mid-1950s.

Because system development was and is so rapid, it was inevitable that today's advanced systems would outstrip the ability of the early range instrumentation to test them properly. New systems confront the range user with a full spectrum of new requirements—greater range and accuracy, more detection and tracking capability, improved reliability.

It is also a fact of life that budgets for range instrumentation rarely, if ever, keep pace with the funding levels for system development. Hence the majority of range operators are faced with the very real problem of providing higher and higher performance on a shoestring.

The response has been two-fold. Shut off from procuring big, complex sensor systems, range operators have directed their attention to upgrading existing equipment and purchasing small, inexpensive radars that are highly mobile and flexible in operation. These approaches have proved to be both operationally effective and efficient in terms of meeting special needs. With relatively minor modifications, present radars can be modernized to meet higher performance requirements; the development of low-cost, highly mobile systems makes it possible to provide instrumentation capability virtually anywhere, on short notice.

As a major supplier of radars, RCA has responded to the range users' special needs with a number of approaches that are both imaginative and practical. This paper traces RCA's early involvement in the range instrumentation field and describes the development of a new breed of inexpensive mobile radars. It also addresses some of the approaches being taken to updating early systems through inexpensive modification.

RCA's range instrumentation involvement

RCA has been an industry leader in the development of precision tracking radars for range instrumentation since the 1950s. More than 90 of these RCA-developed radars have been deployed all over the world, and all are still very much in evidence for tracking satellites and orbiting vehicles. The box on the next page gives a summary of RCA radars developed during the 1950s and 1960s; the following paragraphs describe more recent developments.

Bob Higbee joined RCA in 1958 as a design development engineer. He has been a member of the Range Program Management Organization for the last 15 years and has been the Program Manager on a number of range projects, including coherent signal processors, digital range units, laser tracking systems, and other modifications to various instrumentation radars. He is currently Program Manager for development of five NIDIR systems for the United Kingdom.

Contact him at:
Range Programs
Missile and Surface Radar
Moorestown, N.J.
Ext. PM-3686

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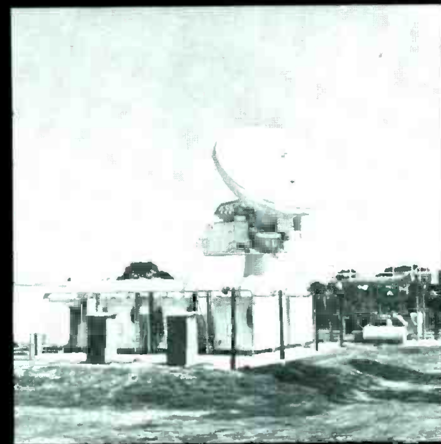
AN/FPS-16 radar installation at MSR, Moorestown. This unit is used as a test bed for system modifications in support of the world-wide range instrumentation network.

AN/FPQ-6 radar, designed in the early 1960s, remains one of the most accurate of all instrumentation radars.



AN/TPQ-18, the transportable version of the FPQ-6, is shown set up on transportable shelters.

RCA's early role

AN/FPS-16—This was the first C-band tracking radar developed for use in missile range instrumentation. It was delivered under a contract awarded to RCA in 1956 by the U.S. Navy Bureau of Aeronautics. A follow-on contract for the **AN/MPS-25** (the mobile version of the same radar) was awarded to RCA by the same agency in 1959. A total of 50 AN/FPS-16 and 7 AN/MPS-25 systems were built.

The basic system has a peak power of 1 megawatt, with precision of 3 yards rms in range and 0.1 mrad rms or better in pointing angle. Early versions of the radar featured a 12-foot-diameter, point-source-fed antenna with electric drive; later versions incorporated a 16-foot-diameter dish with hydraulic drive. The fixed-station AN/FPS-16 is housed in a one- or two-story building containing 30 racks of equipment. The mobile version (AN/MPS-25) is housed in three separate trailers, one for transport of the antenna/pedestal, one for the electronics, and the third for a boresight system.

AN/FPQ-6—In 1959 the U.S. Navy Bureau of Weapons contracted with RCA Missile and Surface Radar to develop and build another instrumentation radar system of even greater range and precision, for both fixed and mobile station use. The AN/FPQ-6 (fixed station) and **AN/TPQ-18** (mobile) radars feature a 3-MW transmitter, a 29-foot Cassegrain antenna, a precision two-axis pedestal, console and signal-processing equipment, and a general-purpose computer.

The AN/FPQ-6 can be installed in a one- or two-story building at a permanent site. The AN/TPQ-18 is packaged in nine air-transportable shelters, each equipped with self-contained air-conditioning, power distribution, and communications. Six AN/FPQ-6 and five AN/TPQ-18 systems were built.

AN/FPS-105—Experience gained on the AN/FPS-16 and AN/FPQ-6 systems, combined with the availability of new techniques and materials in the 1960s, led to the development of yet another generation of precision range instrumentation—the compact, integrated-circuit AN/FPS-105.

The digital instrumentation radar

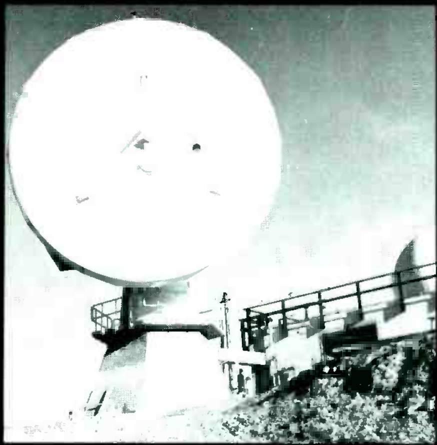
In the early 1970s, the need for small, inexpensive "portable" instrumentation radars led RCA into the development of the Digital Instrumentation Radar (DIR). This is a small, versatile, medium-accuracy, transportable C-band radar system designed to meet the short-range requirements of the widest possible spectrum of worldwide test ranges. Sponsored by the U.S. Air Force Space and Missile Test Center, the original development attained Army, Navy, and Air Force qualification as a low-cost, flexible, one-operator system to meet Defense Department requirements. The resulting radar was given the official designation AN/TPQ-39(V).

Two objectives were achieved by the design: 1) a minicomputer was used to minimize hardware; and 2) system flexibility was built in to accommodate optional equipment as the need or application occurs. The computer performs virtually all radar control functions in the DIR (all track loops are closed through the computer). The system can be set up completely by two men within eight hours, and functions with a single operator.

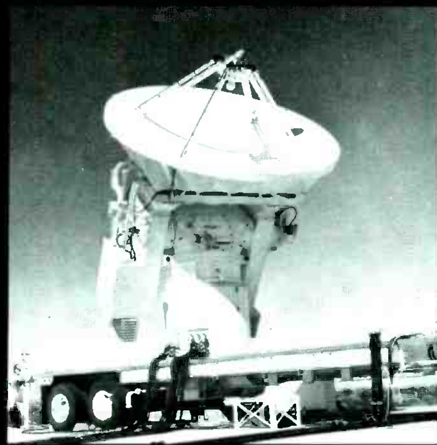
Thus the DIR has the flexibility to meet a wide variety of applications at test ranges of all types, with minimized acquisition and operational costs. Some of the applications of the DIR include range safety, performance evaluation of test vehicles, and determination of discrete events in a mission. The system is designed for operational flexibility through the use of programmable changes that permit the inclusion of any or all of a number of performance modifications to adapt the system to a particular user's specific tracking requirements. Four of these systems are now in operation at U.S. ranges and a fifth is in production for the Federal Republic of Germany.

