RCA ENGINEER

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RCA ENGINEER *Staff*

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OUR COVER

Standing among the more than 50 different loudspeakers used in Home Instruments Division products is W. E. Davis of Radio-"Victrola" Engineering in Indianapolis. H. D. Ward of the Record Engineering Laboratory shows one of the many tape cartridges produced by the Record Division and the YGG45 reel-to-reel stereo tape recorder produced by the Home Instruments Division. The RCA Victor record changer rests on an engineering prototype of the VGT32W stereo console. The loudspeaker enclosure is the MGS40. This sealed enclosure speaker system is part of the "Mark" series modular radio-phonograph line.

Recorded Music—Tape and Disc

Disc recording has been a challenging taskmaster for its companion—magnetic tape recording. Disc recording methods have provided a standard of excellence for performance and an insistent demand for quality in all forms of recorded music for the consumer. Magnetic tape recording became a basic contributor to the great impetus toward attaining high quality in recorded music more than a decade ago when magnetic tape was first accepted for use in the original studio recordings. Since that time, magnetic recording has offered intriguing possibilities of providing high-quality music for the home; cost and handling have been the major deterrents.

But gradual progress has been made. In 1958, RCA pioneered in the introduction of the slow-speed, four-track, coplanar cartridge for recording stereophonic music; however, full advantage of this innovation was not realizable because of the simultaneous introduction of stereophonic records in the same year.

Yet today, RCA's pioneering in recorded music has resulted in a new, simplified tape cartridge that utilizes eight tracks of stereophonic music for use in the automobile. The new tape cartridge allows one to program a selection of music for enjoyment, for avoiding boredom during long trips, and for easing the frustration of traffic tie-ups.

This issue contains details on some of the contributions of RCA engineers and scientists to the recent research in acoustics, to the programs in disc and magnetic tape recording, and to the modern design of stereophonic home instruments and related circuits. It is the constant objective of engineering in the RCA Victor Record Division to provide the best in recorded music by both tape and disc methods so that all the divisions of RCA will benefit in serving the ultimate consumer with their products.

H E Roys

Warren Rex Isom

H. E. Roys
Chief Technical Administrator
RCA Victor Record Division
Indianapolis, Ind.

and

W. R. Isom
Chief Engineer
RCA Victor Record Division
Indianapolis, Ind.

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PAPERS

NOTES

DEPARTMENTS

A TECHNICAL JOURNAL PUBLISHED BY **RADIO CORPORATION OF AMERICA,** PRODUCT ENGINEERING 2-8, CAMDEN, N. J.

● *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.*

RCA ENGINEER articles are indexed
annually in the April-May Issue and
in the "Index to RCA Technical Papers."

ENGINEERS in the Missile and Surface Radar Division design precision equipment for delivery to the customer. However, in today's aerospace electronic business, there is little chance to design and construct an engineering model and then go through a painstaking, cost-reducing production-engineering cycle.

Product cost control starts with the specification engineer, the engineer who sets up design parameters, and the draftsman who puts tolerances on the parts drawings. An engineer can be asked to design a power supply, and, given adequate time, he will design the desired product. However, the exact product cost will be an unknown until the design is built. One can also ask the engineer to design a power supply to sell for $100 or one to sell for $1000 and he will do either. But, the point is that the product cost goals must be established with the first design.

The Engineer and the Corporation

PRODUCT COST GOALS

Engineering's Role in Cost Avoidance

F. H. TILLWICK, Mgr.
Product Engineering
Missile and Surface Radar Div.
DEP, Moorestown, N.J.

Experience demonstrates clearly that the only time to design for product cost is prior to the initiation of drawing effort. Any cost-reducing redesigns attempted after this point are rarely effective and can be quite expensive; quite often they result only in reduced equipment performance and increased total costs.

The next question is how, with 10 to 100 design engineers involved in a project, can the project manager tell all these engineers about his dollar limits on product cost, and exercise the proper control to see that all objectives are met (or deviated from only with approval)? The project manager must be assured that he meets not only the technical requirements, the engineering cost goals, and the schedules, but also that the equipment arriving at the shipping door has been produced to conform with the predicted cost.

This paper explains how to keep the engineers informed and implement a program of cost avoidance during the design and development—and only after setting the goals to establish what the product should cost. There is an old cliche that says "you can't inspect quality into a product"; it should also be noted that you can't manufacture cost out of a product.

A LOW-COST RADAR CONTRACT

Missile and Surface Radar business has been based largely on technical excellence—particularly in the areas of range and angle precision. As a result, RCA has enjoyed a good technical reputation in this field, although it is not known as a low-cost producer. For a number of years, it has been RCA's desire to enter the low-cost instrumentation radar field.

When the Missile and Surface Radar Division was awarded a contract to produce a low-cost instrumentation radar, management decided that not only must the usual contract schedule and cost requirements of the contract be met (no mean task since negotiation had substantially cut the original estimate) but also that MSR must meet the requirements of a broader problem, namely that of gaining an entry into a new product line. How could we design a truly competitive product that would stay competitive? The answer of course was to *limit* the cost of the product itself. This proved to be a new challenge with state-of-the-art technical requirements facing the design engineer, a tighter schedule than we had ever undertaken before for a radar of this type, and exceedingly tight overall cost restraints.

In years past, with the cost-plus-fixed-fee mode of operation, engineering concentrated primarily on sophisticated technical concepts which would make us leaders in our field. MSR engineers succeeded and became known as radar experts in their field. Engineering was primarily concerned with design parameters on performance, engineering costs, and schedule. However, today, the competition for every defense dollar is so keen that both technical excellence and low cost are companion factors, particularly in competing with the smaller firms. The same type of far-out engineering requirements are stipulated as before, but now contracts are set at fixed prices and schedules have penalty clauses. We find that we must add an additional design parameter—*product cost.*

COST-CONTROL PLANNING

Product-cost-control disciplines are not new, but they were new to us. Since management now had four major parameters to consider—engineering cost, schedule, technical requirements, and a fixed product cost to meet (Fig. 1)—it was decided to brainstorm the problem. Chief Engineer R. A. Newell, Plant Manager F. Drakeman, and the writer worked together to outline a program known as "*Product Cost Goals.*" The aim was to assure that at the completion of the contract, the Missile and Surface Radar Division would have a product line that was competitive in the market place.

FREDERICK H. TILLWICK received his BSME from Iowa State University in 1949 and is presently attending engineering graduate school at Drexel Institute of Technology. After a number of years in engineering with Goodyear Tire and Rubber Co. and Goodyear Aircraft Corporation, he joined RCA in 1959 as a Development and Design Leader. Since then, Mr. Tillwick has held increasingly responsible management positions. In 1962, he was appointed Manager of Engineering Documentation established in recognition of the importance of the "software" counterpart to deliverable hardware. During this period he was instrumental in establishing the DEP Documentation Management Committee. In 1964, he was appointed Manager of the newly created Product Engineering Dept., established to handle product line engineering and the manufacturing interface to achieve lowered costs and improved producibility. Mr. Tillwick is also the Engineering representative on the MSR "Make or Buy" Committee. Mr. Tillwick is a member of the ASME, Senior Member of the IEEE, and is a registered professional engineer in both Ohio and New Jersey.

Final manuscript received May 27, 1966

Two phases were adopted as part of the program planning:

1) Provide a budget for both engineering and manufacturing for each subsystem with limits set for both the design cost and the product cost; the design engineer for the particular subsystem would be held responsible for both budgets.
2) Price out the engineer's concept in real time at the conceptual stage, not after the design was complete and parts procurement started.

The plan was to price out the cost at product-cost concept reviews with the responsible engineer. If his concept was predicted to meet the goal, the engineer could go into detail design; otherwise, the engineer must redesign to come up with a concept fitting into the cost structure. If this proved to be impossible, then management approval must be sought to deviate from the goals.

This system controls product costs at the design concept level. Another review was scheduled at the completion of the detailed design to make sure that the concept was followed; an additional review was held in manufacturing after release of the product design to ensure that the lowest possible cost was achieved.

ENGINEERS ADOPT COST PLAN

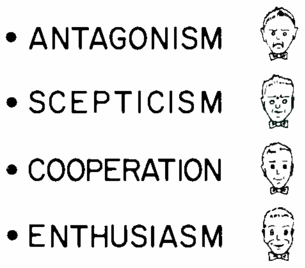
Since the plan was developed in a relatively short time, no one was sure how it would work. At first, the engineers showed a lack of enthusiasm and downright skepticism; most of them felt that this was just another restraint on their creativity. But as the program got underway and the engineers go involved in the task, one could actually feel the change in attitude. Engineers began to ask for yardsticks to help them achieve their objectives as they went along; it became a real challenge to most of them.

The design functions became a real part of the Division effort, and the engineers could measure their contributions quantitatively to a goal; they were well aware that their performance could affect the whole future of MSR as far as instrumentation radar was concerned. Our goal for the radar was predicated on the future and based on a breakeven curve developed from marketing predictions; Fig. 2 is a graphical representation of the success of the engineer's efforts.

As can be seen from Fig. 2, within a short time after the product cost goals were initiated and product-cost concept reviews began, the cost predictions started to go down. All through the concept stage, the cost predictions continued to go down sharply, well below the cost goals. This overshoot was deliberate since the engineers felt some concepts would backfire, or that anticipated vendor costs might not be achieved, resulting in some cost increases. This is exactly what happened, and as we went into the later phases, some of the accumulated reserve was needed to cover cost problems.

Fig. 1—Design parameters.

Fig. 1a—The changing attitudes of the engineers.



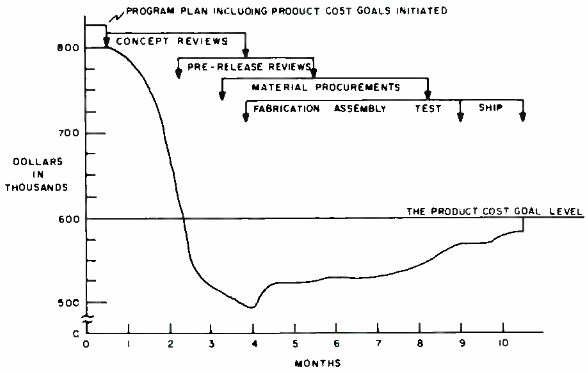


Fig. 2—Product cost curve.

EXAMPLE OF A COST-REDUCTION BONUS

A specific example of a *bonus* cost reduction is worth describing. Sometime before the contract was received, a vendor was talking to our plant manager about the design and cost of a standard transmitter and modulator cabinet that had been part of our product line of radars for a number of years. The vendor pointed out a number of features, not sophisticated examples, but run-of-the-mill items that contributed to the high cost of this cabinet. For example, handles, latches, hinges, and stops were non-standard; hardware was special; and general forming and construction were not up to modern fabrication techniques. This vendor really opened our eyes, especially when it was determined that this transmitter modulator could be used on the new radar project; but the cost goal set for this subsystem was 33% less than the original design. The cost reduction team determined to do something about it. A redesign of this transmitter and modulator was undertaken to meet the cost goal. The answer was a single unit meeting the same technical requirements at a product cost that was actually 40% less than the original design. Figs. 3, 4, and 5 illustrate the difference in the designs. The old transmitter modulator was housed in two identical cabinets; the new one, which meets the same technical requirements, is housed in one cabinet at 40% the cost. One third of the engineering dollars spent for this repackaging was recovered on the product cost of this unit. In addition, MSR now had a dollar-competitive transmitter/modulator product. The additional dollars can be regarded as an investment in the future of this product, although costs were kept within the total engineering budget.

EFFECTS OF THE PROGRAM

Let us examine some of the effects of this "cost control" discipline and the effect it had in Engineering from four points of view: the program, the attitude of the engineer, the technical excellence, and the management.

Program Results

This radar was developed in an unusually short period of time. It had some state-of-the-art technical requirements and was heavily cost-targeted to start with; and all this was required while putting a new discipline into effect.

One possible reaction might be: "Did engineering do a quick and dirty job?" The facts prove that this was not the case. The design releases were made within 1½ weeks of schedule. The number of changes required were within 7% of those planned, and the engineering total cost was within 1% of the goal. From a program point of view, this shows that the quality of both the design and the product can be maintained with this discipline in effect.

The Engineering Attitude

As to the attitude of the engineer, the above statistics should be convincing enough that the engineers performed adequately. As mentioned earlier, a general feeling of skepticism and disbelief on the part of the engineer was evident when this discipline was announced. It did not go over with the engineers; it was a restriction to them and they didn't see how it could be carried out.

Then, many months later, when the design was essentially complete and product goals met, the Plant Manager had a meeting to discuss this concept with other Plant Management personnel. Some of the key design engineers on the job were invited to discuss what had been done and how they had achieved it. The Plant Manager set the stage, expecting to ask some questions and get a few terse answers. However, much to his surprise the engineers took over and explained all the things they had been able to do with this new cost approach and how they had fallen in with the plan. They were all for it, since they could quantitatively measure their results and realize a contribution to a Division effort.

Technical Excellence

As for technical effect, several state-of-the-art developments were involved. For example, a new receiver was developed and designed for this radar; it is completely modularized, using all solid-state circuitry. A building-block approach was used so that the basic design can be used for other radar applications. This receiver provides improved reliability, better gain, and phase stability over a wide dynamic range.

This discipline is not only compatible with a research and development philosophy but it actually provides a catalyst to the engineer to perform better on his job, leading to better technical efforts. It stimulates creativity. Additionally, since the engineer can see immediate measurable effects of his effort, with respect to cost, he goes about the more mundane tasks, such as repackaging equipment, more enthusiastically.

Management Effects

But what have been the management effects of this discipline? Probably the most significant result was to bring management closer to the key decisions on a more timely basis. When the time came for a decision on cost-versus-technical or schedule tradeoffs, management made the decision. If there was a problem, the discipline automatically brought management into the act; in addition to the transmitter/modulator example quoted, there were a great many other management decisions of this nature throughout the job. In addition, this cost control discipline required management to cost-plan the job before it started—not only for the job at hand but, more significantly, for future procurements of the product line.

COST CONTROL PROCEDURE

The procedure for accomplishing this discipline is quite similar to the technical design review. In a normal technical design review (Fig. 6), the engineer, working with the parameters of engineering cost, technical specifications, and schedules, comes up with a design concept. The concept is reviewed and, if found acceptable, the engineer then proceeds to detail the design. A pre-release review is held; if satisfactory, the drawings are released and manufacturing can proceed.

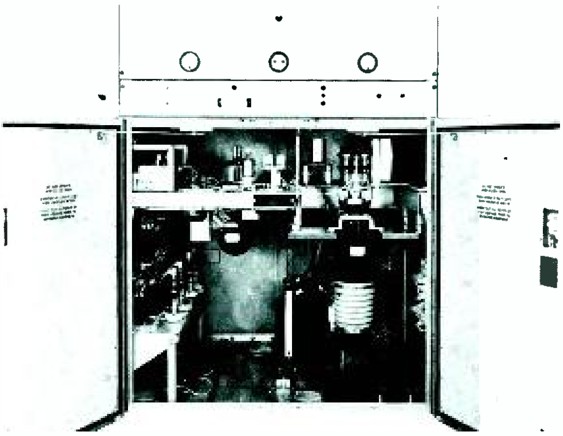


Fig. 3—The old transmitter.

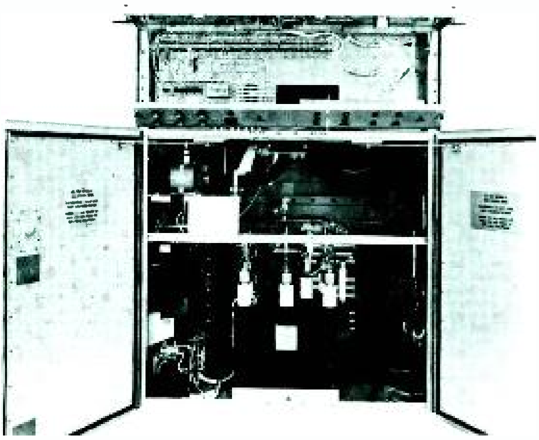


Fig. 4—The old modulator.

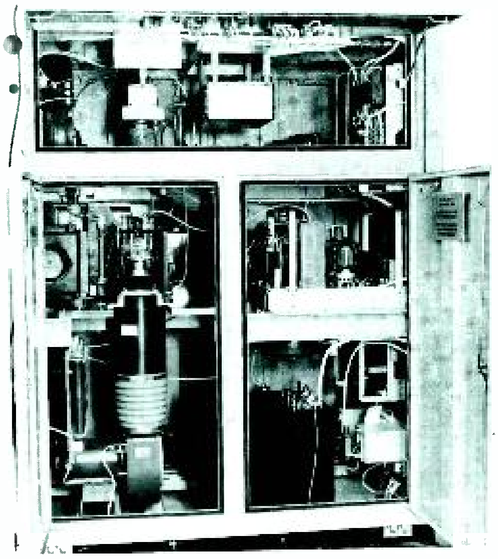


Fig. 5—The new transmitter/modulator.

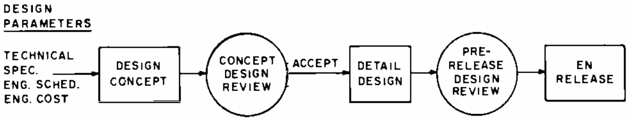


Fig. 6—Technicol design-review flow.

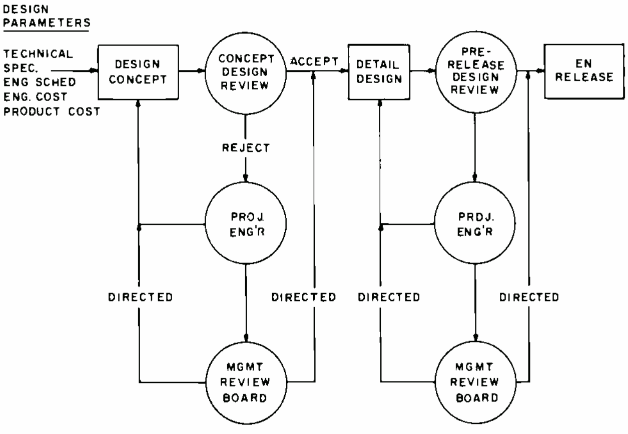


Fig. 7—Product-cost design-review flow.

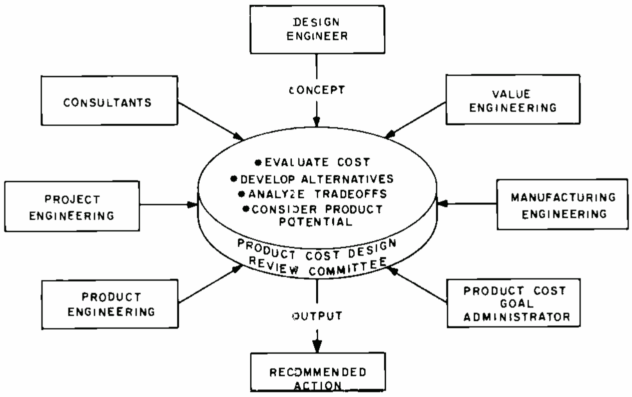


Fig. 8—The product-cost review committee.

The reviews for product cost were similarly held (Fig. 7), except that in most cases the review was held at the engineer's desk or drawing board; and of course, the engineer started with an additional parameter, product cost. The only significant addition to the flow was that if the concept or detailed design was rejected for cost, the engineer could appeal to the Management Review Board, which was established by the Program Manager to evaluate problems and make tradeoff decisions. Management has, at these two points, a chance to get involved in timely tradeoffs with respect to costs.

The most important step in this flow is the concept review. It is at this stage that the engineer is better able to effect changes in thinking; there is more time to do it, and interfaces have not yet been solidified.

Product Cost Review

The Product Cost Review Committee consists of those best able to evaluate the concept from a product-cost viewpoint: the design engineer, the project engineer, members from the product engineering activity and manufacturing engineering, the product-cost administrator (a function established by the MSR Plant Manager F. Drakeman as part of the production cost control activity) and consultants as necessary. This committee evaluates cost, analyzes tradeoffs, helps the design engineer to develop alternatives and considers the product potential (Fig. 8). There are basically three steps of review as shown in Fig. 9:

1) The design is evaluated against the program requirements, since this has been found to be the most fruitful area of cost savings. Many times, cost can be eliminated by eliminating frills or items the engineer thought the customer might like to have, even though not required.
2) The next area is a survey of high-value and common-usage items. The committee looks particularly for state-of-the-art development, standard vs. non-standard items, and across-the-board usage to develop product commonality.
3) A last look is given to the packaging concept, evaluating the structure vs. the application, use of standard hardware, and fabrication techniques.

Levels of Review

The levels of design review were chosen to minimize the risk of not meeting cost goals. Review started at the system level and went down to a point in the design that would achieve this. In general, the package was maintained so that the total cost of the product to be reviewed would be greater than $5,000. This was true whether it was one item at $5,000 or 50 items at $100 a piece. We found that reviewing sums much below this figure did not really justify the effort. One exception was where a common usage was found for the item within either the product line or across several product lines.

The product cost review committee did not "cost estimate" the design. Rather, they tried to evaluate cost so that it would not be exceeded within a 90% probability. This enabled the review to be done in real time, on the average, in less than one hour.

Of course, concept reviews were held a number of times because the cost goals were tight and the technical requirements were rough; and we were not accustomed to thinking in terms of four design parameters. In all cases, the product-cost concept review was scheduled to follow the technical design review, since there was little point in freezing the cost concept of a design until the product concept was frozen technically.

Reducing Costs

This discipline brought out a number of ingenious ways to reduce the cost. For example, on a purchased item, it was discovered that instead of just sending out a cost estimate request to a number of vendors on a competitive basis, our price could more easily be reached by telling a vendor what we wanted, what we were prepared to pay, and what kind of tradeoffs could be made to produce what we wanted for a given price. There were other instances where we were able to call in the vendor during the concept change and get him to advise us as to how the design could change to allow him to produce for the cost goal established. Many vendors were eager and ready to work with us, and they provided special knowledge and skill that paid off for all concerned. They got the procurement order and our goal was met.

A Product-Cost Procedure Manual

Now that a firm foundation and a background of experience is available for achieving low product cost, it is planned to implement an operating procedure in MSR this year. The system will be defined so that it does not offer a restraint to engineering creativity, but rather can be used as a help. All programs are not applicable to this technique, and we want to define those that do apply. Essentially, there must be a number of units involved or some sales potential. There must be a willingness to invest some engineering dollars and time to achieve these goals; more dollars and time are required to create to a demanding product cost goal and one must be willing to make the investment and have the time to do so.

Aids and Feedback

The design engineer must have better aids; if this discipline is really going to pay off, it must start with the engineer. Toward that end, a product-cost manual will be prepared to provide the engineer with guidelines to evaluate the cost of his product in the conceptual stage, both for proposals and for design.

Feedback of cost information to the engineer is an essential feature of this system. It is not enough for the engineer to know what the review board felt the product would cost; he should also know what happened to this cost as it went through the ordering, fabrication, and assembly cycle. During the production of the radar previously discussed, curves were plotted of the product costs on a weekly basis to keep the engineers informed. Interestingly enough, in most cases, the cost that the review committee predicted actually turned out to be somewhat higher than the actual cost. The only exceptions were those items which turned out to be in short supply or were state-of-the-art and for which we had difficulty in getting vendors.

It is planned to provide the engineer with one more tool: guidelines which will keep him up-to-date with the latest innovations in material, parts, fabrication, and other techniques that will place him in a position to select the most competitive design.

During the past several months, several other divisions of DEP have become interested in this discipline and one division has now started to use *Product-Cost Goals* as part of their programs.

RELATION OF COSTS TO PROPOSALS

It is felt that the cost control discipline is applicable at the proposal stage. It will enhance our ability to win contracts and, if we get the contract, make the job of implementing that contract much easier. For example, a Request for Quote comes in and a proposal director is appointed (Fig. 10). As part of the plan, the proposal director should develop product costs goals consistent with the overall program goals; engineering will use these goals as one of the parameters around which a concept is developed. This procedure assumes that sufficient homework has been done prior to the RFQ to have a knowledge of what the customer wants, including what he is prepared to pay.

Now that the proposal director has an approved plan, including product cost goals, he can pass gate 1 (Fig. 10) and the engineers can go to work and develop design concepts consistent with that plan. Gate 2 is where these concepts are evaluated for product cost and, similar to the design stage, the engineer does not proceed unless he can either achieve the goal or has an exception from the proposal director. This is evaluated similarly in real time, and, if it is felt that the goal cannot be met, management then has an opportunity to pass judgement and determine the best course of action.

When this final gate (Fig. 10) is passed satisfactorily, both the technical proposal and the detailed cost estimate can proceed. The third gate is the final evaluation of the cost package, and, if a proper job is done at gates 1 and 2, the management's task is relatively easy since all the facts are before them. On proposals where this approach was used, the cost estimates were so well established that no further tasking or arbitrary cuts were necessary to meet the price Marketing had established. The proposal director's plan, which was based on marketing's best judgement to start with, was met.

There is another interesting aspect to this approach. In the past, when the final costs came out higher than desired, it was not uncommon for manufacturing and engineering to blame any excesses in either cost or schedules on each other. With the new cost-control discipline, this is no longer possible, either in the proposal stage or the design stage, since product costs are evaluated as we go along by representatives of both engineering and manufacturing who perform all key functions as a team.

When this cost-control discipline has been used in establishing the proposal and the contract is won, the implementation during the actual design stage is handled as discussed previously. The program manager, using the proposal plan and estimate as a base of reference (as amended by contract negotiation), then establishes the program plan, including program cost goals. These goals, of course, are much more easily established and a design concept exists as a base compatible with these goals. This allows both the program planning and the design concept to proceed at a much more rapid pace (assuming no major changes occur from the system as proposed). Thus, design gates 1 and 2, as shown in Fig. 11, are much easier to attain. The same product cost reviews are held, both concept and pre-release as represented by gates 2 and 3, with the management review board available in the event of a tradeoff decision.

RESULTS OF COST CONTROLS

The results of cost controls obtained to date are gratifying. When properly applied, the cost-control discipline allows one to plan and predict what the product will cost and also results in all groups pulling together to achieve a common goal, especially the two key activities which must contribute to the success of any product—engineering and manufacturing. Additionally, this technique can be extremely useful to engineering, since the cost control provides a stimulus for creativity and is an additional challenge to the engineer striving for technical excellence.

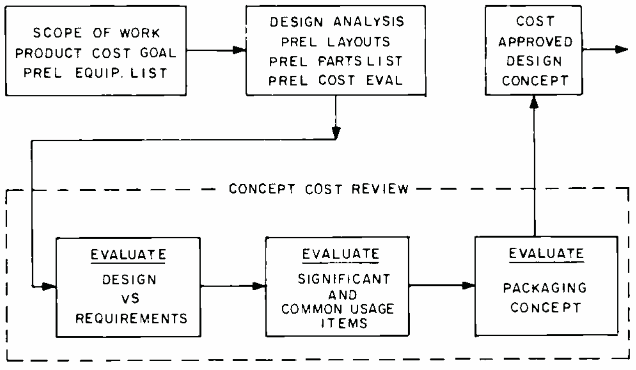


Fig. 9—The concept cost review.

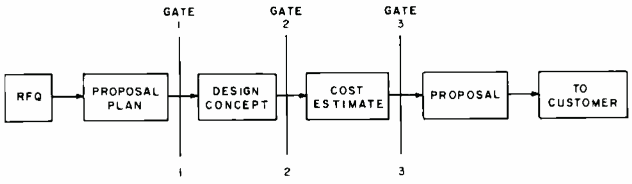


Fig. 10—Proposal flow diagram.

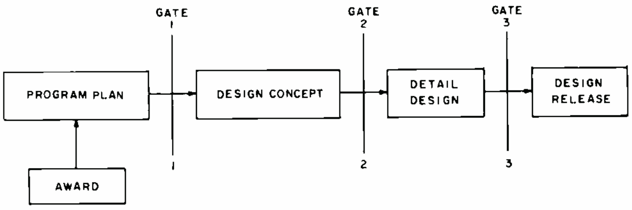


Fig. 11—Design flow diagram.

REVIEWS OF RECENT TECHNICAL BOOKS BY RCA AUTHORS

Presented here are brief descriptions of technical books which have recently been authored by RCA scientists and engineers, or to which they have made major contributions. The reviews were provided by the authors' Editorial Representative. Readers interested in any of these texts should contact their RCA Technical Library concerning their availability for loan, or the book may be purchased through your usual book supplier. For previous reviews of other books by RCA authors, see the August-September 1964 and August-September 1965 issues of the RCA ENGINEER. Additions to these listings should be reported promptly to your Editorial Representative for inclusion in future published reviews.

"MATHEMATICAL ENTERTAINMENTS"

Dr. M. H. Greenblatt
Astro Electronics Div.
DEP, Princeton, N. J.

This book has 17 chapters (about 160 pages) of mathematical tidbits, curiosities, and jokes. However, only those jokes which are vaguely reminiscent of the subject matter (mathematics) are allowed. For example, when talking about number theory (a fairly "hairy" and abstruse part of mathematics), the author relates an entertaining story of three men who went into a diner — etc., etc. In this manner, some classics of number theory and problems in geometry, probability, and electrical theory are presented. A very good high-school mathematics student in his senior year should enjoy this book, and those with additional levels of mathematical maturity will derive even more enjoyment. *(Published by Thomas Y. Crowell Co., New York; price $4.95)*

DR. MANUAL H. GREENBLATT received his BA in Physics from the University of Pennsylvania in 1943, and a PhD in Physics from the same school in 1949. In 1948, Dr. Greenblatt joined the RCA Laboratories and worked on photomultiplier research and completed major projects in the measurement of the time delay in secondary electron emission. At Astro-Electronics Division, Dr. Greenblatt has worked on the hardware implementation aspects of Project ACSI-MATIC and data analysis work on Project DAMP. Dr. Greenblatt has patents on a pulse-height analyzer, a high-frequency sampling oscilloscope, a spectrum, analyzer for nuclear radiations, and an electronic analogue divider. He has written several technical papers and is a member of Pi Mu Epsilon (mathematical honorary fraternity), Sigma Xi, the American Physical Society, and the IEEE.

"TRACE ANALYSIS: PHYSICAL METHODS"

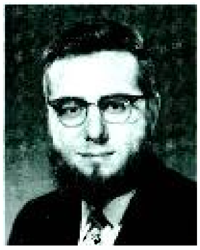
Dr. K. L. Cheng and Dr. L. R. Weisberg
(Contributors)
RCA Laboratories
Princeton, N. J.

This book (edited by G. H. Morrison) brings together the various aspects of modern physical methods that collectively contribute to the specialized field of tract analysis. Dr. Cheng has contributed a chapter, "Spectrophotometry, and Fluorometry" — and L. R. Weisberg a chapter, "Nonspecific Methods For the Analysis of Solids." *(Published by Interscience Publishers; John Wiley and Sons, New York; price $16.00)*

DR. LEONARD R. WEISBERG received the BA degree Magna Cum Laude from Clark University in 1950. His graduate work was carried out at Columbia University, and his PhD thesis was concerned with order-disorder phenomena in Cu_3Au. During 1953-55, he was a research assistant at the IBM Watson Laboratory in New York, working on the preparation and properties of germanium. Since 1955, he has been with RCA Laboratories, and has specialized in materials research on gallium arsenide and other III-V compounds. He received an RCA Laboratories Achievement Award in 1959 for research in this field. He has published twenty scientific papers, and is a member of the American Physical Society, the AIME, and Sigma Xi.

DR. K. LU CHENG received the BS in chemistry from the Northwestern College, China, in 1941, and the MS and PhD from the University of Illinois in 1949 and 1951, respectively. He was a postdoctoral fellow at the University of Illinois after graduation. From 1952 to 1953 he was a microchemist at the Commercial Solvents Corporation, Terre Haute, Indiana. He taught analytical chemistry at the University of Connecticut and later worked as an engineer with the Westinghouse Electric Corporation. In 1959, he joined RCA Laboratories where he is engaged in analytical chemistry research and development. Dr. Cheng is a member of Sigma Xi, Phi Lambda Upsilon, Sigma Pi Sigma, the Electrochemical Society, the American Chemical Society, the American Physical Society, the American Microchemical Society, and a Fellow of the American Association for the Advancement of Science.

"A SYNTAX-ORIENTED TRANSLATOR"

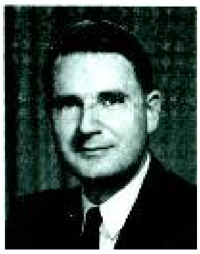


Peter Zilahy Ingerman, Mgr.
Language System Standards and Research
Electronic Data Processing
Cherry Hill, N. J.

This book provides a description of a bottom-up, syntax-oriented translator. Such a translator can be used to translate from any source language whose grammar is subject to rather loose constraints, to any target language which can be considered as a linear string. A syntax-oriented translator will be most useful to the writer of compilers and the designer of languages and as a supplementary text for students in a computer sciences curriculum. *(Published by Academic Press, New York; price $5.95)*

PETER ZILAHY INGERMAN graduated from University of Pennsylvania in 1958 with a BA in physics and an MSE in 1963. He engaged in research investigation in computer programing from 1957 to 1963. He joined the Westinghouse Electric Co. Defense and Space Center in 1963 to do programing research. In 1965 he came with RCA as Mgr., Language Systems, and Standards, and Research. He is a member of ACM, SIAM, AMTCL, Association for Symbolic Logic, Franklin Institute, and a Senior Member of IEEE.

"COMPUTER TYPESETTING"



Dr. Michael P. Barnett
Graphic Systems Division
Princeton, N. J.

This comprehensive work serves a double function: It reports the results of some actual experiments in computer typesetting; and it takes a long view ahead to the potentialities and problems associated with extending the digital computer's utility in this area. The experiments were conducted at the Cooperative Computing Laboratory, Massachusetts Institute of Technology. The practical experience gained in these pioneering tests represents a source of the future growth of this technology, and is presented in detail here. The author does not view the computer as a miracle machine, but takes a sober and critical look at the limitations and problems which are inherent in its use. Nevertheless, he approaches the subject as a diversified and comprehensive activity of great potential, going far beyond the justification-hyphenation issue which has been the main concern of accounts of this field hitherto. *(Published by The M.I.T. Press, Cambridge, Mass. 02142; price $10.00)*

DR. MICHAEL P. BARNETT'S research in theoretical chemistry and computer science has dealt with problems of molecular structure, econometric simulation, mechanized text processing, and analytical mathematics. He has been Head of the Applied Science Department, IBM United Kingdom, Limited; Associate Professor of Physics and Director of the Cooperative Computing Laboratory, M.I.T.; and Reader in Information Processing, University of London. At present, he is Mgr., Advance Programming Development, at the RCA Graphic Systems Division, Princeton, N.J.

"ELECTRIC NETWORKS: FUNCTIONS, FILTERS, ANALYSIS"

Dr. J. Bordogna
(coauthor)
Applied Research
DEP, Camden, N. J.

This book (coauthored by Dr. H. Rustan of Polytechnic Institute, Brooklyn) is designed for a second-year course in electric network theory for students who have completed a first course in network analysis. Distinctly intermediate in level, it differs from most books in this area which assume no prior knowledge on the part of the student. Coverage is roughly two-thirds analysis and one-third synthesis. Emphasis is placed on seven key topics which are covered in depth: network functions; synthesis of two-element-kind one-ports; introduction to two-ports (including scattering parameters); filter design; network analysis (including signal-flow graphs, the indefinite admittance matrix, and analysis by digital computer); lattice networks (including transfer function synthesis); network transmission characteristics. The basic theme of the book is to develop a strong background in fundamental concepts through detailed discussion of each topic. In doing this, an appeal is made to the physical intuition of the student instead of overemphasizing mathematical manipulation. *(Published by McGraw-Hill Book Co., New York, 1966; price $12.75)*

DR. JOSEPH BORDOGNA received the SM degree from MIT and the BSEE and PhD from the University of Pennsylvania. His professional experience includes three years as a line officer in the U.S. Navy, and six years of teaching at the University of Pennsylvania and working at Defense Electronics Products Applied Research.

"MODERN RADAR"

Dr. Walter W. Weinstock
(Contributor)
Missile and Surface Radar
Moorestown, New Jersey

Edited by Dr. R. S. Berkowitz of University of Pennsylvania, this book is co-authored by several well known specialists in the radar field and presents an extensive coverage of the techniques used in radar system design. As one of the co-authors, Dr. Weinstock contributed chapters on "Probability Density and Distribution Functions," "Radar Cross-Section Target Models," and "Illustrative Problems in Radar Detection Analysis." This material discusses probability functions and their application to radar detection; defines the problems of describing the radar cross-section and the development of statistical target models required by the system designer. A hypothetical radar system is used as the basis of analysis for several target models and illustrates how system performance varies with target model assumptions. *(Published by John Wiley and Sons, New York, 1965, price, $19.50)*

DR. WALTER W. WEINSTOCK received BSEE, MSEE and PhD degrees from the University of Pennsylvania in 1946, 1954 and 1964, respectively. From 1946 to 1949 he worked in the design of airborne radar at Philco. He joined RCA in 1949 and until 1953 was responsible for the design of various radar and signal processing equipment. Since 1953 he has been engaged in radar systems engineering. He directed countermeasure studies for the Talos Land Based System and was engaged in overall systems analysis and systems engineering. He provided technical direction for system performance evaluation of the AN/FPS-49 and was responsible for the technical direction of the Advanced Surface Missile System (ASMS) Study for the Navy. Currently he is pursuing systems investigations of array radars and signal processing.

"AUDIO SYSTEMS"

J. L. Bernstein
RCA Institutes
New York City, N. Y.

This book covers the circuits and devices used in all types of audio systems. The author makes use of mathematical analysis wherever possible, and all of the major circuits used in the audio portion of sound studios are covered, including those in broadcast and television stations and high-fidelity systems. The book contains practical theory, examples, problems and solutions, and is suited for classroom use. *(Published by John Wiley Publishing Co., New York City; price $7.95)*

JULIAN L. BERNSTEIN is Associate Dean of the Day School at RCA Institutes, Inc., and has been associated with the school for 11 years, serving as instructor and department head before accepting his present assignment. He has had wide experience in electronics quality control and production engineering, is the author of a previous book, "Video Tape Recording," and has written a number of magazine articles on audio- and radio-electronics. Mr. Bernstein is a member of both IEEE and SMPTE and is chairman of an education committee of the latter organization. He holds a BS in physics and mathematics together with an MS in Education.

"PRINCIPLES OF INDUSTRIAL ELECTRONICS"

Ben Zeines
RCA Institutes
New York City, N. Y.

This basic text presents to the student the principle and applications of industrial electronics, especially information needed for engineering and engineering technician training. Process controls, gaseous tubes, semiconductor devices, electronic amplifiers, photo-electric devices, servomechanisms and computer circuits are covered. *(Published by McGraw-Hill Book Co., price not yet known)*

BEN ZEINES received a BEE from New York University and an MEE from Brooklyn Polytechnic Institute. He has served on the faculty of RCA Institutes for the past 17 years. He has also served as an Adjunct Assistant Prof. at Hofstra Univerity for the past 12 years. A senior member of the IEEE, Mr. Zeines has also published "Servomechanism Fundamentals" and "Principles of Applied Electronics" by McGraw-Hill Book Co.

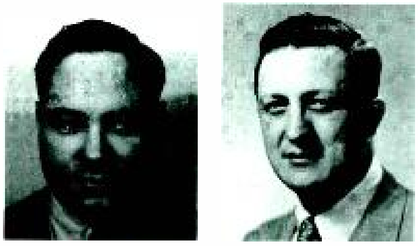
"ELECTRON PARAMAGNETIC RESONANCE IN COMPOUND SEMICONDUCTORS"

Dr. Bernard Goldstein
RCA Laboratories
Princeton, N. J.

The results of electron paramagnetic resonance studies in compound semiconductors are presented and briefly discussed. Most of the results are for GaAs, while some others are for InSb and GaP. The results are chiefly on paramagnetic impurities and conduction electrons. The most interesting single feature of these studies is that all the resonance lines observed in the compound semiconductors are extremely broad, typically about 60 gauss in half-width; similar resonance lines in the elemental semiconductors are about 1 to 2 gauss in half-width. *(Published by Academic Press, New York; price $16.50)*

DR. BERNARD GOLDSTEIN received a BA from Brooklyn College in 1950 after a two year interruption for service in the U.S. Navy. He attended the Graduate School of the Polytechnic Institute of Brooklyn where he held several research fellowships; he received a PhD in 1954. Upon graduation he joined the RCA Laboratories to work on p-n junction properties, atomic diffusion in compound semiconductors, optical and electrical properties of II-VI and III-V compounds, and electron paramagnetic resonance in semiconductors. He has published several articles in each of these fields. In 1960 he was the recipient of the RCA Achievement award. He is currently doing research on radiation damage in silicons.

"MATERIALS PREPARATION BY FRACTIONAL SOLIDIFICATION"



Dr. D. Richman and Dr. F. D. Rosi
RCA Laboratories
Princeton, N. J.

The techniques of crystal growth from the melt usually employed include Bridgman, Stockbarger, horizontal Bridgman, horizontal zone melting, Czochralski, Verneuil, and floating zone. They have been used to successfully grow crystals of many materials, including Ge, Si, III-V compounds, II-VI compounds, metals, laser host materials, thermoelectric alloy materials, alkali halides, and alkaline earth fluorides, among others. Two effects that should be given more attention, especially in the crystal growth of alloys, is constitutional supercooling, and thermal fluctuations in the melt. *(Published by John Wiley, Inc.; price not known)*

DR. DAVID RICHMAN received his BS, cum laude, from Yale University in 1954 and PhD from Cornell University in 1959, majoring in physical chemistry. His research in graduate school dealt with the diffusion of organic molecules in amorphous polymer films. Since joining the staff of RCA Laboratories in 1959, Dr. Richman has worked on the preparation and physical chemical properties of III-V compound semiconductors. He has experience in growing single crystals of these semiconductors both from the melt, and by vapor transport reactions, and has published on both subjects. He has also investigated and published on thermodynamic properties of III-V compounds such as the heats of fusion, dissociation pressures, and vapor transport equilibria. Dr. Richman has been a member of the Lecture Series Committee for the North Jersey Section of the American Chemical Society. He is currently a member of Sigma Xi and the American Chemical Society.

DR. FRED D. ROSI received a BE in Metallurgy from Yale University in 1942, his ME degree in 1947, and a PhD degree in 1949 from the same institution. He was awarded the graduate laboratory assistantship in the Department of Metallurgy at Yale in 1946-49. In 1954, he joined RCA Labs. where he heads up the Semiconductors, Superconductors, and Metals Research section engaged in the preparation of elemental and compound semiconductor crystals for transistor and thermoelectric applications, and in research on superconductivity and electronically active organic materials. Dr. Rosi has more than 30 publications to his credit and 13 filed patents relating to the preparation of semiconductor, thermoelectric, and superconductor materials, and device fabrication. He received a 1955 RCA Achievement Award for "major improvements in the techniques of growing semiconductor crystals useful in transistors." In 1963 he was one of the recipients of the David Sarnoff Outstanding Team Award in Science.

MAGNETIC TAPE RECORDING
AND
ITS FUTURE

Several papers in this issue describe recent RCA products and developments relating to magnetic recording. The purpose of this summary is to point out fields of application of magnetic recording which are now known and newly developing business fields likely to make use of magnetic recording, so as to stimulate thinking for the application of techniques.

T. A. SMITH, Executive Vice President
Corporate Planning
Radio Corporation of America
Camden, N.J.

THE concept of recording information magnetically is a very old one. Devices used for recording telegraph signals and voice on steel wire were available in Germany more than 40 years ago. However, the difficulty of handling springy wire moving at high velocity was such that uses were very limited. With the development of magnetic oxide coated plastic material, new applications appeared rapidly until today magnetic recording has become a universally used method for recording information of all kinds.

Because of its versatility, magnetic recording has become a "business within a business" in RCA. From a novelty whose technology was familiar to a limited number of engineers, it has evolved into a working tool, used in products offered by nine RCA divisions and employed in operational processes by four RCA organizations. As a result of adapting the recording and reproducing techniques to product requirements, development and product design is spread throughout the engineering functions of various divisions, but the technological resources of the company are very complete indeed.

Corporate Staff Engineering maintains channels of technological communications and has periodically held symposia and has provided for exchanges of information as well as sponsoring development programs. In a paper[1] published in 1964, Harry Kihn, Staff Engineer, listed the tape recording products offered by the divisions and pointed out the diverse technical disciplines required.

CONSUMER DEVICES

The industry sale of audio tape recorders of all types for home and semi-professional use has grown from 550,000 units in 1961 to 4.0 million in 1965, and is expected to reach 5.0 million in 1970. A high percentage of these are imported. The RCA Home Instruments Division offers a diversified line of units ranging in price from about $50 to $230, and including both reel-to-reel and cartridge type units.

The relative ease of recording, good fidelity of reproduction, and ability to erase and reuse tape has made audio tape recording a popular hobby; however, the convenience of use and low cost of phonograph records has kept prerecorded tapes from being a mass-production item. Introduction of the Stereo 8 endless loop cartridge for tape playing in cars has resulted in prices comparable with records and equal in convenience of use. The RCA Victor Record Division, which participated in the development, is producing tape and replicating tapes in substantial quantity. It seems likely that the cartridge will find use in home players and for other applications where prerecorded material is required.

In 1965, video recorders selling in the price range of $1,000 to $1,500 were announced. These helical-scan machines, capable of monochrome reproduction only, have had the disadvantage of coming at a time when interest in color is at a peak. While there will be considerable novelty appeal, true consumer applications point toward lower priced units having a capability for color recording. RCA is continuing in the development of helical-scan devices under a Corporate-sponsored program.

Magnetic tape devices do not pres-

THEODORE A. SMITH joined RCA after having received his engineering degree and was initially engaged in research and development including early work in the field of television. Subsequently, Mr. Smith has been involved in commercial and management assignments, many of which have been related to new products and new systems. Among these have been television broadcasting and closed circuit TV, electron microscope, communications products and electronic data processing. Mr. Smith has been variously in charge of his company's operations in defense, industrial electronics and electronic data processing, and is presently Executive Vice President, Corporate Planning. He is a Director of RCA Communications, Inc., a Fellow of the Institute of Electrical and Electronic Engineers, and a Director of the Electronic Industries Association and the Business Equipment Manufacturers Association.

Final manuscript received June 7, 1966

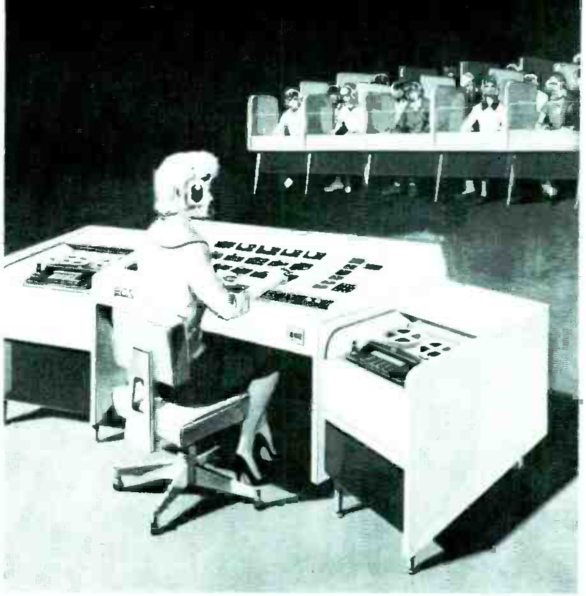


Fig. 1—The instructor's console and student booths house amplifiers, tape recorders and control equipment of RCA EDC-101 Learning Laboratory System.