NIDIR—surplus to state-of-the-art

The DIR concept of low-cost flexibility spawned yet another significant instrumentation radar system program—one involving the conversion of surplus Nike Hercules tracking radars to state-of-the-art instrumentation sensors. This effort involved the economical upgrading of the



AN/FPS-105 mountaintop installation at Ely, Nevada. This was one of the first range instrumentaion radars to provide extra reliability and compact packaging by using integrated circuits.



AN/MPS-36 mobile radar. This modern range tracker combines precision, range, and mobility for a wide variety of range applications.

AN/TPQ-39(V) radar, a recent development designed specifically for the small, low-budget ranges. Known as the Digital Instrumentation Radar (DIR), it is one of the first radars to incorporate functional computer control.

To meet the special requirements imposed for versatility, reliability, and maintainability, the AN/FPS-105 offers both high performance and a selectable level of precision determined by the choice of antenna pedestal. The user selects only as much capability as he requires for present missions, retaining the ability to expand the system for future requirements. The AN/FPS-105 can acquire and automatically skin-track 1-square-meter targets with velocities up to 20,000 yards per second, at ranges up to 4096 nautical miles, with system range precision within 5 yards rms; angle precision is better than 0.2 mrad rms.

Because the AN/FPS-105 uses solid-state and integrated-circuit design, it requires less space and power than the older, conventional systems. Accordingly, it is fully adaptable for installation aboard ship, in a trailer, or in a small one-story building. The basic AN/FPS-105 system consists of an antenna pedestal, a radar console, a load center (power supply and distribution) cabinet, and a cabinet that houses the transmitter/modulator.

AN/MPS-36—This system is an updated version of the AN/MPS-25 mobile C-band radar and was first produced by RCA in 1969. Since that time, 14 systems have been delivered to the U.S. Army and they are now operational at ranges throughout the world. This system has a 1 MW peak power transmitter, an unambiguous ranging capability of 32,000 nmi, and is the first instrumentation radar with built-in pulsed doppler capability.

The entire system is housed in two trailers—one for the antenna/pedestal system, cables, and lifting devices, and the other for the system electronics. One operator controls the system, and a four-man O&M crew can set up the entire complex on a prepared site within eight hours after arrival. Like the earlier AN/MPS-25, the AN/MPS-36 radar system can be transported by rail, flatbed truck, or aircraft.

deactivated Nike Hercules radars to modern, reliable, one-man-operable, precision X-band instrumentation radars by systematically replacing the Nike Hercules electronic subsystems with those from RCA's state-of-the-art DIR. The resulting system is called the NIDIR variant of the AN/TPQ-39(V).

The combining and modifying of the high-performance Nike Hercules antenna pedestal and associated subsystems with the flexible digital processing features of the DIR offers a systems-oriented conversion instead of the usual piecemeal "black-box" approach. This factor is the key consideration not only in the standardization of achievable system performance, but also in terms of system support (personnel, training, logistics) and ensuring compatible growth capability. Such a systematic approach to the conversion guarantees the range user an economical system that will be logistically supportable for many years, using standardized documentation, spares support, overhaul, and training.

RCA received authorization in mid-1975 to supply a NIDIR system to the U.S. Navy-managed National Parachute Test Range (NPTR) in El Centro, California, a Department of Defense designated National Range. Research, development, test and evaluation of parachutes and related aerodynamic deceleration devices are conducted at this range. The NIDIR, which was installed and became operational in February 1977, is being used for skin or beacon tracking of parachutes, payloads, their delivery vehicles, and accompanying aircraft. It provides high-quality time space position information on the tracked object. The system can operate singly or in cooperation with other radars and sensors at NPTR. Such cooperation can involve target handovers and coordinated tracking.

Using product-line NIDIR subsystems and components, the following additional systems can be provided for specific applications:

- X/Ka band dual-frequency NIDIR—This system can be used for both Electronic Warfare (EW) and low-angle tracking and track support in an EW test environment.
- Ka band—A more economical system to be used for low-elevation tracking.

• C-band NIDIR—A system for ranges whose missions require C-band equipment of higher precision than that provided by the standard DIR system.

In addition, modifications can be made to existing Nike Hercules systems ranges to upgrade performance at minimum cost. These modifications include:

Digital ranging subsystem and display
Solid-state receivers
Solid-state servo amplifiers
Digital angle encoders and electronics
Polarization diversity

The combination of the advanced-design DIR and the now-surplus Nike Hercules antenna pedestal provides the range user with a very economical approach to updating or adding to his range instrumentation equipment. These systems provide an expanded high-performance solution to the growing test support requirements.

Radar/laser systems

In recent years, a number of test ranges have developed requirements for tracking data accuracies that are beyond the practical capabilities of the highest-precision radar. In addition, a number of applications require precision tracks at low elevation angles where microwave radar exhibits signal-to-noise degradation caused by surface clutter and multipath propagation problems. Laser technology is an obvious, if expensive and limited, answer to these problems, and laser trackers are finding increasing application for specialized range requirements.

Other firms specializing in laser technology supply the necessary "stand-alone" laser trackers; RCA, on the other hand, has combined the laser with radar in a low-cost package that serves the widest possible range of instrumentation requirements.[1] The laser/radar combination provides the advantages of the radar's relative insensitivity to weather conditions, long-range tracking capability, and ease of target acquisition allied with the laser's advantages of high-precision tracking and insensitivity to target altitude.

RCA has installed two radar/laser tracking systems: on an AN/FPS-16 instrumentation radar located at Wallops Flight Center, Virginia, and on an AN/MPS-36 instrumentation radar at White Sands Missile Range, New Mexico. Both systems use the existing radar pedestal and angle servo system for the laser as well as the radar, thus providing a combination sensor package at a significant cost saving.

The RCA-designed laser tracking system is a medium-range tracking instrument that provides ultra-precise target range, azimuth, and elevation data in real-time output. It is designed primarily for use as an addition to an existing tracking radar, although it could be deployed as a self-contained unit with its own pedestal, displays, and controls. The laser tracker is intended for use with retroreflector-equipped target vehicles, although limited tracking is possible with non-cooperative targets. Range precision of 1.0 ft and angle precision of 0.05 mrad have been achieved.

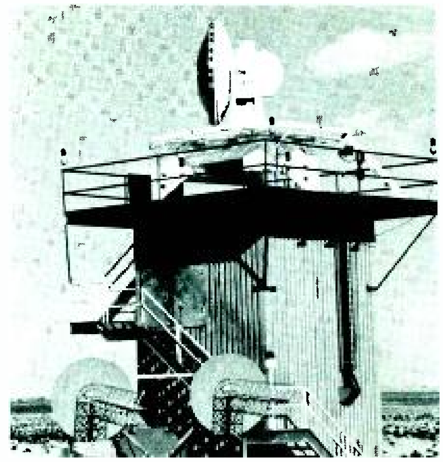
Engineering and logistics support

As the RCA instrumentation radars were being installed on the various test ranges and used on an almost continuous basis by military and civilian agencies for national defense and space explorations, the problem of minimizing radar downtime assumed great importance. Accordingly, a carefully designed "depot-level" maintenance program was implemented as a pilot project in 1960 by the U.S. Air Force and RCA. The concept achieved immediate acceptance, and today the RCA-operated worldwide engineering and logistics program for instrumentation radars provides support to RCA radars, both shipboard and land-based. This support involves 24 U.S. Government agencies and several foreign governments.