Fig. 2—RCA's Spectra 70 magnetic tape unit combines two tape drives with independent electronics. Basic speeds are 30,000 or 60,000 EBCDIC bytes or 7-level characters/sec at a packing density of 800 bits/inch, using ½-inch tape on 2,400-ft reels.

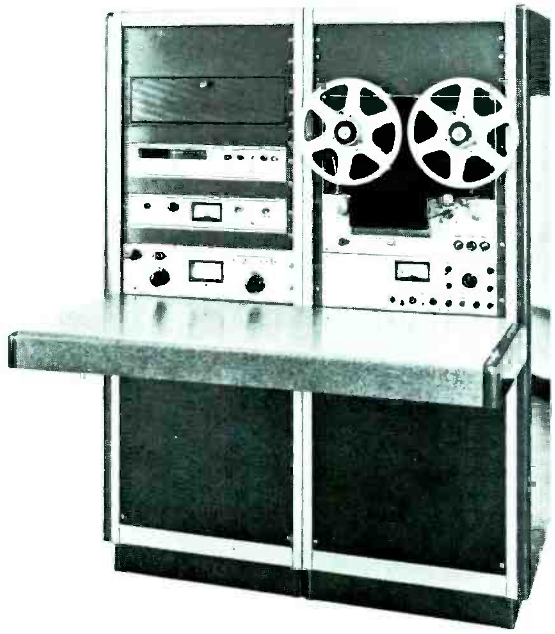


Fig. 3—RCA RT-17 cartridge tape recorder as used in KTSP Broadcast station's tape editing system.

Fig. 4—RCA TR-70 Color TV tape recorder for professional TV station use.

Fig. 5—RCA Stereo-8 tape cartridge as used in a reproducer made by Lear Jet Corporation.

Fig. 6—RCA Victor Solid-State cartridge audio-tape recorder.

Fig. 7—Nimbus satellite high resolution infrared (HRIR) tape recorder top cover removed).

ently play an important role in the home, but it is possible that in the future devices may be widely used for taking down telephone messages, for recording memoranda, or even for controlling appliances, as well as for entertainment.

EDUCATION

"Language Laboratories" have won acceptance in a large number of schools. These employ tape recordings to teach the pronunciation of foreign languages. The RCA Broadcast and Communications Products Division offers such equipment and is now adapting it for use in teaching other subjects. The same division also offers separate audio tape recorders as well as library type systems where picture and sound material may be called up in any classroom from a central control room.

Quadruplex video tape recorders are employed in most educational television stations and in larger closed circuit TV school systems. The Broadcast Division produces a broad line of quadruplex recorders. Helical-scan recorders are likely to find use for recording curriculum material locally and storing it for use at appropriate times.

Research activity is being conducted on programmed teaching machines, although to date acceptance has been slow. Tape is likely to be used both for presenting information as well as for programming.

Tape is important in the educational field, and it may be expected that new applications will occur and general usage will be still further broadened.

INFORMATION HANDLING

Applications of magnetic recording for storing and releasing data when needed cover very wide fields, including business and industry, government, for military purposes, education and medicine. The media employed include tape, cards, discs, magnetic films, and of course, magnetic cores. RCA participates in most of these fields through the engineering activities and product lines activities of RCA Electronic Data Processing and the Defense Electronic Products divisions. Magnetic tape and disc files are presently the major means of bulk file storage in the computer industry. Magnetic cards are just starting to be used in mass files, but will become important in the future.

Time-sharing systems and the growth of information libraries are likely to increase the demand for new, more versatile and lower-cost-per-bit recording systems. Not only is it desirable to be able to store greater amounts of alphanumeric material and to retrieve it rapidly, but also to provide a capability for handling information in other forms, for example, images of documents.

Instrumentation data, whether local or telemetered from a distance (such as from space craft) is frequently stored on magnetic tape for further analysis and application. The RCA Service Company operates a large scale system for missile and space applications at Cape Kennedy. Industrial and other uses of recorded instrumentation data are increasing rapidly. Flight recorders for ground to air communications are other examples of the need to preserve vital information for further analysis.

The RCA Astro-Electronics Division has built highly reliable but low weight recorders for recording pictorial information to be later transmitted to ground stations. The success of this equipment in TIROS satellites has been noteworthy.

RCA participates broadly in the use of magnetic recording for information storage and handling—a field which is almost certain to grow and to become increasingly important.

BROADCASTING

Quadruplex tape recorders have become standard for television broadcasting use and, with the increase in color programming, needs for machines capable of recording and playing color material have risen sharply. The RCA Broadcast and Communications Products Division offers quadruplex machines ranging from small, portable devices to large, highly versatile color recorders capable of recording tapes which may be duplicated several times with good results.

To date, video tape recording has been employed chiefly for delayed broadcasting rather than for syndication. Program material can be converted to film by means of kinescope recording and then syndicated. The Broadcast Division has developed equipment for this purpose, and the same equipment has also been used for the production of films for theatrical presentation.

Audio tape systems are widely used by radio broadcasters and the use of cartridge type players, often programmed by preselection systems, has met with increasing favor.

Recent interest has been expressed in helical-scan machines for use in the field for news applications, although small quadruplex machines have the advantage of compatibility with program systems.

Tape recording has met with great acceptance for broadcast use and a high percentage of television programs are tape recorded. In particular, the ability to replay recorded material with minimum delay has proved advantageous for sports programs. It may be expected that continued demand will exist for conventional devices as well as specialized recorders for unusual applications.

OPERATIONAL

Tape recorders play an important role in NBC's operations. Currently more than 60 video tape machines are in use. As described above, the RCA Service Company operates tape recording for instrumentation purposes on the Atlantic Missile Range and employs some 184 machines. The RCA Victor Record Division uses tape for recording "masters." RCA Communications employs tape recording as a part of its Electric Telegraph Switching System, for storing incoming messages.

SCOPE

In this incomplete listing, it will be apparent that nearly all of RCA's broad spectrum of electronic activities make use of magnetic recording. Supporting the development and product design are research at RCA Laboratories on magnetic materials, reproducers, and storage systems, and a design and production facility maintained by the Broadcast and Communications Products Division for high performance magnetic heads. An allied function, a part of RCA Electronic Components and Devices, is located at Needham, Massachusetts, for the design and production of computer memories.

The RCA Victor Record Division produces blank tape for data recording, for audio recording and for computer applications. It is also producing specially lubricated tape for Stereo 8 cartridges.

The importance of magnetic recording has resulted in a wide variety of products throughout the RCA organization. Future requirements for sophisticated high density storage systems for storing all types of information have already caused investigation of other types of media, some of which may offer advantages for graphic material. Nevertheless, the convenience and ease of use of magnetic recording is likely to result in a continued growth of new products serving all elements of the electronics industry.

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Bibliography of Recent RCA Papers on Acoustics, Audio-Disc, and Audio-Magnetic-Tape Recording

In addition to the papers on these topics in this issue, the below-listed RCA papers have recently been published or presented. Information on these papers was drawn from the 1964 and 1965 Indexes to RCA Technical Papers, and from the bimonthly indexes to papers for 1966. To obtain a copy of one of these papers, contact your local technical library, or refer to the instructions on the inside front cover of the annual Index to RCA Technical Papers.

ACOUSTICS

(theory & equipment)

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CINERAMA Theatre Acoustics—M. Rettinger (BCD, Cam.) *J. SMPTE*, 7/64

LOUDSPEAKER: One-KW Cylindrical-Wave-Front, with Folded Modular Horn—J. E. Volkmann (Labs, Pr) Audio Eng. Soc., N.Y.C., 10/16/64

LOUDSPEAKER Retainer — W. H. Moore (RCA Ltd., Ontario) TN-576, *RCA Technical Notes*, Issue No. 13, 12/64

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RECORDING

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ELECTRODEPOSITS, Factors Which Influence the Structure of—Dr. A. M. Max (RCA Victor Rec., Indpls.) Empire State Regional Conf., Amer. Electroplaters So., Niagara Falls, Ontario, Can., 4/25/64

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RECORDING, AUDIO

(equipment)

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A REVIEW OF DISC AND MAGNETIC-TAPE SOUND REPRODUCTION

A brief history of sound recording and reproduction, from the first cylindrical records to the present complex tape and disc systems, is presented. The major characteristics and controlling parameters of magnetic-tape and disc recording and the reproduction systems are discussed, and problem areas peculiar to each type of system are examined.

Dr. J. G. WOODWARD, Head
Audio Recording Research
Acoustical and Electromechanical Research
RCA Laboratories, Princeton, N. J.

THE first practical systems for recording and reproducing sound were invented near the close of the 19th century. The first records were in the form of cylinders, but these were soon supplanted by disc records in basically the same form used in modern phonographs. In the early phonograph recorders the acoustic signal was converted directly into motion of a diaphragm linked mechanically to the stylus that made the groove and its modulation on the record surface. Similarly, in playback the mechanical motion of the playback stylus, or needle, moving along the modulated groove was coupled by mechanical linkages to a radiating diaphragm at the throat of a horn to produce an acoustic signal in air. Crude as the early phonographs may seem by present standards, they received widespread acceptance by the public and formed the basis for a tremendous new industry which is still growing. Over the years the acoustic phonograph was improved, usually by empirical development, to where promotional literature dared claim that in a staged public demonstration involving live performers and phonograph playback, the majority of listeners were unable to tell when the switch was made from the "live" to the reproduced sound.

Phonograph recording took a great stride forward in the 1920's with the development of electric recorders and pickups, following the necessary prior development of microphones. loudspeakers, and electronic amplification. The electrical recording and reproduction techniques permitted a degree of control and analysis of the record-playback process previously impossible, and opened the way for the steady and spectacular improvement in phonograph records and systems which has continued to the present time, with no sign of deceleration in sight. Concomitant with the improvements in recording techniques and components were improvements in record material and record duplication processes, without which the benefit of the former could not have been realized.

In the first feature-length sound motion pictures the sound track was carried on disc records. However, synchronization of the disc with the motion-picture film introduced serious problems, and it was not long before processes for recording the sound track optically on the film carrying the pictures came into general use. The RCA Photophone Division pioneered much of this work. Parallel developments were carried out by the Western Electric Company and its subsidiary, the Bell Telephone Laboratories. and to this day the RCA and Westrex optical recording systems are the basis for all optical sound tracks recorded on commercial motion-picture films in this country and throughout much of the world. The optical recording process was quickly brought to such a high performance level that in terms of bandwidth, low distortion, and background noise it surpassed what was then possible in commercial practice with the phonograph.

Immediately after World War II the magnetic recorder entered the field of audio recording in this country. Magnetic recording, first done on metallic magnetic wires or ribbons, came into its own following the introduction of tapes consisting of magnetic-pigment coatings on thin, durable, plastic backing. The evolution of magnetic recording during the past 25 years has been phenomenal; today magnetic recording is firmly established as a system and is a basic element in both motion-picture sound and phonograph recording. Original movie sound tracks now are recorded on magnetic film or tape, and not until preparation of the final release print of a motion picture is the sound copied on the optical track or on a magentic stripe on the photographic film. In phonograph recording the original master for a commercial pressing is invariably recorded on a master tape which is kept intact; editing is done on a submaster tape copied from the master. The original phonograph disc master to be used in duplicating pressings receives its signal from playback of the submaster tape. When editing is done in one location and the disc recording in another, a copy of the submaster, i.e., a third-generation tape, may be used in making the master disc. Magnetic-tape and disc-record sound reproduction under carefully controlled conditions are nearly equivalent in the quality attainable at the present time; it is mainly the convenience of editing that has given magnetic recording its basic position in mastering operations.

The major characteristics and controlling parameters of tape and disc recording and reproduction systems are examined in subsequent paragraphs. The application of optical recording is quite limited. and it is not considered in any detail in this discussion.

MAGNETIC RECORDING AND REPRODUCTION

To meet the requirements of various applications of magnetic recording of sound, recording devices and systems covering a wide range of characteristics have been developed. At one extreme are the inexpensive, pocket-size recorders for which the only requirement is that reproduced speech be fairly intelligible. At the other extreme are systems costing thousands of dollars and having exceedingly precise and complex mechanical and electronic elements. Such systems are expected to provide the widest possible dynamic range and the lowest possible distortion over the entire audio range of frequencies. Tape speeds of commonly-used audio recording systems range in a geometrical progression from $^{15}/_{16}$ inches per second (in/s) to 30 in/s. Space does not permit a listing here of even the major characteristics of this great variety of systems. However, many of the limitations of the various tape systems depend on the same basic parameters and, hence, can be discussed in general terms.

Consider first the recording medium.

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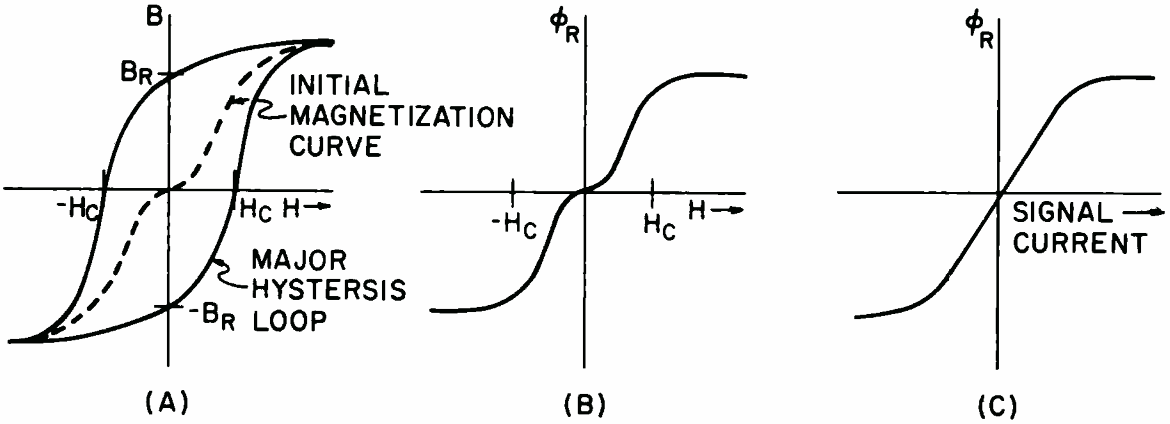


(A) (B) (C)

Fig. 1—Magnetic recording tape exhibits the bulk magnetic properties characteristic of ferromagnetic materials: (A) initial magnetization of an initially demagnetized material for an applied magnetizing field, H, the major hysteresis loop, the coercivity, H_C, and the retentivity, B_R; (B) remanent magnetic flux, Φ_R, following application and removal of a magnetizing field, H, for an initially demagnetized material. (C) transfer characteristic between remanent flux in tape and signal current in recording head when high-frequency bias is used for linearization.

The tape consists of a plastic backing 0.0005 to 0.0015 inch thick on which is laid a magnetic coating having a thickness usually between 0.0003 and 0.0004 inch. The coatings of audio tapes are formed by submicroscopic gamma-iron-oxide particles dispersed in a polyvinyl binder. The characteristics of the coating determine the dynamic range and, to a lesser extent, the bandwidth of recording in a well-designed system. Background noise generated by the tape in playback is determined by the smoothness of the coating surface and by the uniformity with which the magnetic particles are dispersed and oriented within the coating. The linearity and sensitivity of the recording process and the maximum recorded signal level are controlled by the magnetic characteristics of the individual particles in the coating; by the distribution in size, shape, and orientation of the particles; and by the number of particles per unit volume of coating. Print-through (i.e., the undesired, spontaneous copying of a magnetic recorded pattern from one layer of tape onto adjacent layers while the tape is stored on a reel) can be serious with some types of tape. This phenomenon also is controlled by the magnetic characteristics of the individual particles and by their size distribution.

The finished tape coating has the basic magnetic behavior shared by all ferromagnetic materials, namely, an initial magnetization curve, major and minor hysteresis loops, remanence, etc. Some of these properties are illustrated in Fig. 1-A. The coercivity, H_C, of audio tapes lies between 230 and 280 oersteds. The retentivity, B_R, generally is between 800 and 1100 gausses. The initial magnetization curve (dashed in Fig. 1-A) indicates the course of the magnetization of an initially erased, or demagnetized, tape as the applied magnetizing force is increased. If the remanent magnetic flux in the tape following application and removal of a magnetizing force is plotted as a function of applied field, the initial magnetization curve takes the form shown in Fig. 1-B. This curve is nonlinear not only in the approaches to saturation but also in the region of small applied fields. Such a characteristic would lead to very serious signal distortion if audio signals were recorded on the tape by simply feeding the audio-frequency current to the recording head. To eliminate effectively the small-signal distortion, a high-frequency bias is added to the audio signal in the recording head. The bias frequency is so high that any short segment of tape experiences many cycles of the bias field while passing over the recording gap. The magnitude of the bias field is sufficient to saturate the tape in the region directly above the recording gap. The signal field is much weaker. As a segment of tape moves away from the gap, the bias and signal fields fall to zero together, leaving on the tape a residual magnetism bearing a simple-appearing relationship to the magnitude of the signal current, I_{SIG}, in the head. This relationship (Fig. 1-C) is nearly linear until saturation is approached. The symmetry of this transfer characteristic means that only odd-order harmonic and intermodulation products will be produced by large-amplitude signals.

The dynamic range of recording is limited by tape noise at one end and by an arbitrarily-selected level of distortion at the other. The dynamic range

DR. J. G. WOODWARD received the BA from North Central College in 1936, the MS in Physics from Michigan State College in 1938, and the PhD in Physics from Ohio State University in 1942. He held teaching assistantships in Physics from 1936 to 1942 while in graduate school at Michigan State and Ohio State. In March 1942 he joined the research department of RCA in Camden, New Jersey; later that year he moved to the newly formed RCA Laboratories in Princeton, N.J. His research includes the study of vehicular radio noise, underwater sound, ferroelectricity in barium titanate, electromechanical feedback devices, rheological measurements at audio frequencies, musical acoustics, sound-reinforcement systems, stereophonic sound reproduction, magnetic-tape recording, and disk-phonograph recording. He currently holds the position of Head, Audio Recording Research. Dr. Woodward is a Fellow of the Acoustical Society of America, the Audio Engineering Society, and the American Association for the Advancement of Science. He is a member of the IEEE and Sigma Xi.

depends, of course, on the system bandwidth, the tape speed, the track width, and the mechanical and magnetic characteristics of the tape coating. In conventional high-quality 15- and 30-in/s systems a dynamic range (signal-to-noise ratio) of 60 to 65 dB may be expected for a bandwidth of 20 to 20,000 Hz for a first-generation tape.

When a tape carrying audio information in the form of magnetization that varies with distance along the tape is passed over a playback head, a magnetic potential difference is developed between the edges of the playback gap, and a time-varying flux passes through the core of the head. The resulting voltage generated in the coils wound on the core is proportional to the time-rate-of-change of the flux. For a constant current in the recording head, the overall record-playback response as a function of frequency has the general form shown in Fig. 2. For much of the range the response curve slopes upward at a 6-dB/octave rate, reflecting the time-rate-of-change dependency of the EMF in the playback head. The departure from the 6-dB/octave slope at high frequencies is due mainly to wavelength-dependent losses. Chief among these is the scanning loss that occurs when the recorded wavelength becomes comparable to the length of the playback gap in the direction of tape motion. Other wavelength-dependent losses are caused by a separation of the tape from the head at the gap due to surface roughness of the coating or to head wear, by the finite thickness of the coating, and by an angular misalignment of the tape over the head gap.

Since a flat record-playback frequency response is usually desirable, electrical equalization must be included in the circuits to compensate for the basic response shown in Fig. 2. First, an integrating network in the playback amplifier provides an inverse 6-dB/octave slope to make the low-frequency range of the response flat. High-frequency boosting networks, partly in playback and partly in recording, compensate the short-wavelength losses. Since the recorded wavelength at any frequency is proportional to the tape speed, the short-wavelength losses and the corresponding high-frequency compensation in a high-tape-speed system are less than in low-speed systems. Thus, a typical 30-in/s system requires only about 7 dB of boost at 15 kHz, whereas a 3¾-in/s system may require a boost of 30 dB or more at 10 kHz; these equalizations are superimposed on the integrating response that falls off at a 6-dB/octave rate over the entire band. The actual values of high-frequency boost vary considerably from system to system, depending on head design, tape characteristics, and system setup adjustments.

Fig. 2—General form of unequalized record-playback frequency response in magnetic recording. Frequency scale depends on tape speed; high-frequency roll-off is influenced by individual head and tape characteristics.

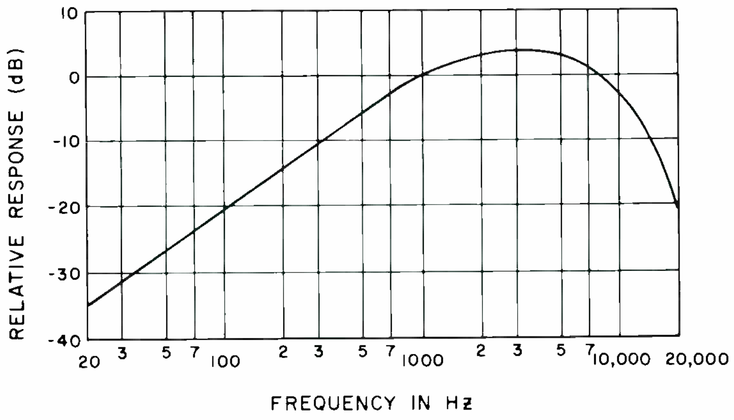
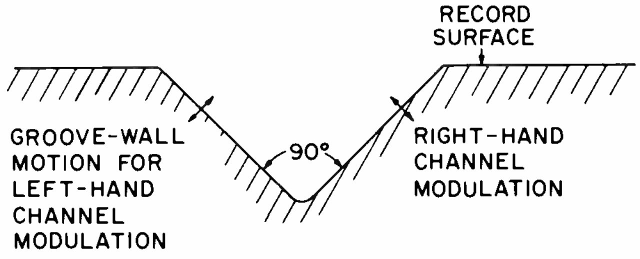


Fig. 3—Cross-section of record groove, indicating directions of independent groove-wall modulation for two-channel stereo recording.



As mentioned previously, the nonlinear transfer characteristic of the magnetic-recording process leads to distortion products. Although these can be negligibly small for moderate signal levels, they become unacceptably large for signal levels approaching tape saturation. Each sinusoidal component of the signal develops odd-order harmonic distortion components. Two or more signal components recorded together develop second-order sum and difference intermodulation products. The dynamic range possible with the best conventional high-quality recorders is barely adequate for critical audio applications. Improved tapes, techniques, and systems that will provide an added 10 to 15 dB of range are continually being sought. This need is particularly critical where copies of tape recordings must be made, since the dynamic range is reduced in each generation of recording. Rerecording a tape on a system identical with that used in making the original increases the noise level by 3 dB and increases the distortion by 30-50%. The significance of this problem can be understood when it is realized that a prerecorded tape purchased for reproduction in one's home is usually a fourth or fifth generation copy. Also, with the recent improvement in disc recording, the tape problem is becoming increasingly serious since the second or third generation tapes used in making the master disc introduce certain types of distortion and noise in magnitudes greater than those generated in the disc system, thus tending to mask some of the improvements made in disc recording systems.

DISC RECORDING AND REPRODUCTION

In disc recording the signal modulation is carried in the form of minute displacements of a spiral groove cut in the

Fig. 4—Type of disk-recording lathe used in commercial disc-mastering.

surface of the record. In cross-section the groove is V-shaped with an included angle of approximately 90°. The bottom of the groove has a radius in the neighborhood of 0.0002 inch. Mean groove depths range from about 0.0007 to 0.002 inch, depending on the magnitude of the signal being recorded. In stereophonic records the information in the left-hand channel is carried as displacements of the left-hand groove wall (as viewed by an observer looking into the front of the pickup playing the groove). The opposite groove wall carries the right-hand channel signal (Fig. 3).

In making the master recording the grooves are cut in a smooth, nitrocellulose (lacquer) coating on the surface of a circular aluminum plate. The cutting tool is a chisel-like stylus made of sapphire or ruby and having a V-shaped tip. The cutting action is similar to that of a lathe in ordinary machine-shop practice, and the machine used to rotate the master record disc and feed the cutter carriage is called a recording lathe. A modern recording lathe of the type used in RCA's commercial recording operations is shown in Fig. 4. A small heater coil wound on the shank of the stylus supplies heat to raise the temperature of the stylus tip during cutting. This further softens the lacquer at the point of cutting to foster the forming of smoother, quieter groove walls. The material removed from the groove comes off the stylus as a fine, continuous thread which is carried away by a small suction pipe situated close behind the stylus.

The motion of the stylus corresponding to the modulating signal is provided by an electrodynamic driving system. Signal current through a drive coil centered in a magnetic field causes the coil to move, and this motion is transferred to the stylus mount by a stiff mechanical linkage. A second, smaller coil tightly coupled to the linkage moves in another magnetic field to generate an EMF proportional to the velocity of the stylus motion. This EMF is fed back to an early stage of the amplifier supplying the driving current, thus completing a feedback loop that includes the electromechanical cutter as well as the amplifier. This feedback provides a smooth recording response with low distortion from 20 to 15,000 Hz. In a stereo recording system two such feedback-controlled drivers, with their driving axes 90° apart, are built into a single structure. Both are coupled to the same stylus through linkages designed to minimize interaction between the two drivers. In this way two independent signals may be conveyed by the stylus to the two groove walls.

The numerous, meticulous steps between the lacquer master and the finished vinyl pressings have been described elsewhere.[1] and will not be discussed here beyond commenting on the truly remarkable fidelity with which even submicroscopic patterns on the lacquer can be duplicated on the finished record. Although the duplication process inevitably adds somewhat to the background noise level, a dynamic range of 60 to 65 dB is obtainable in vinyl records that have not been mistreated or subjected to wear.

This dynamic range is made possible, in part, by the equalization used in recording and playback. The recording equalization characteristic universally used in the industry is shown in Fig. 5, where the velocity of the recording stylus is plotted as a function of frequency, assuming a constant-voltage input to the recording system. In playback, the inverse equalization characteristic is used. Such an arrangement reduces the groove noise relative to the signal in the high-frequency region where the bandwidth is greatest and where the noise is most noticeable on a subjective basis. Unfortunately, the boosting of high-frequency components in recording may lead to overload distortion in playback for some forms of program material unless special precautions are observed during recording. This problem has received increased attention in recent years, and RCA's *Dynagroove** system incorporates elements to reduce these distortions.

With the present state of record engineering, very few playback systems are capable of reproducing with total faithfulness all the signal components that can be put on the records. The reasons

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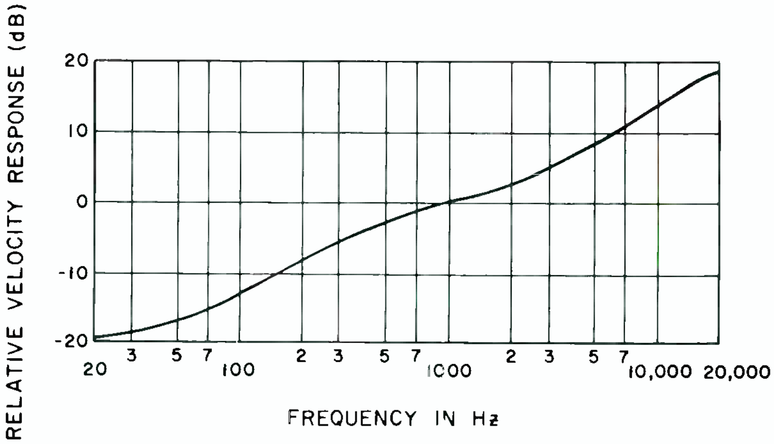
* Registered trademark of RCA.

Fig. 5—Recording Industries Association of America disc-recording equalization characteristic. Inverse characteristic is required in playback system to provide overall flat frequency response.



for this situation are, in part, basic to the nature of the mechanical processes involved in attempting to follow the groove modulation with the pickup stylus. Three of the problem areas responsible for reduced fidelity of reproduction, tracking, groove-wall deformation, and tracing, are discussed briefly below.

Tracking refers to the ability of the pickup to maintain proper contact between the stylus and the two groove walls. Tracking problems most commonly occur at either the low-frequency or high-frequency end of the audio range. High-level, low-frequency signals require the stylus to follow relatively large lateral or vertical excursions of the groove. Unless the moving system of the pickup is highly compliant, the forces required to deflect the stylus may exceed the tracking force intended to hold the stylus in the groove. If this occurs the stylus will slide up the groove wall and may even skip out of the groove. This event is catastrophic as far as the listener is concerned. Most modern pickups (excluding some of the low-quality products made for inexpensive record players). if mounted in a suitable low-friction arm, are capable of tracking all but the most extreme low-frequency signals. Unfortunately, improper adjustment or maintenance of pickups and arms in operation makes improper tracking an all-too-common fault of phonograph systems.

Mistracking at high frequencies (i.e., at 9 kHz and above) may occur when the forces required to accelerate the stylus exceed the tracking force. When this happens the stylus may partially lose contact with one of the groove walls or, more likely, the area of contact between the stylus and the groove wall will be modulated by the signal. This results in midband intermodulation products when two or more high-frequency components occur simultaneously—which is frequently the case in musical program material. High-frequency problems of this sort are most severe in a pickup having too high an effective stylus mass or having a high-frequency mechanical antiresonance that produces a high mechanical impedance at the driving point.

Since the stylus must maintain contact with the groove walls even in the presence of large-amplitude signals, a sizable tracking force (1 to 10 grams for various pickups) is required. The tracking force causes the stylus to deform the relatively soft vinyl groove walls, thus distributing the force over an area of contact. The diameter of the contact area between a standard 0.0007-inch stylus and a groove wall will be of the order of 0.0005 inch, and the bearing pressure averaged over this area may approach and occasionally exceed 10^4 lbf/in^2 under static conditions.[2] In the presence of recorded modulation the contact area and pressure vary in accordance with the modulation. This presents no problem at low and mid-band frequencies; it may become serious in the case of high-frequency signals whose recorded wavelengths are comparable to or smaller than the contact diameter. One well-known manifestation of the problem, called *translation loss,* is a progressively greater loss in high-frequency response as the pickup moves from the outside to the inside of the record. If the pickup has too large a driving-point mass, the peak forces required to accelerate the stylus at high frequencies may lead to groove-wall deformation exceeding the elastic limit of the record material, resulting in permanent damage to the record. The dynamics of the stylus-groove relationship at high frequencies are exceedingly complex and have not yet received adequate analysis. This is an area of active study at the present time.

Even if an infinitely hard record material were used to eliminate groove-wall deformation under the stylus, *tracing distortion* would remain a problem in the reproduction of high-frequency signals. Tracing distortion occurs because the dimensions of the playback stylus tip are comparable to the dimensions of the recorded modulation. Most conventional pickup styli are made of tiny cylinders or chips of diamond tapering through a conical form to a spherical tip. The spherical tip of the stylus is the only portion that makes contact with the record groove. Tip radii range from 0.0002 to 0.0007 inch in pickups for LP or 45 r/min phonograph systems; the standard 0.0007-inch size is used in the vast majority of systems. It frequently happens that high-frequency, high-level recorded modulation contains sections having radii of curvature smaller than the tip radius of the stylus. Clearly, when this occurs the stylus cannot fit into or follow the modulation, and the stylus motion and the resulting voltage at the pickup terminals are not true representations of the modulation. Even before the misfit condition is reached, the reproduced signal is noticeably distorted because of the finite size of the stylus tip. This is most apparent for high-level, high-frequency signals close to the label area of the record.

There are three possible approaches to reducing tracing distortion: reducing the level of the recorded signal, using the smallest practical stylus-tip radius, or canceling the tracing distortion generated in playback by suitably processing the signal during the master-recording process. The theoretical and practical feasibility of the cancellation technique has been demonstrated in the *Dynagroove* process. Viewed in long-range terms it seems most likely that the ultimate solution to the tracing-distortion problem will come about through a judicious combination of the three possibilities referred to, with an industry-wide adoption of suitable standards.

CONCLUSION

Three of the basic problems encountered in the reproduction of sound from disc records have been noted. However, in spite of these problems, and others, disc recording and playback processes and systems have been developed to where they provide one of the most efficient, economical, and convenient methods for the storage of information. The overall quality of sound reproduced from modern phonographs is high and is not equalled by any system of comparable complexity. Additional improvements are being made continually in disc components, systems, and techniques. Although phonographs have been in existence for over three-quarters of a century, disc recording is still a very active and progressive field.

Commercial magnetic recording has a much shorter history, but it has developed very rapidly. Starting as a primitive sound-recording system, magnetic recording branched into a variety of applications including digital, instrumentation, and video. The broader range of applications added impetus to the developments and growth of understanding already well underway in audio systems. At present, the characteristics of the recording medium and the mechanical complexities involved in providing a uniform tape motion present the most definite limitations to magnetic recording and reproduction systems. After rapid advances in the preceding decade, further progress beyond these barriers now comes more slowly. The most important advances in sight are aimed at the more complex professional audio-recording systems, such as are used in mastering operations. The benefit of these improvements, when fully realized, will be enjoyed in all forms of prerecorded music, whether tape or disc.

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Fig. 1b—Details of construction.

Fig. 1a—Stereo 8 cartridge, overall view.

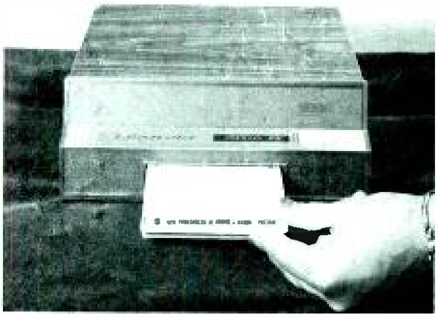

Fig. 1c—Cartridge being inserted into Lear Jet Corp. unit.

STEREO TAPE CARTRIDGES FOR AUTOMOBILE USE

A stereophonic tape cartridge system developed primarily for automobile use has received widespread acceptance by the motoring public. This paper notes the evolution of the system, discusses the cartridge design, describes the system performance characteristics, and briefly reviews the recording, duplicating, and assembly processes.

R. C. MOYER, Mgr.,
Recording Development Group
RCA Victor Record Div., Indianapolis, Ind.

Since the early days of radio in the home, there has been a definite interest in having music in automobiles as well. The development of automobile radios is well known and there is no need for further discussion in this area. However, as a result of technical developments in the sound recording and reproducing field, a new era of musical entertainment in the automobile has given renewed significance to the old slogan "The Music You Want, When You Want It."

Although the disc record is still the most effective and economical way to offer recorded music to the consumer, at least two attempts to introduce this system in the automobile market have been unsuccessful. Recent developments, however, indicate that magnetic tape records in endless-loop-cartridge form are acceptable in spite of their greater cost.

Three basically similar endless-loop-cartridge systems are currently available. Each uses a tape speed of 3¾ in/s and stores the tape on a single hub. The tape is pulled from the center of the tape roll and wound back on the outside. Each system is capable of operating with four- or eight-track tapes. One system, currently enjoying considerable public acceptance as an add-on accessory, uses the standard National Association of Broadcasters (NAB) type A cartridge with four-track tape similar to that introduced in the RCA coplanar cartridge several years ago.

The system under discussion uses a cartridge similar to the standard NAB type with several important modifications to improve reliability of operation, simplify its use in an automobile, and provide a more economical product with respect to cost vs playing time. This system, proposed and basically developed by the Lear Jet Corporation, has been under study and evaluation by RCA and the automotive industry for the past 2½ years. During this period, through the cooperative effort of RCA, Lear Jet, and others, several improvements have been incorporated into the design to improve reliability under the adverse operating conditions likely to be encountered in automobile use.

CARTRIDGE DESIGN

The notable mechanical feature of the system is the straight plug-in operation of the cartridge in a player. A pressure roller is incorporated as an integral part of the cartridge, and a spring-loaded roller in the player holds the cartridge in place by engaging a detent in its side wall.

Fig. 1 shows the internal design and the tape path in the cartridge. All parts are made of molded plastic except the rubber tire, pressure pads, and spring.

The case is made of a medium-impact high-temperature polystyrene. The light

ROBERT C. MOYER received his AB degree from Bowdoin College in 1932. Before coming to RCA he worked in the Commercial Sound Section of the Eastern Co. (RCA Distributor), Cambridge, Mass., and, during World War II, in the Radio Research Lab. at Harvard University. In 1945 he joined RCA, where he is now Manager, Recording Development Group, RCA Victor Record Div. He is a senior member of the IEEE and a Fellow of the AES. He has served on disc and magnetic recording committees with the NAB, IRE, and AES. He was Central Vice-President of the AES in 1954, Chairman of the Audio Group of the Central Indiana Section of the IEEE in 1963, and is currently on the Board of Governors of the AES and Chairman of the EIA P.8 Committee on Sound System Components.

Final manuscript received May 6, 1966.

color was chosen specifically to hold heat absorption to a minimum. The internal parts made of Celcon,* Delrin,† and Teflon† keep friction and tape wear at a minimum. Special attention has been given to the choice of rubber used for the pressure roller tire; it will not take a permanent set from the capstan if the cartridge is left inserted in the player at elevated temperatures, and at the same time it will provide adequate tape drive at very low temperatures. As a result of these precautions the cartridge can withstand temperatures from −40° to +185°F without permanent damage and will operate satisfactorily from about −20°F to temperatures in excess of +165°F.

An interesting feature of the cartridge design is the little compartment in which excess tape accumulates before adequate tape take-up occurs when the cartridge is first inserted in a player. Without this space, loose tape would, on occasion, drive out of the cartridge just beyond the capstan and jam in the player. As an additional precaution against this type of failure, the capstan is located very close to the trailing edge of the opening in the case, or a barrier strip is provided in the player to block the gap between the capstan and the cartridge case at this point.

Other precautions against tape jams include: 1) a thin Mylar† film washer over the tape to prevent the tape from working up around the hub during shipment, and 2) a lightweight plastic stripper which prevents the tape from wrapping around the pressure roller should the tape stick to the roller after prolonged storage in a player at elevated temperatures.

PLAYING TIME

The cartridge is capable of handling up to 400 feet of tape which, at a tape speed of 3¾ in/s, provides a little over 21 minutes of playing time per revolution of the tape. Since the tape contains four stereo programs, the maximum playing time is more than 84 minutes, and nominally is considered to be 80 minutes. A short piece of conductive foil on the tape at the splice actuates a mechanism that automatically shifts the reproduce head position to the next pair of recorded tracks after each program sequence. Track shifting can be performed manually by depressing a knob or button on the front of the player.

TAPE AND TAPE LOOP LENGTH

The magnetic tape used in the cartridge consists of a conventional oxide coating on a 1-mil polyester base with a lubricant on the back. The lubricant reduces layer-to-layer friction when the cartridge is running, since inherently each layer of tape continually slips on the adjacent layers because of the difference in the supply and take-up diameters on the reel.

The tape must be wound with the correct amount of slack in the loop. If the loop is too short, wow and flutter will be high and tape life will be greatly reduced. In addition, if a cartridge having a loop that is too short is exposed to high temperatures, the normal relaxation of the base film may further shorten the loop to where it will not be possible to pull tape or the wow and flutter will be so high that the performance will be unacceptable. On the other hand, if the loop is excessively long, tape take-up may be inadequate and tape jams may occur, despite the precautions taken in the cartridge design.

PERFORMANCE

Wow and Flutter

Wow and flutter result from the combined function of the tape, the cartridge, and the player. Under normal operating conditions encountered in a car, the cartridge wow and flutter will run between 0.1 and 0.15% RMS. If a cartridge and player have been exposed to extreme temperature conditions, wow and flutter are usually considerably higher for a period of from several seconds up to perhaps a minute. Laboratory life tests at normal temperature and humidity conditions with suitable tape show that wow and flutter remain reasonably constant for 500 hours or more of operation. As the end of the tape life is approached, wow and flutter increase rapidly reaching 0.5% RMS or higher in a period of 24 hours or less.

Frequency Response

There is nothing unusual about the magnetic performance of the system. Recordings are made to provide essentially uniform frequency response from 30 Hz to 10 kHz when reproduced on a standard NAB 3¾-in/s reproducer. This reproduce characteristic has recently been adopted by the Record Industry Association of America as standard for 3¾-in/s magnetic tape records.

Fig. 2 shows this characteristic, which may be modified for playback head gap

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* Trademark of Celanese Corp.
† Trademarks of DuPont

Fig. 2—Reproduce characteristic and typical frequency response.

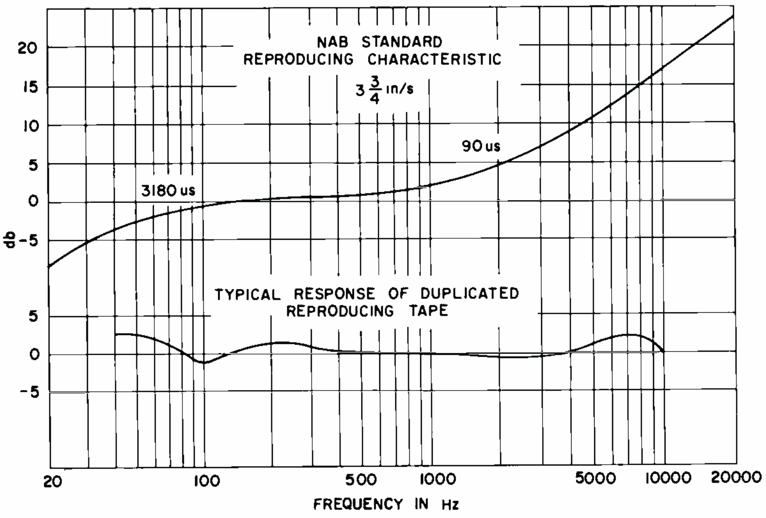
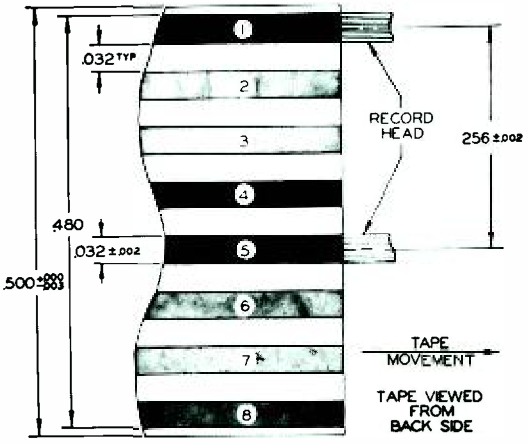


Fig. 3—Eight-track, ½-inch master tape format.



loss, head contour effects, and audio frequency balance at the discretion of the player manufacturer. It also shows a typical response curve obtained from a 3¾-in/s copy tape reproduced on a standard reproduce system. The tape was duplicated from a master tape recorded with constant voltage input to the master tape record system. High-frequency response is not impaired by the use of narrow recorded tracks and reproduce head azimuth adjustments actually become less critical in such usage.

Signal-to-Noise Ratio

The standard reference level (nominal record level) is 10 dB below the 3% third-harmonic-distortion reproduce level at 400 Hz; this nominal level is approximately 2 dB below the NAB standard. Based on the nominal reference level, the weighted signal-to-tape noise ratio is approximately 45 dB; this *S/N* ratio varies to some extent with music tape source material.

MASTER TAPE RECORDING AND DUPLICATING

The store of recorded music of the record industry is potentially available for the motorist. Master tapes are prepared according to the specific requirements of the system.

The master tape is recorded according to the April 1965 NAB standard for 7½-in/s tapes, except that it has eight 0.032-inch tracks on ½-inch tape. The format for the master tape is shown in Fig. 3.

Recorded crosstalk on the master tape is eliminated by moving the complete stereo two-track record and monitor head assembly up or down to record each stereo sequence. The completed master tape is copied on a slave unit identical with the production equipment. The copy tape is checked for audio quality on a professional-type reel-to-reel reproducer and then sent with the master tape to the manufacturing operation.

Here the master tape is loaded on a duplicator master endless-loop tape transport called a *tape tree.* This device, which uses air bearings instead of rotating pulleys, was originally designed to make four-track 3¾-in/s tapes for the RCA coplanar cartridge.[1] The tape tree is capable of handling master tapes up to 1200 feet in length operating at 60-in/s with no detrimental friction or tape drag.

The duplicator slave units operate at 30 in/s to produce 3¾-in/s copy tapes from the 7½-in/s master. They record eight tracks on ¼-inch tape in conformance to the Record Industry Association of America standard (Fig. 4).

Crosstalk

Adjacent-track crosstalk versus reproduce-head displacement for two different playback heads is shown in Fig. 5. It is apparent that low-frequency or long-wavelength adjacent-channel crosstalk is reduced when the head has the shield close to the core.

With a playback head having the recommended track width of 20 mils, the spacing between the edges of the gap and the edges of adjacent tracks is 10.9 mils, under ideal conditions. It can be seen from this chart that crosstalk is at a completely acceptable level. It is also apparent here, as has been verified subjectively, that considerable mistracking can occur before crosstalk becomes objectionable.

CARTRIDGE ASSEMBLY

Upon completion of the duplicating operation, the 3600-foot rolls of recorded tape are removed from the slave transports and placed on a conveyor, which carries them into an adjoining area for assembly into cartridges.

The cartridge assembly operation consists of several separate parts or stages. First, there are preassembly operations where the pressure roller tire is assembled on the hub, the felt pressure pads are applied to the spring, and the tape hub and turntable are assembled. Next, the 3600-foot rolls of tape are broken down onto individual cartridge tape turntables on a machine which cuts the tape automatically.

The next operation includes splicing, applying the conductive foil, and assembling the tape in the cartridge. The procedure for making the splice is critical, since in some cases, particularly with classical music, the musical break must be held to a minimum. This requires great accuracy in recording the master tape, precision cutting of the copy tapes, and care in making the splice. At the same time a controlled amount of slack tape must be provided to insure proper cartridge operation.

At the end of the assembly operation, cartridges are audio tested on a sampling basis on typical automobile players using stereo headphones. Here, as with disc record testing, mechanical or audio defects are noted and corrective actions are taken as required. Completed cartridges are carried by conveyor into the labelling and packing area. Each unit is individually packed or bulk packed as required.[2]

Fig. 4—Eight-track, ¼-inch copy tape format.

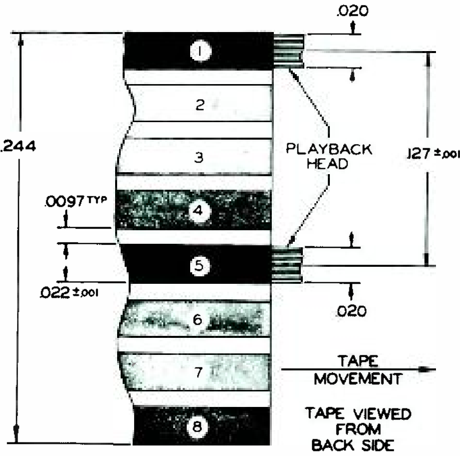
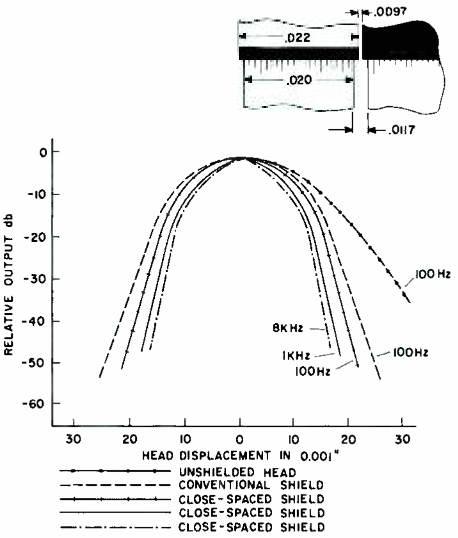


Fig. 5—Crosstalk vs reproduce head displacement.



A MULTI-INDUSTRY ACCOMPLISHMENT

This stereo tape cartridge system is designed primarily for use in the automobile. The widespread acceptance of the system by the motoring public is a far better measure of the success in meeting the original objectives than any set of engineering data presented as compilations, charts, and curves. RCA worked with the Lear Jet Corporation, the Ford Motor Company, General Motors, and Motorola in establishing this system as practical for the severe environment of the automobile. It is interesting to speculate on its acceptance in the home when suitable playback units become available.

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PRODUCTION OF STEREO TAPE CARTRIDGES

A Pictorial Review

R. D. BROWNING, Mgr.
Manufacturing
Tape Duplicating Facility
RCA Victor Record Division
Indianapolis, Indiana

Recorded sound reproduction in automobiles has been attempted in many different forms since 1952. Nominal success using 4-track tape reproducing systems has been achieved in recent years in certain sections of the United States. In 1963, W. P. Lear approached RCA with his concept of a combined radio-tape cartridge instrument for automobiles. With modifications suggested by the RCA Victor Record Division and two years of cooperative testing and development between Lear and Record Division Engineering, the decision was made to set up Stereo 8 prerecorded tape cartridge production in Indianapolis. System design for a high-speed duplicating plant was initiated and work was started on the plant and equipment early in 1965. Operation began in August of the same year. April of 1966 saw the production of the one millionth Stereo 8 cartridge. Shown here is a pictorial sequence of the manufacturing operation.

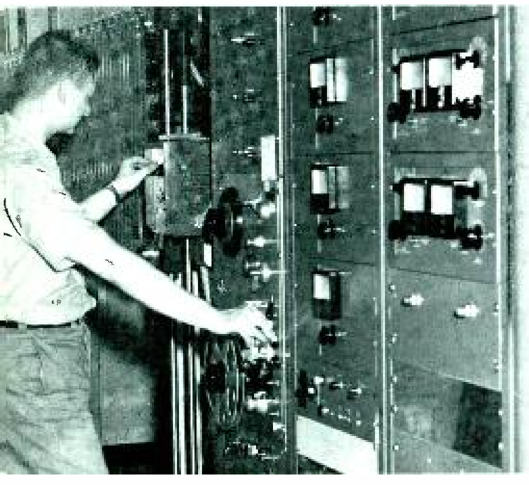


Fig. 1—MASTER REPRODUCING UNIT. The composite eight-track ½-inch master tape, prepared by the New York Recording Studios, is transported on an endless loop accumulator and through the tape reproduce transport in the rack. The upper and lower arms of the accumulator are movable, on a motor-driven-feed screw, so that various master lengths can be accommodated.

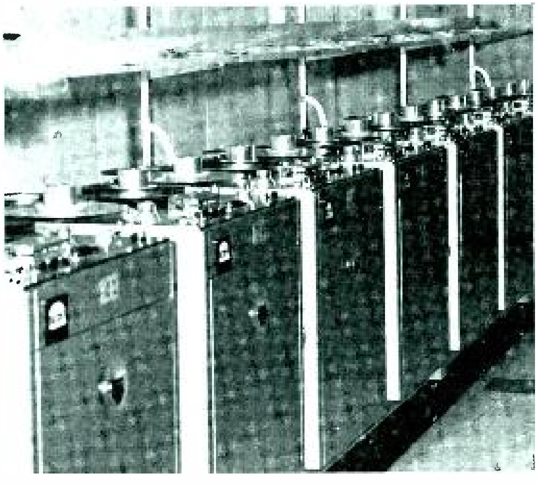


Fig. 2—SLAVE RECORDER LINE. Program material from the master unit is fed to various combinations of slave recorders. The master tape, prepared at 7 in/s, is played at 60 in/s while the slaves are operating at 30 in/s, producing the resultant 3¾-in/s copies.

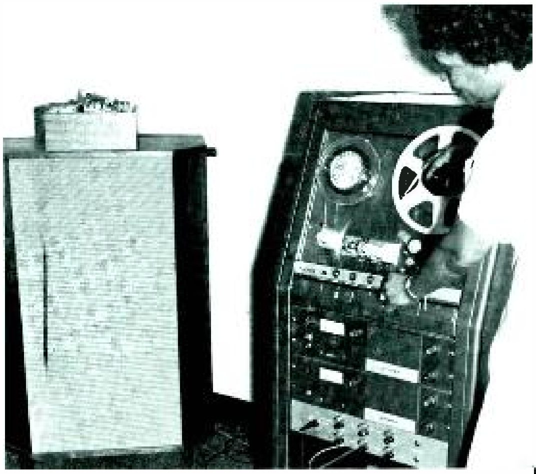


Fig. 3—TEST STATION. First-run tests of tapes from all slave units are made on test units each time a master is changed. Periodic tests are also made during the running of the master to ensure that quality has not degraded during the run.

Fig. 4—BREAKDOWN OPERATION. The multiple recordings on the large reel of tape are separated into individual cartridge lengths on breakdown machines. During recording a subsonic signal is recorded after each cartridge length; this signal activates a cutter on the machine which cuts the tape automatically.

Fig. 5—PARTS SUBASSEMBLY. Except for the tape-supporting platform, parts subassembly off-line and delivered to the production lines in bulk.

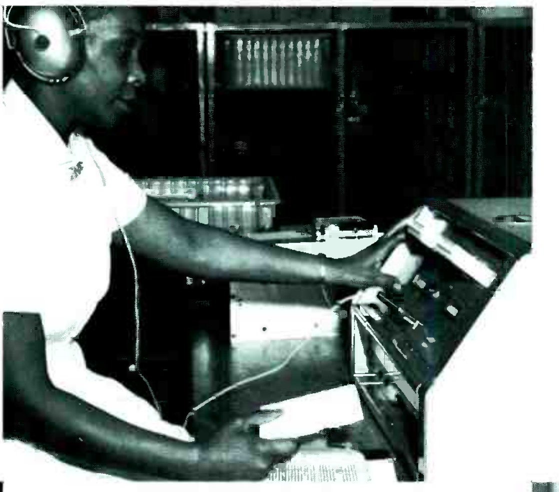


Fig. 8—LINE TESTING. In addition to constant sampling of the product on a statistical basis, the first copy from each reel of tape (which was the last to be recorded on the slave unit) is played through the splice on all programs to assure that the tape has been cut and spliced properly. Copies are also checked against sequence sheets and label copy for content assurance.

Fig. 6—SPLICING. Ends are spliced to create the endless loop of tape. A sensing foil, which actuates a head-positioning solenoid in the player, is affixed during the splicing operation. Cartridge bases delivered to these stations are prenumbered for control purposes. Each group of tapes, from the same original reel, is accompanied by a data-processing card which provides information on efficiency, quality, shrinkage, and finished goods deliveries.

Fig. 7—FINAL ASSEMBLY. Cartridge tops and bottoms are designed for a press-fit, and no fasteners are required for assembly. Each cartridge is run through one complete cycle at high speed to equalize tensions and ensure proper mechanical operation.

Fig. 9—LABELING. Approved runs of finished cartridges are conveyed into the packing room where two heat-activated labels are applied to each cartridge by automatic labeling machines.

Fig. 10—PACKING. Cartridges are packed in a specially designed plastic tray, lined with a polyurethane foam. A plastic lid is then attached to the tray and sealed with a self-destroying warranty seal.

Fig. 11—PACKING. Final packing for shipment to distributors throughout the world is in 5-, 10-, and 40-count cartons, double-lined to afford ample protection to the product.

ROBERT D. BROWNING received his BSEE from Auburn University in 1948. He joined RCA as a recording engineer in the New York Studios in 1949. In 1955 he was transferred to the RCA Chicago Studios and served as Manager, Recording, until 1957. He then joined Ampex Corporation as Manager, Quality Control Division, at their Magnetic Tape Plant in Alabama. He rejoined RCA in 1962. He is presently Manufacturing Manager of the Tape Duplicating facility in Indianapolis, Indiana. Mr. Browning is a member of the Audio Engineering Society and the American Society for Quality Control.

SOUND RECORDING CHARACTERISTICS OF MAGNETIC TAPE

The recording properties of magnetic tape are discussed, including operating bias, sensitivity, output, and signal-to-noise and signal-to-print ratios. Some of the tests commonly specified for magnetic recording tapes are reviewed and evaluated on the basis of their usefulness to the tape recording engineer.

A. G. EVANS, Ldr.,
Magnetic Tape Engineering
RCA Victor Record Div., Indianapolis, Ind.

MAGNETIC tape has been used in the recording of audio signals for many years, yet there is a great deal of misunderstanding of its properties and the measurement and specification of these properties. Magnetic recording is a relatively young science and there are many technological problems that are not satisfactorily solved at the present time. There is, however, much information available concerning magnetic tape which can be invaluable to the user if he knows how to interpret it. Several standardizing organizations, including the National Association of Broadcasters (NAB), the Electronics Industries Association, and the Society of Motion Picture and Television Engineers, have published working standards which are widely used in the industry. The manufacturers and users of tape also have developed test methods and specifications; one of the most widely referenced is the Interim Federal Specification W-T-0070.

The objective of this paper is to review some of the commonly specified tests on magnetic recording tape and evaluate their usefulness to the tape recording engineer.

RECORDING PROPERTIES

The recording properties of a magnetic tape are those characteristics that can be determined by recording and reproducing the tape on a conventional recorder. The properties most commonly reported are: operating bias, sensitivity at medium and short wavelength, output at some given distortion, signal-to-noise ratio, and signal-to-print ratio. All except the last two of these imply an absolute measure-

state of the art, there is no satisfactory method of specifying. Each group doing serious work with magnetic tape must use a calibration system that will permit relative measurements of these properties. The reference, or *standard,* tape is a basic element of most calibration systems for magnetic-tape testing.

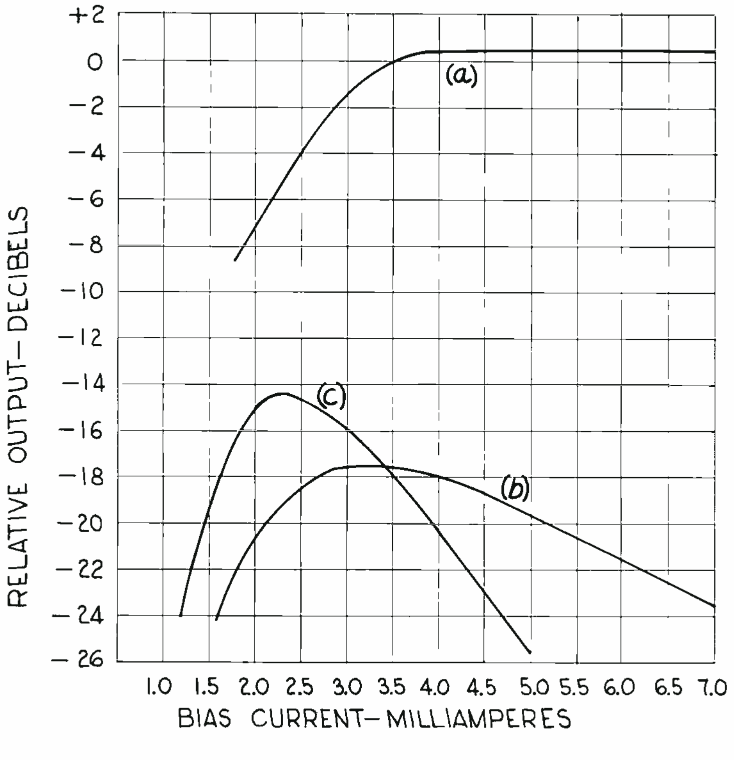
STANDARD TAPES

Two types of standard tapes are desirable for the calibration of a tape test system: 1) a recorded tape that is used for the alignment of the playback system, and 2) an unrecorded tape that is used to calibrate the record process.

The recorded tape is chosen to match one of the standardized response characteristics, such as the NAB characteristic used extensively at tape speeds of 7½ and 15 in/s. This tape serves to check the play-head characteristics, the amplifier response, and the azimuth of the play head. A group of these tapes should be maintained for reference, since this type of standard is easily destroyed by demagnetization.

The unrecorded reference or standard tapes should have very stable characteristics that are as similar as possible to the tapes that will be referenced to it. This tape will be used to establish reference levels for the bias, the sensitivity, and the output of a given tape test system. Data for all other tapes will then be reported relative to the values determined from this standard tape, and thus a direct comparison of results obtained from several test systems is possible. A tape to be used as an unrecorded standard must have a very uniform surface and excellent wear properties. Most audio tapes tend to be polished to a smoother surface finish during the first 50 to 100 passes over a transport, which changes their short-wavelength sensitivity. Since the unrecorded standard has a limited life expectancy, a well-controlled

Fig. 1 — Bias current relationships: a) output at 3% distortion; b) medium wavelength sensitivity; c) short wavelength sensitivity.



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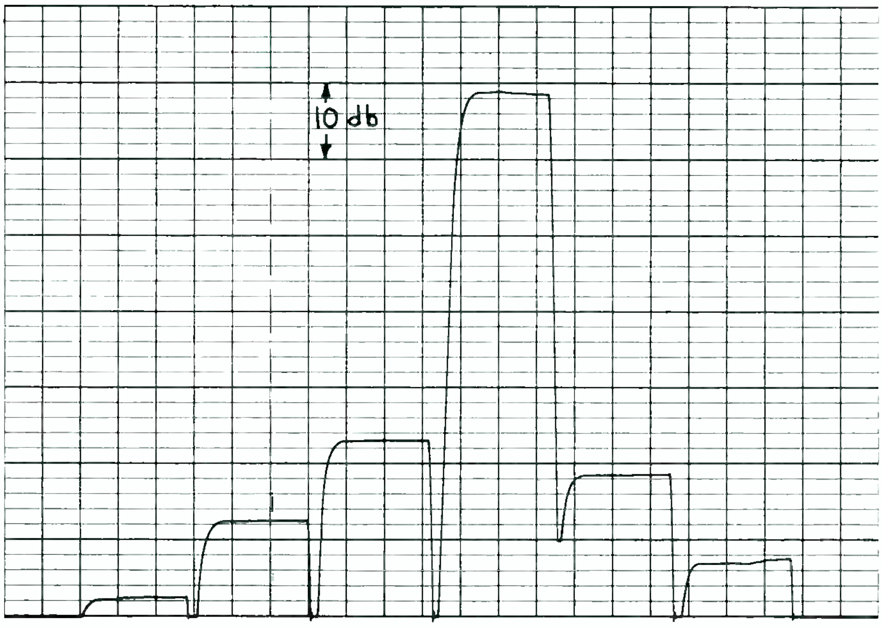


Fig. 2 — Recorded tone with multiple printed tones.

ARTHUR G. EVANS received his BSEE degree from the University of Illinois in 1947. Following graduation he joined RCA Victor Record Division's Record Engineering, where he was responsible for development of disc and magnetic recording techniques and equipment for both monaural and stereo records. In 1964 he was transferred to Magnetic Tape Engineering and promoted to Leader. He is currently responsible for development of audio-tape test equipment and equipment calibration. Mr. Evans is a member of the IEEE and Eta Kappa Nu and a Fellow of the Audio Engineering Society.

system of secondary standard tapes should be established for use in calibrating working standards.

OPERATING BIAS CURRENT

High-frequency bias is used in all high-performance audio-tape recorders to provide better linearity and improved signal-to-noise ratios. Since the bias field strength at the gap in the record head is not easily measured, it is common practice to determine operating characteristics by referring to the bias current through the record head. Proper operating bias current is essential to optimum system performance.

The operating bias current usually chosen for audio tape evaluation produces maximum signal output when recording a medium-wavelength sine-wave signal. Specialized applications may make a higher or lower value of bias current more desirable. Some of the considerations involved in choosing the operating bias current are discussed below under "Choice of Operating Point."

SENSITIVITY

The term sensitivity as used here refers to the output obtained from a tape when it is recorded using operating bias current and a preset signal level well below that which would saturate the tape. Most tapes intended for general sound recording applications are tested for sensitivity at a medium wavelength (7.5 to 20 mils) and at a short wavelength (¼ to ½ mil). The relative sensitivity of the tape at medium and short wavelengths is an index of the frequency response characteristics of the tape.

OUTPUT

The maximum usable output from a tape is generally defined as the output at 3% third harmonic distortion when recording a medium wavelength signal with operating bias current. Only the third harmonic distortion is used in evaluating tapes, because in a properly operating recorder the even-order and higher order odd-harmonic components will be negligible compared to the 3% third harmonic component. Measurements of intermodulation or cross-modulation distortion are well established for some types of audio equipment tests; however, they have not been generally accepted as a basis for evaluating audio magnetic recording tapes.

CHOICE OF OPERATING POINT

The determination of the optimum operating bias current must be made as a compromise between frequency response and output levels. The three curves shown in Fig. 1 provide much basic information about the characteristics of a magnetic tape. The upper curve shows the output obtainable at 3% distortion as a function of bias current; the lower two curves show how medium-wavelength and short-wavelength sensitivities vary with the bias current. Short-wavelength sensitivity decreases rapidly with increasing bias current beyond the point of peak sensitivity; therefore in a system that requires good high-frequency response, the lowest practical value of bias current should be used. The sensitivity at longer wavelengths and the output at 3% distortion fall off quite rapidly as the bias current is reduced below the point of maximum medium-wavelength sensitivity. Here, then, is the decision that must be made: What is the relative importance of frequency response as compared to the loss of maximum output level? The operating point selected for use in the majority of cases is that which gives the greatest undistorted output with the least loss in short-wavelength sensitivity; this corresponds to the point of maximum sensitivity at medium wavelength. Other operating points may be chosen for certain applications, provided the effects of this choice are properly evaluated.

TAPE NOISE

Several different methods are used in specifying the noise contributed by a tape in an audio system. Two types of tape noise seem to be the most significant in determining the performance of audio recording tape: 1) the noise generated by a tape after it has been passed over the erase and record heads with normal bias current in the record head but with no audio signal applied to it, and 2) the noise in the presence of a recorded signal, often called modulation noise.

Noise levels are measured using filters to restrict the bandwidth of the measuring equipment and to prevent extraneous signals from influencing the measurement. A typical measuring system would have flat response from 300 to 20,000 Hz with at least 12-dB-per-octave rolloff beyond these frequencies, where desirable equalization is added to provide weighted noise measurements. The noise level, reported as a ratio (in dB) referenced to the maximum output level of the tape, is a direct indication of the useful dynamic range of signals that can be handled by the tape.

The measurement of the modulation noise is not as straightforward or well defined as that of the noise produced by the record bias. A direct analysis of the noise spectrum in the presence of an audio signal is not satisfactory, in general, because it depends on the selectivity of the analyzer and the frequency modulation present in the reproduced signal. To obtain an indication of the magnitude of the modulation noise level, an indirect method is used whereby a direct current is substituted in the record head in place of the audio signal and recorded with the usual bias field. The noise level measured under these conditions is related to the modulation noise, and it has proved very useful in evaluating tapes.

SIGNAL-TO-PRINT RATIO

A recorded tape tends to transfer or print the signal to adjacent layers of the tape. This printed signal appears as a pre-echo and postecho of the recorded signal and is undesirable in most applications of audio recording. The degree to which this printing takes place is dependent on the magnetic characteristics of the media, the wavelength of the signal, the spacing between magnetic layers, and the environmental conditions under which the tape is stored. The ratio between the original signal level and the highest level printed signal is used to determine the signal-to-print ratio.

The level of the printed signal increases with storage time and temperature, hence the test conditions must be specified. Two different types of storage conditions are commonly used for signal-to-print measurements. The first relates to short-term storage and requires that the tape be stored under room conditions for a period of 24 hours. The second is an attempt to simulate long-term storage conditions by storing the tape at elevated temperatures for a relatively short time, e.g., 150°F for 4 hours. These two types of tests do not necessarily give comparable results on different types of tapes.

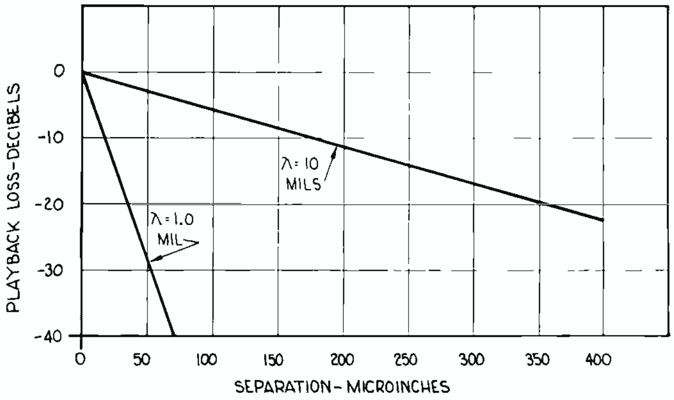


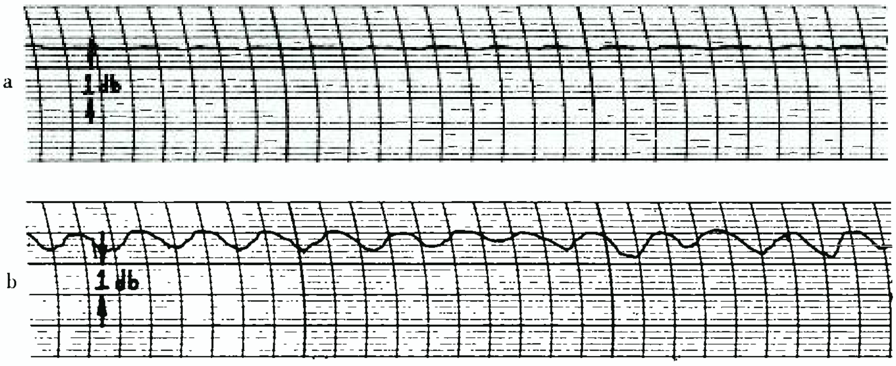
Fig. 4 — Playback separation loss.

The printed signals are not limited to the first layers adjacent to the original signal. Fig. 2 shows a short burst of tone recorded on a tape and the resulting printed signals which are evident through several layers of tape. The tone burst was recorded at the maximum record level and a narrow bandpass filter was used to improve the signal-to-noise ratio of the measuring system.

AMPLITUDE UNIFORMITY

Dropouts or amplitude nonuniformities introduced in the record playback process cause signal distortion in the form of noise on the signal, or significant changes of signal level. This type of distortion is caused by inhomogeneous coatings, variations in the coating thickness, rough or damaged coating surfaces, or foreign matter separating the tape from the heads. There is more difference in the amplitude-uniformity performance of various tapes of the same general class than in any other characteristic. Since this property of a tape is not too well understood by many users, it is discussed here in greater detail than are some of the other properties. However, this discussion is limited to variations corresponding to an effective length of about 5 mils or greater; variations of shorter length are considered in the category of noise.

Fig. 3 — Amplitude uniformity: a) example of excellent uniformity; b) example of coating thickness variation.



One method used to determine the amplitude uniformity is to record a constant-level tone on the tape and chart the reproduced level on a graphic level recorder having a response sufficiently rapid to record the variations of interest. The tape recorder used for this measurement may be equipped with full-width heads to determine an average characteristic of the tape. More detailed information about the tape can be obtained by using multitrack heads to compare the uniformity at several points across the width of the tape.

A tape of excellent uniformity will chart essentially as a straight line, as shown in Fig. 3a; when the coating has a periodic thickness change, a chart of the type shown in Fig. 3b may be seen. This is not a particularly prevalent type of defect in modern recording tapes.

The most universal cause of amplitude nonuniformity is separation of the tape from the heads by dust particles, wear products, tape surface roughness, or tape damage such as creases. The effect of separating a recorded tape from the playback head is shown in Fig. 4. The relationship between separation and playback loss can be shown to be:

$$\text{loss in dB} = 54.6 \frac{s}{\lambda}$$

where s is the spacing between the tape and the head, and λ is the wavelength of the signal.

This loss is appreciable for even relatively long wavelengths and small separation distances; therefore, it is easy to understand why surface defects cause amplitude nonuniformity. Even though this playback loss is appreciable, it is much less than that caused by head-to-tape separation in the record process. The actual recording loss is dependent on the shape and magnitude of the bias field and the magnetic characteristics of the tape. There is no simple relationship

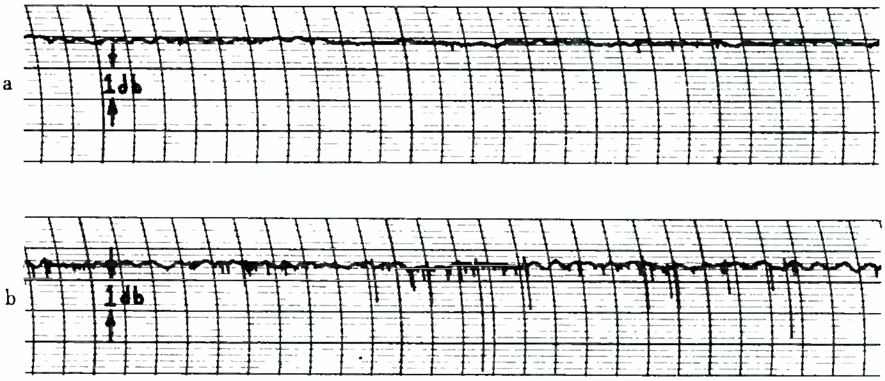


Fig. 5 — Comparison of uniformity: a) near center; and b) at edge of poorly slit tape.

that can be used to calculate the record loss, as there is in the case of playback loss. The recording loss due to separation when using ring-type heads is as much as an order of magnitude greater than that due to playback loss. This difference can be easily shown by comparing the repeatability of amplitude-uniformity charts with repeated recording passes to those of repeated playback passes of the same area of the tape.

The effects of dust particles, slitting defects, and coating defects show up when amplitude-uniformity charts are made using narrow-track heads spaced to permit measurements both at the edges and near the center of the tape. The charts in Fig. 5 show the results of measurements made with a ¼-track head on a tape with good coating uniformity and poor edge quality.

PHYSICAL PROPERTIES

The physical characteristics of a tape are very important in determining the suitability of the tape for a particular application. Many of these properties, such as tensile strength, elongation, elasticity, abrasiveness, and friction, have only a secondary effect on its recording characteristics and, therefore, are not within the scope of this discussion. A few of the properties that relate directly to the recording characteristics are covered in following paragraphs.

LONGITUDINAL CURVATURE

Longitudinal curvature is defined as the deviation of the edge of a tape from a straight line measured in the direction of tape motion. This is rather difficult to measure by direct observation on a ¼-inch-wide audio tape. Wider tapes are tested for curvature by allowing them to assume their natural position on a flat surface and comparing the path of the edge of the tape to a straight edge. The effect of curvature in an audio tape can be found in a change in azimuth alignment where separate heads are used for record and playback. Extreme cases of curvature can sometimes be observed by supporting the tape between two points and noting the difference in length of the two edges of the tape, which may appear as waves or ripples in the longer edge.

CUPPING

Cupping, or transverse curvature, of a tape is defined as the departure across a tape (transverse to motion) from a flat surface. The cupping is specified either as the maximum distance between the flat surface and the tape or as the angle of curvature. These two methods of measurement are shown in Fig. 6. They are related by the following equation if the cupping has a constant radius of curvature at every point across the width of the tape:

$$d = \frac{180W}{\pi\theta}\left(1 - \mathrm{Cos}\,\frac{\theta}{2}\right)$$

where d is the maximum distance from the surface to the tape, W is the tape width, and θ is the cupping angle in degrees.

The cupping is considered positive when the curvature is toward the oxide side and negative when the curvature is toward the base side of the tape. Negative cupping is rarely seen.

Cupping can contribute to amplitude nonuniformity, because of poor contact between the tape and the heads, and to uneven wear patterns on the transport mechanism components.

LAYER-TO-LAYER ADHESION

The tendency for some tapes to block or adhere between layers when stored for extended periods of time or under adverse environmental conditions can completely destroy their usefulness as a recording media. Under the most adverse conditions the oxide layer may almost completely transfer to the back of the adjacent layer, making it very difficult to unwind the tape. It may be possible to retrieve most of the recorded information from a tape with only a slight amount of delamination, but if recording is attempted on such a tape the dropouts will be excessive.

A test has been developed to evaluate tapes with respect to layer-to-layer adhesion which permits a reasonably rapid evaluation of its long-term storage characteristics. The sample for this test is prepared by winding, with suitable tension, a length of ¼-inch tape on a nonoxidizing metal rod of ½-inch diameter. The end of the tape is fastened to prevent it from unwinding. The sample is first stored for 18 hours at 130°F and 85% relative humidity, and then stored at 130^{c} in a dry atmosphere for 4 hours. The sample is then allowed to stabilize at room conditions. The fastening on the end of the tape is removed; if the tape unwinds, careful observations are made for any delamination of the oxide. Care must be exercised in the preparation of the sample for this test, and considerable experience is required for accurate evaluation of the results.

CONCLUSION

The recording characteristics of a tape are determined by its magnetic properties, by the conditions under which the recording takes place, and by the physical properties of the tape. Maximum use of the tape's capabilities is possible only when the user understands the interrelationship of its characteristics and particularly the relationship of high-frequency bias to the other properties. Some tape characteristics (e.g., the *B-H* characteristic) not mentioned in this paper are not considered as useful to the audio recording engineer as the type of measurements that have been discussed.

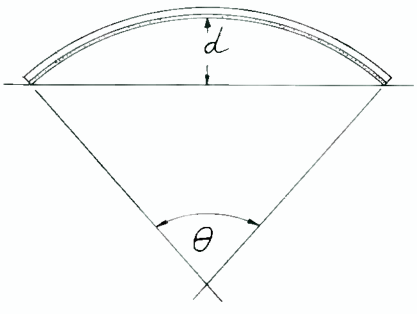


Fig. 6 — Two different methods of cupping measurement.

DISC PHONOGRAPH RECORDS

The recording, manufacture, and playback of disc records are surveyed in this paper. Problem areas, such as recording processes and record materials, are described. Limitations of record materials, due to high stresses developed in the playback of disc records, are discussed.

DR. A. M. MAX, Mgr.,
Chemical and Physical Laboratory
RCA Victor Record Division, Indianapolis, Ind.

Phonograph records are plastic discs on whose surface is reproduced a sound track consisting of a spiral V-shaped groove. The sound or audio modulation is superimposed on this spiral motion. Thus in recording, the groove is cut by a stylus which is driven perpendicularly to the spiral motion by the electrical audio signal to produce the sound track. To reproduce the signal, the disc is rotated with a stylus riding in the groove. The groove walls constrain and thus drive the stylus. By mechanically linking the stylus to a transducer or generator, the electrical signal is reproduced. The groove walls have a surface finish much smoother than machined surfaces. Surface roughness amplitudes are generally well under 1.0 microinch; some of the sound amplitudes are less than 10 microinches. The general surface roughness produces noise, since it is random in character. Therefore, the surface roughness must have mean amplitudes much smaller than that of the signal. The forming and reproduction of grooves with the desired characteristics has led to the development and refinement of many specialized techniques. These are reviewed briefly in subsequent paragraphs.

A disc record originates with the cutting of the sound track in a lacquer-coated aluminum disc. With no signal applied, the cutting stylus is moved linearly toward the center of the disc by a rotating feed screw as the disc is rotated at constant rotational speed. This combination results in a continuous inward spiral motion. The pitch or lines per radial inch can be varied independently by varying the feed screw speed, but the rotational speed must be closely controlled. Rotational speed is used to synchronize the recorded signal with the reproduced signal and obtain corresponding frequencies. Thus deviations, either average or alternating in character, from the desired rotational speed must be kept within close limits. Recording lathes are therefore precision instruments.

The cutting stylus is rigidly linked to an armature in a magnetic field. The signal passing through the armature coils causes the armature and stylus assembly to be driven laterally or vertically. When driven laterally, the stylus superimposes a radial signal on the spiral groove. This lateral recording is the type of groove common in monaural home phonograph records (Fig. 1). Vertical oscillation of the stylus is called "hill and dale" recording.

The stereophonic disc uses the principle that the two modes of motion are 90° apart and can be independent of each other. However, if one signal utilizes the vertical, and the other the lateral mode of motion, distortion would be different in the two channels.[1] Therefore, instead of vertical-lateral recording, the standard stereophonic record has its two tracks rotated 45° from the vertical. Since this coincides with the groove wall, the signal can be viewed as a vertical modulation of each groove wall. When the signal frequencies are of equal amplitude and in phase, the resultant motion is a vertical groove modulation. When the signal frequencies are of equal amplitude but 180° out of phase, a pure lateral vibration results. Although the stereophonic groove appears to have both vertical and lateral motion (Fig. 2), close examination reveals that the modulation on one side wall is not the same as the other side wall. However, since the modulation is vertical with respect to each groove wall, the tracing distortion in the two channels is comparable.

Stereophonic grooves have a 90° included angle with a bottom radius equal

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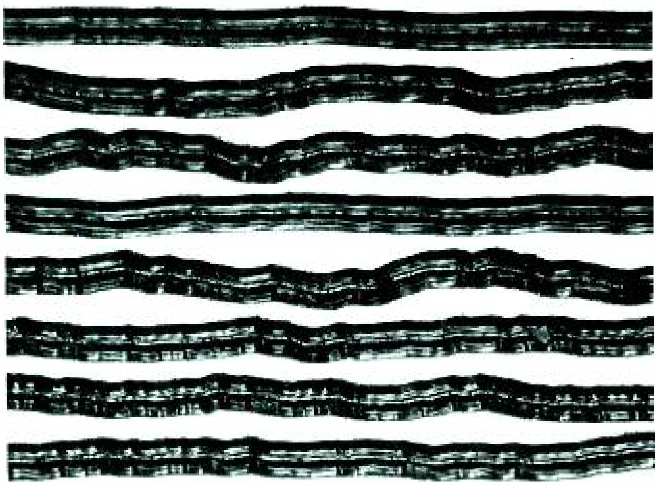


Fig. 1—Monaural record grooves.

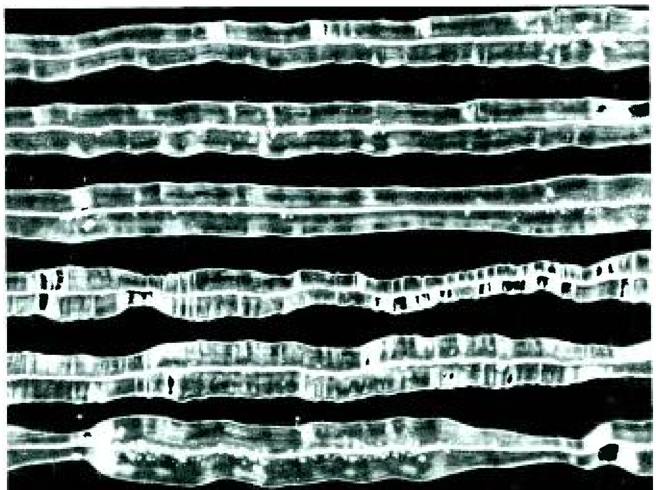


Fig. 2—Stereo record grooves.

DR. A. M. MAX received his BS, MS, and Ph.D degrees from the University of Wisconsin in Chemical Engineering with minors in Physics and Physical Chemistry. After a period with the Ternstedt Division of General Motors and the University of North Dakota as Assistant Professor of Chemical Engineering, he joined the RCA Victor Record Division in 1944 as Supervisor of Metallizing and Plating Development. Since 1950 he has served as Manager, Chemical and Physical Laboratory. Dr. Max holds two U.S. patents in the field of electroforming. He is a member of the American Chemical Society, American Physical Society, Electrochemical Society, Faraday Society, Phi Lambda Upsilon, Tau Beta Pi, and Sigma Xi.

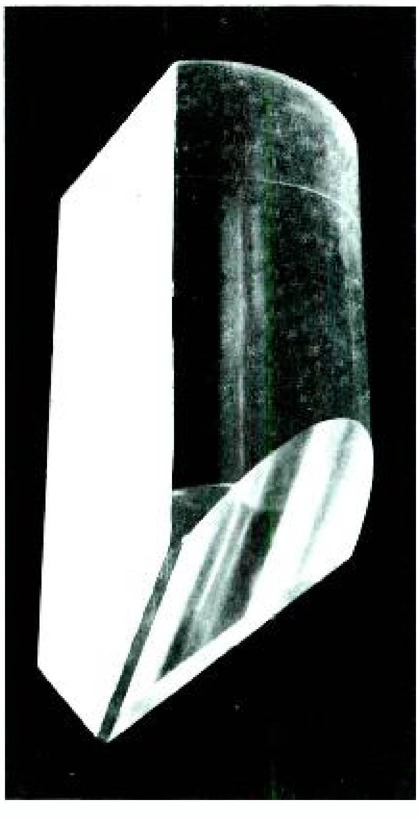


Fig. 3—Stereo groove cutting stylus.

to or less than 0.0002 inch. The mean width at the top of the groove is approximately 0.003 inch. To utilize the surface efficiently, variable pitch and variable average groove depth are usually used. Thus for higher level passages resulting in larger amplitudes, grooves are spaced farther apart. Conversely, for low-level or soft passages, when amplitudes are small, the grooves can be spaced closer to each other. For the smaller amplitudes, the average groove depth can also be made smaller, leading to lower average groove widths. In this fashion more grooves can be cut on a given area. Obviously, for loud passages the average depth must be large enough so that the stylus does not leave the surface of the disc on vertical modulation peaks.

In cutting the groove a sapphire stylus is used. The cutting edge is relieved by a burnishing facet[2] which strengthens the edge and also provides a burnishing action that smooths the groove walls (Fig. 3). In addition to the burnishing facet, the stylus is heated by a small coil. The combination of heating and burnishing results in an extremely smooth groove wall, essential in professional recording.

The disc on which the recording is made is at this time a nitrocellulose-coated aluminum disc. A highly plasticized, low-viscosity nitrocellulose is used to provide a relatively soft material. the discs are larger than the desired record; 14- or 16-inch-diameter blank discs are used for 12-inch recordings. Test grooves are cut outside the significant diameter and when the visual appearance of the groove under a microscope is judged satisfactory, the cutter is spiraled to the starting diameter and the lathe adjusted to music recording pitch.

The desired physical properties of the nitrocellulose coating have not been defined. The coating has evolved from *instantaneous recording blanks* used for home recorders (so-named because they could be played immediately after recording). Obviously, the coating must be relatively soft so that it cuts easily. The thread should be continuous since, in professional recording, the thread is removed through a small suction or "sucker" pipe operated from a vacuum pump. The thread is critical; if it oscillates, for example, the oscillation will perturb the cutting assembly and the disturbance will be noticeable in the recorded groove. If the thread breaks or *balls up*, the recording is usually ruined. Thus if the coating is too weak, thread control will be difficult. Any tendency toward chatter or other mechanical disturbance in cutting also manifests itself as an extraneous sound or noise. Chatter is associated with cutting harder or more brittle coatings. The physical properties of the coating must therefore fall between the limits imposed by thread continuity on the one hand and ease of cutting on the other. Another desirable property of the recording blank is stability with age. The plasticizer system should be such that the coating does not change in physical properties within reasonable time limits, preferably two to three years.

In the manufacture of records, a negative replica of the recorded surface must be made in such a form that it can be used as the surface of a die in a plastic molding press. The press is then used to mold disc records, the surface of which is a reproduction of the recorded surface. Because of the extremely fine detail that must be reproduced, highly specialized techniques have been developed. Extraneous surface characteristics will result in added noise or distortion of the original sound in the final product. Any change in the surface detail will, therefore, result in loss of fidelity of the original sound.

Electroforming techniques are used to reproduce the recorded surface.[3] No other technique approaches these in meeting the requirements of the present record disc. For example, casting a type metal or similar fusible nonshrinking alloy against a metal record surface results in grooves 15 to 20 dB noisier than the original groove.

STAMPER MANUFACTURE

Since electrolytic deposition involves the neutralization of positive metal ions in solution by electrons at a cathode electrolyte interface, the surface of the disc must be electrically conductive. This is accomplishing by metalizing the lacquer surface. Silvering by chemical reduction is commonly used. Vacuum methods such as evaporation or sputtering do not produce as good results because of interference effects due to outgassing residual solvent and plasticizer of the lacquer.

Silvering by chemical reduction must be preceded by careful cleaning and seeding of the surface with stannous chloride solution. Silvering is usually accomplished by spraying solutions of ammonical silver nitrate solution and a chemical reducer at the surface. Twin-nozzle spray guns are available, from the mirror industry, in which the two fluids are separated until mixed in the air. Two separate atomizing guns may be used in a permanent mechanized arrangement. The silver must be bright, uniform and heavy enough to carry the starting current in electrolysis. Any nonuniformities will be reflected in varying surface noise. Any discontinuities in the silver, such as holes, will result in loud *ticks* in the transduced sound.

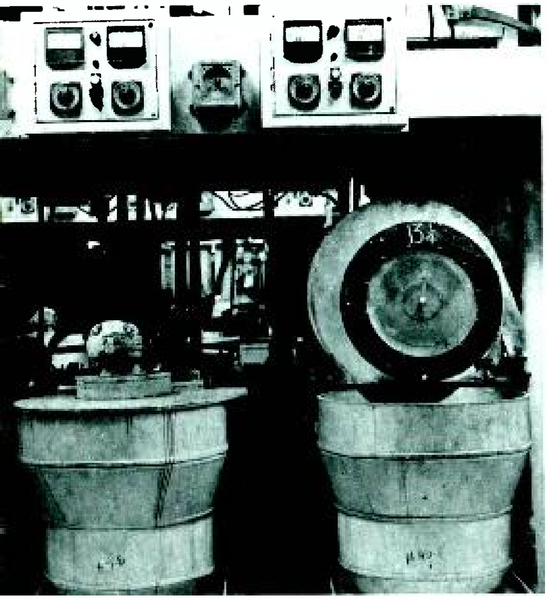


Fig. 4—One type of disc-rotating unit used to make electroformed metal master.

Although both copper and nickel are used for the initial plating of the silver film, nickel is preferred. Electrodeposited nickel has a finer grain structure which results in about a 5-dB lower surface noise than average copper. The nickel electrodeposit must have relatively low internal stress, since there is little adhesion of the silver to the lacquer surface. For this purpose a conventional Watts-type nickel-plating solution with additional agents lowers the deposit stress; in another method, a nickel sulfamate solution in which nickel deposits have inherently low internal stress is employed. The temperature of these solutions should be kept below 100°F if the lacquer is not to be damaged.

Both copper and nickel platings are used for completing the master. For high-speed plating a high degree of agitation is essential, since metal ion depletion of the cathode electrolyte film is the limiting speed factor. In one type of unit (Fig. 4) the disc is rotated at 180 r/min with filtered solution pumped to the center of the disc. After removal from the electrolyte, rinsing, and drying, the electroformed metal master can be separated from the starting lacquer. The master has a silver surface backed by approximately 0.001-inch nickel and 0.020-inch copper, or simply 0.015-inch nickel.

The master—whose surface is a negative replica of the lacquer surface, the grooves in the lacquer being ridges on the master surface—can be used as a die in a record press. This is done when only a small number of records is required. However, commercial records may require many *stampers*, and to attain this goal, duplicating procedures are employed.

A metal positive disc is made in a fashion similar to that used for the master. However in this case the surface is metallic, so that instead of being concerned with conductivity, one is concerned only with avoiding the adhesion of the subsequent metal deposit to the starting metal surface. Adhesion is prevented by passivating the surface.

The master surface, the original metalized silver coating, is electrochemically cleaned followed by a water rinse, a neutralizing weak acid dip, another rinse, and then a passivating treatment. The latter may consist of weak solution, ¼ to ½ ounce per gallon, of sodium dichromate, although other passivating treatments may be used. This is then followed by nickel plating and electroforming. The nickel and copper electroforming are identical with the process used in making the master, except that the nickel usually is deposited from a warm solution.

When completed, the master-mold combination consists of two backs with the significant surfaces sandwiched between them. The two parts separate easily at the passivated surface. The newly formed part has a surface which is a negative replica of the master surface and therefore is a positive, a metal record known as a mold or mother. This metal record is taken to a test booth and played. Any defects or imperfections are noted; if small, they can be removed by an engraver working under a microscope. In practice 60 to 70% of molds made from the first master may have no defects; 25% may have one or two. The groove on a 12-inch long-playing record is approximately one-half mile in length and a defect may be less than 0.0001 inch. This comes close to perfection.

With the mold approved, the cleaning and passivating procedure employed in making the mold from the master is repeated. However, a relatively thin nickel shell is used for the press die or stamper. Therefore, nickel plating is continued until the thickness is 0.007 to 0.008 inch.

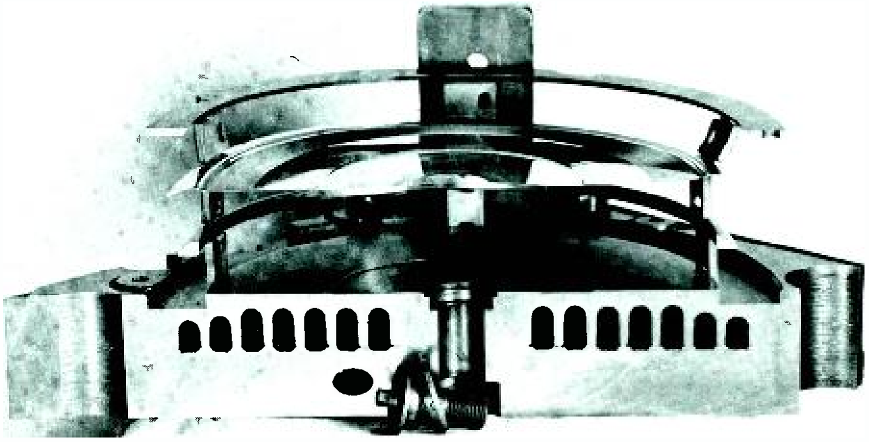
After separation of the stamper from the mold, by the same method used for master-mold separation, the surface is visually inspected. The stampers may then be chromium plated to obtain a harder, more scratch-resistant surface. Since this deposit is upon the significant surface, it must be limited in thickness so as not to change the groove shape. Chromium deposits thicker than 20 microinches also have a tendency to develop fine cracks. These obviously manifest themselves as surface noise.

After chromium plating, the stamper is finished. A relatively simple back grinding, with the stamper mounted against a clean pad of a horizontal spindle wheel, smooths the back, which has a dull matte but smooth finish associated with a dull nickel electroplated deposit. The stamper is then centered by rotating it slowly on a turntable with a microscope focused on the grooves. Off-center is indicated by a deviation from uniform spiral motion. The stamper is adjusted until centered, at which time a pilot center hole is punched. This operation is followed by a combined center and edge punch, which trims the outer edge of the stamper to ½ inch larger than the record and a center hole that is 1.0 inch for a 7-inch record and 2.75 inch for a 12-inch record stamper. The stamper then has its outer edge formed.