This RCA program covers two principal functions: engineering and logistics. The engineering staff serves the various ranges, performing depot-level maintenance overhauls and operating a Reliability and Maintainability program to ensure that all maintenance, repair, and modification services performed will maintain the high level of reliability originally built into the radar systems. The logistics staff provides the support required for procuring and expediting "parts peculiar" (as opposed to Federal Stock parts), stockroom inventory and control, component repairs, parts refinishing, and material movement on a worldwide basis.

Radar system relocations and improvements

RCA's World Wide Engineering and Logistics Program is also active in two other areas of importance toward meeting special requirements and holding the line on range costs: radar system relocations and system improvements.

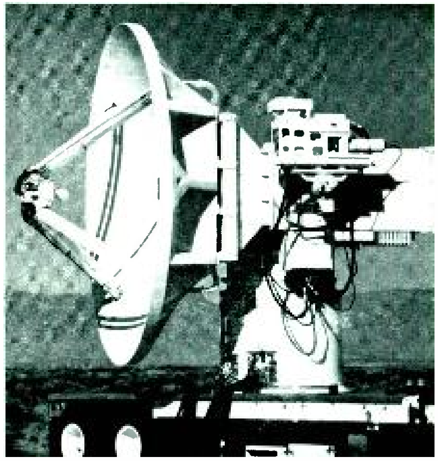


NIDIR installation at the National Parachute Test Range at El Centro, Cal. The basic Nike Hercules X-band antenna/pedestal is modified with updated DIR electronics to fulfill today's range needs at low cost.

As technology changes, so do the specific needs of military and space programs. Some range radars become excess to inventory and are deactivated; other ranges develop new requirements necessitating radar systems, sometimes on short notice. The lead time and expense of the design, fabrication, and installation of new systems frequently become both impractical and cost-prohibitive. The solution in a number of occasions has been to transfer radars from one range to another, with appropriate equipment modification to meet the new requirements.

RCA has been active in working with the government in these transfers in recent years, relocating radar systems from ranges that no longer need them, modifying them for new applications, and reinstalling them at the site or range with the new requirement. In addition, special state-of-the-art modifications have been developed and installed to make the existing radars capable of handling the increasingly complicated mission of the 70s and beyond.

Although some of these systems are 10 to 20 years old or more, the quality of workmanship and material in the basic systems readily accommodates systematic upgrading with state-of-the-art components. Thus the active life of these systems has been extended for many years, often with even greater accuracy and precision than the original equipment. Solid-state components replace the original vacuum tubes; the replacement subsystems, accordingly, are smaller and more



Laser tracker modification at an AN/MPS-36 installation at White Sands Missile Range, N.M. The on-mount laser tracker complements basic radar tracking capability.

compact than those originally available, requiring no increase in power and air-conditioning capacities. Some of these modifications can be carried out during regularly scheduled overhauls—an especially economical approach in terms of cost and radar downtime, adapted to the range user's mission schedule. The major modifications (applicable to a broad spectrum of early-version instrumentation radars) are summarized below:

- *Universal range tracker (URT)*—Designed to replace the electromechanical tube-version range portion of the AN/FPS-16 instrumentation radar system, the new single-cabinet range tracker replaces four cabinets of electronics in the AN/FPS-16. It uses medium-scale integration (MSI) technology for internal signal-processing circuits, with modular interfaces to existing high-signal-level radar circuits.

  The principal advantage of the URT lies in its target acquisition and range lockup time—0.2 s over the full range interval of 32,000 nmi for both stationary and moving targets. The original AN/FPS-16 analog electromechanical systems required several seconds to acquire and lock on to a target, and then only if the range was previously designated to within 1000 yards of the target and the designation point was kept moving with the target.

- *Solid-state receivers*—In this mod, all the receiver tube-type chassis are replaced with solid-state chassis. In addition, all receiver chassis are removed from the rf head and relocated within the controlled environment of the radar equipment room. The solid-state receiver provides a greater range of dynamic tracking plus increased reliability and stability.

- *Solid-state regulators*—This new system replaces two separate subassemblies and provides an output stability better than 0.5% over a period of eight hours with constant line load and ambient temperature. Its improved reliability also reduces the maintenance time and cost.

- *Talyvel level*—Existing pedestal leveling indicators on the older radar systems use oil and a gas bubble within a glass tube. Sun, wind, and shade tend to distort these indicators to a degree that makes accurate pedestal leveling almost impossible. The Talyvel leveling device is a portable electronic unit totally immune to these environmental conditions, providing instantaneous level accuracy of the pedestal to within ±0.028 mrad. This sensor can be permanently attached to the pedestal or installed as required for leveling.

- *Digital data system*—The older strobed-type gray-code encoders in azimuth and elevation are replaced with newer, less expensive, and more reliable natural binary shaft encoders. The older pedestal electronic units are replaced with a 17-bit solid-state assembly designed for use under extreme environmental conditions. Three cabinets of vacuum-tube electronics are replaced with a single solid-state digital data chassis that incorporates transistor-transistor logic (TTL) techniques. This modification offers greatly improved reliability, decimal console readout, and reduced encoder costs.

- *Coherent signal processor*—One of the more extensive modifications to existing instrumentation radars, this package provides significant performance improvement by adding the following features:

  Direct doppler velocity measurement to an accuracy of 0.1 ft/s rms.

  Coherent predetection integration, which significantly improves the signal-to-noise ratio of weak targets, effectively doubling the tracking range of the radar.

  Velocity discrimination of multiple targets that may be present in the range gate.

  Built-in doppler simulation and test equipment that exercises virtually all of the coherent systems.

- *Solid-state servo*—This recent modification was developed to replace the existing vacuum-tube subsystem; it provides better reliability and lower maintenance costs.

Several other modifications have been developed and installed on various radars, including boresight tv systems, new lens systems for existing tv systems, and the addition of a time-and-events recorder. All of these modifications, both large and small, have provided updated instrumentation radar capability at minimum cost.

Conclusions

Radar manufacturers and range users share a very real interest in the design and development of new, sophisticated, state-of-the-art radars; budget restrictions, however, dictate a more modest approach. Small, mobile, inexpensive radars provide part of the answer. Existing systems, with appropriate modification, can also be upgraded at relatively low cost to meet the growing requirements of today's ranges.

RCA has been active in helping the range users to modernize their instrumentation and relocate available radars to new locations. As an industry leader and the original manufacturer of many of the existing range radars, RCA has accepted both the opportunity and the obligation implicit in these efforts. The result is well over a dozen new systems supplied over the past five years and modification packages totaling more than 90 units. Rough estimates of existing and short-term range requirements indicate an even greater potential market in the immediate future.

System technology is changing rapidly, and every advance in systems imposes a new requirement on the test ranges; these requirements, in turn, beget a continuing pattern of configuration and performance changes in range instrumentation radars. Surely the range sensors of 10 to 20 years from now will be performing at levels that are virtually unimaginable today. Almost as surely, these sensors will be provided within budget constraints every bit as tight as those presently imposed. It is all the more interesting, then, to consider the implications for a repeating pattern of upgradings and modification to basic radar systems developed in the mid-1950s.

References

1. Dempsey, D.J.; and Schlegel, H.; "The laser-radar tracker: coupling complementary technologies," *RCA Engineer*, Vol. 22 No. 6 (Apr/May 1977) pp. 62-67.