RECORD MOLDING

The mounting of a stamper is shown in Fig. 5, a cross-section of a die showing the parts used and the assembly. The center of the stamper is clamped by a center plate having a small lip overhanging the center of the stamper. In the outer ring well there is an edge ring which supports the raised edge portion of the stamper. This raised edge forms the annular orifice which molds the edge of the record and creates the back pressure

Fig. 5—Stamper mounting.



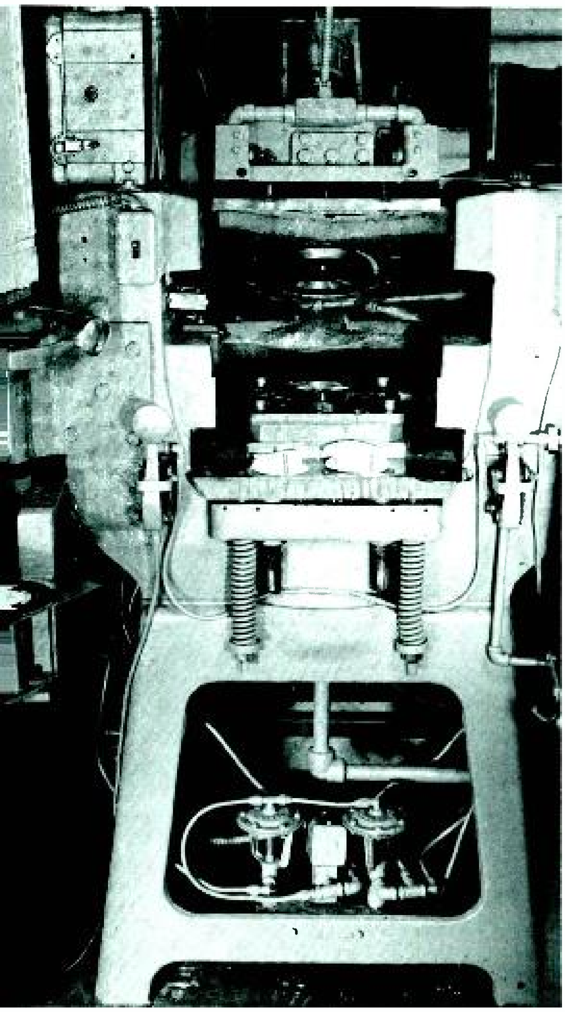


Fig. 6—Press.

in the cavity during molding. The outer edge of the stamper is restrained by a hold-down ring. This type of edge mounting, where there is no crevice at the outer edge, has been necessary for unbreakable records, since flash in a crevice would cause *hang up* in molding.

The stampers are mounted on a die cored with channels through which steam and cooling water can be alternately fed. In operation a hot wad of plastic is placed in the steam-heated cavity. Labels have previously been placed on the projecting center pins. A press (Fig. 6) is closed and 1800 lbf/in^2 hydraulic pressure applied. Before the plastic completes its flow, the steam valve is closed and cooling water turned on. The hydraulic pressure is maintained until the plastic cools to approximately 100° F. Then the pressure is released and the press opened. Good molding requires that the annular orifice gap be small so that back pressure in the cavity will result from the restriction in flow. On the other hand, if metal-to-metal contact is made at the edge, the force will be taken up by metal rather than the plastic in the cavity. In practice a gap of less than 0.003 inch can be maintained within the mechanical tolerances experienced and still avoid *cutting off* the flash by metal-to-metal contact.

During the outward flow of the plastic the stamper must be able to move freely. If the edge of the stamper is tightly clamped, the slight outward movement of the stamper results in additional flexing of the stamper edge. This leads to premature failure and splitting of the edge. If the restriction is on one side the stamper will shift off center. The movement and working of the stamper edge requires a ductile nickel for reasonable stamper life.

ELECTROFORMING CONTROL

In nickel electroforming, where physical properties of deposits are the important criteria, the solutions must be carefully controlled. The usual chemical analyses for the primary ingredients are important but not sufficient. Small amounts of impurities can result in brittle rather than ductile deposits. Fortunately, relatively simple precautions can keep impurities under control.

Metallic impurities that have an important effect on properties of deposits usually deposit at lower potentials than nickel. Therefore, low-current-density electrolysis can be used to keep these metallic impurities at a low level. In this process the solution is circulated through a separate tank and agitated by a stirrer. Agitation removes the impurities efficiently, since diffusion is the limiting factor in their removal.[4] Of the metallic impurities, iron is the most troublesome, causing highly stressed deposits. It has been shown that iron can be kept under control by aeration at a pH of 4.0, which is the solution pH usually employed. At this pH, ferric ion has a low solubility. Agitation in the dummying tank, as the low-current-density electrolysis unit is called, therefore serves the dual function of aeration as well as agitation.

Commercial salts have impurity levels 10 times higher than their proportions in an operating solution. It is therefore considered good practice to purify salts before addition to the solution. Activated carbon has beneficial effects in removing organic contaminants which embrittle electrodeposits. In one scheme, additions are made automatically through a proportional feeder operating from an ampere hour meter.[5]

Continuous filtration is essential to remove all solid contaminants which may stray into the solutions as well as the insoluble ferric hydroxide. A precoat of diatomaceous filter aid is used on the filter medium. Activated carbon can then be used to remove unwanted organic contaminants.

Physical properties can be monitored by a bend test, since the groove structure deposits have a weakness along the grooves. By cutting a 2-inch strip about ¼ inch wide perpendicular to the grooves and bending the strip back and forth over a radius until failure, a measure of ductility can be obtained. This bend test is more sensitive to impurities than either tensile strength or elongation. When the bend test is within limits, the tensile strength of the nickel is between 65,000 and 75,000 lbf/in.^2 The other important property of the deposit to be controlled is stress. This can be measured by various techniques, e.g., a spiral contractometer.[6]

SIGNAL RELATIONS IN RECORD GROOVES

A single frequency signal can be represented by the following equation:

$$Y = A \sin (\omega t - \varphi) \qquad (1)$$

where Y = displacement from mean position (cm or inch)
A = amplitude (cm or inch)
ω = angular frequency (rad/sec)
t = time (seconds)
φ = phase angle (radians).
Since $\omega = 2\pi f$ where f = frequency in Hz, the equation can be written as:

$$Y = A \sin (2\pi ft - \varphi) \qquad (2)$$

The velocity of a stylus describing such a wave would be equal to the derivative of Equation 2,

$$v = \frac{dY}{dt} = 2\pi fA \cos (2\pi ft - \varphi) \quad (3)$$

The acceleration would be obtained from the second derivative of Equation 2,

$$a = \frac{d^2 Y}{dt^2} = -4\pi^2 f^2 A \sin (2\pi ft - \varphi) \qquad (4)$$

Or:

$$a = -4\pi^2 f^2 Y \qquad (5)$$

There are two velocities to be distinguished. The tangential component of the relative groove-stylus velocity is called the groove velocity; the radial component of the groove-stylus velocity is called the stylus velocity. The groove velocity is simply the rotational speed multiplied by the circumference.

A record does not have constant groove velocity, since with constant rotation the groove velocity is proportional to the radial distance of the groove to the center of rotation. Therefore, it may be desirable to express the relationships in terms of groove velocity. The phase angle can be ignored, since it refers to an arbitrary start of the time scale. The wave on the record can then be expressed by the following relation:

$$Y = A \sin KVt \qquad (6)$$

where $K = \omega/v = 2\pi/\lambda$
where V = groove velocity
λ = recorded wave length

Then the stylus velocity becomes

$$v = \frac{dY}{dt} = KVA \cos KVt \qquad (7)$$

and the stylus acceleration is

$$a = \frac{d^2Y}{dt^2} = -K^2V^2A \sin KVt \qquad (8a)$$

$$= -K^2V^2Y \qquad (8b)$$

This can also be written as

$$a = -\frac{4\pi^2}{\lambda^2} V^2Y \qquad (8c)$$

Or:

$$a = -4\pi^2f^2Y \qquad (8d)$$

From these relations it can be seen that if grooves were recorded with constant amplitude for equal sound levels, the accelerations required for high frequencies would be unreasonable. Being proportional to the square of frequency, Equation 8d. the ratio of accelerations at 15,000 to 30 Hz would be 250,000 to 1. This also implied groove curvatures which a stylus could not follow.

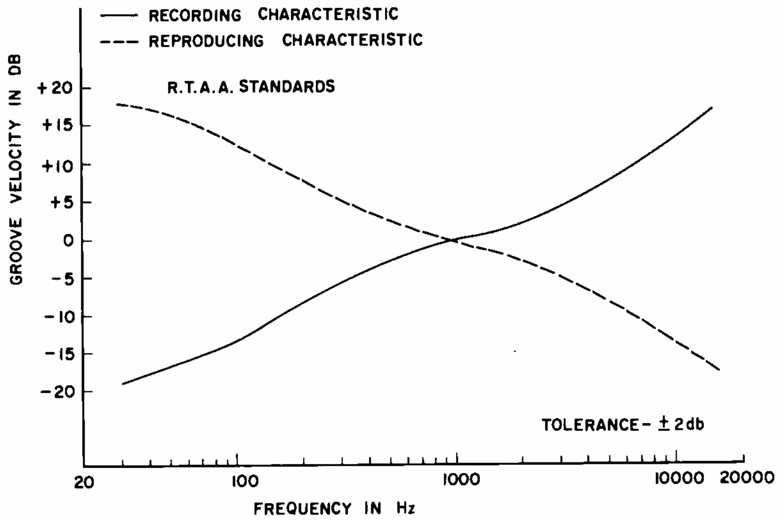
If constant stylus velocity is used with frequency, a more reasonable relation exists in the high-frequency end of the sound spectrum. In this case. $2\pi f\, A=c$, a constant, for constant sound power and thus $A=c/2\pi f$. From this it can be seen that the amplitude decreases inversely with increasing frequency. Conversely. the amplitude increases with decreasing frequency. Thus a signal of 50 Hz with the same power as a 1000 Hz signal having an amplitude of 0.002 inch would have a 0.040-inch amplitude. This is also somewhat unreasonable. As a compromise, the ideal recording characteristic is based upon a constant velocity in the high-frequency region and constant amplitude at the low frequencies. The frequency at which the two have equal velocity and equal amplitude for a given signal power is called the crossover.

In practice, if a constant-velocity frequency characteristic is used, the amplitude in the high-frequency range approaches the amplitude of the random irregularities of the surface. Therefore, the noise would mask the signal in the high-frequency region. For this reason, record companies used a rising characteristic in the high-frequency region. Then by reducing the high-frequency response of the reproducing system in proportion to the high-frequency preemphasis, the noise in this part of the spectrum can be reduced in relation to the signal. Similarly, it is desirable to add low-frequency preemphasis to reduce rumble and other low-frequency noise due to mechanical vibrations. This general characteristic has been accepted and adopted as a standard recording characteristic.[7]

An amplitude-frequency relation can be obtained by resistor-capacitor-inductor networks. The characteristic of such a circuit can be specified by a time constant. In accord with this, the recording characteristic is now specified by the algebraic sum of the ordinates of the following curves expressed in dB or relative stylus velocity:

1) Crossover—A curve which conforms to the admittance of a series resistor and capacitor network with a time constant of 318.0 microseconds.
2) High-frequency preemphasis—A curve which conforms to the admittance of a paralleled resistor and capacitor network with a time constant of 75 microseconds.
3) Low-frequency preemphasis—A curve which conforms to the admittance of a paralleled resistor and inductor network with a time constant of 3180 microseconds.

Fig. 7—Magnetic-pickup frequency reproduction characteristic.



The playback system is adjusted to the inverse or complement of the recording curve. To determine the proper response characteristic, test records are recorded with known characteristics. By playing such a record and measuring the output voltage at the speaker coils, the amplifier circuit can be adjusted for a constant output with respect to the recorded characteristic (Fig. 7). With these characteristics the normal recording level, referred to as the 0-dB level, corresponds to a stylus velocity of approximately 5.5 cm/sec. at 1000 Hz.

PICKUPS

In general, pickups fall into two classes: those which measure displacement (e.g., piezoelectric crystal) and those which measure velocity (e.g., magnetic pickup).

A piezoelectric crystal develops an electric charge on certain crystal planes when the crystal is subjected to mechanical stress. Within limits, the voltage is proportional to the stress. When the crystal is coupled to the stylus through a torsion wire, the stress will be proportional to the displacement of the stylus. Although older crystal pickups used primarily rochelle salt crystals, ceramics such as barium titanate or lead zirconia titanate are now being used. Ceramics are more stable than rochelle salts, which are sensitive to humidity and temperature.

Magnetic pickups are of various types. In the moving-coil type, a coil is coupled to the stylus. This coil is in a permanent magnet field; movement of the coil in the field generates a voltage proportional to the velocity of the coil. In another design the magnet is coupled to the stylus and the motion of the magnet generates a voltage in a stationary coil. A third type is the moving iron or variable reluctance, in which the magnetic flux is changed by pickup motion.

Since magnetic pickups generate a voltage proportional to stylus velocity, the output-voltage frequency-reproducing characteristic must be modified to provide the response shown in Fig. 7. The output of magnetic pickups is in general two decades lower than that of crystal pickups, and it is customary to provide a preamplifier stage. The compensation network can be built conveniently into this preamplifier.

Crystal pickups are frequently used without compensation, particularly in lower priced phonographs. These pickups measure displacement, and no compensation is needed in the low-frequency range. Since high-frequency preemphasis is used in recording, adequate high-frequency response will be present without compensation.

STRESSES AND DEFORMATION OF A RECORD SURFACE IN PLAYBACK

In the playback of a disc-record sound groove, there is a problem of stresses and yield in the material due to the bearing weight of the pickup and the accelerations of the stylus. A brief summary of the present status is presented. The stylus can be viewed as a hard, inelastic, spherical indenter on an elastic surface. First, we shall examine the case of a horizontal surface and then consider the modifications necessary for a record groove. The general Herz theory of elastic contact will be specialized to the particular case where the radius of the elastic surface is infinite, and the modulus of elasticity of the spherical indenter is infinite.[3]

When a hard, relatively inelastic indenter is in contact with a horizontal elastic surface, the surface is deformed under the forces (Fig. 8). There is a region, denoted by radius r_o from the vertical z axis of symmetry, where the sphere and deformed surface are in contact. In this region forces between the indenter and elastic surface are assumed perpendicular to the contact surface; tangential components at the surface are assumed to be zero. At the outer edge of the area of contact, $r = r_o$, the normal pressure reduces to zero. Note that the surface is deformed beyond $r = r_o$.

Fig. 8—Hard indenter in contact with elastic horizontal surface.

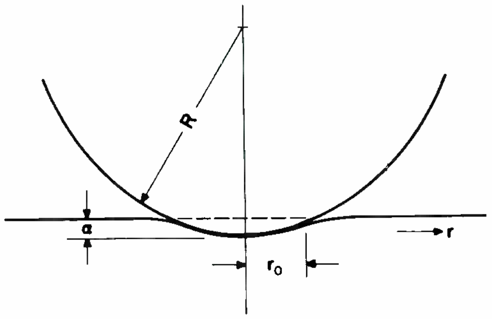
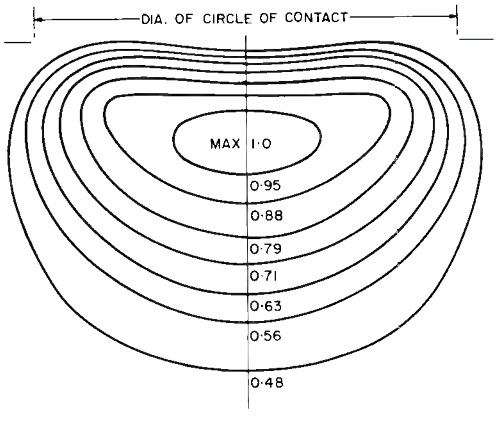


Fig. 9—Equation 16 represented as a contour plot of maximum shear stress under the surface of contact.



In the region of contact, $r < r_o$, the surface pressure is given by

$$P = P_o\left[1 - \left(\frac{r}{r_o}\right)^2\right]^{1/2} \qquad (9)$$

where P_o is the maximum pressure that occurs at the axis $r = 0$. This maximum pressure is given by

$$P_o = \frac{3w}{2\pi r_o^2} \qquad (10)$$

where W is the bearing load.

The radius of contact, r_o, is given by

$$r_o = \left[\left(\frac{3\pi}{4}\right) W \left(1 - \frac{\nu^2}{E}\right) R\right]^{1/3} \qquad (11)$$

where ν is Poisson's ratio, and E is the modulus of elasticity. If Poisson's ratio is assumed to be ⅓, a reasonable value, this equation reduces to

$$r_o = \left[\left(\frac{2\pi}{3}\right)\frac{WR}{E}\right]^{1/3} \qquad (11a)$$

The displacement or penetration, α, of the contact point into the surface is given by

$$\alpha = \left[\left(\frac{9\pi^2}{16}\right)\left(\frac{W^2}{R}\right)\left(1 - \frac{\nu^2}{\pi E}\right)^2\right]^{1/3} \qquad (12)$$

which reduces to

$$\alpha = \left[\left(\frac{4}{9}\right)\left(\frac{W^2}{RE^2}\right)\right]^{1/3} \qquad (12a)$$

with the assumption of $\nu = ⅓$.

The normal forces on the surface are supported by a stress distribution in the interior of the deformed material. The stresses, σ, in the material due to the pressure distribution on the surface are obtained by integration of the stresses due to concentrated loads over the contact surface. Thus in cylindrical coordinates z, θ, r,

$$\sigma_z = -\frac{P_o}{\left[1 + \left(\frac{z}{r_o}\right)^2\right]} \qquad (13)$$

$$\sigma_\theta = \sigma_r = \frac{P_o}{2}\left[\frac{1}{1 + \left(\frac{z}{r_o}\right)^2} - \frac{8}{3}\left(1 - \frac{z}{r_o}\tan^{-1}\frac{r_o}{z}\right)\right] \qquad (14)$$

The maximum shear stress at each point is given by

$$\tau_{\max} = \frac{(\sigma_\theta - \sigma_z)}{2} \qquad (15)$$

$$= \frac{P_o}{4}\left[\frac{3}{1 + \left(\frac{z}{r_o}\right)^2} - \frac{8}{3}\left(1 - \frac{z}{r_o}\tan^{-1}\frac{r_o}{z}\right)\right] \qquad (16)$$

Fig. 9 represents Equation 16 as a contour plot of maximum shear stress under the surface of contact. The maximum shear stress is found below the surface at approximately $z = 0.5r_o$.

The only modification to the equations necessary to apply them to the case of a stylus in a record groove is that the component of bearing load normal to the groove wall is proportional to $1/\sin\beta$ where β is equal to one-half the included angle of the groove. Since the load is supported by both groove-wall surfaces, the load on each groove wall will be one-half the total. Thus the bearing load becomes $W/2\sin\beta$. When this substitution is made in Equations 10, 11a, and 12a, the following equations result:

$$P_o = \frac{3W}{4\pi r_o^2 \sin\beta} \qquad (10a)$$

$$r_o = \left[\frac{1}{3}\frac{RW}{E\sin\beta}\right]^{1/3} \qquad (11b)$$

$$\alpha = \left[\left(\frac{1}{9}\right)\left(\frac{W^2}{E^2R\sin^2\beta}\right)\right]^{1/3} \qquad (12b)$$

To this point only the static bearing load has been considered. In addition, there are the dynamic loads from the reactive forces of the stylus acceleration. The stylus and its suspension has mass. In addition to the inertial mass, the stylus is supported by a suspension that acts as a spring exerting a force which tends to return the stylus to its center position.

TABLE I—Maximum Normal Pressure and Shear Stress in a 90° Groove Under a Spherical Stylus Load

Stylus (in.)	Radius (cm.)	Stylus Load (grams)	Maximum Normal Pressure*		Maximum Shear Stress*	
			(10^8 dynes/cm²)	(10^3 lbf/in²)	(10^8 dynes/cm²)	(10^3 lbf/in²)
0.001	0.0025	10	72.1	104.5	21.5	31.2
		5	57.2	83.0	17.0	24.7
		2.5	45.4	65.8	13.5	19.6
		1.0	33.4	48.5	10.0	14.5
0.0008	0.0020	10	83.6	121.2	24.9	36.1
		5	66.3	96.2	19.8	28.7
		2.5	52.6	76.3	15.7	22.8
		1.0	38.8	56.3	11.6	16.8
0.0006	0.0015	10	101.1	146.6	30.1	43.7
		5	80.2	116.4	23.9	34.7
		2.5	63.7	92.4	19.0	27.5
		1.0	47.0	68.1	14.0	20.3
0.0004	0.0010	10	132.6	192.4	39.5	57.3
		5	105.0	152.3	31.3	45.4
		2.5	83.6	121.3	24.9	36.1
		1.0	61.5	89.2	18.3	26.6

*Young's modulus used in calculations: 3.7×10^{10} dynes/cm²
Poisson's ratio assumed to be 1/3

The reaction to the accelerating force is given by:

$$F_a = M_s a_s \qquad (17)$$

where M_s = stylus inertial mass in grams
a_s = stylus acceleration in cm/sec²
F_a = reactive force on groove wall due to accelerating force of the wall on the stylus.

The reactive force on the groove wall by the spring can be written as:

$$F_s = Y/C_s \qquad (18)$$

where F_s = reactive force of the wall against the spring action of the stylus suspension in dynes
Y = radial displacement of the stylus in cm
C_s = compliance of the pickup suspension in cm displacement per dyne force.

Compliance of the stylus and pickup bearing weight are related in pickup design. Since the accelerating reactive force on the stylus is exerted by one groove wall at a 45° angle above the horizontal, this force tends to lift the stylus out of contact with the opposite groove wall. This can result in distortion and in extreme cases results in a rattle like sound in high-sound-level passages. From Equation 17 it can be seen that the inertial mass of the stylus assembly should be small to reduce the accelerating force. On the other hand, stylus compliance should be as large as possible to reduce the returning spring force. There is a trend therefore to the development and use of low-inertia, high-compliance pickups. Recent stereophonic pickups have compliances in the 1 to 3 × 10^{-6} cm/dyne range and are designed for use with a stylus bearing weight of 2 to 3 grams.

Because of the compliance term in the sum of forces acting on the pickup, there exist resonance frequencies. These frequencies are usually above 10 kHz. Damping blocks of a viscoelastic material are incorporated in the stylus mounting to reduce these resonances.

From the above relations, one can see that the forces on the record surface in playback are large, exceeding the ordinary elastic limit of the material. Table 1 shows resultant maximum normal pressure and sheer stress as calculated from the Hertz equations for static load. Add to this static load the additional acceleration reactive force, and one can see that the force on the groove walls, and its resultant deformation of the plastic under the stylus, can be appreciable.

It is also apparent from the relations that the stresses in the playback of records are appreciable. There are two explanations of the record's ability to withstand such stresses. One is the size effect in which the resistance to high stresses is attributed to the higher observed strength of materials as the volume or area of the test specimen becomes smaller.[9]

The second explanation relies upon the time-dependent or viscoelastic properties of plastics.[10] Plastics, as the name implies, are subject to time-dependent phenomena, such as creep, and its converse, relaxation. Because of these properties, stress waves are damped and do not reach the levels predicted by the Hertz equations.[11,12] In addition to the recovered relaxation, there may be permanent deformations of the groove wall under the stylus.[13]

From the above, one can see that many factors exist in the playback of records which will become more apparent as requirements become more critical.

DISTORTION IN DISC RECORDS

No discussion of disk records would be complete without consideration of the limitations imposed by geometry. However, since the subject is too extensive to treat adequately in this broad survey, we can only indicate the source of the problem and list a few of many references to the subject.

The groove cut by the recording stylus is described by the motion of the two cutting edges. These edges are in a radial plane with respect to the disc center. The playback stylus is a sphere whose motion is described by the constraints of the groove walls moving with constant angular velocity. The motion of the playback stylus, therefore, does not correspond to the motion of the cutting stylus. The deviation between the two motions is a function of groove curvature. Thus the distortion introduced by geometry is a function of wavelength and amplitude.[1,14,16] This provides an inherent limitation on groove velocity and amplitudes without introducing noticeable distortion. To overcome or minimize this distortion is the function of the dynamic stylus correlator part of the *Dynagroove** package.[17,18]

SUMMARY

In the disc record industry, which is old compared to the youthful electronics age, the art has been developed to a relatively high stage. Techniques have involved materials, processing, recording and playback. All of these can be seen to be related to the current results obtained. Continued improvement in all these aspects is to be expected. It is therefore premature to consider the disc record at the peak of its development.

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*RCA trademark.

THE RCA VICTOR DYNAGROOVE SYSTEM

The Dynagroove sound system is the culmination of RCA's efforts to "bring the concert hall into the American living room." This paper discusses the four principal elements of the Dynagroove system—the dynamic spectrum equalizer dynamic stylus correlator, vertical tracking, and engineered acoustics—and other considerations involved in the development of Dynagroove.

D. L. RICHTER, Mgr.
Recording Engineering
RCA Victor Record Div., New York City

A discussion of the RCA Victor *Dynagroove** system could easily deteriorate into a technical "snow job," since there are 18 points of emphasis concerning the technical development that encouraged the RCA Victor Record Division to attempt to bring the concert hall into the American living room—figuratively speaking, of course.

Many people in the division had been thinking about this concept for some time. To bring the concert hall into the living room is something more than the ability to reproduce highs and lows, something more than signal-to-noise ratio and frequency response, something more than power-density curves and loudness controls. It is all of these things and more, technically, because the purpose is to display the brilliance of the artistry in the living room to the full extent of the state of the electronic, acoustical, chemical, mechanical, and molding arts. To do this realistically, the artists were also made a part of the program.

Technically, the development of *Dynagroove* involved four principal elements: the dynamic spectrum equalizer, the dynamic stylus correlator, vertical tracking, and engineered studio acoustics. These developments were matched in importance by artist participation and by the introduction into the market place, by RCA's Home Instruments Division, of stereo and monaural record players capable of reproducing *Dynagroove* satisfactorily in the home. The *Dynagroove* sound system is depicted in Fig. 1.

THE DYNAMIC SPECTRUM EQUALIZER

The dynamic spectrum equalizer is a signal processor that continuously, dynamically, and automatically compensates for the loudness, frequency response, and dynamic differences between the living room and the concert hall.

Final manuscript received May 23, 1966
*Registered trademark of RCA

DONALD L. RICHTER received his BSEE degree from Iowa State College in 1943. During World War II, he served 4 years in the Signal Corps as a radar maintenance officer. He joined RCA in 1947 as Inspector, Quality Control Recording and became Quality Manager for the RCA Victor Record Division in 1950. In 1957 he was named Administrator, Audio Engineering. He was appointed to his present position as Manager, Recording in 1960. Mr. Richter holds two patents, one for "Gruve Guard" and the other on the dynamic-spectrum-equalizer principle. He is a member of AES and NARAS.

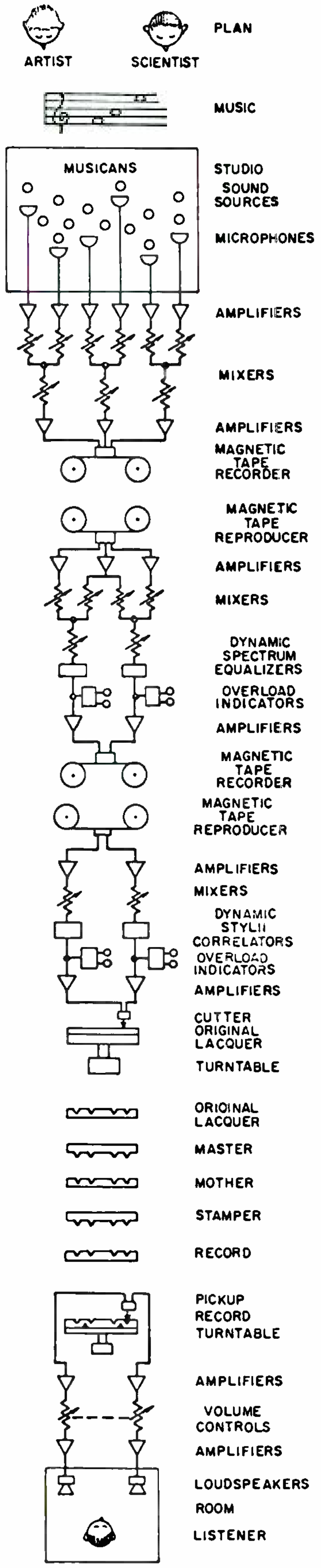


Fig. 1 — Simplified flow chart of the system from the recording to the reproduction of music.

These differences are so great that if a record produced with clarity, presence, low nonlinear distortion, uniform transfer characteristics, and all the other desirable attributes of a great recording is reproduced on a home instrument in a living room, it will not sound like the original music.

There are basic reasons for this. The sound level of a concert hall can exceed 120 dB, but music is seldom reproduced in the home at a level higher than 85 dB. In addition, the average ambient noise level in the home is 45 dB for the frequency range of 30 to 15,000 Hz (cps). Subjective tests have shown that the perceived loudness of a sound at a certain level in a small room is greater than the perceived loudness for the same level in a large hall. In view of this, the time-honored statement that "music must be heard at the same loudness at which it was performed in order to perceive the proper quality of that music" becomes meaningless for the home.

The practical answer had to be found other than in the direction of larger and quieter living rooms. The use of a loudness control was not the answer; although it could be used to emphasize the lower and higher frequencies when the volume was reduced, it had no dynamic discrimination between loud and soft music. The dynamic spectrum equalizer, on the other hand, operates in a continuous manner to change the response frequency characteristic as a function of amplitude but correlated to the loudness versus intensity relation in hearing, the frequency response of equal loudness in hearing, and the reverberation characteristics of the average home. These three

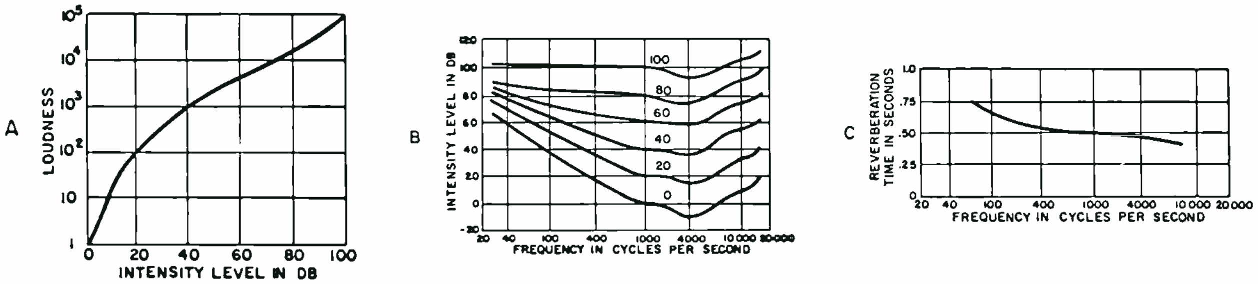


Fig. 2 — Reverberation characteristic of average home. The following characteristics are equalized and compensated by the dynamic spectrum equalizer: a) loudness perception for the average person as a function of sound intensity; b) frequency response of equal loudness; c) reverberation characteristics of typical living room.

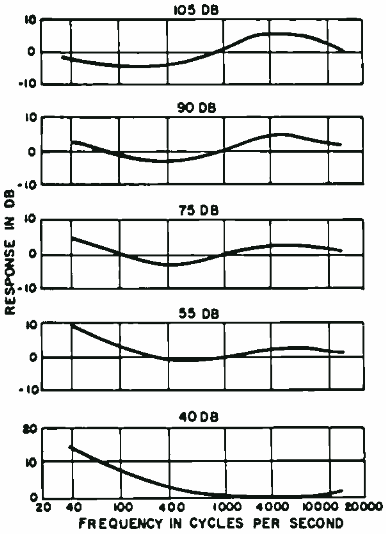


Fig. 3 — Frequency response of dynamic spectrum equalizer at various sound levels.

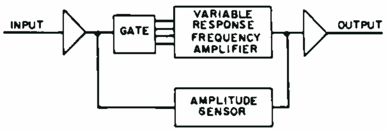
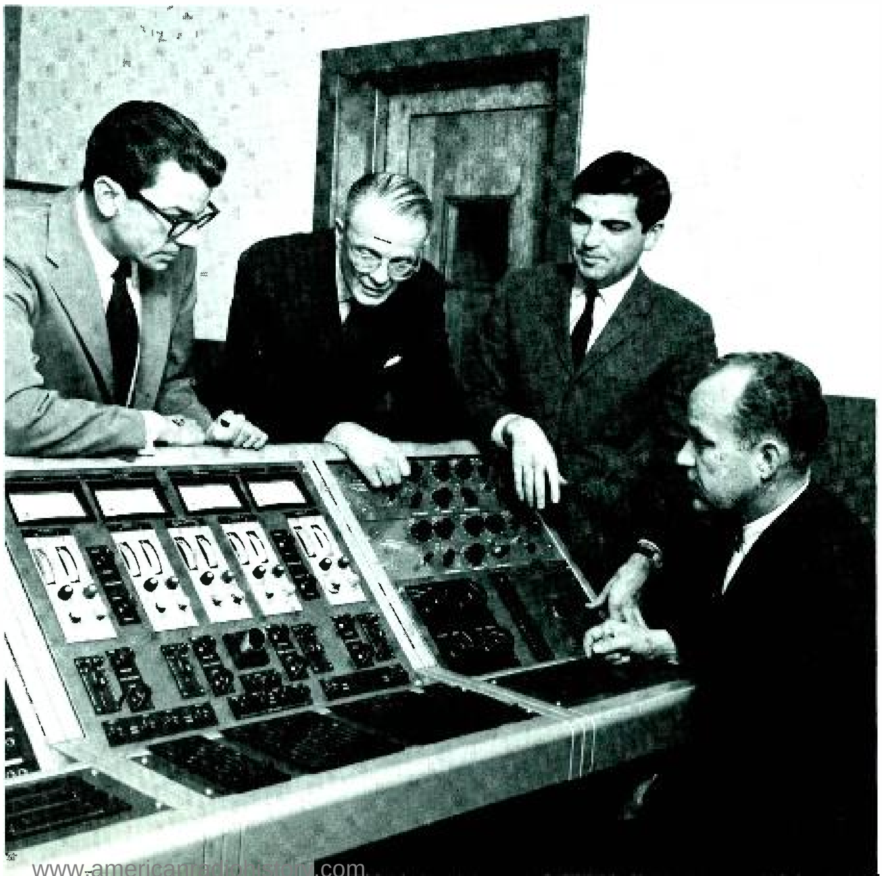


Fig. 4 — Block diagram of dynamic spectrum equalizer.

Fig. 5 — Recording console, including dynamic spectrum equalizer. L. to R.: J. Pfeiffer, G. Marek (Vice President and General Manager), J. Somer, and author D. L. Richter, all of the RCA Victor Record Division. See "Acknowledgments" at end of article.)



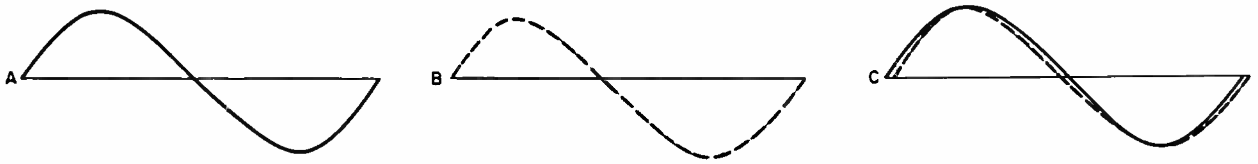


Fig. 7 — Display of phase shift produced by difference in geometry of chisel-type lacquer-cutting stylus and ball-tipped stylus of playback pickup.

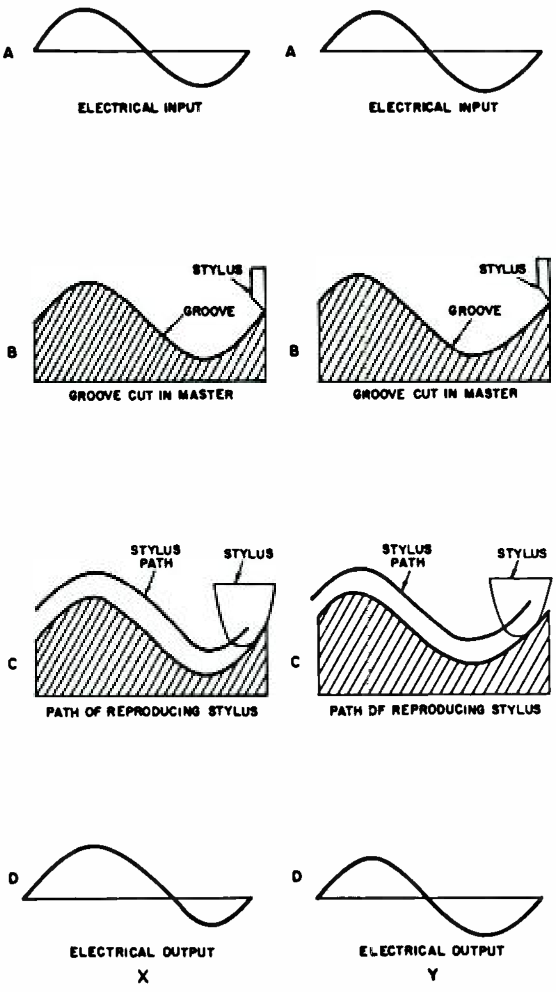


Fig. 6 — Relationship between recorded and reproduced signal in disc recording; *X* is normal uncorrelated output, *Y* is correlated output.

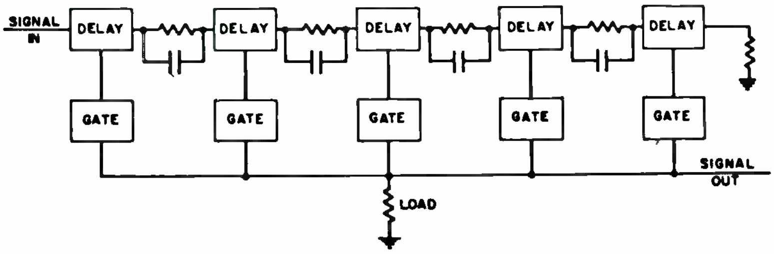


Fig. 8 — Block diagram of dynamic stylus correlator.

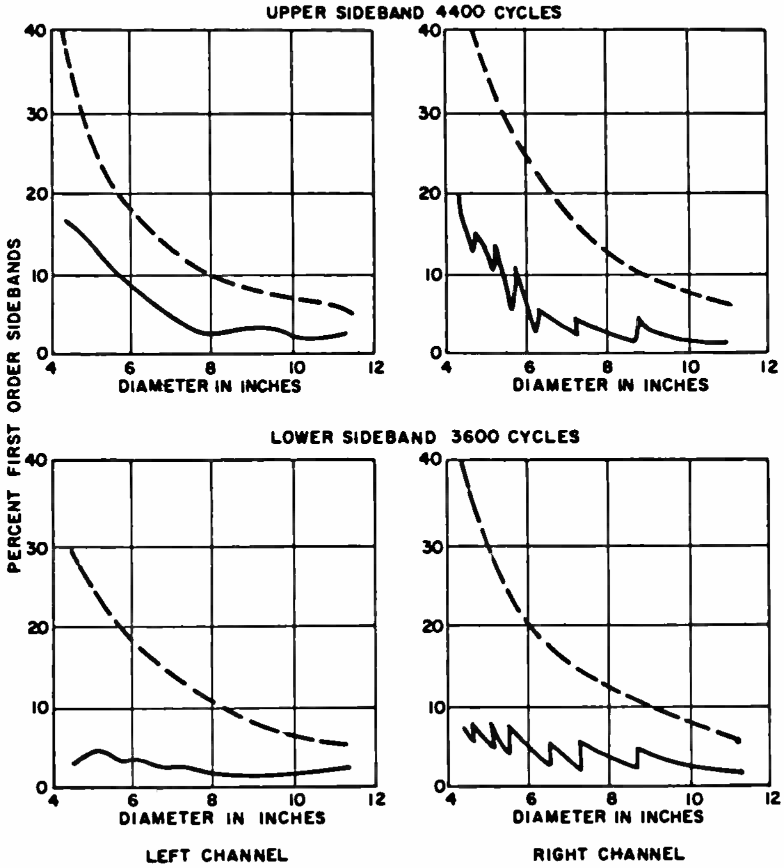


Fig. 9 — Intermodulation distortion as a function of diameter. Dashed line shows the normal; solid line indicates results obtained with dynamic stylus correlator.

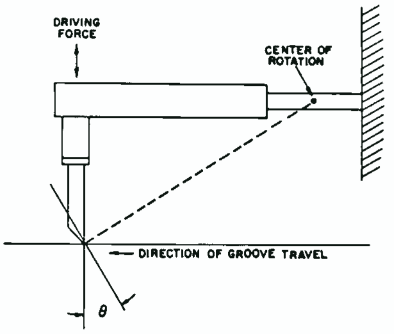


Fig. 10 — Geometry of cutter stylus suspension.

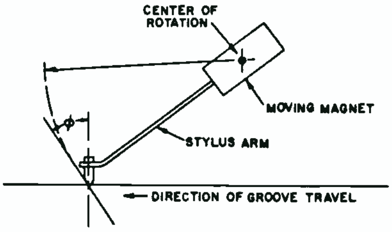


Fig. 11 — Geometry of playback stylus suspension.

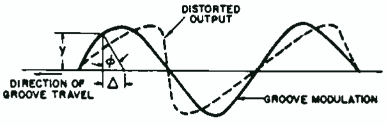


Fig. 12 — Distortion produced when effective tilt angle of cutter does not correspond to vertical tracking angle of playback stylus.

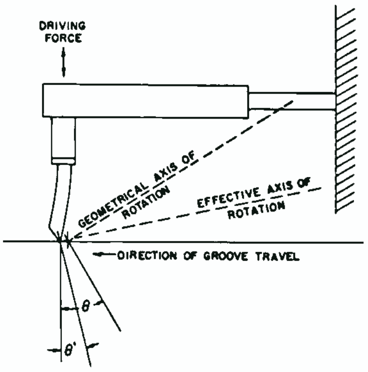


Fig. 13 — Change in rotation axis produced by loading of cutter by lacquer.

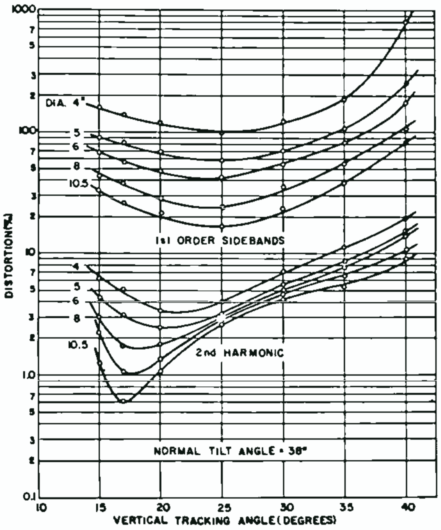


Fig. 14 — Distortion produced by various vertical tracking angles with normal cutter tilt angle.

considerations are shown in Fig. 2. Typical frequency response characteristics of the dynamic spectrum analyzer are shown for various levels in Fig. 3, and a block diagram of the unit is shown in Fig. 4. In operation, the dynamic spectrum analyzer accentuates the lows when the level is low; for medium levels, the low-frequency region below 400 Hz and the presence region between 2000 and 6000 Hz are slightly accentuated; for high sound levels the response is accentuated in the presence region.

This procedure enhances the dynamic balance of sound reproduction in a small room. The soft passages of music are given full body and minute detail; the loudest sections of the music are projected with extreme intensity. Consequently, the listener perceives in his home the dramatic impact and intense realism of the music from *Dynagroove.* Fig. 5 is a photograph of the dynamic spectrum equalizer.

THE DYNAMIC STYLUS CORRELATOR

The original master is cut with a chisel-type stylus. A ball-tipped stylus is used to reproduce the record in the home. Since the pickup stylus does not reproduce the motion of the cutting stylus, particularly at short wavelengths, the dynamic stylus correlator compensates for this by insuring that the output signal from a ball-tipped stylus riding in the record groove is a replica of the signal that drove the chisel-type stylus used to cut the groove in the original lacquer. This is done by predistorting the signal used to cut the lacquer. In the progression of diagrams in Fig. 6, x indicates the extent of the distortion encountered, and y shows the effectiveness of the correction.

Analysis showed the error to be a phase-shift distortion (Fig. 7). The schematic of the delay line approach used for correction is seen in Fig. 8. A typical case applying a combination of a 400- and a 4000-Hz tone to the cutter with and without the correlator showed distortion reductions of 6 to 1 at the inner grooves of the record (Fig. 9).

VERTICAL TRACKING

For distortionless performance, the vertical modulation of the cutter stylus in recording sound must be the same as that of the stylus reproducing the sound. The problem is that the cutter stylus must remove material from the lacquer, whereas the reproducer stylus rides the groove. The cutter stylus deflects—bends—under the load; the reproducer stylus does not bend. (See Figs. 10 through 13.) Tests were made, and it was found that 17° was the pickup vertical tracking angle that yielded the lowest nonlinear distortion. The results are shown in Fig. 14. It was found that the particular cutter stylus bent as much as 21° in recording. A corresponding tilt angle was introduced in the cutter mount to compensate for this condition and to provide the optimum vertical modulation angle as the effective cutter angle (Fig. 15). Cutters developed as the result of this work in the industry now have design accommodations for this loading factor.

ENGINEERED STUDIO ACOUSTICS

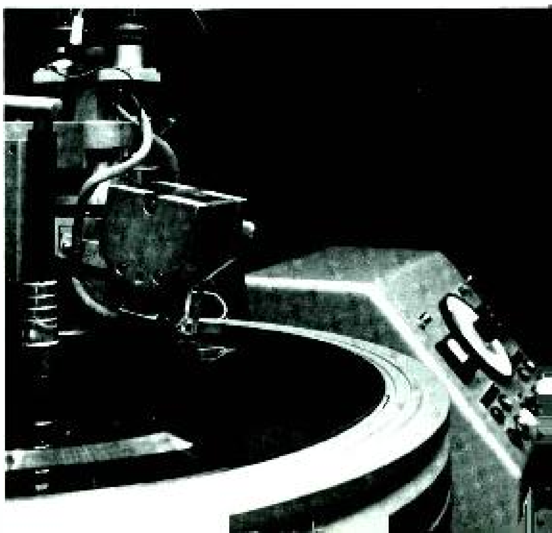
In a sense, the recording studio is the first transducer that the sound encounters. It is not surprising that full attention was paid to its critical characteristics, including its transfer characteristics. In this work, studies indicated that the significant information on the acoustics of an enclosure used for recording is the growth and not the decay reverberation characteristic that had been assumed in the past. An examination of the energy density curves in Fig. 16 shows the relative importance of growth and decay as a function of time. The acoustic design of the studios are affected by this consideration.

The transfer characteristics of the studios were explored and all anomalies in the sound pickup systems that were attributed to acoustics were eliminated by tracing the envelope of the transfer characteristic and examining it for sharp spikes or dips (Fig. 17A). The success with which this task was accomplished is shown in Fig. 17B. Growth and decay reverberation and transfer characteristics were obtained for all studios, and all frequency accentuations or discriminations were eliminated.