Dates and Deadlines

Upcoming meetings

Ed. Note: Meetings are listed chronologically. Listed after the meeting title (in bold type) are the sponsor(s), the location, and the person to contact for more information.

AUG 21-26, 1977—**Soc. of Photo-optical Instrumentation Engingeers Symp.** (SPIE) Town and Country Hotel, San Diego, CA **Prog Info:** SPIE, P.O. Box 1146, Palos Verdes Estates, CA 90274

AUG 22-26, 1977—**Laser Applications and Engineering** (SPIE) San Diego, CA **Prog Info:** SPIE, PO Box 10, Bellingham, WA 98225

AUG 26-SEP 4, 1977—**Intl. Radio and TV Exhibition 1977 Berlin,** Berlin, W. Germany **Prog Info:** Intl. Radio & TV Exhibition, Press Center, Mr. Bodo H. Kettelhack, P.O. Box 19 17 40, D-1000, Berlin 19, W. Germany

AUG 28-SEP 2, 1977—**Intersociety Energy Conversion Eng. Conf.** (IEEE et al) Sheraton Park, Washington, DC **Prog Info:** Glen A. Graves, Office of Energy R&I Policy, NSF, 1800 G St., N.W., Washington, DC 20550

SEP 6-9, 1977—**COMPCON Fall** (IEEE) Wash., DC **Prog Info:** COMPCON Fall '77, POB 639, Silver Spring, MD 20901

SEP 14-16, 1977—**Optical Communication** Technical University of Munich, Munich, W. Germany **Prog Info:** Dr. W. Harth, Lehrstuhl fur Allgemeine Elektrotechnik der Technischen Universitat Munchen, D-8000 Munchen 2, Arcisstrasse 21, W. Germany

SEP 18-21, 1977—**American Ceramic Soc. Fall Mtg., Electronics Div.** (ACS) Queen Elizabeth Hotel, Montreal, Que. **Prog Info:** Henry M. O'Bryan, Jr., Bell Telephone Laboratories, Inc., Room 6D-307, Murray Hill, NJ 07974

SEP 19-21, 1977—**Western Electronic Show and Convention (WESCON)** (IEEE) Civic Auditorium, Brooks Hall, St. Francis Hotel, El Segundo, CA **Prog Info:** W.C. Weber, Jr., WESCON, 999 N. Sepulveda Blvd., El Segundo, CA 90245

SEP 25-28, 1977—**Electronic & Aerospace Systems Convention (EASCON)** (IEEE) Sheraton Natl., Arlington, VA **Prog Info:** J.H. Sidebottom, EASCON, Raytheon Co., 4000 Army-Navy Dr., Arlington, VA 22202

SEP 26-28, 1977—**Design Engineering Technical Conf.** (ASME) Pick-Congress Hotel, Chicago, IL **Prog Info:** Technical Affairs Department, ASME, 345 E. 47th St., United Engineering Center, New York, NY 10017

SEP 27-29, 1977—**Data Communication Conf.**(IEEE) Snowbird, Snowbird, UT **Prog Info:** J.F. Marchese, IBM, 18100 Frederick Pike, Gaithersburg, MD 20760

OCT 6-8, 1977—**Very Large Data Base Conf. (VLDB)** (IEEE) Tokyo, Japan **Prog Info:** S.E. Madnick, MIT Sloan School of Management, 50 Memorial Dr., Cambridge, MA 02139

OCT 10-14, 1977—**Optical Society of America 1977 Annual Mtg.,** Royal York Hotel, Toronto, Ont. **Prog Info:** Optical Society of America, 2000 L St., N.W., Washington, DC 20036

OCT 16-21, 1977—**119th Technical Conf. and Equipment Exhibit** (SMPTE) Century-Plaza Hotel, Los Angeles, CA **Prog Info:** SMPTE, 862 Scarsdale Ave., Scarsdale, NY 10583

OCT 25-27, 1977—**Electro-Optics/Laser '77 Conf. and Expo.,** Anaheim, CA **Prog Info:** Bill Ashman, Industrial & Scientific Conference Management, Inc., 222 W. Adams St., Chicago, IL 60606

OCT 25-28, 1977—**Radar International-RADAR 77** (IEEE, AES, IEE, *et al*) IEE, London, England **Prog Info:** IEE, Conference Dept., Savoy Place, London , WC2R OBL England

OCT 26-28, 1977—**Ultrasonics Symp.** (IEEE) Phoenix, Arizona **Prog Info:** F.S. Hickernell, Motorola Inc., 8201 E. McDowell Rd., Scottsdale, AZ 85257

OCT 31-NOV 1, 1977—**Joint Engineering Mgmt. Conf.** (IEEE *et al*) Stouffer's Inn, Cincinnati, OH **Prog Info:** Paul H. Bluestein, Paul H. Bluestein & Co., 3420 Section Rd., Cincinnati, OH 45237

NOV 2-4, 1977—**Automatic Support Systems for Advanced Maintainability (AUTOTESTCON)** (IEEE) Dunfey's Cape Cod, Hyannis, MA **Prog Info:** E.B. Galton, AUTOTESTCON 77, c/o RCA, POB 588, Burlington, MA 01801

NOV 6-10, 1977—**Engineering in Medicine and Biology Conf.** (IEEE) Hilton, Los Angeles, CA **Prog Info:** AEMB, Suite 404, 4405 East-West Hwy., Bethesda, MD 20014

NOV 8-10, 1977—**Mechanical Engineering in Radar** (IEEE) Sheraton Natl., Washington, DC **Prog Info:** Harry C. Moses, Naval Research Lab., Code 5307, 4555 Overlook Ave., Washington, DC 20375

NOV 8-10, 1977—**MIDCON** (IEEE) O'Hare Conv. Ctr., Hyatt Regency, Chicago, IL **Prog Info:** W.C. Weber, Jr., EEEI, 999 N. Sepulveda Blvd., El Segundo, CA 90245

NOV 8-11, 1977—**COMPSAC '77 (Computer Software & Applications)** (IEEE) Sheraton-O'Hare, Chicago, IL **Prog Info:** Stephen S. Yau, Dept. Computer Sci., Northwestern Univ., Evanston, IL 60201

NOV 8-11, 1977—**Magnetism & Magnetic Materials Conf.** (IEEE) Raddison Hotel, Minneapolis, MN **Prog Info:** C.D. Graham, Jr., Univ. of Penn., Dept. of Metallurgy and Matls. Sci., Phila., PA 19174

DEC 5-6, 1977—**Chicago Fall Conf. on Consumer Electronics** (IEEE) Ramada-O'Hare Inn, Des Plaines, IL **Prog Info:** Richard Sudges, Rockwell Intl./The Admiral Group, 1925 N. Springfield Ave., Chicago, IL 60647

DEC 5-7, 1977—**Intl. Electron Devices Mtg.** (IEEE) Hilton, Wash., DC

DEC 5-7, 1977—**Natl. Telecommunications Conf.** (IEEE) Marriott Hotel, Los Angeles, CA **Prog Info:** Stanley A. Butman, JPL, 4800 Oak Grove Drive, Pasadena, CA 91103

JAN 24-26, 1978—**Reliability & Maintainability conf.** (IEEE *et al*) Biltmore, Los Angeles, CA **Prog Info:** D.F. Barber, POB 1401, Branch PO, Griffiss AFB, NY 13441

JAN 30-FEB 1, 1978—**Automated Testing for Electronics Manufacturing,** Marriott, Los Angeles, CA **Prog Info:** Sheila Goggin, ATE Seminar/Exhibit, 167 Corey Rd., Brookline, MA 02146

FEB 15-17, 1978—**Intl. Solid State Circuits Conf**. (IEEE, U. of Penna.) Hilton, San Francisco, CA

MAR 21-23, 1978—**Industrial Applications of Microprocessors,** Sheraton, Phila., PA **Prog Info:** W.W. Koepsel, Dept. of E.E., Seaton Hall, Kansas State Univ., Manhattan, KS 66506

Calls for papers

Ed. Note: Calls are listed chronologically by meeting date. Listed after the meeting (in bold type) are the sponsor(s), the location, and deadline information for submittals.

OCT 4-6, 1977—**Material for Highpower Lasers** (NBS) Boulder, CO **Deadline Info: 9/1/77 (150-wd ab) to** Arthur Guenther, AFWL/CA, Kirtland AFB, NM 87117 or Alexander J. Glass, Lawrence Livermore Laboratory, PO Box 808, Livermore, CA 94550

APR 10-12, 1978—**1978 IEEE Intl. Conf. on Acoustics, Speech, & Signal Processing** (IEEE) Camelot Inn, Tulsa, OK **Deadline Info: (ab) 9/22/77 to** Thomas H. Crystal, Inst. for Defense Analyses, Thanet Rd., Princeton, NJ 08540

JUL 16-21, 1978—**Power Engineering Soc. Summer Meeting** (IEEE) Los Angeles, CA **Deadline Info: 2/1/78 to** G.A. Davis, Southern Calif. Edison Co., POB 800, Rosemead, CA 91770

Pen and Podium

Recent RCA technical papers and presentations

To obtain copies of papers, check your library or contact the author or his divisional Technical Publications Administrator (listed on back cover) for a reprint. For additional assistance in locating RCA technical literature, contact RCA Technical Communications, Bldg. 204-2, Cherry Hill, N.J. extension PY-4256.

Advanced Technology Laboratories

E.S. Shecter
Quality and reliability assurance committee activities of NSIA—Sixth DCAS/Industry Conf., Brooklyn, NY (6/7/77)

Automated Systems

J.G. Bouchard| D. Bokil
Automatic assembly of hybrid circuits on a substrate—Keystone and Metropolitan Chapters of the Intl. Soc. of Hybrid Microelectronics, Princeton, NJ (4/20/77)

G.T. Burton
Electronic solid-state wide-angle camera system (ESSWACS)—NAECON, Dayton, OH (5/17-19/77) and SPIE/SPSE Technical Symp., Reston, VA (4/18/77)

M.L. Johnson
Reliability of the AN/GVS-5 hand held laser rangefinder—15th Spring Reliability Seminar, Lynnfield, MA (4/28/77)

J.J. Klein
A high-performance tv camera for multiplexing of parallel FLIR video—IRIS-25th Natl. Infrared Information Symp., San Francisco CA (6/15/77)

E.W. Richter| V.D. Holaday
Designing microwave ATE to meet UUT requirements—Automatic Testing Conf. (AUTOTESTCON), Arlington, TX (11/10-12/76)

M.W. Stewich| R.E. Handon| S.C. Hadden
Vehicle monitoring system—Mechanical Failures Prevention Group, Chicago, IL (5/19/77)

Government Communications Systems

H.R. Barton
RCA design-to-cost tracking model—EIA Engrg. Design Integration (G-47) Committee Mtg., St. Louis, MO (5/23/77)

D.G. Herzog
A tactical laser-beam recorder for near-real-time high-resolution image generation—NAECON, Dayton, OH (5/17/77)

Laboratories

A. Bloom| W.J. Burke
Specific wavelength sensitization of dichromated poly(vinyl alcohol)—Electrochemical Soc., Phila., PA (5/12/77)

K.R. Bube
Solderability of thick-film metallization—American Ceramic Society, Annual Mtg., Chiacgo, IL (4/27/77)

G.W. Cullen| J.F. Corboy| J.T. McGinn
The influence of deposition conditions on the properties of heteroepitaxial silicon: nucleation density—*Proc.* ECS Silicon Symp., Phila., PA (5/77)

A.G.F. Dingwall| R.E. Stricker
C^2L: a new high-speed, high-density bulk CMOS technology—*IEEE J. Solid-State Circuits*, Vol. SC-12, No. 4 (8/77)

R.L. Ernst| R.L. Camisa| A. Presser
Graceful degradation properties of matched n-port power amplifier combiners—*Digest* 1977 IEEE MIT-S Intl. Microwave Symp., San Diego, CA (6/21-23/77) pp. 174-177

J.I. Gittleman| B. Abeles
Optical properties and solar performance of composite materials—2nd Intl. Conf. on Metallurgical Coatings, San Francisco, CA (3/28-4/1/77)

K.G. Hernqvist
Long-life hollow cathode laser—1977 Conf. on Laser Engineering and Applications, Washington, DC (6/-3/77)

T.T. Hitch
Gold and silver thick-film conductors—*Proc.*, IEEE-EIA Electronic Components Conf., Arlington, VA (5/16-18/77) pp. 260-68

H. Kressel
A review of degradation phenomena in heterojunction lasers and LEDs—Electrochem. Soc., Phila., PA (5/8-13/77)

A. Rosen| O. Mawhinney| L. Napoli
A novel FET frequency discriminator—*RCA Review*, Vol. 38 No. 2 (6/77)

A. Rosen| H.J. Wolkstein
J. Goel| R.J. Matarese
A novel dual-gate FET RF power limiter—*RCA Review*, Vol. 38 No. 2 (6/77)

G.L. Schnable
Reliability of MOS devices in plastic packages—*Proc.* Intl. Microelectronics Conf. NEPCON '76 East, New York, NY (6/9/77); pp. 82-91

G.L. Schnable| L.J. Gallace| H.L. Pujol
Reliability of CMOS integrated circuits—*Proc.*, 27th Electronic Components Conf., (5/77) pp. 496-512

E.K. Sichel| J.I. Gittleman| J. Zelez
Electrochromism in the composite material Au-WO_2—*Appl. Phys. Lett.*, Vol. 31, No. 2 (7/15/77) pp. 109-111 (Also presented at 19th Electronic Matls. Conf., Cornell U., Ithaca, NY, 6/29-7/1/77)

A.J. Stranix
Television, a telecommunications media—Kutztown State College, Kutztown, PA (1/77)

K.H. Zaininger
Present status of CCD image sensors for solid-state tv cameras—*Proc.* Intl. TV Symp., Montreux, Switzerland (6/3-10/77)

Missile and Surface Radar

J.A. Bauer
Use of chip carriers for high-packaging-density, high-reliability, high-performance products—*Proc.*, NEPCON '77 East, Phila., PA (5/17-19/77) Also, Drexel University, Phila., PA (5/25/77)

M.W. Buckley
Project management—Bank Automation Assoc., 8th Annual Seminar Program, Wilmington, DE (5/26/77)

M.W. Buckley
Project management—planning, scheduling, and control—Seminar, IEEE Milwaukee Sect., Milwaukee, WI (5/6-7/77)

J.W. Hurley
Industrial logistics management—Soc. Logistics Engrs., Garden State Chap., Temple U., Phila., Pa. (5/19 & 5/26/77)

R.D. Kempt| T.W. Taylor
AMPS—A maintenance technical data system for AEGIS—American Defense Preparedness Assoc., Orlando, FL (5/5/77)