OTHER WORK

The artist and the engineer work as a team to produce the maximum impact upon the listener in his home. The story of RCA's recording of *Lohengrin* with the Boston Symphony Orchestra is told elsewhere.[5] Instruments or vocal soloists are featured by prearrangement and the

Fig. 15 — Cutter head tilt.



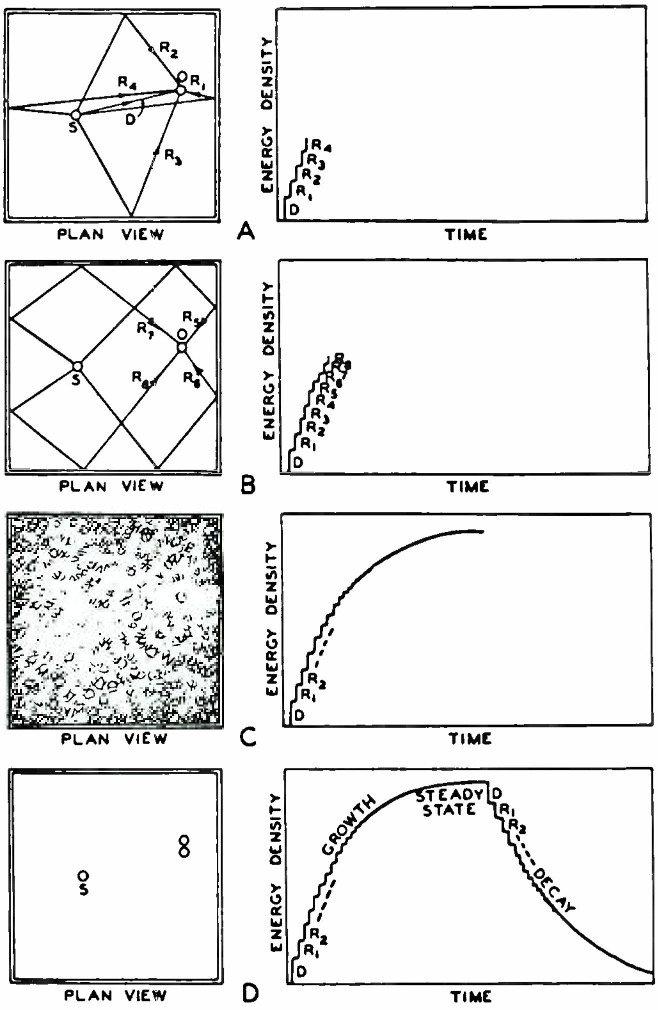


Fig. 16 — Energy density curves related to source (S) and reflected sound to observer (O) through direct sound (D) and various reflections (R. . .) showing predominance of growth characteristics.

planned effect is obtained within whatever dynamic range limitations the circumstances impose. The directional patterns of the microphones, their sensitivity, and their frequency range must be matched to that of the instruments and the performers. Microphone placement is even more important in stereo recordings. The capacity of a microphone to handle a sound level of 130 dB with less than 0.1 percent nonlinear distortion over a frequency range of 30 to 15,000 Hz requires that precise care be given in every aspect of its use. Circuitry for *Dynagroove* was optimized for every application.

The magnetic tape for the original recording was used at 30 in/s instead of the usual 15. The gain from this was twofold: one in signal-to-noise, and the other in wow and flutter. The tape itself was further developed for higher retentivity and a lower noise level. Heavier base material was used for the tape in order to guard against print-through.

New and more convenient master recording consoles were designed, peak indicators were improved, and transfer recording consoles were modified. A recording overload indicator was designed for monitoring the maximum allowable signal that can be applied to the cutting of the master stereophonic disc record. Overloading that might occur in the high-frequency range is presented separately from that which occurs in the low-frequency range. Also, much work was done in revising and updating amplifiers to assure adequate driving power without distortion. Simultaneously, developments were completed to improve the compounds from which the record for the home is molded.

The decision to produce home instruments that would meet the performance standards of professional broadcasting associations made *Dynagroove* a corporate achievement. *Dynagroove* indicates consistency of purpose throughout the years; from the day that Little Nipper first sat before the Gramophone to today, that purpose has been the faithful reproduction of "His Master's Voice."

ACKNOWLEDGMENTS

The *Dynagroove* concept was initiated, developed, directed and implemented by George Marek, Vice President, RCA Record Division. In a project of this magnitude, it is impossible to list all those who contributed to its success. Those intimately concerned with the artistic elements and tasks of the *Dynagroove* project include John Pfeiffer and J. A. Somer of the RCA Victor Record Division. Those intimately concerned with the scientific elements and tasks of the *Dynagroove* project include: A. L. McClay, H. E. Roys, R. C. Moyer, and D. L. Richter of the RCA Victor Record Division; and H. F. Olson, J. G. Woodward, John Volkmann, E. C. Fox, and R. W. George, of the RCA Laboratories.

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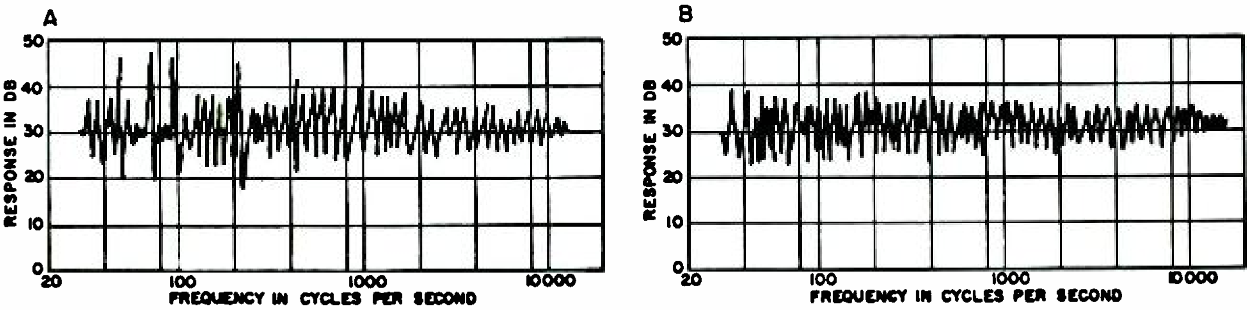

Fig. 17 — A) Transfer characteristics of typical studio with sharp spikes and dips.
B) Transfer characteristics with anomalies removed by engineering the acoustics.

RESEARCH IN SOUND REPRODUCTION

An Introduction

Dr. H. F. OLSON, Staff Vice President
Acoustical and Electromechanical Research
RCA Laboratories, Princeton, New Jersey

The reproduction of sound is the process of picking up sound at one location and reproducing it at the same location or some other location, either at the same time or at some subsequent time. The most common sound-reproducing systems are the telephone, phonograph, radio, sound motion picture, television, hearing aids, reinforcing, and intercoms. Sound reproduction may be divided into two categories: the transmission of intelligence by menas of speech and high-fidelity reproduction of voice and music. The main objective in speech transmission is to provide the highest order of intelligibility; in high-fidelity reproduction the main purpose is to provide the listener with the highest order of artistic and subjective resemblance to the "live" rendition. To achieve the latter objective requires optimum physical performance of the equipment as directed by the psychological factors involved in the process.

Sound reproduction involves both objective and subjective considerations of the mechanisms and phenomena required to achieve a high order of performance. From the objective viewpoint, sound reproduction is a complex process because a large number of acoustic, mechanical, and electronic elements and combinations thereof are involved. The performance of these elements must be of a very high order to achieve a resemblance to a perfect transfer characteristic. In general, the state of the art in sound reproduction has advanced to where a high order of physical performance can be obtained if cost is not a consideration. Therefore, future efforts in this area must be directed toward achieving excellent physical performance in the lower cost instruments. In addition, there is always the challenge of improving the objective characteristics of the elements, because every advance is a significant step toward the ideal in performance.

From a subjective viewpoint, sound reproduction is a complex process because a large number of psycho-acoustic effects are involved. These effects must be used appropriately to produce an ideal transfer characteristic that supplies a close artistic resemblance to the live rendition.

Until very recently, the application of the psychological characteristics to sound reproduction has lagged far behind physical considerations. The commercialization of stereophonic sound in the consumer complex has accelerated the work in the subjective aspects of sound reproduction.

Recent work in the field of psychological acoustics, as related to the performance of a sound reproducing system, involves the following subjects: tolerable sound pressure levels; sound pressure level and ear frequency response; loudness and dynamics; dynamics, noise, and masking; auditory perspective; reverberation; quality and timbre.

The growth, duration, decay, and reverberation characteristics as perceived by the listener involves the combination of two rooms. Here the objective is to provide an overall growth, duration, decay, and reverberation characteristic that provides the listener with a subjective impression of these properties that resembles the live rendition. Since these characteristics in the average room in the home play a minor part in the impression of the reverberant sound, the design of the studio and the placement of the microphones are the important considerations.

DR. HARRY F. OLSON received the BS, MS, PhD, and EE degrees from the University of Iowa, and an honorary DSc degree from Iowa Wesleyan College. He has been affiliated with the research department of RCA, the engineering department of RCA Photophone, the research division of RCA Manufacturing Co., and RCA Laboratories, where he is Staff Vice President, Acoustical and Electromechanical Research. He holds more than 100 U. S. patents and has written numerous papers and books, including Elements of Acoustical Engineering, Acoustical Engineering, Dynamic Analogies, and Musical Engineering. He is a past president of the Audio Engineering Society (AES) and the Acoustical Society of America (ASA) and past chairman of the Administration Committee of the IRE Professional Group on Audio. He has been honored with awards from the AES, Society of Motion Picture and Television Engineers (SMPTE), Professional Group on Audio of the IRE, and American Society of Swedish Engineers. He is a Fellow of the IEEE, SMPTE, American Physical Society, and ASA. He is a member of Tau Beta Pi, Sigma Xi, National Academy of Sciences, and an honorary member of the AES.

The auditory perspective of the reproduced sound should approximate that of the best location in the standard live condition. To achieve this result requires the correct placement of microphones in the pickup of the sound and the appropriate separation of the loudspeakers in the reproduction of the sound.

The quality of the reproduced sound must be preserved in reproduction; therefore, all the characteristics of the musical instruments must be faithfully reproduced. Technical data relating to the characteristics of musical instruments must be employed to provide faithful reproduction of voices and instruments.

The dynamics of the sound, which involves the relation between the subjective and objective aspects of the amplitude of the sound, should simulate the live condition in the reproduced sound. A very important consideration relating to sound dynamics is the subjective effect of the approximately 20-dB drop in sound level between the level of the live program and the tolerable level of the reproduced sound. Since the frequency response of the human hearing mechanism is a function of the sound level, suitable dynamic frequency response compensation as a function of the amplitude must be introduced by appropriate electronic means.

The preceding exposition has shown that sound reproduction involves both objective and subjective considerations in the mechanisms and phenomena required for high-fidelity performance. From an objective viewpoint, sound reproduction is a complex process involving a large number of acoustic, mechanical, and electronic elements and combinations thereof. The performance of these elements must be excellent to provide a resemblance to a perfect transfer characteristic. From a subjective viewpoint, sound reproduction is a complex process because a number of psycho-acoustic effects are involved. These effects must be used appropriately to produce an ideal transfer characteristic that closely resembles the live condition.

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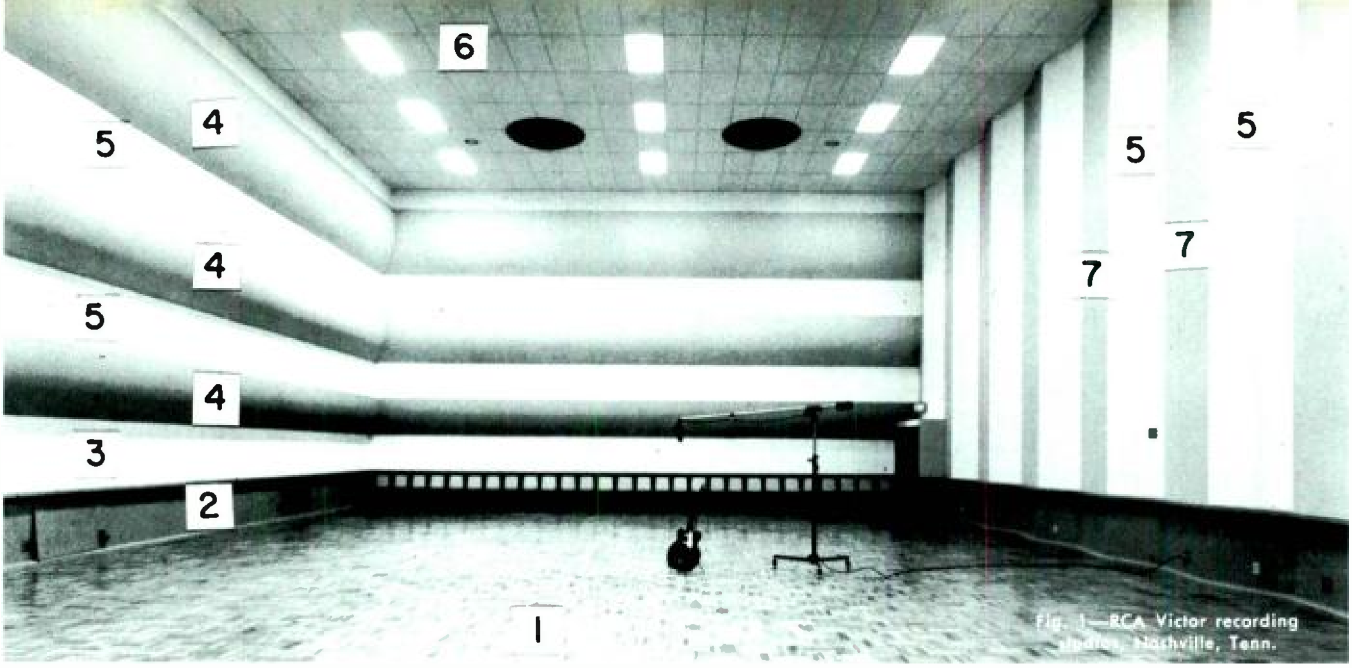

Fig. 1—RCA Victor recording studios, Nashville, Tenn.

ACOUSTIC REQUIREMENTS OF STEREO RECORDING STUDIOS

The basic requirements of good acoustic design for a stereo recording studio are considered from the viewpoints of control of the early reflected energy and control of the direct and reverberant energy components in the studio space. Control-room acoustics and monitoring loudspeakers are also discussed.

J. E. VOLKMANN
Acoustical and Electromech. Research
RCA Laboratories, Princeton, N.J.

THE NEED for greater acoustic separation between acoustic pickups of musical groups in the stereo recording of popular (*pop*) music has resulted, among other things, in an increased use of close-up directional microphones, lower reverberation times, and larger studios in order to achieve higher ratios of direct to indirect sound energy levels. Use is also made of reflecting surfaces that direct energy primarily toward the musicians, rather than toward the microphones, to improve the audibility and liveness effect for the musician who is otherwise under a "dead" environment. Close microphone pickup and lower reverberation times require flat response characteristics. Accordingly, a flat reverberation characteristic, ideal for recording purposes, is again emphasized. A uniform reverberation time implies higher than normal absorption coefficients at lower frequencies, which, in turn, help to suppress standing-wave phenomena and acoustic cross talk at frequencies where maximum isolation is more difficult to achieve.

BASIC REQUIREMENTS FOR GOOD STUDIO ACOUSTICS

In the design and analysis of any room for good acoustics—be it studio or auditorium, large or small, active electronic acoustics or passive natural acoustics—three major energy components[1] in the general room acoustic equation should be fully considered: the original direct energy, the early growth or reenforcement energy, and the later diffuse or reverberant energy. Ideally, all three components should be uniform in response-frequency characteristics, in energy ratios between them, and in sound level distribution over the listening or pickup areas. In the case of the passive or natural acoustics of an auditorium or large space, it is usually very difficult to achieve uniform distribution of the direct energy component, without elevating the sound source itself, because of its nondirectional characteristics. However, where active electronic room acoustics are involved, it is reasonably easy to control the uniform distribution of all three energy components, and with proper design, active electronic room acoustic elements often can be blended with the natural acoustic elements of the space for a simple integrated solution.

With these general acoustic principles in mind, the engineers at RCA Victor Record Division designed a number of new studios[2,3] during the past few years in connection with the program of "new sound" improvements that culminated in the introduction[4] of *Dynagroove.** The new studios are in Rome, Italy; Hollywood, California; and Nashville, Tennessee.

SHAPE AND ACOUSTIC DESIGN FEATURES OF STUDIO

The RCA Nashville studio is shown in Fig. 1. The numbers in the picture refer to the tabulation of absorption coefficients given in Table I and to items parenthetically numbered in subsequent paragraphs.

Final manuscript received May 16, 1966.

* *Registered trademark of RCA*

JOHN E. VOLKMANN attended the University of Illinois, where he received his BS (1927) and MS (1928) degrees and a Professional Degree (1940) in Engineering Physics. Since joining RCA he has worked continuously in the field of acoustics, specializing in large-scale auditorium loudspeakers and stereophonic sound systems. He also has served as a consultant on architectural acoustics and electronic room acoustic problems. He has contributed to: stereo sound systems for Radio City Music Hall and Hollywood Bowl; recording acoustics for Walt Disney's "Fantasia"; custom loudspeakers for the New York World's Fairs and the Jones Beach Marine Stadium; and the acoustic design of RCA Italiana's 364,000-ft³ studio A, believed to be the largest and the first ever built specifically for the recording of full-scale operas and large symphonic orchestras. Mr. Volkmann is a member of the Technical staff of RCA Laboratories, Princeton, N.J. He is a fellow of the SMPTE, the ASA, and the AES.

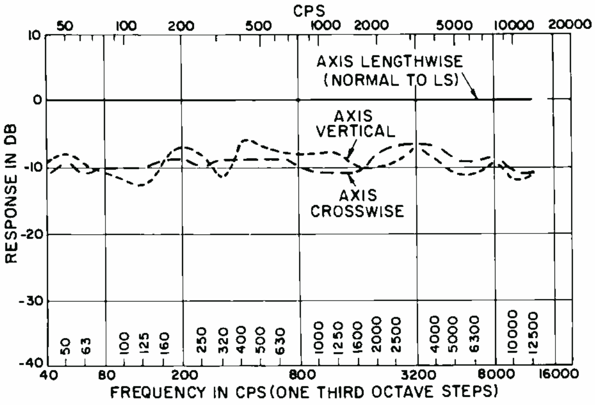

Fig. 5—Relative "orthogonal" acoustic response in Nashville studio A with pressure gradient microphone.

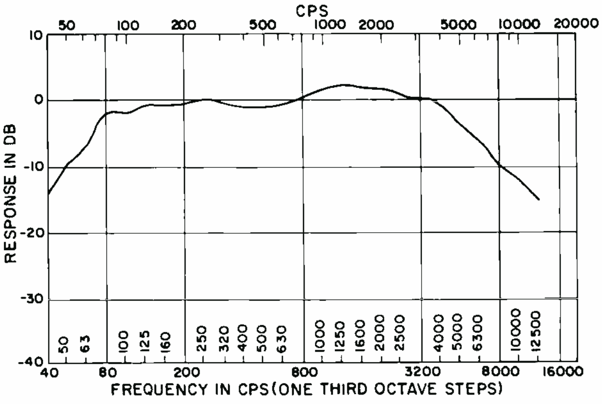

Fig. 6—Average acoustic response at console in Nashville studios (average of three rooms).

The structural shell of the Nashville studio is approximately 75 ft. x 50 ft. x 25 ft. with an internal cubical content of approximately 78,000 cu. ft. The floor (1) is parquet wood cemented to concrete.

To complement the high reflectivity of the floor, the entire ceiling (6) is made sufficiently absorptive to give an average coefficient in the vertical orthogonal plane similar to the average coefficient in the other two orthogonal planes, hence providing a uniform decay rate in all three (orthogonal) planes. The high coefficient of the ceiling (approximately twice the room average), which also eliminated the need for shaping the ceiling to suppress standing-wave resonance between floor and ceiling, provides complete freedom in microphone orientation and maximum isolation between pickups of instrumental groups. Since the ceiling height usually is the shortest dimension of a studio, the floor and ceiling (without absorption) are most vulnerable to standing-wave reflections (resonances).

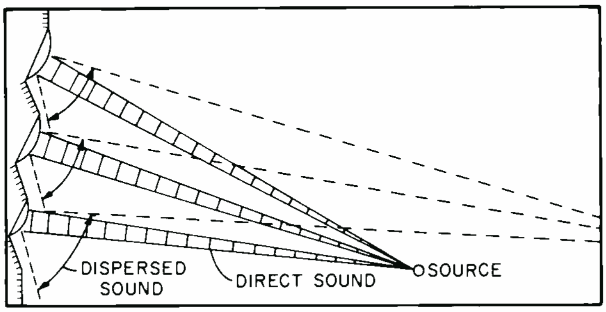

Fig. 2—Dispersion effect of convex panels.

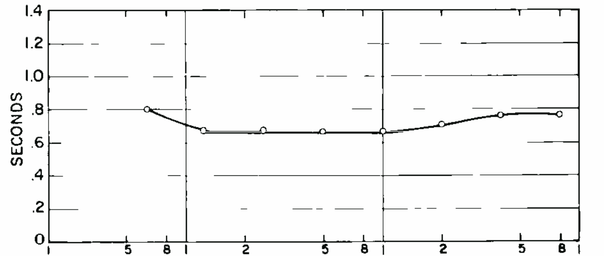

Fig. 3—Reverberation characteristic for Nashville studio.

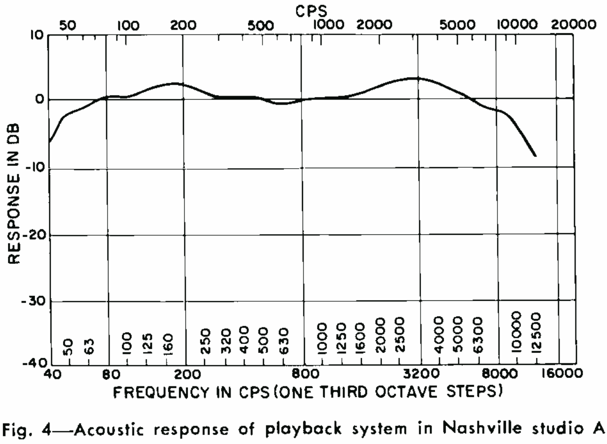

Fig. 4—Acoustic response of playback system in Nashville studio A.

One side wall and the end wall opposite the control room have three convex wood panels (4) disposed horizontally and tilted inward at such an angle as to direct most of the reflected energy downward toward the musicians' area. Thus, the energy incident on the panels from any one instrument is reflected back not just to one musician or localized area, but to all the musicians. This dispersion effect is shown in Fig. 2. The convex wood paneling (4) consists of two ¼-inch laminations of plywood backed with a 2-inch thickness of glass fibre blanket having a density of 2 lb/ft^3. The dispersive action of the convex paneling helps reduce the effect of sound-wave interference at the microphone.

The remainder of the two walls above the wainscot level consists of ¾-inch acoustic tile (3) (5). These surfaces are angled approximately 7° and spaced from the block wall at varying distances of 18 to 48 inches. The wainscot (2) consists of ¼-inch perforated plywood furred out 4-inches and backed with 2-inch glass-fibre blanket. For a diversification of materials, the acoustic tile (3) on the section just above the wainscot has a slightly different absorption characteristic than the remaining tile.

The other side wall (Fig. 1) consists of serrated vertical absorbing panels consisting alternately of acoustic tile (5) and perforated plywood (7) similar to the tile and plywood on the opposite wall. The horizontal disposition of panels on the one wall and the vertical disposition on the other aids the rapid diffusion of sound in the studio.

The end wall against the control room (not shown in Fig. 1) is treated with acoustic tile above the wainscot. The wainscot is of perforated plywood, spaced, and backed with glass-fibre blanket, similar to the other walls in the studio. The glass in the control room windows is tilted inward to deflect the sound downward.

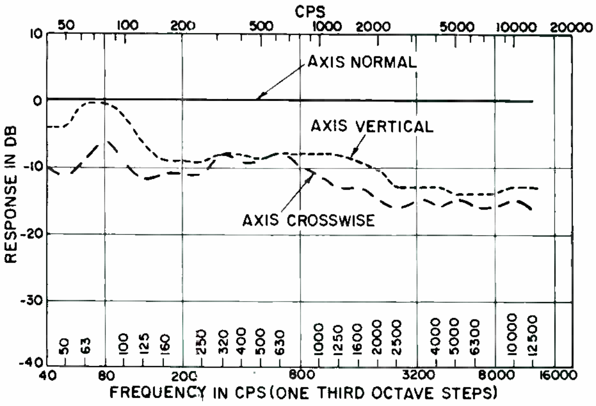

Fig. 7—Relative "orthogonal" acoustic response at console in control room of Nashville studio A.

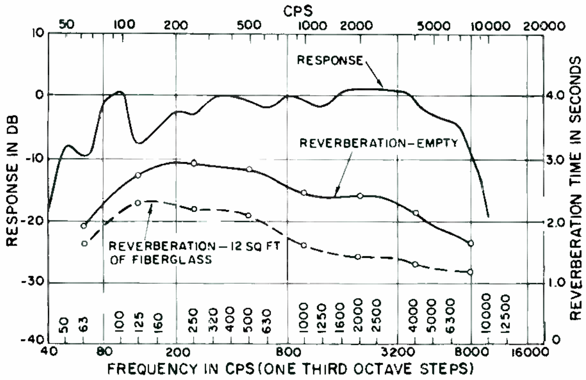

Fig. 8—Reverberation chamber No. 5, RCA Victor Studios, Hollywood, Calif.

MEASURED REVERBERATION AND RESPONSE CHARACTERISTICS OF STUDIO

As mentioned previously, a uniform reverberation time-frequency characteristic is preferred for stereo recording studios to aid in low-frequency acoustic separation and to maintain a natural frequency balance. Any embellishment or modification of characteristics should be done at the mixer console or in the rerecording process on the tape master.

The degree to which a flat reverberation characteristic was achieved for the Nashville studio (Fig. 3) is representative of the requirements for pop-music studios and close-in microphone pickup techniques. This is a much lower time than usual for a studio of 78,000 ft^3. A more live characteristic, of course, is still in vogue for strictly classical recordings, where the optimum reverberation of the hall or studio is usually incorporated in the original tapes.

The acoustic response of the playback loudspeaker system in the studio is shown in Fig. 4. Fig. 5 shows the degree to which the studio maintains a uniform ratio of direct to indirect energy levels in the three orthogonal planes of the studio as measured with a pressure-gradient microphone oriented with the axis lengthwise (normal to loudspeaker system), crosswise, and vertical to the studio center line. The fact that the three orthogonal response curves are similar in shape and that the crosswise and vertical curves are similar in level confirms the uniformity of reverberation (and hence absorption) characteristics in the three orthogonal planes. A random noise signal of one-third octave bandwidth was used in these measurements.

CONTROL ROOM CHARACTERISTICS

It is essential, for effective monitoring, that the overall acoustic performance characteristic of the monitoring loudspeaker system and room acoustics be as nearly uniform as possible. Fig. 6 shows the average of the response frequency characteristics measured with a sound level meter at the console in three rooms, using a random noise signal of one-third octave bandwidth to feed the monitoring loudspeaker systems.

To maintain a high ratio of direct to indirect energy at the console, the monitor loudspeakers must be placed no farther than 8 to 10 feet from the mixer's ears.

The degree of direct to indirect energy levels attained in the three orthogonal planes at the console in the control room of the Nashville studio "A" is shown in Fig. 7. A high ratio is required to properly gauge stereo perspective, recording errors, etc. A minimum ratio of 6 dB between the normal and 90° components is considered necessary for satisfactory auditory discrimination.

The reverberation time in the control rooms was too low to measure accurately with a high-speed level recorder.

REVERBERATION CHAMBER CHARACTERISTICS

The reverberation time and response-frequency curves of the reverberation chambers at the Hollywood studios is shown in Fig. 8. The dashed line shows the effect of acoustic padding used for adjusting the time. The amount of acoustic padding required for other reverberation times is tabulated in Table II.

CONCLUSIONS

It is essential in stereo recording studios to retain first reflections for the benefit of musicians while attaining greater acoustic separation and higher ratio of direct to indirect energies through the use of shorter reverberation times and larger volumes. Good studio acoustics require uniform (flat) ratios between the direct energy, the early growth or reenforcement energy, and the later reverberant energy components which comprise the complex energy wave in all room acoustics. These refinements have been applied in the design of a current studio. The acoustic performance of the type of studio described has received enthusiastic acceptance by recording engineers, artists and repertoire personnel, and clients.

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TABLE I—Tabulation of Absorption Material Coefficients in Nashville Studio.

Material	Absorption Coefficient 125 ~	 500-1000 ~	 4000 ~
Wood (parquet)	0.05	0.03	0.03
perforated plywood (¼-in.) with 2-in. acoustic blanket	0.60	0.40	0.25
acoustic tile—type A (¾-in.)	0.63	0.79	0.93
convex plywood (½-in.) with 2-in. acoustic blanket	0.30	0.18	0.10
acoustic tile—type B (¾-in.)	0.75	0.83	0.82
acoustic tile—type C (¾-in.)	0.76	0.78	0.78
perforated plywood (¼-in.) with 2-in. acoustic blanket	0.60	0.40	0.25

TABLE II—Reverberation Time Versus Area of Absorbing Material in Reverberation Time.

Square feet of batts (coef. 0.8)	0	4	6	16	34
Reverberation time of chamber in seconds	3.0	2.5	2.0	1.5	1.0

SUBJECTIVE ASPECTS OF STEREOPHONIC PERSPECTIVE

To create a realistic illusion of sounds in space, a stereophonic sound reproduction system must provide two independent channels, identical in frequency response and gain. Any departure from these requirements will distort the auditory perspective. This paper describes the process by which the illusion of auditory perspective is produced.

Dr. D. S. McCOY, Head
Electro-Acoustics Research
RCA Laboratories, Princeton, N.J.

THE appreciation of music is a highly personal and subjective experience, regardless of the manner of presentation. Each person listens for and hears something different, depending upon his mood, his previous listening experiences, and his hearing response. The success of stereophonic records, tapes, and FM stereo radios and tuners proves that the subjective enjoyment of listening is enhanced by stereophonic presentation.

In comparison with monophonic sound reproduction, stereophonic reproduction has a number of advantages:

1) It is possible to perceive the location of the instruments or sound sources. The attention of the listener may be shifted from one location to another as each new instrument or section of the orchestra is featured.
2) There is strong evidence that it is easier to discriminate the sound of a particular instrument from others playing simultaneously if the sounds appear to come from different locations.
3) The two channels not only reproduce different direct sound signals, but also contain different reverberent sound information so the impression of realistic reverberation is improved.

Since these are subjective advantages they can be evaluated only by subjective measurement, which is always more difficult and less precise than objective measurements of currents and voltages. Nevertheless, some understanding of the process by which the illusion of auditory perspective is produced for the human listener is necessary to permit proper design of stereophonic systems.

SOUND LOCATION

Considerable information about the process by which a listener locates the source of a sound can be gained by studying his ability to locate sounds of different frequency. One way to determine ability to localize sound is to determine the minimum angular displacement of a point source of sound that can be detected by a human listener as a function of the frequency of the sound. In one series of tests[1] the listener was blindfolded, and a sound was produced from a point source at some reference orientation relative to the fixed position of his head. The sound source was then moved through a small angle either to the left or to the right, and a second sound was produced. The listener was asked to identify the direction of movement. Fig. 1 shows a plot of the minimum detectable angular movement as a function of frequency for the case in which the reference position was directly in front of the listener, the position at which discrimination was best.

Sound waves arriving at the listener's ears may differ in time of arrival (or phase for a sinusoidal wave) or in intensity. Although the neurological processes that permit sound location are not well understood, it is believed that both phase and intensity differences are used by the human ear-brain combination.

At the higher frequencies sounds arriving from a source at one side are attenuated at the far ear by the presence of the head. At these frequencies location is thought to be determined by interaural intensity differences. At low frequencies the sound wavelengths are large with respect to the diameter of the head, and it no longer serves as an effective obstacle. The location process at the lower frequencies is thought to depend upon detection of interaural differences in phase or time of arrival. When wavelengths are comparable to head diameter, at about 2000 Hz (cps), the accuracy of both location methods becomes poorer (Fig. 1).

The ability of listeners to locate sound sources accurately becomes poorer as the source is moved to the side, away from the median plane of the head. If the listener moves his head slightly, his ability to locate the sound improves because the motion of the head increases or decreases the interaural phase difference at the low frequencies and the amplitude differences at the higher frequencies. From this standpoint stereophonic reproduction is more desirable than binaural reproduction with earphones, which effectively fixes the position of the listener's head relative to the orchestra.

STEREOPHONIC SOUND REPRODUCTION

A good stereophonic sound reproduction should create the illusion that the sound images are located properly relative to each other at any point between the loudspeakers. To realize the maximum effective width of the *sound stage* (the total distance between the loudspeakers) the crosstalk between the stereo channels must be held to a small value. Also, the proper difference in time-of-arrival of the sounds at the two ears must not be altered if the relative positions of the sound images are to be correct. Fig. 2 depicts a subjective test setup that was used to determine the importance of these effects.[2]

The results of the initial tests, in which the listener was equidistant from the loudspeakers, are given by curve (a) of Fig. 3. With the sound levels of the two loudspeakers equal, the sound image appeared to be located in the center. As the level of the right loudspeaker (LSB) was raised and the level at the left loudspeaker (LSA) lowered, the image shifted to the right. A difference in level of 20 dB was sufficient to shift the sound image all the way to the right. Similarly, the image was shifted to the left by reversing the relative sound levels. These results show that interchannel crosstalk must be reduced to a minimum if the maximum separation of sound images is to be realized.

Curve (b) of Fig. 3 shows the result of moving the right loudspeaker 1 foot farther from the listener. It is apparent that the sound image, formerly near the center, has been shifted to the left for the same interchannel intensity difference. The effect is even more pronounced if the right loudspeaker is moved 2 feet farther from the listener than the left loudspeaker, as shown by curve (c) of Fig. 3. Even though the ratio between the intensity levels could be readjusted to move the image back to the center, the rate of transition of the image through the center for a given change in interchannel intensity differences has been greatly increased. This accounts for the familiar *hole-in-the-middle* effect observed when the listener moves off of the center line of the loudspeaker system.

Final manuscript received May 2, 1966

DISTORTION OF AUDITORY PERSPECTIVE

Although stereophonic sound reproduction opens up a new dimension of subjective listening enjoyment, it also creates new possibilities for producing distortions and departures from ideal reproduction. If the two stereo channels are not identical in their frequency responses, auditory perspective will be distorted. For example, if the response of one channel falls off at high frequencies and the response of the other drops off at low frequencies, the fundamental of a note may appear to come from one side and the higher harmonics from the other side. This is, in fact, a way of producing a *pseudostereo* effect from a monophonic program source. Although stereo systems are seldom so unbalanced as in this extreme example, a few dB of unbalance will contribute to an apparent shift in the position of the sound source or to a spreading of the sound source. The importance of the kind of unbalance may be judged from the data in Fig. 3. A spread of the apparent sound source is likely to be more annoying than a shift in position, because the listener can detect it as an obviously unrealistic situation.

FM STEREO

When stereophonic program material is broadcast on FM radio, the broadcast signal must be compatible with monophonic receivers. A compatible signal, derived by adding together the left and right stereo signals, is used to modulate the carrier in the same fashion as a monophonic signal. A difference signal, consisting of the left audio signal minus the right, may be thought of as containing the directional information. This signal is transmitted on a subcarrier. In the stereophonic receiver the left-plus-right and left-minus-right signals are detected and processed by a matrix amplifier or network to recover the original left and right signals. If the left-plus-right and left-minus-right signal channels differ in frequency response or in gain, the auditory perspective will be distorted.

Before standards for FM stereophonic broadcasting were established, it was conjectured that only the midrange audio frequencies, from 300 to 3000 Hz, of the left-minus-right signal were important for locating the sound image. If this were true the total bandwidth required for the transmission of stereophonic programs could be reduced without degrading the quality of the reproduction.

A series of subjective tests conducted at RCA Laboratories[3] demonstrated that as the audio components of the difference signal L-R were attenuated at either high or low audio frequencies, the sound source appeared to shift in position or spread in width by an amount depending upon the frequency and harmonic composition of the sound. The subjective impression created is shown in Fig. 4.

It was concluded from the results of these subjective tests that although the extremely high or low frequency components of the L-R difference signal are somewhat less important, the entire range of frequency components convey information useful to the human listener in detecting sound location. Any attempt at bandwidth reduction of the L-R signal results in fairly obvious distortion of normal auditory perspective.

In stereophonic broadcasting, as in monophonic broadcasting, it is desirable to compress loud sounds to prevent spurious responses and distortion in the detected signal. In stereo broadcasting, however, a choice must be made between compression of the original left and right audio signals or compression of the derived L + R and L − R signals. Another group of subjective tests conducted at RCA Laboratories[4] indicated that compression of the sum and difference signals permits a slightly higher mean level of modulation, but to a degree that depends on program content. A more serious distortion of proper auditory perspective resulted, however, if the two signals were not compressed equally and simultaneously. In this case, the apparent position of a singer, for instance, would change as a function of the loudness of the singing.

Dr. DONALD S. McCOY attended Yale University, where he received his B.E. in Electrical Engineering in 1952, M.Eng. in 1954, and Ph.D. in 1957. He was a member of the faculty of Yale's Electrical Engineering Department from 1955 through 1957. Since joining RCA Laboratories, Princeton, N.J. in 1957, Dr. McCoy's research has included theoretical considerations of frequency response and noise in magnetic tape recording, signal-to-noise considerations in stereo disc recordings, stereophonic broadcast systems, psychoacoustical phenomena, colorimetry, and seismic detector sensitivity. He is a member of Sigma Xi, the Audio Engineering Society, and the IEEE Professional Group on Audio.

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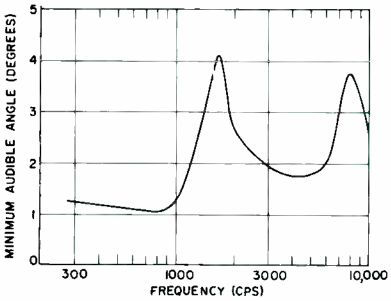


Fig. 1—Minimum detectable change in angular position of a sound source about the median plane.

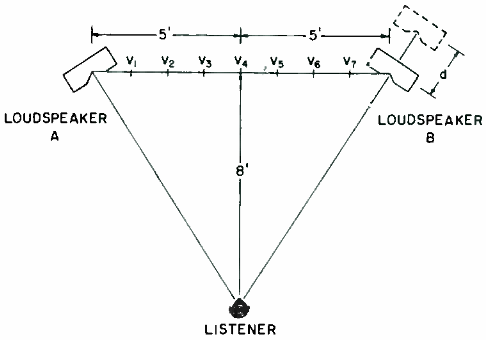


Fig. 2—Positions of loudspeakers and listeners for subjective tests.

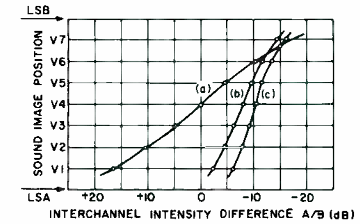
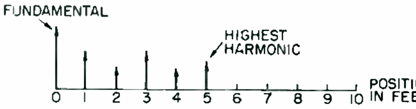
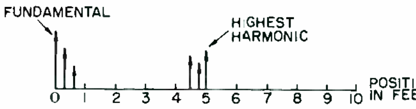


Fig. 3—Apparent position of sound image as a function of relative sound level at the two loudspeakers (after Leakey).



6 db/OCTAVE LOW PASS FILTER IN L-R CHANNEL



36 db/OCTAVE LOW PASS FILTER IN L-R CHANNEL

Fig. 4—Apparent spatial distribution of harmonic components.

SOUND REPRODUCTION IN THE HOME

Dr. H. F. OLSON
Staff Vice President

Acoustical and Electromech. Research
RCA Laboratories, Princeton, N. J.

Operational, geometrical, and environmental factors are involved in stereophonic sound reproduction in the home. This paper describes the manner in which these parameters influence the reproduction of sound in a room in the home.

DR. HARRY F. OLSON received the BS, MS, PhD, and EE degrees from the University of Iowa, and an honorary DSc degree from Iowa Wesleyan College. He has been affiliated with the research department of RCA, the engineering department of RCA Photophone, the research division of RCA Manufacturing Co., and RCA Laboratories, where he is Staff Vice President, Acoustical and Electromechanical Research. He holds more than 100 U.S. patents and has written numerous papers and books, including Elements of Acoustical Engineering, Acoustical Engineering, Dynamic Analogies, and Musical Engineering. He is a past president of the Audio Engineering Society (AES) and the Acoustical Society of America (ASA) and past chairman of the Administration Committee of the IRE Professional Group on Audio. He has been honored with awards from the AES, Society of Motion Picture and Television Engineers (SMPTE), Professional Group on Audio of the IRE, and American Society of Swedish Engineers. He is a Fellow of the IEEE, SMPTE, American Physical Society, and ASA. He is a member of Tau Beta Pi, Sigma Xi, National Academy of Sciences, and an honorary member of the AES.

The main purpose of sound reproduction is to provide the listener with the highest order of artistic and subjective resemblance to the condition of a live rendition. To achieve this objective requires the optimum in the physical performance of the equipment as directed by the psychological factors involved in the process. In this connection, the operation and geometry of the system and the acoustic environment play an important part in the reproduction of sound in the home. Specifically, the level of sound reproduction influences the subjective performance. The ambient conditions of noise level and reverberation time of the room are factors that modify the reproduced sound as perceived by the listener. The geometrical configuration and the dimensions of the equipment are important factors in the auditory perspective of stereophonic sound. This paper describes the operational, geometrical, and environmental factors involved in the reproduction of stereophonic sound in a room in the home.

LOUDNESS OF THE REPRODUCED SOUND

The subjectively tolerable loudness of the sound reproduced in a small room in a home is an important factor in the reproduction of sound. Extensive subjective tests have been conducted on the stereophonic reproduction of sound at various sound-pressure levels under the acoustic conditions and environments of the average living room. Studies have also been made of the reproduction level employed by consumers in their homes. These tests have shown that peak sound-pressure levels of sound reproduction in consumers' homes are from 70 to 90 dB for 90% of the listeners. The average listener in the home operates a sound-reproducing system at a peak sound-pressure level of 80 dB.

The peak sound-pressure level of a live performance in an acoustic enclosure is about 100 dB. Thus, it can be seen that the peak level of sound reproduction in the home is much lower than the level of a live performance.

The main reason the average listener prefers a lower level of sound reproduction in the home, as contrasted to the sound level in the concert hall, is that the tolerable peak sound level in a small room is lower than the tolerable peak sound level in a large hall. The shorter mean free path and resultant faster growth and decay of sound in a small room appears to lead to a lower toler-

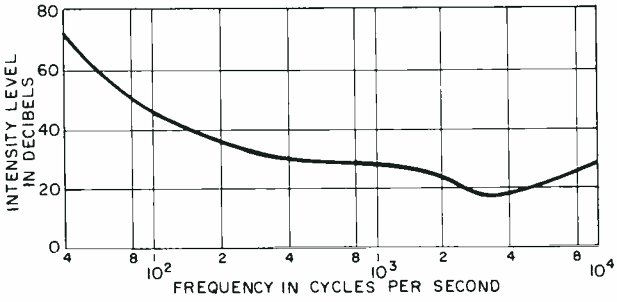


Fig. 1—Hearing limit for pure tones for a typical listener in a typical residence.

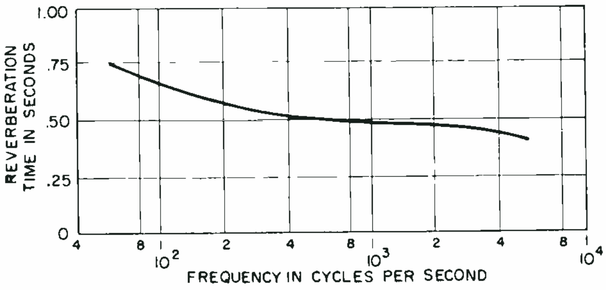


Fig. 2—Reverberation time as a function of frequency for typical rooms in a residence.

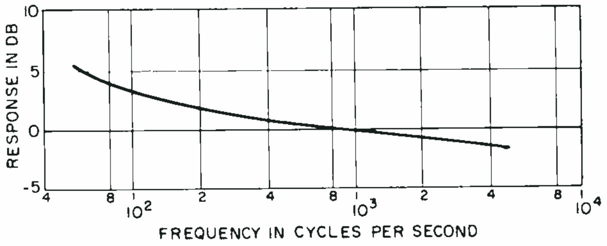


Fig. 3—Relative response derived from dynamic average of direct and reflected sound reproduced in a room in a residence.

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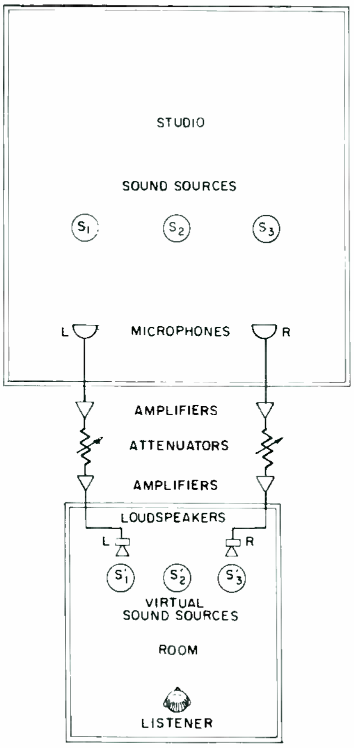

Fig. 4—Stereophonic sound reproducing system.

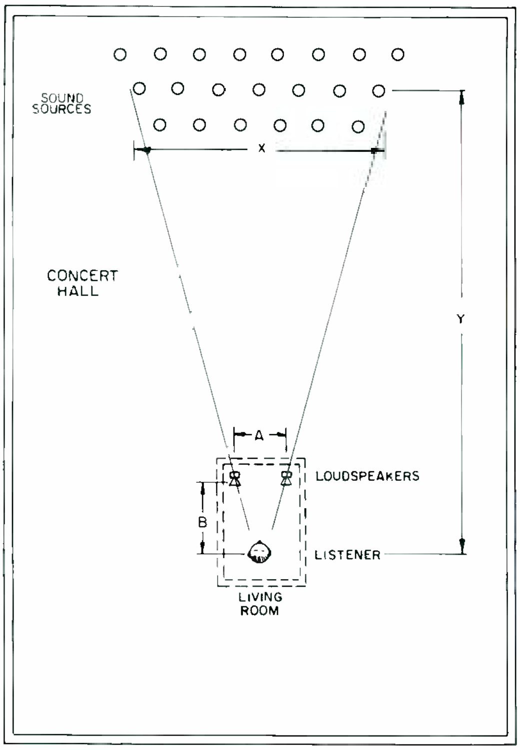

Fig. 5—Geometry of loudspeakers and a listener in a room in the home superposed upon geometry of live sound sources and a listener in an auditorium.

able peak in the small room. Subjective tests have indicated that the results are the same for both live and reproduced sound programs.

The response frequency characteristics of the human hearing mechanism indicate that certain frequency ranges must be increased or decreased in amplitude to maintain the quality balance of music when it is reproduced at a lower level than the original. Therefore, means must be provided to dynamically correct for the change in response of the ear with respect to frequency for a level drop of 20 dB. There must be a continuous variation in the response frequency characteristic as the level changes. Consequently, dynamic compensation and equalizers are employed in the recording or transmitting process to dynamically alter the projection qualities of sound, so that under conditions of playback that differ from the original, the best perception of the qualities of the original performance will be obtained.

NOISE LEVEL, DYNAMICS AND MASKING

Since the level of sound reproduction in the home is relatively low, consideration must be given to the amplitude range between the lower level established by the ambient noise and the average upper level of 80 dB.

The ambient noise in a room masks and renders inaudible the reproduced sounds below a certain level. Therefore, the ambient noise level in the average residence must be considered in the reproduction of sound.

The ambient noise level for the entire audible range in 90% of the residences falls somewhere between 33 and 52 dB. The noise level in a room in an average residence is 43 dB.

The spectrum of room noise also affects the level at which sounds disappear in the ambient as a function of frequency. The spectrum of typical room noise decreases 5 dB per octave with increase in frequency. This characteristic appears to be the nature of practically all types of ambient noise.

From the average sound level and spectrum of the ambient noise it is possible to determine the lower hearing limit for pure tones. The graph of Fig. 1 depicts the level below which a pure tone cannot be heard for a room in which the total sound level is 43 dB. A large number of direct-listening tests have been conducted to determine the level below which a pure tone disappears in the ambient. These data substantiate the characteristics of Fig. 1 within the usual limits of subjective tests. The threshold characteristic of Fig. 1 establishes the lower level of hearing in a room in an average residence.

REVERBERATION

The growth, duration, decay, and reverberation characteristics of sound as perceived by the listener involves the combination of two rooms. Here the objective is to provide an overall growth, duration, decay, and reverberation characteristic which provides the listener with a subjective impression of these properties which match those of the live rendition in the acoustic enclosure. The reverberation time characteristic of a typical living room in the home is shown in Fig. 2. In general, the studio or enclosure in which the sound is picked up exhibits a much longer reverberation time than the room in the home. Therefore, the reverberation time of the room plays a minor part in determining the overall effective reverberation. This is fortunate, because the recording or transmitting medium determines the reverberation of the sound as perceived by the listener.

DYNAMIC RESPONSE OF A LOUDSPEAKER IN A ROOM

In the reproduction of sound in a room there are two sources of sound with respect to the listener: the direct sound from the loudspeaker, and the generally reflected sound. The acoustical characteristics of the average room in a residence accentuates the low-frequency response as can be deduced from the reverberation characteristic of a typical living room in a home (Fig. 2). The general run of direct radiator loudspeakers exhibit increased directivity with increase of frequency. The combination of the acoustical characteristics of the room and loudspeaker produce an accentuation in the low-frequency response as perceived by the listener. The relative response at normal listening distances derived from the dynamic average of the direct and generally reflected sound for the case of music reproduced in a room in a residence is shown in Fig. 3.

AUDITORY PERSPECTIVE

Stereophonic sound reproduction provides auditory perspective of the reproduced sounds and thereby preserves a subjective illusion of the spatial distribution of the original sound sources in reproduction. In the two-channel stereophonic reproducing system depicted in Fig. 4, the three original sound sources are S_1, S_2, and S_3. Under favorable reproduction conditions, the corresponding reproduced sources of sound appear to originate S'_1, S'_2, and S'_3. Thus, in actual practice the two-channel stereophonic sound reproducing system provides very good sound reproduction in auditory perspective.

To achieve good auditory perspective in streophonic sound reproduction some acoustical conditions must be satisfied in the pickup of the live sound and the dispersion of the reproduced sound. In listening to a live performance the maximum angular distribution of the sound sources is determined by the maximum lateral dimension, X, of the distributed sound sources and the distance from the sound sources to the listener, Y (Fig. 5). If the listener of the reproduced sound in the living room wishes to duplicate the angle for what he considers the best seat in the house, the following relation must be satisfied

$$\frac{X}{Y} = \frac{A}{B} \qquad (1)$$

where A = separation between the loudspeaker, and B = distance from the listener to the loudspeakers. (Fig. 2).

Equation 1 establishes the separation between the loudspeakers and the distance from the loudspeakers to the listener necessary to obtain realism in the auditory perspective. The dimensions of the stereophonic reproducing system are considered in the following paragraph.

LOUDSPEAKER CONFIGURATION AND DIMENSIONS

Stereophonic sound reproducers for the home are inherently capable of satisfying the conditions of auditory perspective as depicted in Fig. 5. There are two general classes of stereophonic sound reproducers: module and integrated.

The most versatile module system, from the standpoints of flexibility of disposition in the room and selection of the elements, is one in which each module represents a single element, as for example, FM tuner, record player or changer, magnetic-tape reproducer, amplifier, and loudspeaker. There are two general types of module reproducers: bookcase designs and console designs.

A bookcase type of module stereophonic sound reproducer comprising a tuner, record player or changer, magnetic-tape recorder, amplifier, and loudspeakers is shown in Fig. 6. This module system consists of relatively small and independent units which can be disposed in various ways in the room. Low-frequency performance is determined to a large extent by the size of the loudspeaker cabinets.

The console type of module shown in Fig. 7 provides some flexibility of disposition in the room combined with the finest performance. The loudspeakers, housed in relatively large cabinets, provide excellent low-frequency response. The record player or changer, magnetic-tape recorder, FM radio tuner, and amplifier are housed in the center console.

The integrated stereophonic sound reproducer is one in which all the elements (record changer, magnetic-tape reproducer, FM radio tuner, amplifier, and loudspeakers) are housed in a single large cabinet (Fig. 8). The space allocated to the loudspeaker is relatively large and therefore provides excellent low-frequency response.

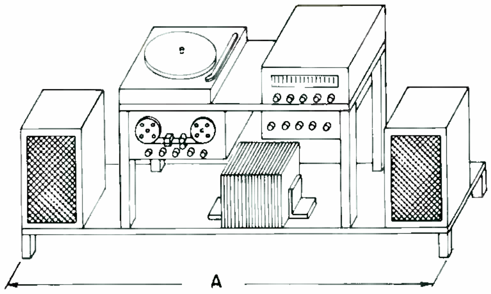

Fig. 6—Bookcase type of module stereophonic sound reproducer.

The loudspeakers of the stereophonic sound module systems shown in Figs. 6 and 7 can be arranged so that the distance between the loudspeakers, A, satisfies the condition of Fig. 5. Under these conditions the auditory perspective of the reproduced sound will be realistic. In the early days of reproduced sound, the integrated systems were relatively small and the distance between the loudspeakers did not satisfy the condition of Fig. 5. In the last two or three years, however, the cabinets of the higher priced consoles have become much larger, with the result that the distance A between the loudspeakers (Fig. 8) satisfies the condition of Fig. 5.

In conclusion it can be said that both module and integrated stereophonic sound reproducers are capable of reproducing sound with excellent auditory perspective in a room in the home.

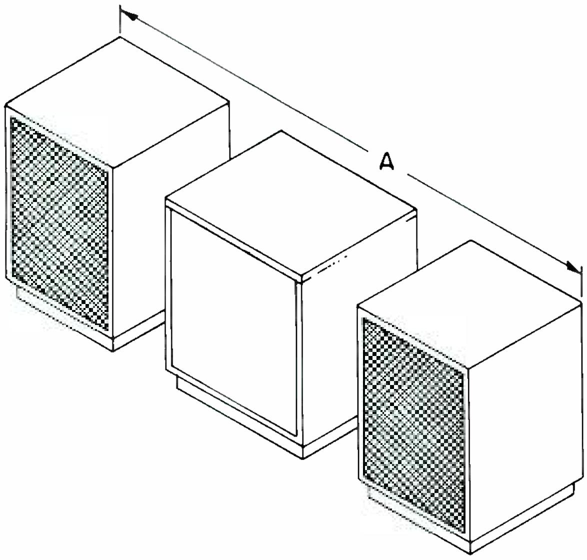

Fig. 7—Console type of module stereophonic sound reproducer.

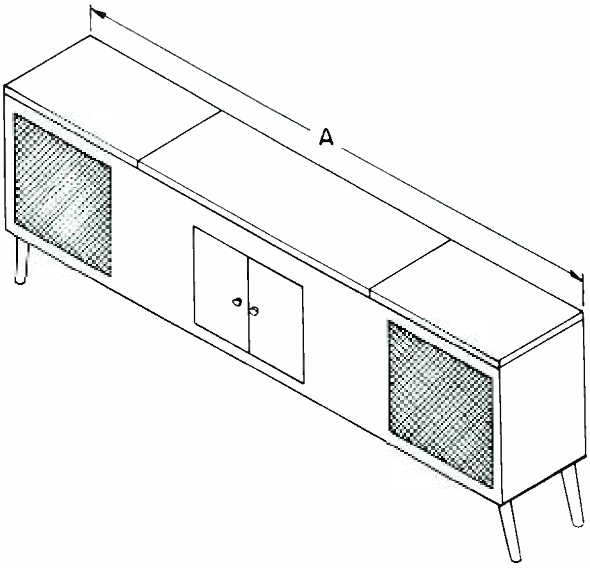

Fig. 8—Integrated type of stereophonic sound reproducer.

DESIGN OF A HIGH-FIDELITY STEREO RADIO-PHONOGRAPH

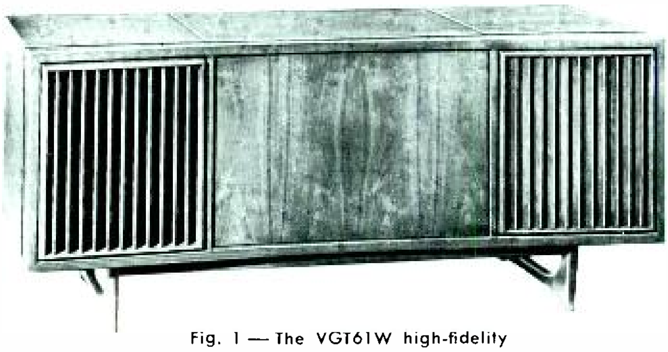

Fig. 1 — The VGT61W high-fidelity stereo instrument.

This paper describes some of the factors confronting the high-fidelity instrument design engineer in achieving his design goals. Consumer considerations of style and appearance, speaker performance, problems of howl and hum, standardization of parts, and the goals of high quality are discussed.

W. E. DAVIS

Radio Victrola Engineering
RCA Victor Home Instruments Div.
Indianapolis, Ind.

THE development of a high-fidelity stereo combination for mass production presents the instrumentation engineer with a number of practical problems. To gain an insight into some of these problems, a typical instrument is described as it progresses through part of its normal channel of development. The VTG61W high-fidelity instrument (Fig. 1), which is slightly above the average of RCA's line of stereo combinations, was selected for this purpose. This instrument is optionally priced at about $500.00 and incorporates nearly all the current major features.

BACKGROUND

Some background is necessary relative to the conception of the instrument. First, a product planning group decides that such an instrument is needed to fill out the product line and sell for an optional dealer price of approximately $500.00. Market research indicates that (for this price range) the public would favor a cabinet about 60 inches long, 27 inches high, and 19 inches deep; the cabinet should have Danish modern styling with a walnut finish. The instrument should contain a high-quality receiver for AM, FM, and FM stereo with a power amplifier capable of producing 60 watts of EIA power. A four-speed automatic record changer, lights for the changer compartment, and a pilot light also are required. Additional features should include provisions for home use of a tape recorder with the unit, provisions for connecting external speakers and an FM antenna, headphone connections with switching, and a record storage well. At least eight speakers must be used and two must be 15-inch speakers.

A styling concept is then developed which includes vertical wooden bars placed across the grill cloth; the cabinet should be concave in the front. A styling mock-up of what the instrument should look like when completed is then turned over to the Engineering Department.

During this portion of the development, the instrumentation engineer acts in a liaison capacity between the various component design groups to ensure the proper mating of all finished components with respect to performance, connections, etc.

PLACEMENT OF COMPONENTS

Once the instrument is turned over to the engineering department, the major components must be physically located within the cabinet.

The placement of all visible components and controls must form a pleasing pattern to the eye. All controls must be positioned for ease of operation. Then, the remaining internal components must be arranged for maximum efficiency, minimum circuit interaction, and ease of construction. The record changer, radio receiver, and preamplifier normally have controls and their design must ensure that:

1) Fields created by the phonograph motor will not induce hum into the radio or preamplifier circuitry.
2) Dangerous potentials do not exist on any component or between any components, and are not readily accessible from outside the enclosure.
3) Other components or wiring do not increase high-frequency radiation from the radio section.
4) The operation of any system will not cause deterioration in the performance of any other system.
5) Electrical or mechanical interferences will not occur.

When the components are safely located, the speakers are placed for optimum performance. The low-frequency speakers are normally located in the lower portion of the enclosure, since they are less directional than the high-frequency speakers. The mid-range and high-frequency units are placed as close to the ear level of the listener as possible. To maintain maximum stereo separation, the mid- and high-frequency elements are moved toward the ends of the cabinet.

A popular misconception of the general public is that the larger the number of speakers used, the better the quality of the sound reproduced. The fact that this belief exists results in the necessity for a variety of speakers covering various sound ranges. The range of these speakers must overlap somewhat to maintain an overall response free from voids. Elaborate crossover networks then become necessary to cut off the overlapping areas. These networks contain various values of inductance, resistance, and capacitance, depending on the speaker ranges to be trimmed. However, by choosing one wide-range speaker and trimming only the lower frequencies of other carefully selected speakers, these crossover networks can be kept relatively simple and inexpensive.

SPEAKER SYSTEM PERFORMANCE

The speakers for the VTG61W instrument were chosen in the following manner. Since the space available for speaker mounting was limited, it was decided to use a 15-inch oval speaker for low-frequency performance. A wide-range, duo-cone, 15-inch speaker was chosen; the performance curve for this speaker operating on an infinite baffle is shown in Fig. 2. The free-air resonance of the speaker was kept well below 100 Hz(cps) for smoothness of sound at low frequencies, and the output level was reduced

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over the range from 130 Hz to 1300 Hz. Since it was necessary to use another speaker to fill in this range, a 5- x 7-inch midrange speaker was selected to provide additional sound output through the weak range of the 15-inch oval speaker. (The performance curve for the 5- x 7-inch speaker is shown in Fig. 3.) Then it was noted that the 15-inch speaker delivers sound output over the entire range to 11 kHz, but the midrange unit has a cutoff range after 5 kHz.

A basic problem was created by the vertical bars that were necessary to fulfill the styling concept. These bars caused considerable deterioration of the high-frequency sound output. To compensate for this, a high-frequency, 3½-inch speaker having the response range shown in Fig. 4 was added. To fill out the complement of four speakers per channel and allow the high-frequency response to be more easily tailored, a second 3½-inch speaker of this type was also used.

After the speakers were mounted in the cabinet, cancellations occurred between the speaker output and backwaves coming from the rear of the cabinet. Thus, the actual response of the system was not what one would expect when all curves are added together.

Since the desired amplifier was designed to deliver its rated power into an 8-ohm load, the speaker system should represent this load to the amplifier at any frequency. The 15-inch speaker selected has a rated impedance of 8.5 ohms. However, it can be seen from Fig. 2 that the impedance increases at frequencies exceeding 500 Hz. A 35-ohm mid-range (5 x 7 inches) speaker was selected to prevent a lowering of the impedance to the amplifier when the mid-range unit is connected across the 15-inch speaker. A 20 μF capacitor was placed in series with the 5- x 7-inch speaker to activate the speaker at 230 Hz, which is just beyond the resonance point. The two 3½-inch speakers were then connected in parallel and placed across the 5- x 7-inch speaker through a 4 μF capacitor. The use of a 20-ohm, 3½-inch speaker resulted in an overall system impedance curve that remains very close to 8 ohms throughout the sound production range.

WILLIAM E. DAVIS received his BSEE degree from Indiana Technical College in August 1961. Since that time, he has been with the Radio-Victrola Engineering section of the RCA Home Instruments Division at Indianapolis, Indiana. Mr. Davis' work has been concerned primarily with the development of systems for stereophonic radio-phonograph combinations and the design of audio amplifiers.

The speaker system shown in Fig. 5 was placed in a cabinet, and an overall system curve was made in an anechoic chamber, resulting in the final curve shown in Fig. 6. A listening test was then held in a special listening room and final approval of the sound was given by a sound evaluation committee. At this point we shall leave the development and design of the VGT61W and consider other design problems common to most high-fidelity systems.

HOWL

Throughout the development stage of an instrument, an insight into certain potential problem areas must be maintained. One ever-present problem is acoustic howl. Howl is a condition that occurs when a high-gain system is subjected to in-phase feedback through a mechanical or acoustical loop. The most severe howl problems generally occur in the phonograph and AM radio sections.

Phonograph Howl

The vibrations within the cabinet which result from the speakers acting on the baffle board can be transmitted directly to the phonograph. The motion of the phonograph modulates the phonograph cartridge and when this signal is in phase, a low-frequency oscillation occurs in the system. The higher frequency vibrations are damped in the coupling links; therefore, the changer must be kept free from mechanical coupling during operation by mounting it on springs or some other such material. The wiring to the record changer must be very flexible, or it will also transmit these vibrations.

The same condition occurs when the air pressure from the backwave of the speaker is allowed to modulate the now-floating record changer. This motion will be picked up by the stylus and can again cause a low-frequency oscillation within the system. This form of howl can be eliminated by the use of a howl tray which encloses the bottom of the changer and prevents the backwave from reaching the changer.

AM Radio Howl

A similar form of howl occurs in the AM radio section. In this case, however, the mechanical loop creates most of the problems. The mechanical feedback through the cabinet causes the radio receiver section to vibrate. Components within this section, such as the plates of the tuning gang, may vibrate at their natural frequency causing modulation of the oscillator; such oscillations are amplified and return to the speakers to complete the loop. This howl occurs at the frequency at which the component is free to vibrate, commonly at about 2 kHz.

There are a number of approaches to the solution of this problem, all leading to the conclusion that the component must be prevented from modulating the RF signal. The most foolproof scheme is shock mounting the entire receiver section. This approach not only solves the AM problem but stops any tendency of the FM section toward a similar problem. Shock mounting whole components, however, is an expensive proposition in high-quantity production instruments. Since howl is a function of system gain, materials used, and cabinet construction, it is often desirable to do something less than the ultimate, depending, of course, on the tendency of any one unit to howl. In cases where there is but a slight tendency toward howl, only the RF section of the receiver need be shock mounted. In other cases, the placement of a damping material in contact with the drum on the tuning gang is sufficient. In very small receivers, a damping material is sometimes applied directly to the plates of the gang.

Checking Howl

The tendency of a system to howl may be easily determined by driving the speakers from an external source and recording the output at the amplifier terminals. If the amplifier output approaches the driving signal level, the gain approaches unity and the system will howl. This test must be performed in such a manner that the relative phase can be determined; howl will not occur when the two signals are sufficiently out of phase.

HUM

Hum also is an ever-present problem in the design of any AC-operated high-gain system. This is especially true of high-fidelity sound systems when they are operated at low-volume levels. The frequency of the hum is a prime factor in determining the maximum acceptable level of the system hum. For instance, at a given low-listening level, a sound at 120 Hz will be 14 dB louder than a similar sound at 60 Hz. Since 120 Hz is the natural ripple frequency of a common power supply, the ripple component becomes very important, especially in low-voltage, high-current, transistorized power amplifiers. The filtering of the power supply and amplifier layout is very critical in this respect. In addition, the signal leads that connect the units within the cabinet must be adequately shielded, and the connections must be kept clear of the power leads. The 60-Hz hum, which is harder to shield against than the 120-Hz hum, is generated by many sources, such as the AC line, the power transformer, and the phonograph motor. It may be radiated electromagnetically or picked up electrostatically.

The first step in reducing this type of hum is to place the hum sources as far as possible from the small-signal locations. Next, all signal leads in the area are well shielded. An effort is then made to reduce the stray field from the transformer by using a copper shorting band around the transformer and insulating the end bells from one another. Another problem must be considered; the primary of the transformer will commonly have one end physically closer to the transformer core than the other. Consequently, a capacitance exists between the end of the winding and chassis ground. If the line cord is in a position that causes the chassis ground to be considerably different from the earth ground, a strong field will exist between the two and the instrument will have a tendency to hum when touched; thus, the normal 60-Hz hum level will be increased considerably.

To reduce this effect, a capacitor is connected from the high side of the transformer primary to chassis ground. This provides a balanced capacitance from both sides of the line to ground and reduces both hum and hand capacitance effect. For this system to work properly, it is necessary for all transformers to have the same winding sequence. It should also be kept in mind that the phonograph motor has the same problem. Therefore, both items must have their low-capacitance sides connected together. The capacitor used for balancing this system must be capable of handling the high-voltage peaks that could occur on the line, or a shock hazard could result in case of capacitor failure.

We must now consider a hum that does not come from the speakers. This hum, generally 120 Hz, occurs when a power transformer is fastened to the floor of a cabinet. The transformer vibrates and transmits these vibrations to the cabinet floor, which acts as a sounding board. The transformer is usually mounted to a chassis or bracket of some type, and when the mounting is sufficiently rigid the same effect occurs; the transformer is very quiet when it is not in contact with the cabinet. Thus, the cure for this problem is to shock mount the unit containing the transformer. In less severe cases, such measures as mounting the transformer so that the laminations are parallel to the mounting surface, bracing the cabinet floor, mounting the unit in a node of the vibration pattern, or raising the stack of the transformer above the mounting surface are all effective to some degree.

STANDARDIZATION

Our basic philosophy is to supply the customer with a high-quality instrument at a reasonable cost. By using mass production techniques, volume component buying, and the standardization of parts, considerable sums of money are raised each year. In addition, the entire line of instruments is evaluated to determine how the minimum number of similar parts can be used in the maximum number of instruments.

By maintaining constant relationships and distances between components, such as the receiver, phonograph, and amplifier, the number of interconnecting cable lengths may be kept to a minimum. Also, the use of standard speaker systems, such as the one described previously, permits the volume buying of crossover components and related items.

In addition to the savings resulting from volume buying, there are other hidden savings which accrue with this system. When only one such element must be used, less time is required to purchase the item, shipping and packaging costs are reduced, time and space factors required for the inspection of incoming assemblies are reduced, the time and equipment required to handle material and convert an assembly line to build another instrument type are reduced, and the possibility of accidently using incorrect parts for a given instrument is greatly reduced.

Another interesting aspect of maintaining constant relationships between parts is that problems such as stray fields, high-frequency radiation, and feedback need only be solved for any one case.

CONCLUSION

It is essential that the instrument engineer give considerable attention to even the smallest details of design. The entire instrument product line must also be kept in the foreground when dealing with the design problems of a single instrument to ensure that nothing has been overlooked. To assure that the highest instrument design standards are fulfilled, a complete set of standard tests are performed on each instrument before it is released from the engineering laboratories.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to L. H. Carmen and S. Walczak for their many discussions and suggestions concerning this paper.

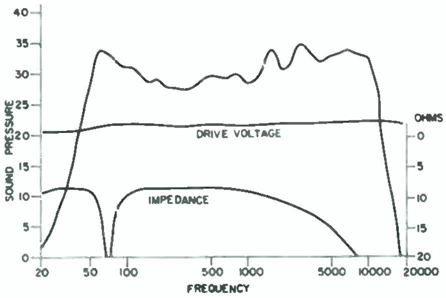

Fig. 2 — Typical 15 inch oval speaker performance curve.

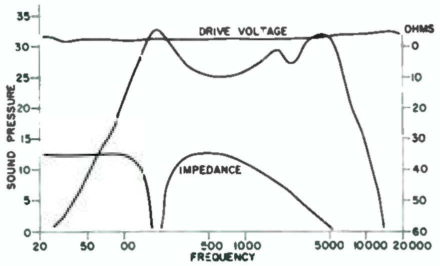

Fig. 3 — A 5 x 7 inch, mid-range speaker performance curve.

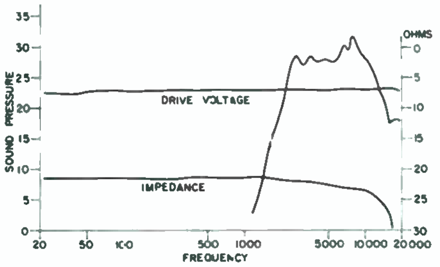

Fig. 4 — A 3½ inch, high-range speaker performance curve.

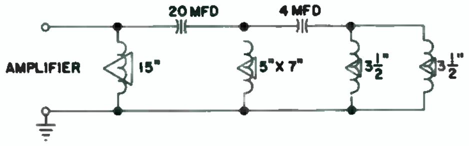

Fig. 5 — Circuit showing the model VGT61W speaker array for one channel only.

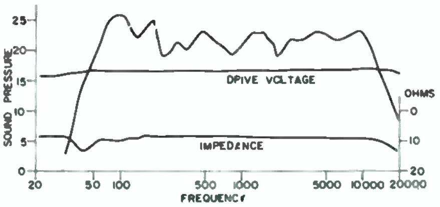

Fig. 6 — The overall VGT61W speaker-cabinet performance curve.

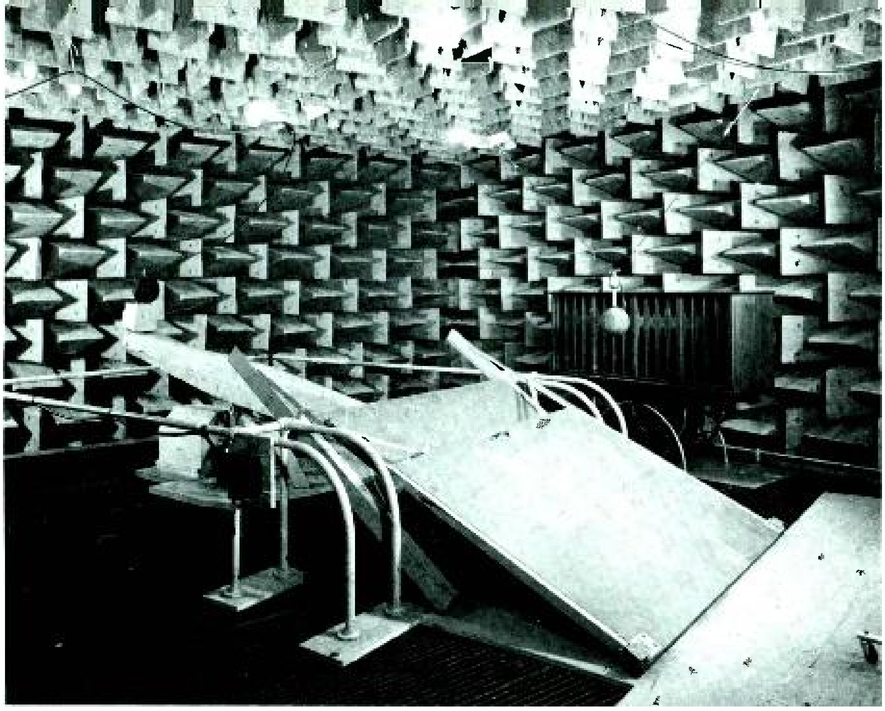

Fig. 1—Anechoic chamber.

R. K. VARGASON
and
J. M. VALENTINE

Electromechanical Product Engineering
RCA Victor Home Instruments Division
Indianapolis, Indiana

HOME INSTRUMENTS ACOUSTICS

A Systems Design Approach

The Home Instruments Acoustics group uses a systems approach to achieve balanced acoustic performance for all RCA Victor Home Instruments ranging from vest pocket radios to living-room home entertainment centers. To illustrate the techniques used, a high-fidelity console is followed through acoustic development from concept to completion. The instrument illustrated incorporates sealed speaker enclosures, which are also discussed.

Fig. 2—VHT-71F high-fidelity console.

THE RCA Victor Home Instruments Acoustics group provides engineering services for a wide range of products through the use of unique facilities and techniques. These products range from vest pocket radios to living room home entertainment centers.

SCOPE OF SERVICE AND FACILITIES

Radios, phonographs, television sets, and tape recorders all have in common the reproduction of sound. It is the Acoustics group responsibility to optimize each system for the best overall acoustic performance. This task involves examination of acoustical, electrical, and electromechanical components.

Development work in the Acoustics group centers on the anechoic chamber (Fig. 1) and its associated sound pressure recording apparatus. This installation, one of the finest in the industry, permits accurate, repeatable acoustic measurements which are free of environmental effects.

The anechoic chamber is large enough to permit the use of both fixed and rotating microphones. The fixed microphones, including both velocity and pressure types, are used for plotting sound-pressure-level vs. frequency curves of small sets and loudspeakers.

The rotating microphone, a pressure-sensitive unit, is mounted on a rotating boom to average out the sound pressure over a large area. This technique is useful for weighing the directional characteristics of multiple speaker systems found in high-fidelity consoles.

An *infinite* baffle wall is available for evaluation of individual loudspeakers. This baffle wall also serves as a reflection wall for evaluating environmental effects on large console sets. Rotating-microphone curves are plotted using this wall and when examining low-frequency response should not be compared directly with free-field curves obtained with a fixed microphone.

The recording apparatus which is associated with the anechoic chamber is also used to evaluate audio-frequency response of RF tuners, amplifiers, record changers, and tape recorders. This flexibility allows the use of the systems approach in incorporating electronic and electromechanical components into an integrated acoustics system.

A special listening room is available for subjective evaluation of the final product. This room has known acoustic characteristics and simulates the home environment. *Blindfold* listening tests are conducted to compare new designs with past designs and competitive products. This final subjective test augments previously collected acoustical and electrical laboratory data.

The chronological order of the steps in the acoustic development of a complete design is as follows:

1) Preproduct planning
2) Preliminary acoustic investigation
3) Final cabinet evaluation
4) Electronic and electromechanical component evaluation
5) Final subjective evaluation by management.

To illustrate the functions of the RCA Victor Home Instruments Acoustics group, the development of a specific in-

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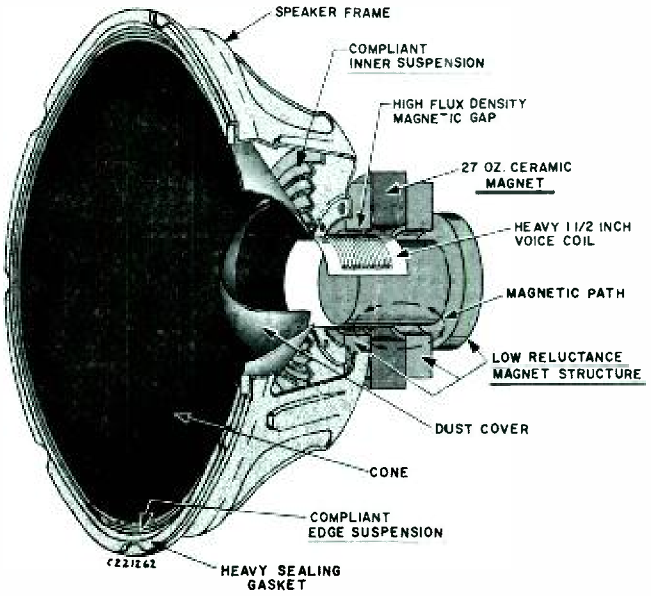


Fig. 3—VHT-71F 15-inch loudspeaker.

strument is followed from concept to production. The instrument selected is the VHT-71F high-fidelity console (Fig. 2), which represents the highest performance portion of the 1967 RCA Victor line (introduced in May 1966).

PREPRODUCT DESIGN PLANNING

The basic concept of an instrument originates with a product planning group. They decide the type of product needed and the features it must have for successful sales. The VHT-71F high-fidelity console was conceived to meet the demand for the highest possible quality in a home instrument. It was decided that the basic acoustic design should have a sealed or closed-box type of loudspeaker enclosure which would require the use of a special high-compliance *woofer* (Fig. 3) or low-frequency speaker. For compatibility with the remainder of the product line and for balanced performance, the speaker types chosen for each channel were: 1) a 15-inch woofer, 2) a mid-range speaker, 3) a horn-type speaker, and 3) a high-frequency *tweeter*.

The appearance of the set was defined as similar to the VGT-75 high-fidelity console of the 1966 line (introduced in May 1965); in addition, it was decided to use our finest tuner and highest power amplifier.

Based on this information, the Acoustics group determined that some additional design features needed: 1) speaker compartments for each channel that would be airtight when fully assembled, 2) an enclosed volume of at least 4 ft.^3 (based on earlier work), 3) overall construction rigid enough not to vibrate under the pressures built up in the sealed compartments, and 4) sound-absorbing material on at least three surfaces of each speaker compartment to damp out reflections and standing waves.

A discussion of enclosure systems is in order at this point to illustrate the differences between the conventional open-back speaker enclosure and the sealed enclosure used in this set.

SEALED ENCLOSURE PRINCIPLES

Loudspeakers are electromechanically driven air pistons. When air is compressed on the forward surface of the piston, the resulting potential energy moves rapidly outward as an adiabatic sound wave. At the same instant, the air at the rear of the piston is rarified and this energy radiates rearward 180° out of phase relative to the forward wave. This condition requires that the loudspeaker be mounted on a baffle to isolate the front and back waves and prevent cancellation of energy in the lower half of the audible spectrum where wavelengths are very long (Fig. 4).

The loudspeaker of a conventional home instrument is mounted on the front surface of the enclosure. The back surface of the enclosure is open to the atmosphere. The front, top, bottom, and side surfaces are dimensioned to provide adequate front-back isolation for the desired range of sound reproduction. When this range is to be extended to include the lower limits of audibility, the cabinet dimensions grow to enormous proportions.

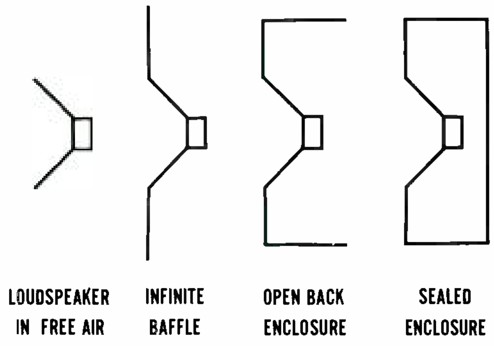
A logical design step is to seal the rear of the enclosure and pad the inside walls to absorb almost all of the energy radiated from the rear of the loudspeaker. Although this approach solves the baffle problem, it also dictates new loudspeaker design considerations.

First let us examine the mechanical and electrical analogs of a loudspeaker (Fig. 5). A loudspeaker can be represented as a mass, a resistance, and a spring or compliance. The mass represents the inertia of the moving parts plus

RONALD K. VARGASON received a BSEE from the University of Michigan in 1962. Upon graduation he joined RCA as a specialized trainee and later joined the Home Instruments Division. He is a member of Eta Kappa Nu and Tau Beta Pi.

JOSEPH M. VALENTINE received a BSE in Physics from the University of Michigan in 1962. Prior to attending the University of Michigan he was an electronics technician with the Michigan Bell Telephone Company. He joined RCA Victor Home Instruments Division as a summer student employe in 1961 and returned upon graduation in 1962. He is a member of the IEEE and the AES.

Fig. 4—Evaluation of sealed enclosure.



the reactive component of the air load. The resistance is derived from flexure of the piston or cone suspension components plus the resistive component of the air load. The compliance results directly from the cone suspension system.

An electrical analog of this mechanical system appears as a series *L-R-C* network. The mass becomes an inductor, the resistance becomes a resistor, and the compliance becomes a capacitor. The resonant frequency of this system can be computed using the appropriate system of units:

$$\omega_o L\ (\text{kg}) = \frac{1}{\omega_o C_{c_s}\left(\frac{\text{sec}^2}{\text{kg}}\right)} \text{ at resonance}$$

$$\omega_o^2 = \frac{1}{LC_{c_s}\ (\text{sec}^2)}$$

$$f_o = \frac{1}{2\pi\sqrt{LC_{c_s}}}\ (\text{Hz})$$

This resonant frequency is extremely important, since it determines the lower limit of sound reproduction and the low-frequency transient response when all the parameters are taken into consideration.

The suspension system of a conventional loudspeaker is designed to supply the correct compliance for the desired resonant frequency. When such a conventional design is mounted in a sealed enclosure, the trapped volume of air adds stiffness to the system. Then, the resonant frequency and the *Q* of the system rise, low-frequency response is lost, and damping or transient response is poor.

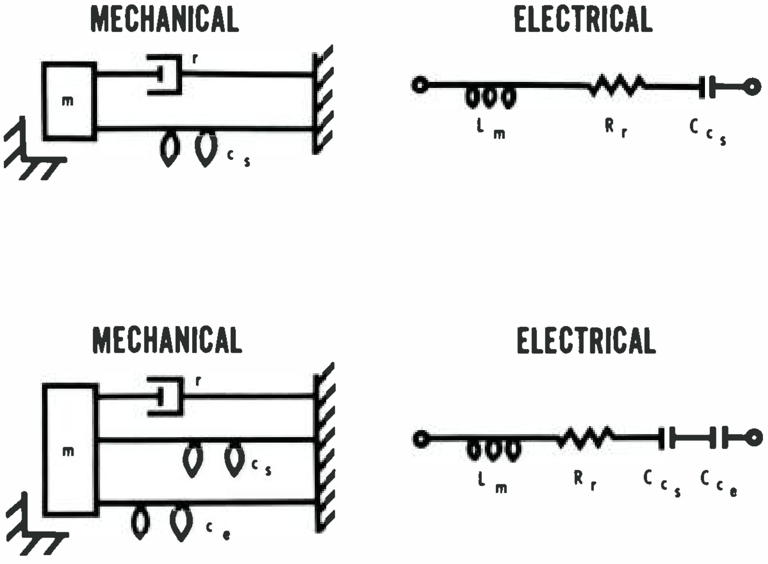
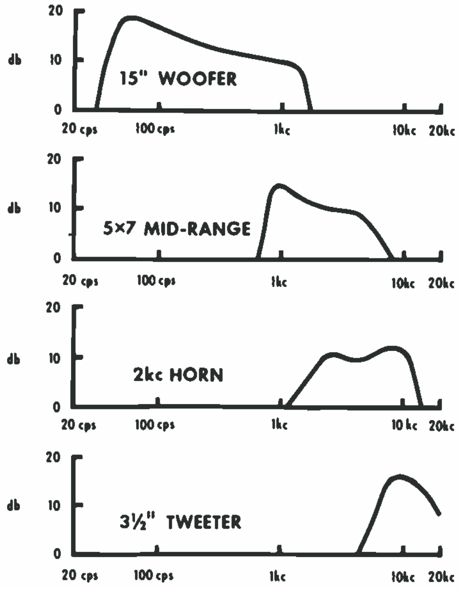


Fig. 5—Mechanical and electrical loudspeaker analogs.

Fig. 6—Response of individual speakers in VHT-71F obtained with fixed microphone in anechoic chamber.



The analogs for the sealed enclosure system should be inspected to determine the modifications necessary to keep the resonant frequency low. The added compliance (compliance equals the inverse of stiffness) due to the enclosure appears mechanically in parallel with the loudspeaker compliance; in an electrical system it appears as a series capacitor. If a high-compliance loudspeaker is inserted in this system, the resonant frequency will be governed principally by the lower compliance (or greater stiffness) of the enclosure.

In the electrical analog, the speaker compliance now appears as a very large series capacitor and has little effect in determination of the resonant frequency:

$$\frac{1}{C} = \frac{1}{C_{c_s}} + \frac{1}{C_{c_e}}$$

$$\lim\left(\frac{1}{C}\right) = \frac{1}{C_{c_e}}$$

$$C_{c_s} \rightarrow \infty$$

$$f_o = \frac{1}{2\pi\sqrt{LC_{c_e}}}\ (\text{Hz})$$

This enclosure compliance has the value:

$$c_e = \frac{V_e}{\rho\, c^2 A^2}$$

where: c_e is the enclosure compliance, V_e is the enclosure volume, c is the velocity of sound, A is the area of the piston, and ρ is the density of air.

An extremely important advantage derived here is that the air compliance is linear for very large excursions of the speaker cone, whereas mechanical compliances have high-level excursion limits where Hooke's law no longer holds true. This fact accounts for a marked reduction in harmonic distortion in the lower frequencies near resonance.

A high-compliance loudspeaker can be recognized by the following physical characteristics: the rim of the piston or cone will be very soft, and the center suspension will be large and soft. These characteristics result in a free-moving cone with longer travel to improve low-frequency linearity. The natural resonant frequency of the speaker in free air will be very low. Such a unit cannot be operated at rated power unless it is mounted in a sealed enclosure, because it lacks sufficient stiffness or restoring force to prevent damage due to excessive motion at resonance.

Some of the design problems to be solved in the successful design of a high-compliance loudspeaker are: 1) Lower acoustic efficiency, 2) Higher heat-dissipation requirements, and 3) Less extension of high-frequency response.

The first two problems are solved by using larger magnetic and voice-coil assemblies to compensate for the longer voice-coil which is used to compensate for the greater excursion of the free-moving cone. The third problem is solved by using mid-range and tweeter speakers.

The results of this type of design are gratifying. Reproduction is extended to the lower limits of hearing and transient response is improved (the bass has less *boom*). Harmonic distortion is reduced, the low frequencies are richer in fundamental component, and the resulting acoustic system is much more independent of its environment.

With this basic understanding of open-back and sealed-enclosure speaker systems, let us return to the basic product design of the VHT-71F high-fidelity instrument.

PRELIMINARY ACOUSTIC INVESTIGATION

First, a wood box having the same internal volume as the final cabinet was assembled to allow for one of the speaker compartments. One side was marked off to simulate the final grille cloth area. Within this area the placement of the speaker was outlined; the 15-inch woofer was centered in this area, as close to the bottom as possible.

The next consideration was a mid-range speaker, and power handling became an important consideration. Although a horn could be selected to cover the full mid-range, none of those available could handle the power expected. Thus, a closed-back 5- x 7-inch speaker had to be designed to handle the lower mid-range frequencies and the expected power. A closed back was necessary to prevent the pressures developed by the woofer from distorting the cone of the mid-range speaker.

The next higher range of frequency is provided by a horn speaker; the use of a mid-range speaker permits also the use of a smaller horn to keep within the space limitations of the grille area. The horn selected has a 2- x 6-inch mouth opening with a low-frequency cutoff at 2 kHz (kc).

The selection of the tweeter, our standard 3½-inch unit, completed the group of four speakers needed to cover the audible spectrum. These four units were arranged closely within the grille area with consideration for optimum dispersion, separation between right and left, and interference from overlapping frequency ranges.

The completed box, with the speakers properly arranged, permitted each speaker's acoustic response to be recorded independently (Fig. 6). Using these curves, a crossover network was designed for the four speakers so as to result in a smooth, well-balanced overall response curve.

Special attention was given to maintaining a near-constant impedance as a function of frequency. This network was tested by running overall acoustic performance and impedance curves. After some trial and error a design was selected. The complete speaker system was then tested for its ability to handle the power delivered from the RS211 amplifier, rated at 300 watts peak power, under maximum signal conditions. This test completed the preliminary design phase in developing the VHT-71.

Enough information was available at this point to build a complete cabinet with final components. For this job the Mechanical Engineering Design group was consulted so that they could proceed with the cabinet design. Results of our preliminary design were given also to the Electrical Engineering Design group to assure that the engineering sample cabinet (when completed) would accommodate all components, chassis, and wiring.

FINAL CABINET EVALUATION

The next contact was with the completed engineering sample instrument. Preliminary inspection revealed minor problems in sealing the speaker compartments. These problems were discussed with the Mechanical Design group and resolved. The overall speakers-cabinet-crossover response was obtained in the anechoic chamber (Fig. 7) and evaluated, using past experience in correlating response curves with listening test performance. Some minor changes were made to the crossover network to satisfy listening tests.

The intent of the first design was to use, if possible, the existing tuner, amplifier, and changer used in RCA's best high-fidelity instrument; thus, before setting up for the listening test, these three units were checked to ensure that they conformed to nominal design.

The instrument was then set up in the listening room and compared by means of remote control switching to the following:

a) An existing top-quality modular system used as a permanent reference system in the listening test room
b) A competitive instrument of comparable price and design
c) The best RCA Victor high-fidelity console (the VGT-75) having a conventional open-back speaker cabinet.

Several people listened to these four units and gave their subjective evaluation. Some of these people are asked in regularly and have developed well-trained ears, whereas others may have never heard similar tests. The consensus of those hearing the instrument (VHT-71) at this point was that the tone balance should be improved.

After several attempts to achieve a desirable balance by modifying the speakers and crossover network, it was concluded that we could not use a tuner-preamplifier common with other open-back instruments in the product line. The decision was made to modify the preamplifier of the RC1218 tuner to provide a special unit for this instrument. Since the design of this preamplifier unit was the responsibility of the Electrical Design group, desirable response curves were furnished to them so that they could modify the preamplifier to meet these performance curves. The modification was accomplished by changing part values on the existing preamplifier board.

Another listening test was conducted and the participants agreed that the performance of the VHT-71 was ready to be demonstrated.

With the major problems resolved, we were able to concentrate on smaller but still very important problems such as hum, noise, rumble, howl (or feed-back), and final power-life tests. Problems discovered in some of these areas were worked out with the Changer Design group. With all of these factors satisfactorily resolved, the design was ready to be demonstrated to management personnel for their approval. Management was pleased with the results, which meant that the design was complete.

After management approval of the instrument, the only further contact that the Acoustics group has with the instrument is upon receipt of a preproduction instrument. This instrument is built in the factory with final factory parts and is tested to see that its performance is the same as that of the engineering sample.

ACKNOWLEDGMENT

The authors wish to express their appreciation to S. Walczak, Leader, RCA Victor Home Instruments Acoustics group, for guidance in the preparation of this paper.

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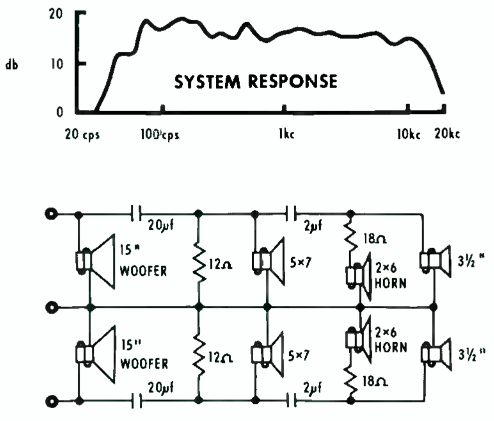
Fig. 7—VHT-71F speaker system response obtained with rotating microphone in anechoic chamber.



SYSTEM SCHEMATIC

HIGH-QUALITY, LOW-COST, 15-WATT, COMPLEMENTARY-SYMMETRY POWER AMPLIFIER

This high-quality, low-cost audio power amplifier features a transformerless, direct-coupled, complementary-symmetry driver-output circuit. The class B output stage develops an RMS power output of 10 watts into an 8-ohm load (15 watts into 4 ohms), and has an EIA rating (stereo) of 30 watts into 8 ohms.

M. S. FISHER received the BSEE from Northwestern University in 1961. He joined RCA as a co-op student in 1958, and worked in various assignments related to semiconductor testing and applications. Since 1961, he has been associated with the Commercial Receiving Tube and Semiconductor Division at Somerville as a consumer applications engineer specializing in the audio applications area.