L.W. Martinson| J.A. Lunsford
A CMOS/SOS pipeline FFT processor—construction, performance, and applications—*Record*, NAECON '77, Dayton, OH (5/17-19/77)

C.E. Profera
A technique for obtaining pattern symmetry and low sidelobes from a TE_{11} mode coaxial radiator—*IEEE Trans. Antennas and Propagation*, Vol. AP-25, No. 3 (5/77) pp. 365-9

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Complex radiation patterns of flared dual-mode pyramidal horns—*IEEE Trans. Antennas and Propagation*, Vol. AP-25, No. 3 (5/77) pp. 436-438

Patents

Advanced Technology Laboratories

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Tri-state logic circuit—4029971

Astro-Electronics

A. I. Aronson
Passive cooler—4030316

E.A. Goldberg
Non-integer frequency divider having controllable error—4031476

C.L. Jones| W.L. Schulte, Jr.
Multifrequency signal receiver with digital tone receiver—4021620

L.D. Meixler
Stable wide-deviation linear voltage-controlled frequency generator—4023114

J.S. Pistiner| L. Muhlfelder
Spacecraft closed loop three-axis momentum unloading system—4010921 (assigned to U.S. Government)

Avionics Systems

R.A. Holt| K.C. Adam
Signal modification techniques—4023165

Broadcast Systems

W.L. Behrend
Sideband analyzer for am transmitters—4028625

N. Hovagimyan| A.D. Iadicola
W.P. Ianuzzi
Universal/assigned night answering system for EPABX—4028499

R.N. Hurst| R.A. Dischert
Signal defect compensation—4021852

Consumer Electronics

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Transducer drive circuit for remote control transmitter—4027280

T.A. Bridgewater
Color function display system—4025945

L.A. Harwood
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J.K. Kratz| E.W. Christensen, II
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J.C. Peer
Vertical deflection circuit—4023069

H.R. Warren
Recorder-reproducer system—4025959

K.R. Woolling, Jr.
Counter-type remote-control receiver producing binary outputs correlated with numerical commands of a companion remote-control transmitter—4023105

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P. Foldes
Multimode coupling system including a funnel-shaped multimode coupler—4030048

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Phase lock-loop modulator using an arithmetic synthesizer—4021757

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C.H. Anderson| S. Bloom
Guided-beam flat-display device—4028582

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D.L. Ross| D.M. Gavrilovic
Novel liquid crystal compounds and electro-optic devices incorporating them—4029595

F.N. Sechi
Rf-drive equalizer for multicell microwave transistor—3997851 (assigned to U.S. Government)

I. Shidlovsky
Method for preparing cathodochromic sodalite—4020147

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L.I. Mengle
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Method of making viewing-screen structure for a cathode-ray tube—4025661

J.G. Ottos
Method of detecting heater resistance independent of contact resistance—4020416

M.R. Royce| R.P. Thompson
Method for preparing filter-coated phosphor particles—4021588

J.F. Sterner
SCR, diode, diac, and triac tester—4031465

RCA Ltd., Canada

R.A. Crane| A.K. Ghosh
Method for achieving gas dynamic lasing—4031485

R.C. Graham
Read/write character generator memory loading method—4028724

RCA Ltd., England

B. Crowle
Current divider provided temperature-dependent bias potential from current regulator—4025842

B. Crowle
Temperature-sensitive current divider—4021722

Solid State Division

A.A. Ahmed
Current amplifiers—4028631

R.R. Brooks
GTO switching circuits—4023049

B.A. Krischner
Analog to digital converter—4023160

H.D. Scheffer
Wire lead bonding tool—4030657

B. Zuk
Flip-flop with setting and sensing circuitry—4021686

SelectaVision Project

J.A. Allen
Video-disc playback system and pickup cartridge therefor—4030124

B.K. Taylor| J.A. Allen
Stylus adjustment apparatus for a video-disc player—4030123

Engineering News and Highlights

Pritchard given Zworykin Award

Dalton H. Pritchard, a Fellow of the RCA Laboratories, received the Vladimir K. Zworykin award for "significant contributions to color television technology."

The award was established in 1950 by Dr. Vladimir K. Zworykin and is made by the Board of Directors of the Institute of Electrical and Electronics Engineers, upon the recommendation of the Field Awards Committee and the Awards Board, for outstanding technical contribution to electronic television. The award consists of a certificate and one thousand dollars. It is awarded annually when the Institute determines that there is a qualifying candidate.

Most of Mr. Pritchard's 31-year career with RCA has been devoted to research on color television. He has received eight RCA Laboratories Outstanding Achievement Awards for his research in television and related areas. This work included the planning and testing of systems and circuits proposed for adoption by the National Television Systems Committee (NTSC). He has been granted 34 U.S. patents, with several others pending, and has authored a number of technical papers. In this issue, he reviews "U.S. color tv fundamentals," p. 64.

Christopher named Vice President

John Christopher was named Vice President of Technical Operations for RCA Americom. Most recently Director of Space Systems and Program Management, Mr. Christopher joined RCA Global Communications in 1973 as Manager, Spacecraft Engineering. He has had responsibility for the RCA Satcom spacecraft, launch vehicle procurement, overall spacecraft and mission operations and support services. Mr. Christopher's over 24 years aerospace design experience include work at General Electric's Space Division and Goodyear Aerospace Corp. He holds the BSME from New York University and the MSME from the University of Pennsylvania.

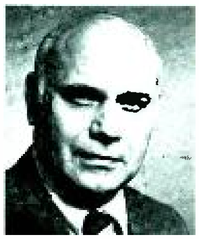
Mr. Christopher's appointment was part of a complete reorganization at RCA American Communications, Inc. (see p. 96).

Professional achievement honored at Burlington

Professional recognition for 33 members of Automated System's technical community. The tenth annual Professional Recognition Dinner was held aboard the *SS Peter Stuyvesant* in Boston Harbor recently to honor engineers who had published or presented papers, received patent awards, or earned Engineering Excellence Awards.

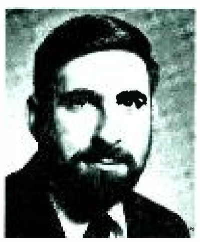
Project engineering excellence brought an individual Technical Excellence Award to **Lionel Arlan** (center). Division V.P. and General Manager **Harry Woll** (left) and Chief Engineer **Gene Stockton** are pictured with Arlan, who is project engineer on the A101 Television System. This system includes a camera package and a receiving station designed to display processed video imagery.

Conn



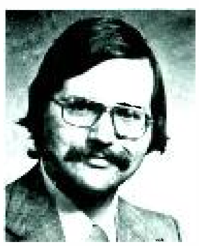
Corso

Drenik



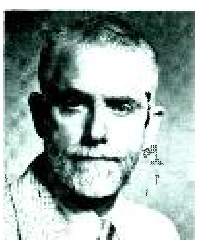
Fell

Hawkins



Kingsley

Levy



Metzger

Eight receive technical excellence awards at Moorestown

Art Conn—for major contributions to definition and implementation of the AEGIS missile engagement process in three critical areas: engageability prediction, intercept prediction, and kill evaluation.

Joseph Corso—for his work in the checkout and certification of the AEGIS mid-course guidance algorithms that control the flight of SM-2 missiles.

John Drenik—for his achievements in implementing weight reduction and cost-effective redesigns into the recently completed AEGIS AN/SPY-1A array.

Barry Fell—for outstanding contributions in the system conception, analysis, and development on the Seek Frost radar study.

John Hawkins—for significant contributions to TRADEX operating capability through system software modifications.