M. S. FISHER
Commercial Receiving Tube & Semiconductor Div.
Electronic Components & Devices
Somerville, N.J.

The primary objectives in the design of the 15-watt complementary-symmetry audio-amplifier system were to achieve a performance level superior to that previously attained, and at the same time to keep the cost at a level which would be competitive with present commercial designs. The success achieved in meeting these objectives is demonstrated by a review of the performance and cost of the system.

Performance of the 15-watt power amplifier is illustrated in Table I and Figs. 1 through 8. Typical harmonic-distortion levels are below 0.15% from 40 to 20.000 Hz both at full power output of 8 watts and at low power outputs. Intermodulation distortion is typically 0.1% at power levels of 8 watts or less. Other features include a hum and noise level of 94 dB below rated output, a frequency response (3 dB down) of 8 to 90,000 Hz. and a clean 20,000-Hz square wave with no ringing.

The low cost level of the amplifier results from three factors: 1) the system uses only 4 stages and no transformers other than the power transformer; 2) the first 3 stages use small-signal silicon transistors; and 3) the circuit is simple and straightforward and the number of electrolytic capacitors and diodes is very low.

ADVANTAGES OF TRANSFORMERLESS DESIGN

In order to achieve the desired cost and performance objectives, it was considered necessary to eliminate the driver transformer. A high-quality driver transformer is expensive and also has two major technical disadvantages. First, a rapid change in phase response to a total phase rotation of 180° at both high and low frequencies (when the transformer is capacitively coupled) makes it impossible to stabilize high amounts of feedback. (Feedback stability criteria are analyzed in Ref. 2, *RCA Application Note* No. AN-3185, which describes this amplifier.) Second, magnetic radiation of the power transformer causes a hum pickup in the driver transformer.

Use of the right type of transformerless circuitry also makes it possible to eliminate two major problems associated with capacitive coupling to the speaker. One problem is that the natural unbalance of the system prevents ripple cancellation at the speaker. The second is that the center voltage may go off-center under drive and cause premature clipping because there is no direct control over this voltage. Both problems are eliminated in the complementary-symmetry system when a high level of DC feedback is used to hold the center voltage at the proper point and a high level of AC feedback is used to cancel the ripple signal.

REQUIREMENTS OF COMPLEMENTARY SYMMETRY

Pure complementary symmetry is the only type of transformerless output circuitry that has very good thermal stability and thus permits the use of germanium output devices. (*Pure* complementary symmetry should not be confused with *quasi* complementary-symmetry circuits, which have poor thermal stability and thus can normally be used only with all silicon devices. These circuits also have relatively higher circuit complexity.) Because pure complementary symmetry also has a high performance level and low circuit complexity, it was selected as the best circuit configuration for this application.

The key to success of this complementary-symmetry design is the use of an *n-p-n* output transistor that complements the high-performance, high-frequency 2N2148 *p-n-p* power transistor. Three significant characteristics are necessary for the *n-p-n* complement: 1) a gain-bandwidth product f_T nearly the same as that of the 2N2148; 2) a minimum beta (measured at low collector-to-emitter voltage and peak collector current) high enough to maintain reasonable loop feedback and linear operation in the driver stage; and 3) static

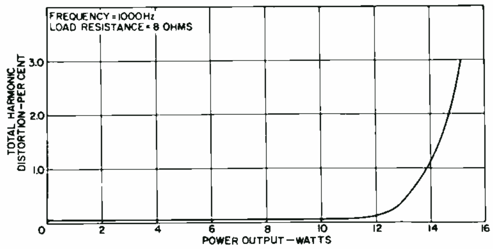


Fig. 1—Total harmonic distortion as a function of power output.

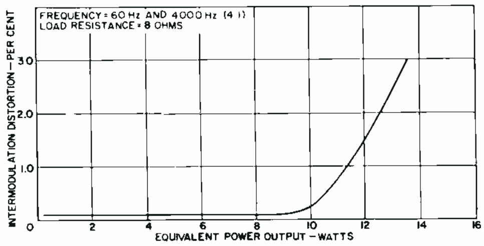


Fig. 2—Intermodulation distortion as a function of power output.

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characteristics at least as good as those of the 2N2148. A mismatch in beta or "fall-off" characteristics of the two output devices is not significant because of the high degree of feedback employed. Either a germanium or a silicon transistor can be used, therefore, provided it has the required characteristics of matched f_T, high minimum beta, and adequate static characteristics.

The RCA Dev. No. TA2577A used as a complement for the 2N2148 is a silicon power transistor in which the base region is grown epitaxially to form the collector-base junction. The emitter is then diffused into the base region to form the emitter-base junction. This type of construction results in the desired f_T of 3 to 5 MHz, a minimum beta of 50 at a collector-to-emitter voltage of 1 volt and a collector current of 2 amperes, and static characteristics equal to or better than those of the 2N2148.

Gain-Bandwidth Product

It is important that the two output transistors have matched f_T's for feedback-stability considerations. If the f_T's are not nearly the same, the phase-correction capacitor in the feedback cannot properly correct for both output units and ringing or oscillation will result on one half of the output.[2] A mismatch in f_T also causes very distorted output at the point where the gain of the lower-frequency transistor starts to decrease. The match in response of the 2N2148 and the TA2577A is illustrated by the 200-kHz sine-wave output shown in Fig. 5. The 20-kHz square wave shown in Fig. 6 demonstrates that no ringing occurs on either half of the square wave.

It is also desirable that the actual f_T's of the two devices be in the vicinity of 5 MHz. Feedback-stability rules[2] dictate that the response of one stage within a loop be inferior to that of the rest. Because the output transistors are usually the limiting factor in high-frequency response, the output-stage response should be as low as possible without materially affecting the 20-kHz distortion. An f_T of about 5 MHz provides the best results. In addition, higher-f_T devices tend to have poorer transient breakdown capability, and it would not be desirable to sacrifice transient-handling capability for unnecessary added high-frequency response. The TA2577A, for example, can handle pulses up to 100 watts (at collector-to-emitter voltages up to 25 volts) for periods as long as 50 milliseconds.

Beta

The minimum beta of 50 at peak current makes it possible to limit driver dissipation to 1.5 watts. Thus a metal-case, small-signal silicon transistor with a heat sink can be used in the driver stage. Use of a small-signal transistor is desirable both from a cost standpoint and because, as mentioned previously, the response in the driver stage should be very high compared to that of the output stage. The driver stage for the 15-watt complementary-symmetry amplifier must have a collector-to-emitter breakdown voltage rating $V_{(BR)CEO}$ of 40 volts and must be capable of linear operation at currents up to 200 milliamperes with a low saturation voltage $V_{CE(sat)}$. The 2N4074 *n-p-n* silicon epitaxial driver transistor is suitable for this type of operation.

CIRCUIT DESCRIPTION

Fig. 9 compares a block diagram for the complementary-symmetry power amplifier with that of a typical power amplifier using a driver transformer. These diagrams show that the front end (*Q1* and *Q2*) is essentially the same in either system. The major differences in the complementary-symmetry system are that the driver transformer is replaced by an additional transistor with a feedback loop and that the output uses a complementary pair of transistors rather than two transistors of the same polarity.

If the two systems shown in Fig. 9 were to have approximately equivalent cost levels, the cost of the output transistors would have to be the same for both systems, and the cost of the additional transistor *Q3* would have to match the cost of the driver transformer it replaces. If the cost of *Q3* is less than that of the driver transformer (the pentafilar-wound transformers used in high-quality systems are expensive items), the savings can be added to the cost of the complementary pair to obtain equivalent systems cost.

The complementary-symmetry system has improved technical performance, primarily because of the additional AC

TABLE I—Performance of 15-Watt Complementary-Symmetry Power Amplifier

Power Output:	
At 1000 Hz for harmonic distortion = 5%	15 watts
At 1000 Hz for harmonic distortion < 0.15%	10 watts
From 40 to 20,000 Hz for harmonic distortion < 0.15%	8 watts
Distortion Levels:	
Total harmonic distortion as a function of power output at 1000 Hz	See Fig. 1
Intermodulation distortion as a function of power output at 60 and 4000 Hz (4:1)	See Fig. 2
Total harmonic distortion as a function of frequency at a power output of 8 watts	See Fig. 3
Frequency Response:	
At an output of 1 watt:	
1 dB down	20 to 50,000 Hz
3 dB down	8 to 90,000 Hz
Power Bandwidth:	
At an output of 8 watts for total harmonic distortion of 5%	15 to 100,000 Hz (See Figs. 4 and 5)
Sensitivity:	
For power output of 8 watts at 1000 Hz	160 mV into 3300 ohms
Hum and Noise, input open	94 dB below 8 watts
(Note: proper grounding and shielding of input circuit is necessary to obtain this measurement.)	
Electrical Stability:	
20,000-Hz square wave	See Fig. 6
20-Hz square wave	See Fig. 7
1000-Hz tone bursts	See Fig. 8

All measurements made at AC line voltage of 120 volts with 8-ohm load and one channel operating, using internal power supply shown in Fig. 10. Performance with 4-ohm or 16-ohm load is essentially the same except that power output at the clipping level is increased slighty with 4 ohms and decreased slightly with 16 ohms.

Fig. 3—Total harmonic distortion as a functicn of frequency.

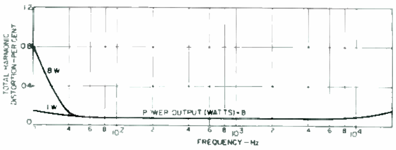


Fig. 4—Sine-wave output at a frequency of 5 Hz (vertical scale = 2V/cm, horizontal scale = 50 ms/cm).

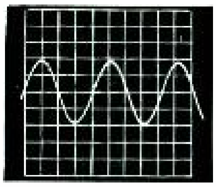


Fig. 5—Sine-wave output at a frequency of 200,000 Hz (vertical scale = 2V/cm, horizontal scale = 1 µs/cm).

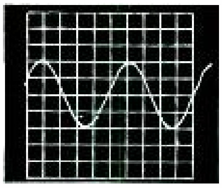


Fig. 6—Square-wave output at a frequency of 200,000 Hz (vertical scale = 2V/cm, horizontal scale = 10 µs/cm).

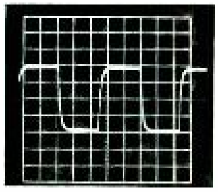


Fig. 7—Square-wave output at a frequency of 20 Hz (vertical scale = 2V/cm, horizontal scale = 10 ms/cm).

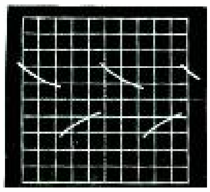
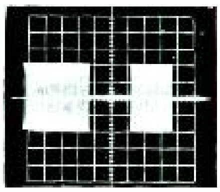


Fig. 8—Tone bursts at a frequency of 1000 Hz (vertical scale = 2V/cm, horizontal scale = 0.5 s/cm).



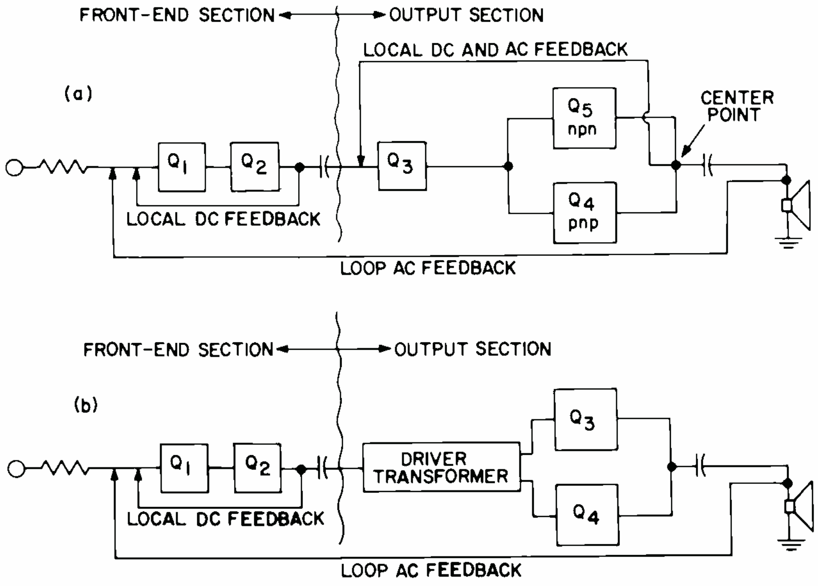


Fig. 9—Block diagrams of (a) a complementary-symmetry system, and (b) a driver-transformer system.

and DC feedback loop from the center point of the output stage to the base of the driver *Q3*. This feedback provides the following technical advantages: 1) the DC feedback from the center point holds the center voltage at the desired bias point and prevents premature clipping as a result of variations in output transistors; 2) the ripple level (which might otherwise be a problem in an unbalanced, single-supply output stage) is greatly reduced; 3) distortion levels are greatly reduced (so that linearity and matching of the output devices are not very significant); 4) frequency response is greatly improved; and 5) high-frequency phase shift can be held close to 90° (if the frequency response of *Q3* is very high) at frequencies up to the point where open-loop gain is less than unity (it is then much easier to stabilize the loop feedback). The additional feedback does not result in a lower overall current gain (from the output of *Q2* to the load) because the transistor *Q3* has a much higher current gain than the transformer it replaces.

CIRCUIT OPERATION

A schematic diagram of the complementary-symmetry power amplifier is shown in Fig. 10. Operating fundamentals for the complementary-symmetry driver-output stage are described in the RCA Application Note[2] mentioned earlier. The idling current in the output stage is established by the voltage drop across the 1N3754 silicon bias diode *D1*, and is stabilized by the two 0.51-ohm emitter resistors *R11* and *R12*. The DC drop across the bias diode is virtually independent of changes in the current through it (i.e., the diode has a low dynamic impedance). However, this voltage decreases with increases in temperature, and thus partially compensates for changes in the base-to-emitter voltage of the output transistors. As a result, the idling current is extremely stable. With the output transistors used, the single bias diode provides an output idling current of about 10 to 20 milliamperes. This low idling current does not create a crossover distortion problem because the output stage is driven from a high AC impedance. The result is cool and stable operation in the output stage.

The idling current in the driver stage (which must at least equal the maximum peak base current required by the *n-p-n* output transistor) is established by the two 120-ohm bias resistors *R9* and *R10*. The driver current is equal to the difference between the supply voltage and the center voltage divided by the series resistance (*R9* + *R10*), and is about 92 milliamperes.

For proper operation of the circuit, the current shown as I_1 in Fig. 10 must remain essentially constant during AC excursions of output voltage. For this purpose, a 250-microfarad "bootstrap" capacitor *C5* is connected between the bias resistors and the emitter of the *n-p-n* output transistor *Q5*. Because the voltage across the capacitor does not change during AC output-voltage excursions, the change in voltage at point *B* is the same as the change in voltage at point *A*. The change in voltage at point *C* is almost the same as that at point *A*, and differs only by the small change in the base-to-emitter voltage of *Q5*. Therefore, the voltages at points *B* and *C* change by essentially the same amount, the voltage across the 120-ohm resistor *R10* remains constant, and a constant current I_1 results.

The "bootstrap" capacitor *C5* is returned to point *A* rather than to the center point (as is the usual practice) to keep the change in voltage across the 0.51-ohm emitter resistor *R11* from appearing across resistor *R10*. When the change in voltage across *R11* appears across *R10*, the current I_1 is less constant and the dynamic-range requirements of the driver transistor *Q3* are increased.

It is important to note that a reverse base-to-emitter bias voltage is applied to the output transistors during the *off* half-cycles.[2] This condition also occurs in an output stage that uses a driver transformer, but not in many transformerless circuits. When reverse bias is applied to the output transistors during the *off* half-cycle, they are turned off in a very short time (the stored base-emitter charge is removed rapidly). As a result, the high-frequency operation remains in the highly efficient class B mode. When the output transistors are not reverse-biased, but instead are allowed to drift off, the stored charge holds the transistors on during part or all of the *off* half-cycle. Operation then shifts into class A push-pull, and efficiency is low and current drain, dissipation, and operating temperatures are high.

Bias for the base of the driver stage is derived from the center point of the output stage. As a result, a DC and AC feedback proportional to the center voltage is fed to the base of the driver stage. The actual DC center voltage which the feedback establishes depends on the ratio of resistors *R6* and *R7* and on the base-to-emitter voltage V_{be} and base current I_B of *Q3*. If a heavy direct current is bled through *R7*, changes in the base current of *Q3* become insignificant The DC voltage at the center point is then determined by the base-to-emitter voltage of *Q3*. Because the percentage of variation in V_{be} of a silicon transistor is small, the center-point DC voltage is held close to the desired value. The resistor values *R6* and *R7* must be chosen so that: 1) the bleeder current in *R7* is large compared to the base current in *Q3*;2) the ratio of the resistors provides the desired center-point voltage; and 3) the desired amount of AC feedback current is obtained.

ON-OFF TRANSIENTS

An important consideration in any type of output circuit, and especially in a transformerless circuit, is turn-on and turn-off transients. These transients must neither sound too objectionable nor cause operating conditions which would result in transistor failure.

In the circuit of Fig. 10, the speaker coupling capacitor *C6* charges through *Q5*, which is biased on, and the capacitor *C5*. As a result, there is a slight noise in the speaker, and the center-point voltage rises to its steady-state value in an underdamped manner. The turn-on transient is thus of a relatively short duration, and the operating conditions during the transient are well within the capabilities of the output devices.

After turn-off, *C6* discharges through *Q4*, which is also biased on. The resulting noise in the speaker is usually not noticeable because the amplifier continues to deliver output signal while the capacitor discharges. Again, no operating conditions occur which could cause transistor failure.

In some transformerless output circuits, including some variations of the basic complementary-symmetry circuit, voltage is obtained from a decoupled point in the power supply, rather than from the *B*+ point right at the rectifier diodes. Because such a decoupled point comes up to voltage much more slowly than the point right at the diodes, the very long turn-on transient in this type of circuit can cause adverse operating conditions which can exist for as long as several seconds. As a result, one of the output transistors is biased to a high current for a period of time long enough to be essentially DC, and thermal runaway may occur during the turn-on transient at high ambient temperatures.

FEEDBACK LOOP

The front end of the power amplifier shown in Fig. 10 consists of a pair of *n-p-n* silicon transistors in a direct-coupled circuit. The feedback from the emitter of *Q2* to the base of *Q1* serves primarily to hold the DC operating point of *Q2* within the limits necessary to prevent a dynamic-range limitation, despite variations in individual transistors or in temperature. The loop feedback resistor *R8* also serves as the DC bias resistor from the base of *Q1* to ground (the resistor returns to ground through the output voltage-divider resistors *R13* and *R14*).

For high-frequency stabilization of loop feedback, it is necessary that one element within the loop have relatively poorer high-frequency response than the rest.[2] Because of the local feedback established by resistor *R6*, the response of the output section is very high. Therefore, the response must be limited somewhere in the front-end section. The collector-to-base feedback capacitance C_{ob} of transistor *Q1* can be used for this purpose. The high collector load impedance of *Q1* causes a high-frequency local feedback current to flow through this capacitance and thus limits the high-frequency response of *Q1*.

The same rules hold for low-frequency loop-feedback stabilization. It is necessary that one element within the loop have relatively poorer low-frequency response than the rest. The low-frequency response is limited by *C6*, the speaker coupling capacitor.

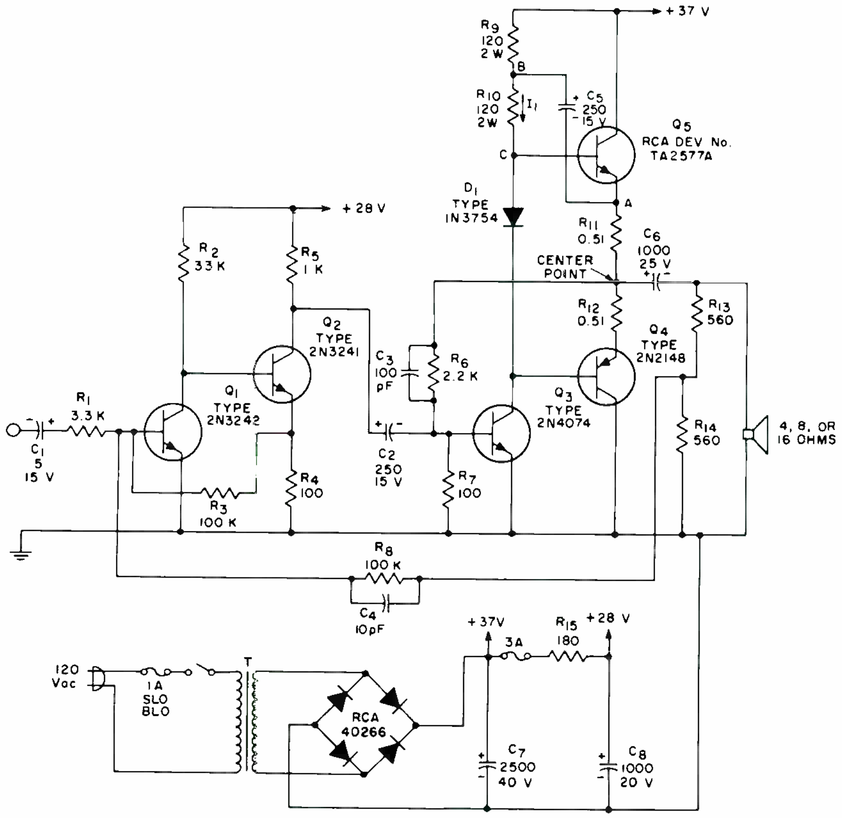
Because the value of resistor *R8* is established by the DC bias considerations for the front end, the proper amount of AC loop feedback is established by deriving the feedback from a voltage divider across the output. Resistors *R13* and *R14* divide the output voltage down to a level which provides the desired feedback current through *R8*. Resistors *R13* and *R14* also serve as an output termination when there is no speaker load.

It is important to note that, because there is no driver transformer, negative feedback can be applied only to certain points in the circuit. (When a driver transformer is used, the primary can be phased either way to provide the proper phase to the feedback signal, wherever it is located.) The points that can be used in the circuit of Fig. 10 are the base of the driver transistor *Q3* (which is used for local feedback), the emitter of *Q2*, and the base of *Q1* (which is used for the loop feedback).

When feedback is applied to the base of a transistor, the transistor must be driven by a current source. If a resistor is used to provide a current source, the resistor also isolates the feedback from the rest of the circuit. The 3,300-ohm resistor *R1* serves as a current source for *Q1* and prevents the feedback from interacting with the preamplifier circuit.

The high degree of feedback (about 32-dB local in *R6* and 34-dB loop in *R8*, for a total of 66 dB) results in an extremely low output impedance and a high degree of speaker damping. This large amount of feedback is the main reason for the extremely low hum and distortion levels in the amplifier. In spite of the large amount of feedback, the stability is excellent, as shown by the square-wave and tone-burst responses in Figs. 6, 7, and 8. This stability results from elimination of the driver transformer and careful observation of the rules of feedback stability (discussed, as noted before, in Ref. 2).

Fig 10—Schematic diagram of the 10-watt complementary-symmetry audio power amplifier.



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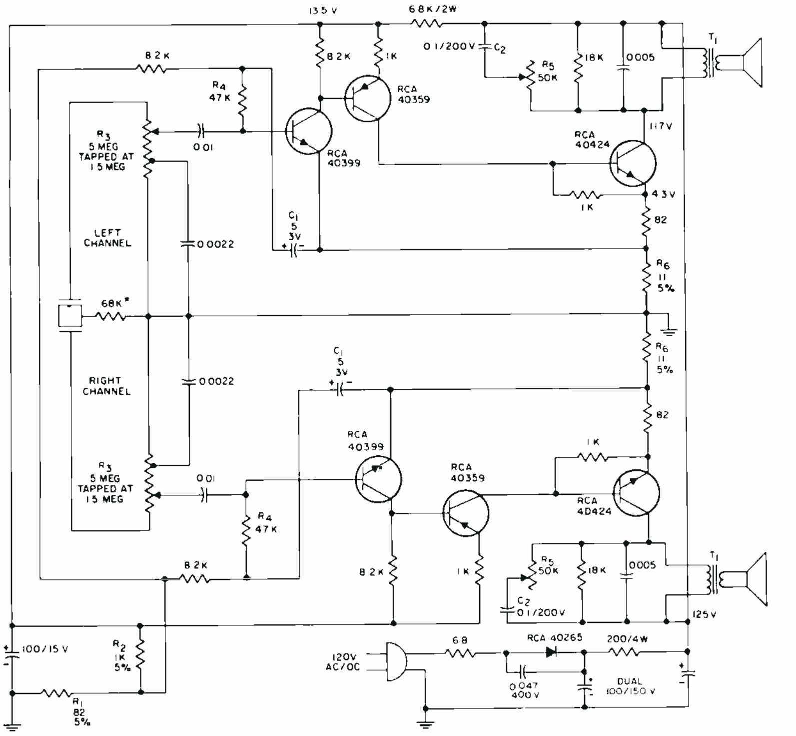

Fig. 1—Schematic Diagram of 4-watt, line-operated stereo amplifier. NOTES: *Resistor may be replaced by 0.047-µF, 400-volt capacitor; T_1 = output transformer, 2500 ohms to speaker (Freed R6A-8, Triad S-12x, or equivalent); all resistors in ohms, all capacitors in microfarads.

LINE-OPERATED 4-WATT STEREO AMPLIFIER USES RCA-40424 HIGH-VOLTAGE SILICON TRANSISTOR

R. S. HARTZ

Electronic Components and Devices, Somerville, N. J.

This low-cost, line-operated, three-stage, direct-coupled amplifier is designed for use with ceramic or crystal pickups with an output voltage of 500 mV and an output capacitance of 800 pF or more per channel. The amplifier deliver 2 watts-rms or more per channel at a total harmonic distortion of 10%. Direc operation from a 120-volt-ac power line is made possible by the RCA-4042 high-voltage silicon transistor in the output stage of each channel.

Editor's Note: The RCA-40424 is an improved version (power capability increased from 1 watt to 2 watts) of RCA's development of the first transistor for practical and economical transistorization of line-operated radios and phonographs. The forerunner of the 40424 was selected by Industrial Research magazine in 1965 as one of the 100 most significant new developments of the year, and won the David Sarnoff Outstanding Team Award in Engineering for the author and three of his associates.

THE design of audio equipment for direct operation from an AC power line normally requires the use of either a power transformer or a large voltage-dropping resistor to reduce the 120-volt-AC line voltage to a level that is appropriate for transistors. Both of these techniques have disadvantages. The use of a transformer adds cost to the system. The use of a dropping resistor places restrictions on the final packaging of the instrument because the resistor must dissipate power. In addition, low-voltage supplies are usually more expensive to filter than high-voltage supplies.

In the circuit[1] shown in Fig. 1, the use of high-voltage silicon transistors eliminates the need for either a power transformer or a high-power voltage-dropping resistor, and thus permits the use of economical circuits and components. For each channel, a 40424 high-voltage *n-p-n* silicon transistor is operated in a common-emitter class A transformer-coupled output stage. The 40424 is direct-coupled to a 40359 *p-n-p* germanium common-emitter driver. The 40399 *n-p-n* silicon pre-driver maintains the high input impedance of the amplifier and controls the DC operating point of the 40424. The emitter current of the 40424 output transistor is determined by the divider network R_1 and R_2. The voltage across R_6, which is proportional to this emitter current, is degeneratively fed back to the emitter of the 40399 pre-driver. The operating point of the 40424 is, therefore, insensitive to changes in the current transfer ratios of all three stages within the design limits, as well as to changes in the voltages across the emitter-base diodes of the 40359 and the 40424. Because an AC voltage proportional to the output current appears across R_6, this connection also provides negative AC feedback to control distortion and improve interchangeability.

The only electrolytic capacitor used outside the power supply is the "bootstrap" capacitor C_1, used to raise the input impedance of the first stage. In this configuration, the bias network is AC-coupled to the emitter of the 40399 to eliminate shunting by the bias network.

PERFORMANCE

Table I shows typical performance data for the 4-watt line-operated stereo amplifier. When typical transistors of the types shown in Fig. 1 are used, the 4-watt stereo amplifier has a sensitivity of about 500 mV for a power output of 2 watts per channel. The distortion at this power level is approximately 7.5% at room temperature and a line voltage of 120 volts. Feedback from R_6 provides nearly constant voltage sensitivity independent

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Final manuscript received June 8, 1966.

of the composite current transfer ratio of the transistor complement. The change in sensitivity from all high-gain to all low-gain transistors is less than 2 dB. The power output at a total harmonic distortion of 10% and the sensitivity remain essentially constant to 65°C, as shown in Fig. 2.

Frequency-response curves for the amplifier are shown in Fig. 3. The tapped volume-control potentiometer R_3, provides bass boost of about 12 dB at 100 Hz at low volumes. Treble cut is provided by the RC network R_5-C_2, across the primary of the output transformer. The overall useful response has a range from about 50 Hz to 12 kHz, depending on the cartridge and speakers used.

The pi filter used for the high-voltage supply results in an overall level of hum and noise more than 60 dB below full power output. Total harmonic distortion is shown as a function of power output in Fig. 4.

RELIABILITY CONSIDERATIONS

Power dissipation in the 40424 output transistor is about 5.25 watts at a line voltage of 120 volts, and can increase to about 6.3 watts as a result of line-voltage variations alone. The average dissipation should be kept as close to 5.25 watts as possible. For this reason, resistors R_1, R_2, and R_8 should have a tolerance of only 5%. The "worst-case" dissipation should then be no greater than 5.8 watts at normal line voltage and approximately 7 watts at high line voltage. A heat sink that has a thermal resistance of 5°C per watt can then be used for each channel for ambient temperatures up to about 50°C.

A 5°C-per-watt heat sink made of 3/32-inch aluminum requires approximately 32 square inches of surface area. A typical heat sink for this purpose is a 4-by-4-inch aluminum plate 3/32-inch thick. Both sides should be exposed for convection cooling.

PROTECTION AGAINST TRANSIENT VOLTAGES

In a class A audio-output stage that uses transformer coupling between the transistor and the load, the collector voltage may reach instantaneous values as great as 5 to 7 times the DC supply voltage. Such high-voltage transients are usually developed when the transistor is overdriven to a very high value of collector current and is then abruptly cut off.

The peak value of the transient voltage depends on the inductance, capacitance, and resistance of the output transformer and load, and on the value of the collector current immediately prior to cutoff. The reactive components of the transformer and load act as a parallel-resonant circuit, with series and shunt damping (loss) elements provided by the associated resistances. For a given set of load-circuit conditions, the peak value of the transient voltage is directly proportional to the collector current, and can be limited to a value within the maximum rating for the transistor by limiting the maximum value of the collector current (i.e., by limiting the dynamic range of the transistor).

In most cases, this type of limiting can be accomplished, and the desired maximum power output can be obtained without clipping and without compromise in performance or cost factors, by a judicious choice of circuit constants. The amplifier shown in Fig. 1 provides protection against excessive collector voltages without the use of transient-suppression devices. Collector-current limiting is provided by the ratio of the driver-supply voltage to the emitter-bias voltage of the 40424 output transistor. Because this ratio is about 3 to 1, the maximum current that can flow in the 40424 is 3 times the bias current even if the base of the transistor is shorted to the 13.5-volt supply. This type of current limiting does not affect the dynamic range within the desired power range of the amplifier, but limits the peak voltage developed for the given collector load constants. The treble-cut control placed across the transformer primary provides additional damping with no sacrifice in performance.

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R. S. HARTZ received the B.S. degree in physics from Monmouth College in 1960, and has done graduate work in Electronics Engineering in 1961 and 1962. From 1960 to 1961, he worked on applications of power transistors at the Bendix Semiconductor Division. Since 1962, he has been a member of the Commercial Transistor Applications Laboratory, and has worked on AM receiver and audio amplifier design. He was one of the recipients of the David Sarnoff Outstanding Team Award in Engineering in May 1966. He has published several papers, articles, and application notes in the field of transistor circuit design.

TABLE I—Typical Performance Data for 4-Watt Stereo Amplifier

Measured at a line voltage of 120 volts rms, an ambient temperature of 25°C, and a frequency of 1000 Hz, unless otherwise specified.

Power Output (continuous sine wave, both channels operating at total harmonic distortion of 10%)	4 watts (min)
Sensitivity (at power output of 2 watts/channel)	500 mV
Hum and Noise	<60 dB below 2 watts
Total Harmonic Distortion (typical) at:	
2 watts/channel	7.5%
1 watt/channel	1.4%
0.5 watt/channel	1.5%
0.1 watt/channel	1.65%
Frequency Response (3 dB down, typical)	100 to 12,000 Hz
Sensitivity Variation:	
All low-gain to all high-gain transistors	2 dB
25 to 55°C	<1 dB

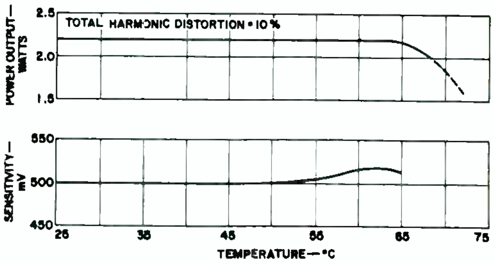

Fig. 2—Temperature stability of power output at a total harmonic distortion of 10% and of sensitivity.

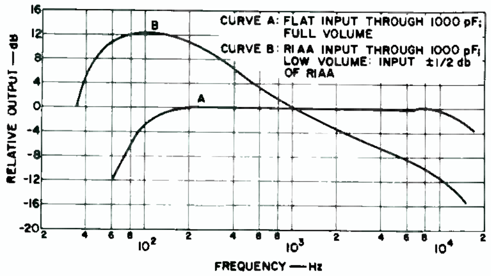

Fig. 3—Frequency-response curves for the amplifier of Fig. 1.

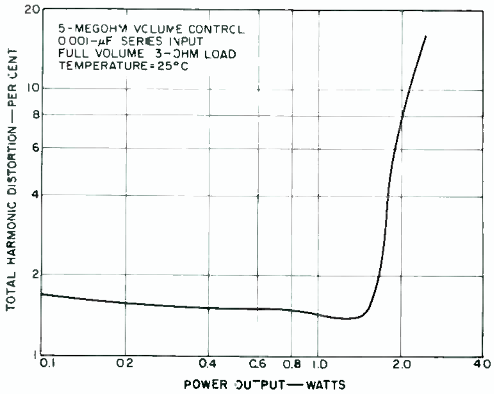

Fig. 4—Total harmonic distortion of the 4-watt stereo amplifier as a function of power output.

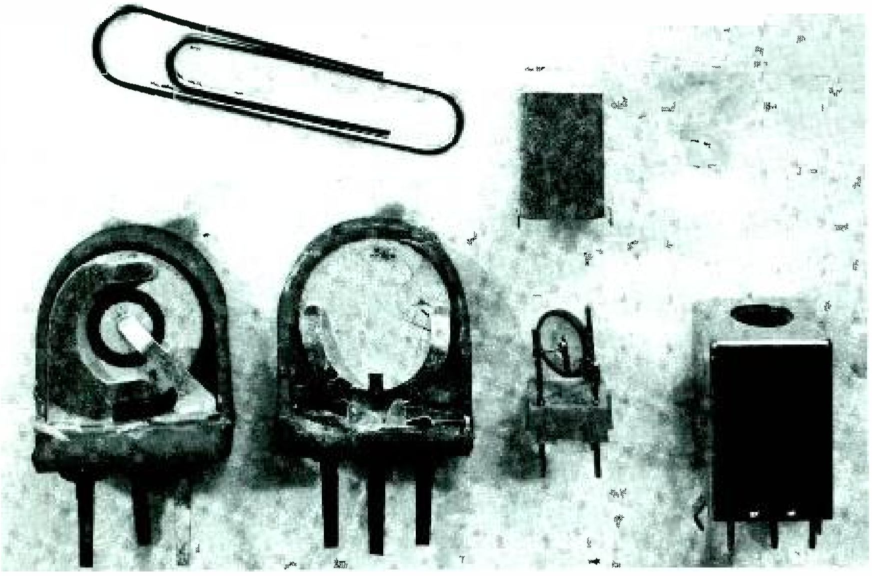

Fig. 1—Left to right: Overtone resonator, front view; overtone resonator, back view; fundamental resonator; standard 3/8 inch IF transformer.

CERAMIC FILTERS IN BROADCAST RECEIVERS

Ceramic filters are piezoelectric devices exhibiting bandpass characteristics suitable for use in 455-kHz IF amplifiers. The cost of these units is becoming competitive with IF transformers currently used in AM table and portable radios. A receiver using ceramic filters is described herein and compared with a similar receiver using conventional IF transformers.

E. H. DIAMOND and J. M. KEETH
Radio-Victrola Engineering
RCA Victor Home Instruments Division
Indianapolis, Ind.

The trend toward smaller and more compact electronic equipment has brought about an increasing use of piezoelectric solid-state tuned circuits in communication receivers. Since solid-state tuned circuits became available several years ago, their commercial use has been confined mainly to military and industrial communication systems. These units are now becoming increasingly attractive for applications in the consumer electronics field.

Piezoelectric solid-state tuned circuits designed for use in IF circuitry are commonly referred to as ceramic filters, solid-state filters, or *Transfilters.** The devices are fabricated from a piezoelectric ceramic material and exhibit bandpass filter characteristics having good frequency stability with temperature changes and aging. Ceramic filters possessing these characteristics are available for use in 455-kHz IF amplifiers of standard AM broadcast receivers.

CERAMIC FILTER CHARACTERISTICS

Ceramic filters are currently available in several different configurations for operation in the 455-kHz range. The most widely used types are the overtone resonator, the fundamental resonator, and the ladder filter. All three types make use of the piezoelectric characteristics of lead-zirconate-titanate ceramics. As the names imply, the overtone resonator operates at the first overtone of the radial vibrational mode, while the fundamental resonator operates at the fundamental mechanical resonant frequency. The third filter, the ladder type, is made up of combinations of cascaded and coupled individual filters packaged in a convenient container. The elements are selected to give the desired bandpass characteristics. The ladder filter is designed primarily for communications equipment and its relatively high cost makes its use impractical for home entertainment equipment. The overtone resonator was chosen over the fundamental resonator for this work, because the available overtone types showed less insertion loss at the impedance values to be matched.

The overtone resonator consists of three electrodes plated on a ceramic disk. The high-impedance electrode is the small circular metallic plate shown in the front view of the filter in Fig. 1. The low impedance electrode is the ring

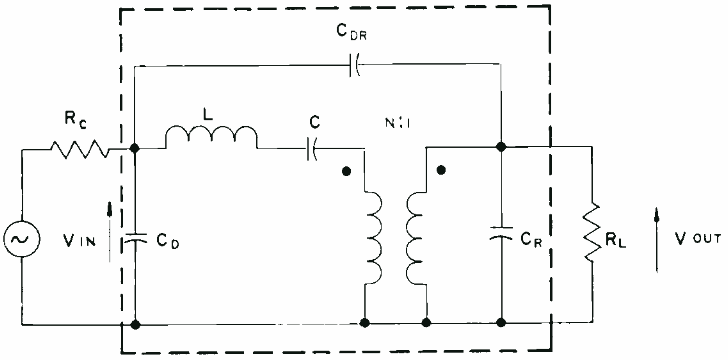

Fig. 2—Overtone resonator equivalent circuit.

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* *Transfilter* is a registered trade name of Clevite Corporation.

EARL H. DIAMOND received a Bachelor Degree in Electrical Engineering from the Georgia Institute of Technology in 1958. He joined the Home Instruments Division of RCA in September of 1962, after serving 3½ years as an officer in the United States Air Force. Since joining RCA, he has been engaged in the design of transistorized receivers. He has designed several portable receivers including models RFG20 and RGG29, and the AM and audio portions of Model RHM39. Mr. Diamond is a member of IEEE.

JAMES M. KEETH received his BSEE Degree from Washington State University in February, 1965. Upon graduation he was employed by RCA Home Instruments Division where he is currently working in the portable and table radio design group. Mr. Keeth is a member of IEEE.

near the edge of the disk. The common electrode is on the opposite side, and is shown in the back view in Fig. 1. Electrical connection to the electrodes is made by the spring contacts shown. This method of connection has been found to be superior to soldered connections.

The fundamental resonator is smaller than an overtone resonator for the same frequency. It also differs from the latter in that the input and output electrodes are on opposite sides of the disk while the common terminal is between the two sides. One example of this filter is shown in Fig. 1; the filter is housed in a metal can similar to a conventional IF transformer, although some manufacturers use nonmetallic packages.

The ceramic materials used in the filter are chosen for maximum stability consistent with electrical and mechanical characteristics. Commercially available filters show a frequency stability in the order of 0.2% over a five-year period and less than 0.2% over a temperature range[1] from −20°C to +60°C. The size of the unit determines the frequency of operation. The impedance ratios obtainable are directly proportional to the ratio of the areas of the electrodes. Impedance transformation is in the order of 10:1 and at 455 kHz, the maximum impedance of the dot terminal is in the order of several thousand ohms, while the minimum impedance of the ring electrode is a few hundred ohms.

Fig. 2 shows an equivalent circuit given by Clevite Corporation to predict the performance of their overtone filters. Like most other equivalent circuits, this one will not accurately describe all types of ceramic filters, but is representative of one type of filter commercially available.

A family of selectivity curves of a typical ceramic filter is shown in Fig. 3. The data was taken with a 2.7 kilohm source impedance connected to the dot terminal and various resistive loads connected to the ring terminal. The filter showed only a very small change in center frequency over a large range of resistive loading. However, the center frequency will change as the load becomes more reactive.

DESIGN CONSIDERATIONS

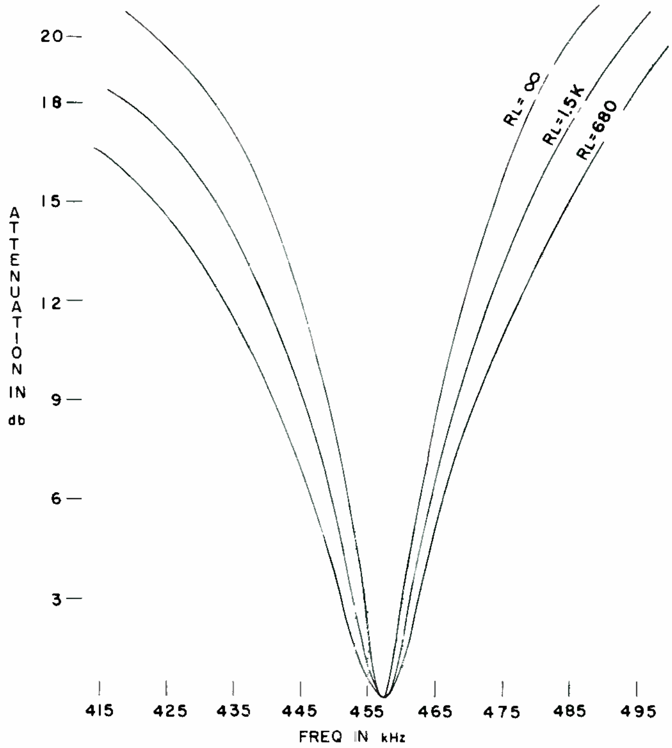
Most portable and table-model AM broadcast receivers use two stages of IF amplification coupled by three single-tuned IF transformers. Automatic gain control (AGC) is usually applied to the first IF stage, and a detector is coupled to the second stage by the third IF transformer.

When designing an IF amplifier using ceramic filters, the first problem encountered is the lack of a DC path through the filter. An alternate method of supplying DC to the collector can be realized by connecting a resistor from the supply voltage to the collector of the transistor. The value of this resistor will be determined by:

1) The minimum value of collector to emitter voltage required for proper operation of the transistor.
2) The transistor terminating impedance required for stability.
3) The desired source impedance for the filter.

If the collector to emitter voltage becomes too low, the gain, linearity, and signal handling capability of the stage are reduced. Consequently, there is a

Fig. 3—Selectivity curves for typical ceramic filter.



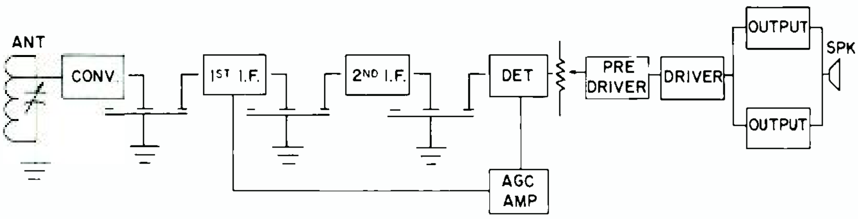


Fig. 4—Ceramic filter receiver.

maximum practical value of resistance which will satisfy the first criteria. Secondly, a transistor, being essentially a constant current device with high impedance, must be terminated with a relatively low impedance to obtain sufficient losses for stable operation. Thus the resistor should also be chosen to give proper terminating impedance for the transistor. Finally, the resistor should be chosen to give desired source impedance to provide optimum power transfer to the filter. The final choice of resistor value will be a compromise of these three conditions.

Although an RF choke may be used to provide a DC path for the collector, a resistor will almost always be required in parallel with the choke to provide proper stability. The choke is a relatively large and expensive component, and can introduce a number of electrical problems in this type circuit. For these reasons, a choke is undesirable for applications in low cost AM receivers.

Although the supply voltage in a portable receiver may be only 6 volts, it was found by careful design that resistor feed could be successfully used at this voltage. In some designs, there may be a problem of the oscillator action of the converter failing to occur at low supply voltages. This problem may be solved by using separate oscillator and mixer transistors. This method offers a further advantage in that it allows AGC to be applied to the mixer stage, resulting in the possibility of better overload performance.

The ceramic filter is constructed to minimize the possibility of spurious responses, however, the filters tested did show a few responses in the frequency range between 1 and 2 MHz. These responses were in the order of 20 dB below the peak response at 455 kHz for each filter. Thus, with three filters in the IF amplifier, the responses in this range were 50 to 60 dB below the main response. These responses are particularly troublesome because they lie in the frequency band of the local oscillator. The oscillator voltage that leaks through the IF amplifier *is* sufficient to cause AGC action to start in some cases. No significant improvement in this condition was noted by using various oscillator circuits, but by careful selection of impedance levels and ratios in the ceramic filter used for this stage, these responses could be reduced. Further improvements will ultimately have to be worked out with the manufacturers of the devices.

Sometimes a slight hump in the selectivity curves was observed somewhat higher than the center frequency. This can be explained by the action of C_{DR}, the mutual capacitance between the dot and ring, and the *L-C* branch of the equivalent circuit in Fig. 2. Above the center frequency, the *L-C* branch looks inductive. At some frequency, it will resonate with C_{DR} causing a slight hump in the response curve. The presence of the hump did not cause any adverse effects in the overall performance of the receiver.

When AGC is applied to a stage, care must be taken to see that the changing input reactance of the transistor does not affect the resonant frequency of the filter. Satisfactory performance was obtained as long as the input capacitance of the transistor was below 200 pF.