Robert Kingsley—for outstanding performance in the design and implementation of workable software for a classified system.

Beryl Levy—for her contributions in the design, coding, and testing of the AEGIS simulation program, MEDUSA, and particularly for her outstanding performance in converting the program for operation on a new computer system.

G.V. Metzger—for his outstanding system engineering performance in conceiving and specifying two major functions for the AEGIS C&D Interface Simulator System (ISS).

Farnum cited for work on SATRACK at Government Communications Systems

Phil Farnum of Communications Equipment Engineering received the Technical Excellence Award for his highly professional development of the dual channel receiver portion of the SATRACK transponder. Mr. Farnum was cited for the total spectrum of his work on this program, but particularly for his work in developing and integrating SAW (surface acoustic wave) filters into the unit, a significant step in the technology of receiver design.

Phil Farnum (center) explains his award-winning receiver design to Leader **John Shedahl** (left) and Manager **Irv Joffe.**

Design and Construction of a portable data interrogator used to test and address points on the data buses of all AEGIS cabinets earned a team Technical Excellence Award for **M.D. Brazet, R.L. Jameson,** and **D.A. DeMarco.** In the photo, left to right, are **H.J. Woll,** Div. V.P. and General Manager; team members **Brazet, DeMarco,** and **Jameson; R.J. Monis,** Mgr. Automatic Test and Monitoring Systems Engineering; **R.J. Wildenberg,** Mgr., Design Engineering; and **E.M. Stockton,** Chief Engineer.

A101 Television System work won a TE Team award for fifteen engineers at Automated Systems. From left to right are team member **R. Tetrev;** Div V.P. **H. J. Woll;** team members **M.L. Johnson, J.J. Klein, D.A. French, P.M. Royce, R.P. Sharland, P.J. Morand, L.B. Blundell, W.K. Shubert, D.F. Dion, R.B. Mark, R.C. Blanchard,** and **E.L. Wirtz;** Manager of Radiation Systems Engineering **W. B. Hannan;** individual winner **L. Arlan;** Team member **R.G. Spiecker;** Chief Engineer **E.M. Stockton;** and team member **M.W. Stewich.**

Automated Systems engineers contribute best automotive electronics papers

Steve Hadden, Robin Hulls, and Eldon Sutphin, of the Non-Electronic Test Engineering Section at Automated Systems in Burlington, Mass., received the 1976 SAE Vincent Bendix Automotive Electronics Engineering Award for their paper "Non-Contact Diagnosis of Internal Combustion Engine Faults Through Remote Sensing." This paper was presented at the 1976 Automotive Engineering Congress and Exposition, SAE, Detroit, in February 1976. [A version of this paper also appeared in the *RCA Engineer*, Vol. 22, No. 2 (Aug|Sep 1976).]

Prize-winning authors (left to right) **Eldon Sutphin, Steven Hadden,** and **Robin Hulls.**

Professional Activities

Mertens is guest editor

Larry E. Mertens, Project Manager, RCA AEROSTAT Systems, Service Company, was co-author of the Guest Editorial for the March /April 1977 issue of *Optical Engineering,* the journal of the Society of Photo-Optical Instrumentation Engineers. This issue dealt with Ocean Optics, a field in which Dr. Mertens is internationally recognized. He solicited and edited all the papers on Ocean Optics published in that issue of the journal.

Van Raalte elected fellow

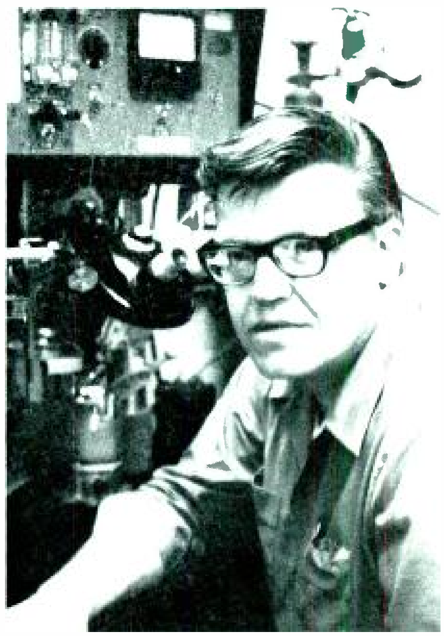
John A. Van Raalte, Head, Display and Device Concepts, RCA Laboratories, was elected a Fellow of the Society for Information Display. He was cited for "outstanding contributions to light valve and matrix display technology."

Rosen honored by EIA

Boris Rosen's seven productive years as Chairman of Solid State Devices Committee (G-12)) of the Electronic Industries Association earned him a certificate of appreciation. During Mr. Rosen's tenure, attendance and participation have increased making G-12 a more effective interface with DOD on problems related to the solid state industry. Mr. Rosen is an Engineering Leader in Central Engineering, Government Communications Systems, Camden, N.J.

Obituary

James J. Napoleon, a Member of the Technical Staff of the Microwave Technology Center, RCA Laboratories, died in February. He joined RCA in 1958 in Harrison and transferred to RCA Laboratories in 1974. A U.S. Army veteran, he received his BS in Electrical Engineering from New Jersey Institute of Technology in 1958 and took additional graduate courses at Rutgers University.



Degrees granted

Missile and Surface Radar

M. Mazin—MSEE, University of Pennsylvania.

Earl Dixon—MA, Physical Science; Glassboro State College.

Michael Perro, Jr.—MBA, Drexel University.

B.J. Matulis—MS, Engineering Management; Drexel University.

Solid State Division

Patrick J. Howard—BS, Electrical Engineering; New Jersey Institute of Technology.

RCA Records

Gurdial Saini—MBA, Butler University.

Picture Tube Division

Fred Shepherd—BS, Engineering Technology; Franklin University.

Paul Justus—BS, Engineering Technology; Franklin University.

RCA Laboratories

Abe Abramovich—MSEE, Columbia University.

James M. Cartwright, Jr.,—MS, Electrical Engineering; City University of New York.

A. Roberto Criado—MSEE, Princeton University.

John J. Risko—MSEE, New Jersey Institute of Technology.

Charles F. Smollin—MSEE, Polytechnic Institute of New York.

Peter J. Maruhnic—AB, Statistics; Princeton University.

Arthur Merritt—BS, Business Management; Rutgers University.

William C. Saunders, Jr.,—BSEE, Monmouth College.

Licensed Engineers

Missile and Surface Radar

Walter H. Petri, Moorestown, N.J.; PE-24156 N.J.

RCA American Communications, Inc.

James M. Walsh, Piscataway, N.J.; PE-24142, N.J.

Promotions

Solid State Division

James J. Rudolph from Member, Technical Staff, to Leader, Computer Aided Mfg.—IC.

RCA Alaska Communications, Inc.

H.H. Galekovich from Senior Engineer to Manager, Switching Projects.

Consumer Electronics

D.L. Bump from Senior Liaison Engineer to Leader, Liaison Engineer.

Leroy W. Nero from Senior Member, Engineering Staff, to Manager, Deflection Subsystems Development.

Missile and Surface Radar

H. Carpenter from Senior Member, Engineering Staff, to Unit Manager, Engineering Systems Projects.

R. Poston from Senior Member, Engineering Staff, to Leader, Engineering Systems Projects.

W. Zimmerman from Leader, Engineering Systems Projects, to Manager, Engineering.

D. Webdale from Senior Member, Engineering Staff, to Leader, Engineering Systems Projects.

Staff announcements

Distributor and Special Products Division

Gene W. Duckworth, Division Vice President, Engineering and Marketing Services, appointed **J. David Callaghan** Chief Engineer.

J.D. Callaghan, Chief Engineer, announces the organization as follows: **R.M. Wilson,** Manager, Special Products Development; **J.F. Sterner,** Manager, Special Products Development; and **F.R. DiMeo,** Manager, Design and Drafting.

Edward A. Boschetti, Division Vice President, Components, appointed **Donald R. Weisenstein** Director, Parts and Accessories Product Management.

President and Chief Executive Officer

Edgar H. Griffiths, President and Chief Executive Officer, announced the election of **Rocco M. Laginestra,** Vice President, Operations Analysis; and **Paul Potashner** Group Vice President, with responsibility for Banquet Foods Corporation, Coronet Industries, Inc., and Oriel Foods Group.

RCA Laboratories

Nathan L. Gordon, Staff Vice President, Systems Research, announced the organization as follows: **David D. Holmes,** Director, Television Research Laboratory; **Paul M. Russo,** Head, TV Microsystems Research; **Alfred H. Teger,** Head, Advanced Systems Research; and **Allen H. Simon,** Fellow, Technical Staff.

David D. Holmes, Director, Television Research Laboratory, announced the organization as follows: **Ronald L. Hess,** Head, Deflection and Power Supply Systems Research; **David D. Holmes,** Acting, Signal Processing Research; **Kern K. N. Chang,** Fellow, Technical Staff; **Dalton H. Pritchard,** Fellow, Technical Staff; **Stanley P. Knight,** Head, Signal Conversion Systems Research; and **Robert M. Rast,** Head, TV Systems Technology Research.

Gerald B. Herzog, Staff Vice President, Technology Centers, appointed **Philip K. Baltzer** Head, LSI Systems and Applications.

Marvin A. Leedom, Manager, Mechanical and Instrumentation Technology, appointed **William G. McGuffin** Manager, Instrumentation.

James J. Tietjen, Staff Vice President, Materials and Components Research, appointed **David E. Carlson** Head, Photovoltaic Device Development; **Charles J. Nuese** Head, Semiconductor Device Research; **Henry Kressel** Director, Materials and Processing Research Laboratory; and **Brown F. Williams** Director, Energy Systems Research Laboratory.

RCA American Communications, Inc.

Andrew F. Inglis, President, announced the organization as follows: **John Boning,** Vice President, Government Communications Services; **Carl J. Cangelosi,** General Counsel; **John Christopher,** Vice President, Technical Operations; **Dennis W. Elliott,** Director, Finance; **Harold W. Rice,** Vice President, Video & Audio Services; **Charles H. Twitty,** Director, Industrial Relations; **Jack F. Underwood,** Vice President, Commercial Communications Services; and **Donald E. Quinn,** Director, Public Affairs.

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Contact your Editorial Representative, at the extensions listed here, to schedule technical papers and announce your professional activities.

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KRISHNA PRABA Gibbsboro, N.J. Ext. PC-3605
ANDREW BILLIE Meadow Lands, Pa. Ext. 6231

Mobile Communications Systems

FRED BARTON* Meadow Lands, Pa. Ext. 6428

Avionics Systems

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JOHN McDONOUGH Van Nuys, Cal. Ext. 3353

Government Systems Division

Astro-Electronics

ED GOLDBERG* Hightstown, N.J. Ext. 2544

Automated Systems

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AL SKAVICUS Burlington, Mass. Ext. 2582
LARRY SMITH Burlington, Mass. Ext. 2010

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Government Engineering

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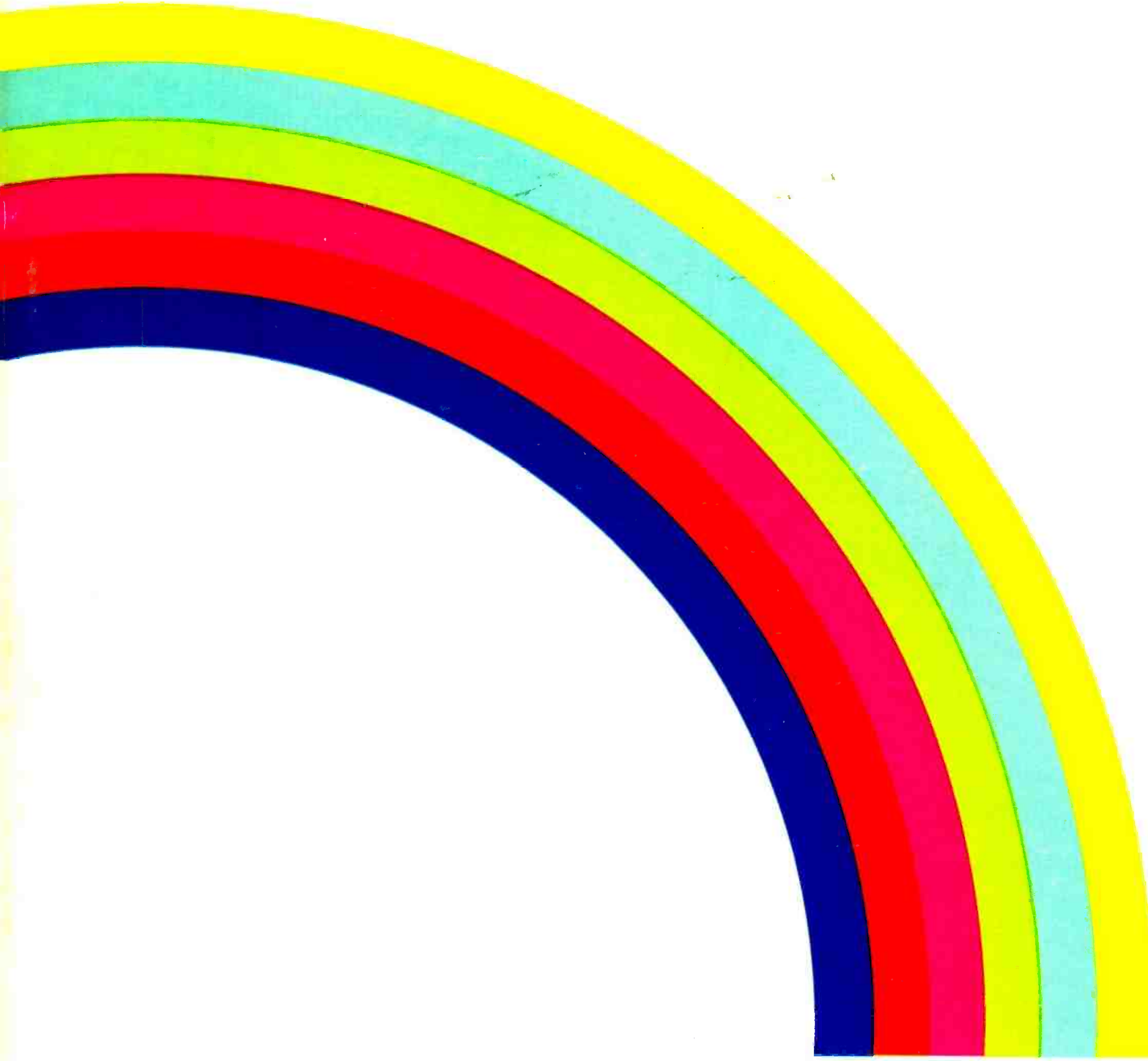

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