TABLE I—Performance Of Ceramic Filter Receiver VS 4RG5 Receiver

Measurement	Ceramic Filter Receiver	4RG5 Receiver
50 mW SENS (1,000 kHz)	300 μV/m	80 μV/m
20 dB S/N (1,000 kHz)	180 μV/m	320 μV/m
6 dB BW (1,000 kHz)	6.8 kHz	7.7 kHz
6 dB BW (455 kHz)	8.2 kHz	8.5 kHz
ACA$_{10}$ (1,000 kHz)	22 ×	14.7 ×
Image Rejection (1,400 kHz)	240 ×	110 ×
IF Rejection (600 kHz)	58 ×	70 ×
AGC figure of merit ref. to 0.1 V/m (1,000 kHz)	38dB	39.5dB
910 kHz Tweet	5.5% @ 5K μV/m	6.6% @ 2.5K μv/m

TABLE II—Ceramic Filter Manufacturers

Manufacturer	Filter Designation	Operational Mode
Clevite	TO-01A, TO-02A	Overtone
Sonus	041-455-2	Fundamental
Murata	SF 455B, SF 455C	Fundamental
TDK-Electronics	CF-01	Fundamental
Matsushita	EFC-D455K1	Fundamental

PERFORMANCE OF A RECEIVER

A block diagram of a receiver constructed to test the application of ceramic filters to a portable receiver is shown in Fig. 4. The circuit contains an AGC amplifier because it was anticipated that the low supply voltage of six volts would limit the power available for proper AGC action. The circuit contains approximately the same number of components as the RCA Model 4RG5 portable receiver and this model provided a good comparison for ceramic filters versus IF transformers. The transistors used were the same types used previously in sets designed for operation from a 3-volt supply. This assured good performance at the reduced collector-to-emitter voltage.

Performance comparisons of the ceramic filter receiver and the 4RG5 receiver are shown in Table I. It must be kept in mind that the filters used in this receiver are standard ceramic filters. A receiver designed for production could take advantage of filters designed with impedance ratios for optimum coupling, and as a result, better performance could be obtained.

CONCLUSION

Ceramic filters can be used as a practical replacement for IF transformers in AM standard broadcast receivers. Although several problem areas exist, it is possible, with careful design procedures, to build receivers with performance similar to receivers employing conventional IF transformers. From an economic point of view, ceramic filters are not yet competitive with the most inexpensive IF transformers, however, as the use of ceramic filters increases, the prices in production quantities are expected to fall below those of transformers. Ceramic filters will also eliminate the IF alignment procedure resulting in additional cost savings.

Standard filters are available from several manufacturers, both domestic and foreign. A partial list of manufacturers is shown in Table II. Special filters made to the circuit designers specifications, within limits, are expected to be available in the near future.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to L. M. Krugman, J. B. Schultz, M. C. Mehta, and D. E. Kowallek, for their comments and assistance in the preparation of this article.

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UNIFIED FILTER DESIGN CHART

The concept of the "unified filter design chart" is derived from the fundamental formulae for filters with Tchebychev and maximally flat responses. Since most filters are specified in terms of usable bandwidth and isolation bandwidth, these parameters are used in formulating the design chart. Other parameters used are passband reflection coefficient, stopband isolation, and number of cavities The filter design best suited to a given application can be determined by using this chart, and without recourse to other graphs and calculations.

Dr. N. K. M. CHITRE and M. V. O'DONOVAN
Antenna Engineering
RCA Victor Co., Ltd., Montreal, Canada

With the increasing use of high-index FM in wide-band satellite and earth-bound communication systems, the optimization of filter characteristics becomes increasingly important. Filter designs for these applications usually must have low reflection coefficients in their passbands.

The advent of modern swept-frequency-reflectometer techniques has led to the supersedure of the *insertion loss* method of filter tuning by the *reflection coefficient* method. In the latter method, filters are tuned to exhibit the passband reflection characteristics predicted from theory. It is regrettable, therefore, that design techniques based on the concepts of half-power bandwidth for maximally flat and amplitude ripple for Tchebychev filters are still widely used. In particular, the merits of Tchebychev designs with very small passband ripples are often overlooked because of the lengthy computations involved and the paucity of data in the literature.

The *unified filter design chart* is derived from the basic Tchebychev and maximally flat formulae using the parameters of usable bandwidth and isolation bandwidth in preference to the practice of defining maximally flat filters relative to the half-power bandwidth and Tchebychev filters to the ripple bandwidth.

This design chart, compiled for Tchebychev and maximally flat filters containing 3 to 12 sections, provides data previously unavailable within the bounds of a single chart. It permits the filter best suited to a given application to be completely specified, thus dispensing with a multiplicity of graphs and calculations. It calls attention to a significant attribute of both Tchebychev and maximally flat filters that is not widely appreciated: that passband reflection coefficients can be traded off directly, dB for dB, against stopband isolation. This trade-off facility is particularly valuable when dealing with small-ripple Tchebychev filters, since isolation can be significantly improved at the expense of a relatively small degradation in the passband reflection characteristics.

Approximations used in the derivation of the design chart reduce its accuracy when it is used in the design of filters with large passband reflection coefficients or small stopband isolations (< -16 dB). A single error curve is plotted in Fig. 1 to extend the accuracy of the design chart to filters with passband reflection coefficients and stopband isolations of -3 dB.

DESIGN CHART NOMENCLATURE

The nomenclature used in this article is illustrated in Fig. 2, which shows the standardized low-pass response curves for a maximally flat and an equal-ripple Tchebychev filter. The filters are assumed to have no losses.

The insertion loss or isolation, A in dB, is plotted on the $+ve$ y axis, whereas the reflection coefficient or return loss, R in dB, is plotted on the $-ve$ y axis. The convention followed throughout is that both these quantities are negative and are referred to the input power, thus:

$$A = 10 \log \left(\frac{\text{transmitted power}}{\text{incident power}} \right) \qquad (1)$$

$$R = 10 \log \left(\frac{\text{reflected power}}{\text{incident power}} \right) \qquad (2)$$

The x axis is the frequency axis and the three frequencies of interest are:

1) W_1 is the usable bandwidth. The return loss below this frequency is less than R_1 in dB. For a Tchebychev filter this also corresponds to the ripple bandwidth. The associated transmission loss at this frequency is A_1 dB.
2) W_2 is the half-power bandwidth of the maximally flat filter; R_2 and A_2 are both -3 dB at this frequency.
3) W_3 is the isolation bandwidth. The isolation provided by the filter above this frequency is numerically greater than A_3 dB. The associated reflection loss at this frequency is R_3 dB.

The design chart is based on the following mathematical relationships, which can be derived from the basic filter-response equations[5].

For maximally flat filters:

$$(A_3 + R_1) + (A_1 + R_3) = 20\, n \log \frac{W_3}{W_1} = F_M \qquad (3)$$

For Tchebychev filters:

$$(A_3 + R_1) + (A_1 + R_3) = 20 \log \left(T_n \frac{W_3}{W_1} \right) = F_T \qquad (4)$$

where n is the number of sections in the filter, and $T_n\,(x)$ is the Tchebychev function of the first kind and order n.

The unified filter design chart is simply a plot of F_M and F_T, as defined by equations (3) and (4), with W_3/W_1 as the variable and n as the parameter. By its definition the chart is valid for maximally flat or Tchebychev filters with any ripple coefficient, and it has been plotted for 3- to 12-section filters. To provide maximum readout accuracy it is divided in two parts: Fig. 3 covers values of W_3/W_1 from 1 to 2, and Fig. 4 covers values from 2 to 10. Higher values of F vs. W_3/W_1 can be deduced by linear extrapolation.

Of the four quantities on the left-hand side of Equations 3 and 4, only two are independent, since in lossless filters R_3 (or R_1) is a function of A_3 (or A_1) in accordance with: (5)

$$A_1 = 10 \log \left[1 - \text{antilog} \frac{R_1}{10} \right]$$

It can be verified that R_1 and A_1 can be exchanged in the above equation and that a similar relationship exists between A_3 and R_3. This equation is plotted in Fig. 1.

USE OF THE CHART

Choice of Filter Parameters

Most filters can be specified in terms of only four quantities:

1) Minimum width of passband W_{1S}
2) Maximum reflection coefficient in the passband R_{1S}
3) Maximum width of stopband W_{3S}
4) Minimum isolation in stopband A_{3S}

(The subscript S above refers to the specified values.)

Introducing a factor F' which is the sum (Fig. 2) of the passband return loss and the stopband isolation of a filter,

$$F' = -(A_3 + R_1) \qquad (6)$$

the above specifications can be interpreted as: (7)

$$F' \geq F'_S \geq (A_{3S} + R_{1S}), \text{ for } \frac{W_3}{W_1} \leq \frac{W_{3S}}{W_{1S}}$$

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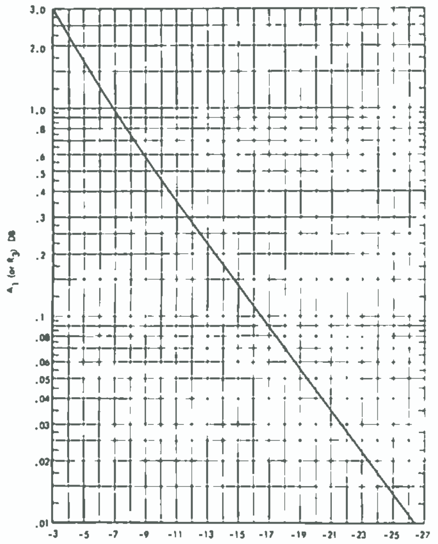

Fig. 1—Error curve.

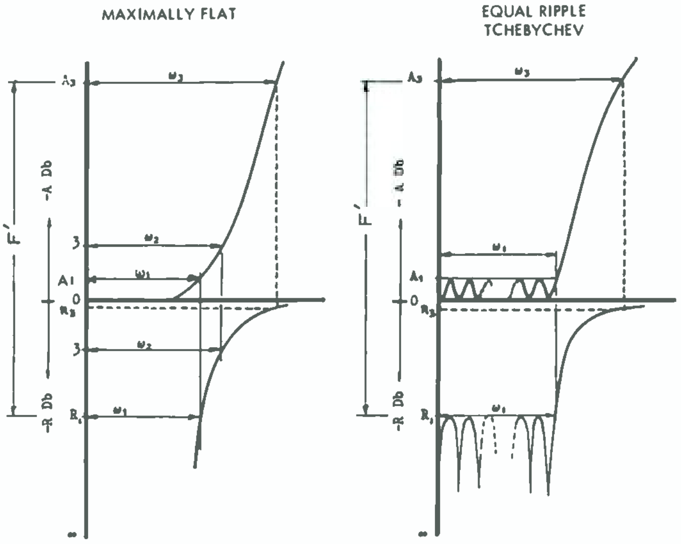

Fig. 2—Filter bandwidth nomenclature.

The unified design chart is not a plot of F' but of F, which has two more terms: $(A_1 + R_3)$. However, both A_1 and R_3 are very small negative quantities, since at W_1 virtually all the incident power is transmitted and at W_3 virtually all the incident power is reflected. Within these limits, therefore, the chart can be used directly to choose the filter parameters.

By plotting the point F'_S vs. W'_{3S}/W'_{1S} on the chart, it is seen that all filters in the area above and to the left of this point will satisfy Equation 7. If a filter with $F > F'_S$ is selected, the isolation can be increased or the return loss in the passband can be reduced; selection of a filter with $W_3/W_1 < W'_{3S}/W'_{1S}$ means that the passband can be increased or the stopband decreased.

The major advantage of the chart is that it eliminates: 1) the half-power bandwidth of the maximally flat filters and 2) the amplitude-ripple factor of the Tchebychev filters. It uses the much simpler ratio of stopband-to-passband widths and the sum of the attenuation at W_3 and return loss at W_1.

An important conclusion derived from Equations 3 and 4 and illustrated by the chart is that the return loss in the passband can be traded dB per dB for attenuation in the stopband for a specified W_3/W_1. This information is particularly useful to the designer of filters with small passband VSWR's.

Example 1: To illtustrate the method, consider a filter with the following requirements:

1) Minimum width of passband, 10 MHz
2) Maximum return loss in passband, —26 dB
3) Maximum width of stopband, 20 MHz
4) Minimum isolation in stopband, —20 dB

Reducing the requirements to the format of Equation 7,

$$F' \geq 46 \text{ dB, for } \frac{W_3}{W_1} \leq 2.0$$

From the chart it is seen that the minimum number of sections required for a maximally flat filter is 8 and for a Tchebychev filter the minimum is 5. The limits of choice in the two cases are:

Maximally flat: $n = 8$

$\frac{W_3}{W_1}$ from 1.91 to 2.0

F from 46 to 48 dB

Tchebychev: $n = 5$

$\frac{W_3}{W_1}$ from 1.80 to 2.0

F from 46 to 51 dB

Thus the maximally flat filter can be designed to provide 2 dB of additional isolation at the 20-MHz stopband or can be widened to accommodate a 10.47-MHz passband while meeting all other requirements. Similarly, the Tchebychev filter can provide 5 dB of additional isolation in the specified stopband, 5 dB less return loss in the specified passband, or a wider passband of 11.1 MHz.

Filter Response

The format of Equations 3 and 4 suggest the method by which the chart can be used to plot the detailed response of any filter. It has been pointed out that F is a function of only two quantities, since the other two are related by equation 5. Thus if either R_3 or A_3 and A_1 or R_1 are known, W_3/W_1 can be calculated exactly.

With two quantities known (say R_1 and R_3), the procedure is to find the complementary quantities (in this case A_1 and A_3) by use of the error curve and then compute the value of F. When the value of F, and the number of sections and the type of filter, are known, the value of W_3/W_1 can be determined from the unified filter design chart.

Example 2: Given a 5-section Tchebychev filter with $R_1 = -20$ dB and a pass-

N. K. M. CHITRE received his B.Sc. and M.Sc. degrees in Physics from Banaras Hindu University in 1953 and 1955, respectively, and the M. Tech. degree in Electronics from the Indian Institute of Technology, Kharagpur in 1956. After a year with Van der Heem, N.V., The Hague, he studied at the Imperial College, London, where he received his diploma (D.I.C.). In 1962 he received his Ph.D. degree from the University of London. In March 1963 Dr. Chitre joined RCA Victor Co., Ltd., Montreal, where he is now assigned as a Specialist Engineer in the Antenna Engineering Department. He has worked on Microwave communications systems, both overland and satellite, and has designed various microwave multiplexing networks, filters, and ferrite components. Dr. Chitre is a member of the IEEE.

M. V. O'DONOVAN graduated from Cambridge College of Arts and Technology in 1959 with the H.N.C.E.E. degree. He worked as a design engineer on microwave relay links at Pye Telecommunications Ltd., Cambridge, England from 1959 to 1963. He joined RCA Victor Co., Ltd., in November 1963 and is currently the Engineering Leader heading the design team on microwave components and branching networks. He has worked on microwave subsystems for satellite communications, ground stations, and high-quality microwave links. Mr. O'Donovan is a graduate member of IERE (Great Britain) and a member of the IEEE.

band of 10 MHz, find the half-power bandwidth. Since $(A_3 - R_3)$ is equal to zero at the half-power frequency,

$$F(3\text{dB}) = -R_1 + A_1$$

In most cases A_1 can be neglected since the error is 0.04 dB for $R_1 = -20$ dB and increases to only 1.0 dB for $R_1 = -6.8$ dB. Thus the 3-dB bandwith is easily found by looking up $F = R_1$ on the design chart. In the example given, $W_3/W_1 = 1.18$ and the half-power bandwidth of the filter is 11.8 MHz.

Example 3: Find the 1-dB bandwidth of the above filter. Given $R_1 = -20$ dB and $A_3 = -1$ dB. From the error curve (Fig. 1),

$$A_1 = 0.04 \text{ dB} \approx 0 \quad R_3 = -6.8 \text{ dB}$$
$$F = -(A_3 + R_1) + (A_1 + R_3)$$
$$= 14.2 \text{ dB}$$

From the chart, $W_3/W_1 = 1.11$. Therefore, 1-dB bandwidth = 11.1 MHz.

Example 4: What is the ratio of the bandwidths at $R = -16$ dB for a 7-section filter with a passband return loss of −40 dB. Given $R_1 = -40$ dB and $R_3 = -16$ dB. Therefore, $F = 24$ dB. From the design chart W_3/W_1 is for maximally flat = 1.49 and for Tchebychev = 1.13.

THE TCHEBYCHEV IMPROVEMENT FACTOR

It can be seen from the design chart that as W_3/W_1 increases, the improvement in F yielded by a Tchebychev design over a maximally flat design tends toward a constant value. A useful rule-of-thumb improvement factor is:

Tchebychev improvement over maximally flat $= 6(n - 1)$ dB

CONCLUSION

Considerable literature exists on synthesis techniques and circuit elements for filter designs in both waveguide and transmission-line media. However, in the initial design stage (when the electrical characteristics of the filter best suited to a specified requirement are defined) it is still necessary to use numerous graphs and calculations. The unified design chart and the associated table of low-pass prototypes should simplify this task considerably.

The unified filter design chart clearly shows that reflection coefficients in the passband can be traded off for isolation in the stopband, and it draws attention to the merits of Tchebychev filters even for very small pass-band ripples. It contradicts the commonly held belief that the limiting case of a Tchebychev filter with decreasing ripple is a maximally flat filter and indicates that, irrespective of the pass-band ripple, a Tchebychev filter can provide about $6\ (n - 1)$ dB more isolation than a maximally flat filter with the same passband VSWR.

The chart and the normalized low-pass prototype elements may be used to design waveguide or transmission-line filters with the aid of the appropriate frequency transformations.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the invaluable computing assistance of G. Payette and P. Palchat. The authors are also indebted to J. Hansen for his help in the preparation of this paper.

The material published in this paper and the derivation of the pertinent formulae are presented in more complete form in another article.[5] For the filter designer, this article also contains a table for the low-pass prototype elements expressed in terms of the passband return loss for Tchebychev filters and a table for the ratio of passband to half-power bandwidths for the maximally flat filters.

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Fig. 3—Unified design chart: W_3/W_1 varying from 1 to 2.

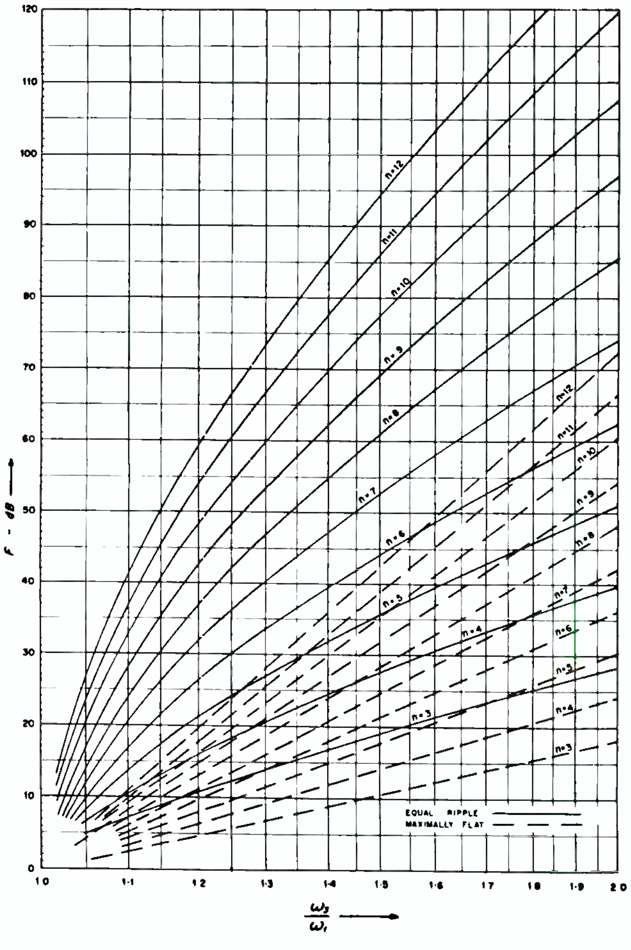
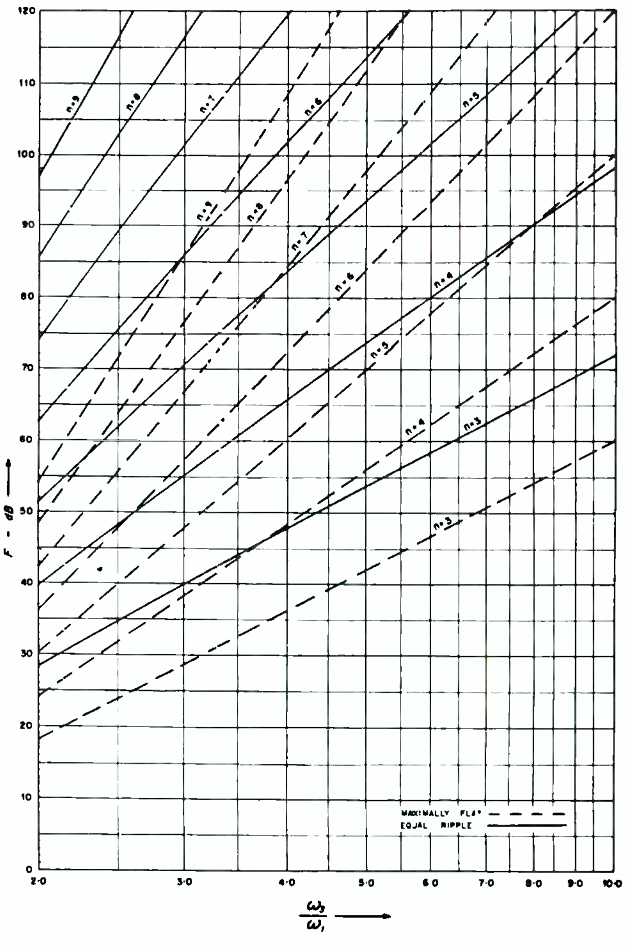


Fig. 4—Unified desigr chart: W_3/W_1 varying from 2 to 10.



APPROACHES TO A UNIVERSAL CIRCUIT

A "universal" circuit that could be instrumented to fulfill any desired electronic function would be an invaluable tool for the circuit designer. This paper discusses the concept of a universal circuit, considers the functional requirements of such a circuit, and describes a potential circuit and possible applications.

B. COLA
Systems Engineering
Missile and Surface Radar Div., DEP, Moorestown, N.J.

FOR many years engineers have felt the need for a *universal circuit* that would fulfill any electronic function that their design work required. Such a device would be an active circuit with many modes of operation and it would require very little power to operate. In order to produce a given circuit design, the device would be connected in the required mode, with some components added for certain applications to produce the desired result.

Such circuit standardization is useful because: 1) the high cost of engineering design time requires that design duplication be reduced as much as possible; 2) reliability would be increased because a relatively large amount of time would be devoted to perfecting the standard circuit; 3) electronic equipment sent into the field would require stocking a smaller variety of spare parts; and 4) the cost of circuit construction would be reduced, since the tooling could be made for one standard circuit which would be stamped out in large numbers.

CIRCUIT FUNCTIONAL REQUIREMENTS

The first point to be considered is: "What operations must be performed by the versatile circuit device to take care of most of the circuit problems that a design engineer faces?" To design the universal circuit, it is necessary to know the bulk of the circuit requirements. This question was studied, and the nine circuit functions described below in block diagram form will provide for most of the circuit requirements that a designer will encounter. Not all of these functions can be provided by one circuit because they are too diverse; however, it is possible to design a circuit that can perform many of these operations. The circuits described have a frequency range from DC to 20 MHz (Mc/s). Above 20 MHz, circuits must be tuned and universality starts to break down because of the many filters that can be inserted into amplifiers. Practically all integrated circuits used today are built for frequencies of DC to 20 MHz, and low impedances yield the circuit responses up to this high frequency range.

The mixer circuit (Fig. 1) is found in almost all analog equipment and little need be said about this device.

A high-gain feedback device such as the operational amplifier (Fig. 2) is needed to provide for the transfer function required in various circuits. This circuit must have good DC balance to prevent drift in the various configurations that are used. This amplifier cannot easily be tuned for high frequencies.

A power amplifier (Fig. 3) is needed to drive the various output equipment lines to transmit the signals. This is apparently a stumbling block because all the components are within the integrated circuit package, and the dissipation heats up the transistors, increasing the failure rate of the circuit.

A difference amplifier (Fig. 4) is useful to add and subtract signals in analog form. It is possible to have a differential type of input to the operational amplifier.

Quite frequently it is necessary to switch analog data at a convenient time. In such a case, the circuit output is zero except at a time when a digital level closes the switch, and at this time the output equals the input. The design of the analog switch (Fig. 5) is most difficult because of DC balance and AC feedthrough problems. However, the usefulness of this device cannot be overestimated. It can code RF signals, act as a phase detector, and switch signals *off* and *on* for a myriad of reasons.

In almost every type of electronic equipment there are oscillators (Fig. 6) of various kinds. A universal circuit must be able to perform this function as a multivibrator and crystal oscillator, with few or no additional components.

A circuit that heavily limits input information is very frequently encountered, and it appears that the versatile circuit must have precision limit extremes to square up any input function where required. (Fig. 7)

There are two digital circuits that can do almost all the digital circuitry jobs that a designer requires: the gate and the JK flip-flop. A multi-input gate (Fig. 8) is a required circuit function for the versatile circuit device. The JK flip-flop (Fig. 9) is useful in the construction of counters and shift registers, and it is a necessary building block for other digital circuits. This circuit is DC coupled through the S and R inputs and AC coupled through the J and K inputs. Since the truth table for this device is quite well known, it is not discussed here; however, it should be mentioned that this device, which also is a set-reset flip-flop, can perform most of the digital flip-flop functions that are encountered in design work.

EVOLUTION OF THE CIRCUIT

In the conception of the versatile circuit, it was concluded that only one configuration could possibly fulfill all the requirements. The device would have to be essentially a difference amplifier for the following reasons: 1) a difference amplifier can produce 360° of phase shift, making various types of oscillators possible; 2) push-pull signals (sometimes called complimentary output) are available from a differental amplifier and in many cases this is a requirement; 3) it can stay balanced over wide temperature and voltage variations; 4) it has the advantage of similar output waveforms or rise times; a current decrease in one side equals the current gained in the other side; 5) it is not noise sensitive, i.e., it will not amplify noise on grounds or power supplies as

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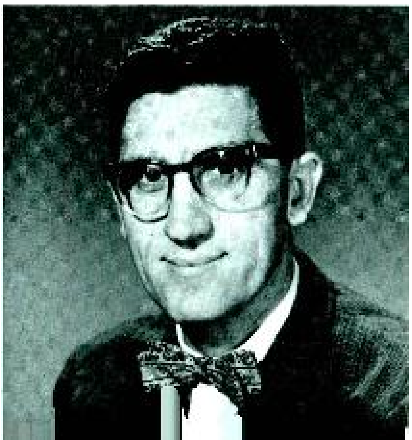
BENJAMIN A. COLA received his BSEE degree from Drexel Institute of Technology in 1950 and his MSEE in 1955 from the University of Pennsylvania. Since joining RCA in 1950, he has worked on the design of power supplies, video circuits, TV cameras, naval radar tracking equipment, and servo mechanisms in the Special Devices Department. He also spent one year on systems analysis of shoran bombing and reconnaissance equipment. In 1955 he transferred to Missile and Surface Radar Div., where he worked on analog data processing assignments for TALOS, ATLAS, BMEWS, DAMP, and TRADEX. He was design project engineer on the preliminary development of a precision high-speed tape recorder (described in the March 1964 RCA ENGINEER). Recently he has worked on AADS-70, Terrier radar improvements, and undersea warfare projects.



easily as other circuits because both sides of the difference amplifier receive the same noise voltage and these effects cancel out.

The term *difference amplifier* as used here means a basic central control device; the addition of other active devices is required to provide multiple inputs or low-impedance outputs. Thus, the universal circuit would contain a number of transistors to achieve the intended goals.

The circuit should be capable of driving output lines and, therefore, its output impedance must be low; this could possibly be achieved with the popular common-emitter-follower circuit. The impedances in the device would have to be kept low to achieve a 20-MHz flat frequency response, which is equivalent to approximately 15 nanoseconds of rise time. The device should use RC coupling, since it is impossible to standardize on filters within the package; however, provision should be made so that a filter could be connected as an external appendage.

It was mentioned previously that the circuit should have push-pull output, but nothing has been said about the input circuit except that it is a differential amplifier. A simple switching device must be incorporated in the input circuit to turn the input signal *on* and *off* for analog gating, mixing, etc. This can be accomplished by placing transistor collectors and emitters in parallel so that when a gating signal lifts the emitter of a signal transistor it can be turned *off* (Fig. 10).

Since the circuit will be used frequently, it must have low power consumption, which could be achieved by careful design. The gains through the multiple inputs to the push-pull outputs should be equal, as should the phase shift from the multiple inputs to the outputs. These gain and phase-tracking specifications enable the circuit to be used in mixers and balanced transformers, where accurate requirements are usually the case.

One serious problem is immediately apparent; it is almost physically impossible to build a high-gain-feedback operational amplifier with 20- to 30-MHz bandwidth and maintain accurate gain and phase tracking. Thus, it might be more efficient to amplify in a separate device that could provide all the operational and video amplifier functions; the universal device, with low gain, could provide for most of the other circuit functions.

CIRCUIT DESCRIPTION

The universal circuit shown in the schematic diagram in Fig. 10 is a differential amplifier with multiple inputs on one side and push-pull emitter-follower outputs fed from the collectors. RCA makes several such circuits for digital applications (TA5061, CD2100, and CD2101), and, although they were not designed for this versatile application, they come close to meeting many of these requirements. The circuit shown in Fig. 10, TA5061, meets a number of the requirements of the universal circuit. It is a balanced differential amplifier, constructed on one integrated silicon chip; it has multiple inputs, switched inputs, limit stops, complimentary output, low-impedance outputs, and a limited linear range; and, most important of all, the circuit exists and can be tested in typical circuit functions. The TA5061 circuit has a rise time of 10 nanoseconds and uses only 40 MW of power.

The most important characteristic of the universal circuit device is that in form it is a differential amplifier. There is a great deal of integrated-circuit work going on today, and in the desire to capture a wide segment of the market for each circuit designed, many of the foregoing considerations are used. A recent check of some integrated circuits now on the market revealed that differential circuits are the central control of these designs in almost all cases.

Fig. 1—Mixer.

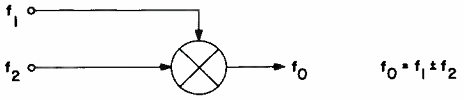


Fig. 2—Operational amplifier.

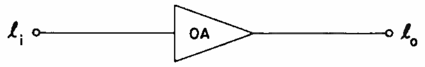


Fig. 3—Power amplifier.

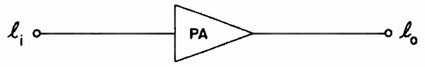


Fig. 4—Difference amplifier.

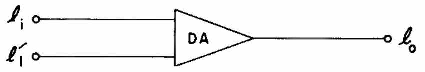
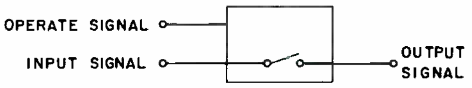


Fig. 5—Analog switch.



COMMON CIRCUIT FUNCTIONS

Fig. 6—Oscillator.

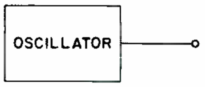


Fig. 7—Limiter.

Fig. 8—Multi-input gate.

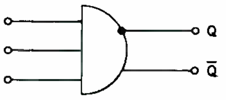


Fig. 9—JK flip-flop.

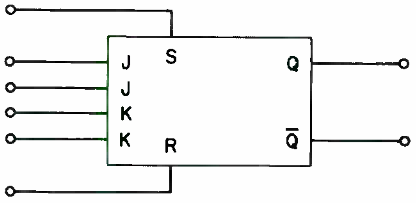


Fig. 10—The TA5061 amplifier, which approaches a universal circuit.

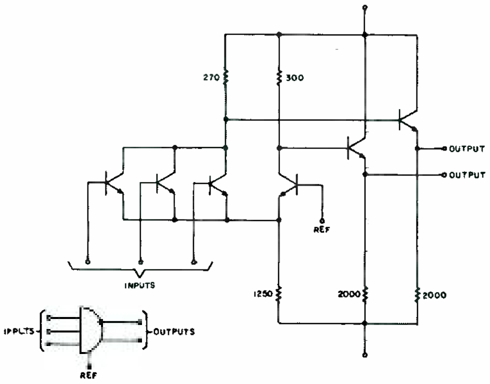
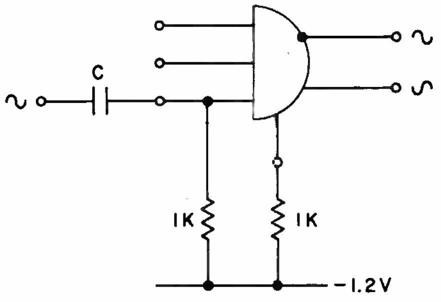


Fig. 11—Universal circuit connected as balanced transformer.



UNIVERSAL CIRCUIT APPLICATIONS

By wiring the emitter-coupled gates of the universal circuit (Fig. 10) in various configurations, a number of circuit functions can be obtained, including: balanced transformer, shaper, limiter, analog switch, oscillator, multibrator, flip-flop, mixer, phase detector, and digital gate. These applications are briefly discussed in subsequent paragraphs.

Since the emitter-coupled gate is linear over part of its range and has a push-pull output for a single-ended input, it can produce sine-wave outputs (when an input signal is applied) that are identical with the outputs of a balanced transformer. The sine-wave outputs must be 180° out of phase plus or minus a small fraction of a degree for any signal frequency input; the size of the output amplitudes should be within a fraction of a percent of each other. These are the gain and phase-tracking specifications previously mentioned, and they are important in many of the circuit applications that follow. The circuit connection for a balanced transformer equivalent, made from the versatile circuit device, is shown in Fig. 11.

As almost everyone is aware, it is frequently necessary to take a rounded waveform and sharpen its edges or baseline crossings. A protective circuit should be placed at the input to prevent the circuit from being damaged by very large inputs. Various input networks can be used: DC coupling, AC coupling, or diode biased to clip a particular level of the signal. When using AC coupling with a diode input limiter, back-to-back diodes should be employed to prevent a DC buildup on the capacitor that could change the limited output waveform as function of input level. The universal circuit connected as a shaper is shown in Fig. 12.

Since integrated circuits are very small and the power dissipation is very low, it is possible to place two or more of the circuits in the same package. The 2D2100 has two circuits per package, and the 2D2101 has four circuits per package. This is a very convenient choice for a heavy limiter circuit where a number of these devices may be needed to provide limiting for a signal that varies over a wide dynamic range. The dual gate connected as a two-stage limiter circuit is shown in Fig. 13.

If the multiple inputs of the versatile circuit device are properly connected, it is possible to switch a signal *on* and *off* with another input of standard digital levels. The signal input should be DC biased to the same level applied to the reference input of the difference amplifier, which is midway between the digital levels. The voltage pedestal created when the signal is switched *on* can be cancelled out by operating another gate (preferably on the same silicon chip) in push pull and adding its output to the switched signal output. When this switch was constructed in the laboratory, the outputs of the gates could be connected together with a jumper wire for signal addition, because the outputs are emitter followers and the one is biased *on* when the other is cut *off*. The configuration of the versatile circuit device to form an analog switch is shown in Fig. 14.

Since a difference amplifier has one output signal that is in phase with a given input signal, an oscillation will result when a series-tuned crystal is placed across the integrated-circuit connections. The signal will build up until limiting occurs, and push-pull square waves will be available as outputs at useful digital levels. At the input side of the crystal, which acts like a narrow filter, a sine-wave of the oscillation frequency appears. Three output waveforms are available (Fig. 15).

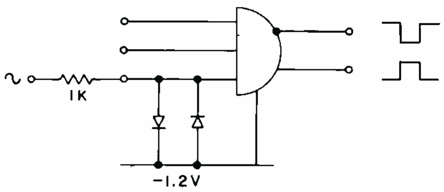


Fig. 12—Shaper configuration of universal circuit.

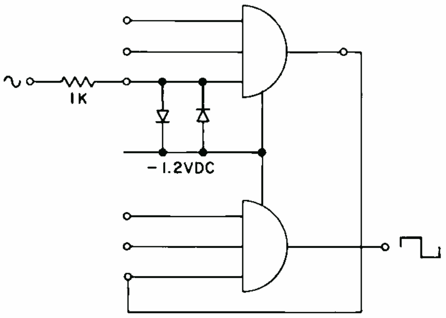


Fig. 13—Limiter configuration of universal circuit.

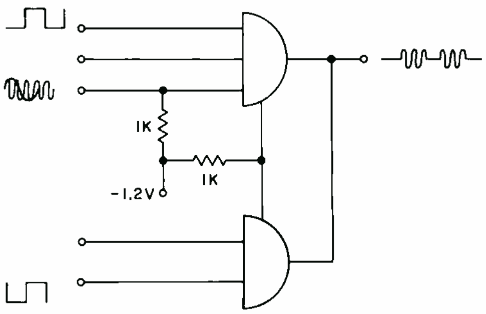


Fig. 14—Universal circuit configuration for analog switch.

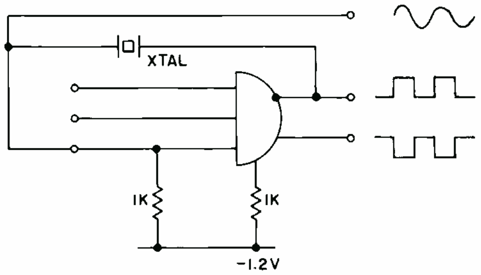


Fig. 15—Universal circuit connected as crystal oscillator.

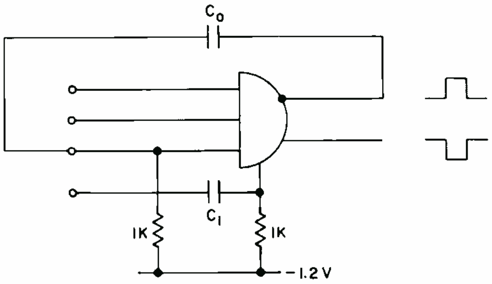


Fig. 16—Multivibrator configuration of universal circuit.

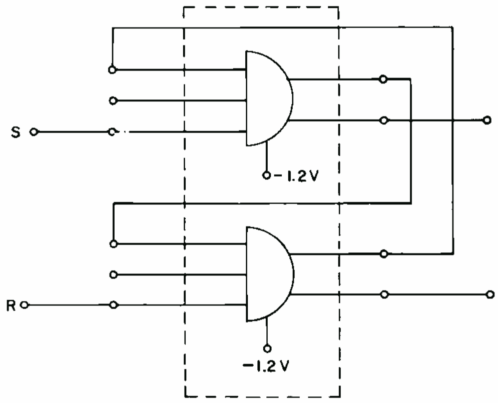


Fig. 17—Universal circuit connected as set-reset flip-flop.

If a capacitor is placed between the proper output and input, as in the crystal oscillator, the resulting oscillation will produce push-pull square waves at the output. The time-constant-product RC determines the oscillation frequency. If a trigger is placed in the circuit (Fig. 16), the multivibrator will lock to an external generator.

If two gates are cross coupled (Fig. 17), a set-reset flip-flop action is created. If a dual gate is selected, the set-reset flip-flop can be made with the circuits in one package.

Since a mixer can be constructed with an analog switch, a balanced mixer can be achieved by using two switches operating in push-pull. In this case the gates are fed in push-pull and are the equivalent of the local oscillator. The signals are fed into the circuit in push-pull, and after gate modulation they are added. An integrated circuit having two gates on one chip in one package is required. This circuit produces about a −40-dB reduction of the signal and local oscillator in the output without any balance controls. If controls that change the gate and signal level of one phase relative to the other are added, the local oscillator and signal can be balanced out to −60 dB relative to the sum and difference frequencies. This balanced mixer, shown in Fig. 18, is useful up to 10 MHz. Note that it is fed from two previously described building blocks.

A circuit that yields a DC level proportional to the phase difference between two signals can be constructed by heavily limiting the signals and feeding the resulting square waves into an *and* gate (Fig. 19). The *and* gate will yield an output only when the signals are coincident. If the resultant output is filtered, the phase-detected signal will be available for use.

The use of the universal circuit as an *and-or* gate is obvious, and this application is not further described.

CONCLUSIONS

In devising a circuit that could be instrumented to handle most of the circuit designer's requirements or applications, typical requirements were determined for frequencies below 20 MHz. On the basis of these findings a circuit was evolved that could be connected to perform the desired functions. It was concluded that the most versatile circuit is a saturable differential amplifier with push-pull inputs and outputs, and with provision on one side for multiple switchable inputs. The universal circuit should also have a filter-attachment provision. The circuit used for the experiments was not tunable and lacked some features of the universal circuit.

Since the design of an integrated circuit that could solve many design problems would be very costly, a search was made for an integrated circuit similar to the universal circuit. The survey of presently available integrated circuits revealed none that had all the universal requirements; however several have an approximate universal configuration. ECD's Integrated Circuits Engineering has designed an emitter-coupled logic amplifier for digital use that is available in quantity; moreover, it appears to have a number of the desired features of the universal circuit. The circuit cannot easily be tuned, but it proved to be of great use in constructing many of the desired circuit functions. This circuit, RCA 2D2101, is available as a quad gate (four circuits in one package) but in this configuration the gates do not have push-pull outputs.

When the emitter-coupled gates were wired in different configurations, the following circuits were obtained: balanced transformer, shaper, limiter, mixer, crystal oscillator, multivibrator, analog switch, and *and-or* gate. The circuits performed well and, as the result of the differential construction, were insensitive to temperature and power-supply variations. There is no limit to the number of circuits that can be built using the emitter-coupled logic gate as a nucleus. If these emitter-coupled circuits were redesigned to accommodate universal features, it is reasonable to assume that better performance could be obtained and that many more circuits could be built. It is conceded that the universal circuit in some cases would be more cumbersome than one specifically constructed for a given application. As an example a JK flip-flop can be made from these gates and a few other components, but this circuit can be purchased complete in integrated form.

Experimentally it was found more useful, in many cases, to realize the gain requirements with an RCA integrated operational amplifier. A complete chassis of precision-measuring equipment was designed and constructed using universal emitter-coupled logic circuits and integrated operational amplifiers. The measuring equipment was a hybrid device, partly digital and partly analog in nature. By augmenting the emitter-coupled differential amplifier with a few other purchased integrated circuits, such as an operational amplifier and a JK flip-flop, it was possible to construct the most complicated analog and digital functions; moreover, the universal gate was used more often than the other available circuits. There is no limit, except man's ingenuity, to the number of circuits that can be developed using the emitter-coupled universal circuit device. Perhaps this circuit, or a refined version, will be specifically developed as a universal circuit.

Fig. 18—Universal circuit connected as doubly balanced mixer.

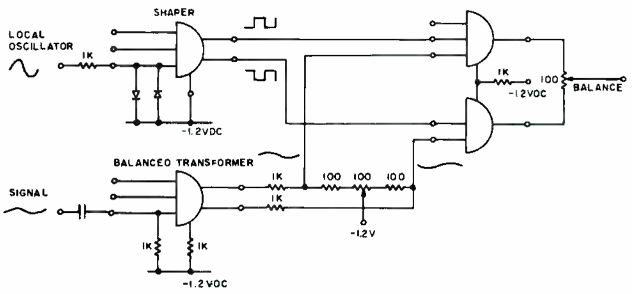
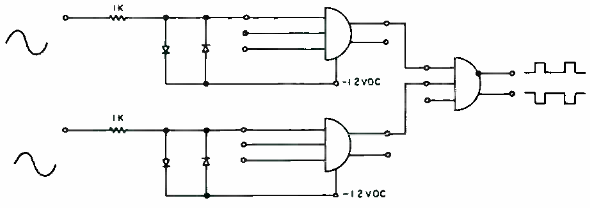


Fig. 19—Phase-detector configuration of universal circuit.



PROGRAMMING AIDS FOR AUTOMATIC TEST EQUIPMENT

The history of programming aids for automatic test equipment (ATE) at Aerospace Systems Div. includes the design of compilers, simulators, and assemblers to assist in the production and verification of test programs for DEE, MTE, DIMATE, and LCSS. This paper describes the ATE programming problem and presents one approach to the solution.

B. H. SCHEFF, Ldr.
Data Processing Engineering
Aerospace Systems Div., DEP, Burlington, Mass.

The programming problem for an automatic test equipment (ATE) system includes all facets of the process of translating the requirements for testing a unit into an operational program which conducts the tests. The operational program: 1) addresses the required stimuli generators and measurement devices and sets them to the proper scale, 2) provides the commands which connect the stimuli and measurement device, 3) specifies the numerical limits for comparison with the measured test results, 4) generates the commands which start the test, and 5) displays the test results.

During the initial development phases of the ATE system, the operational programs are written manually. The programmer makes direct reference to each of the desired ATE subsystems, using the precise digital code required. Each instruction in the program is written in digital code and can be read into, and executed by, the ATE system without retranslation. Debugging the program consists of thorough desk checking followed by execution on the ATE system in which the program is manually forced through all of its logical paths.

When the number of programs becomes sufficiently large, it becomes economical to develop programming aids to assist the engineer in writing and debugging his equipment test programs. Assembler and compiler programs facilitate the program-writing process, whereas simulator programs facilitate program-debugging.

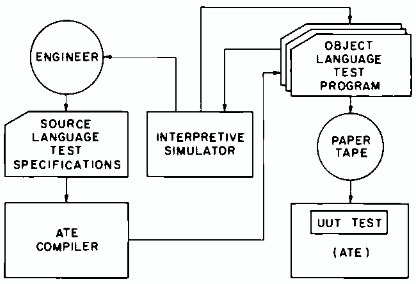
PROGRAMMING AIDS

By allowing the engineer to use mnemonic and symbolic instructions—rather than the ATE system machine code—to specify his test, an assembler program relieves the programmer from many of the bookkeeping details with which he would otherwise be plagued. The mnemonic letters are a substitute for the machine code, and hence have more meaning for the programmer. Symbolic references permit memory locations to be denoted by a letter or number code so that the programmer need not be concerned with the exact location in storage of any instruction or data. In general, each instruction in assembly language represents one machine-language instruction.

The compiler program permits the test engineer to write the test specifications in an engineering-oriented language which is functionally independent of the specific characteristics of the equipment system hardware. The compiler translates these test input specifications to the required ATE digital code. For example, from a specification of the particular signal a compiler would determine the ATE units needed to generate that signal and would produce the digital coding required for the test system to address these units. Of prime importance is the relative freedom from nonproblem-oriented conventions in the source language which the engineer uses to describe the test parameters. Terminology and notation which have no direct meaning, or conflict with existing meanings in his application, can cause difficulties for the engineer.

A computer program that simulates the characteristics of the test system is a valuable debugging tool. Such a simulation program permits the test engineer to verify (debug) his test program prior to validation (operational checkout) on the ATE system with a unit under test (UUT). Verification minimizes the program checkout required on the test system and ensures that the equipment test program will not produce a catastrophic UUT failure.

Fig. 1—ATE programming aids system.



The process by which test programs are generated, verified, and validated is shown in Fig. 1. The source-language deck describing the equipment test procedures is keypunched directly from coding sheets prepared by the test engineer. The test program is translated to the operating test system's machine code by the assembler/compiler. The output of the translation process (object deck, paper tape) can be exercised by the simulator program or used on the ATE system.

DESIGN APPROACH

Aerospace Systems Division has been developing a family of programming aids to permit engineers to program equipment checkout tests efficiently and effectively. Programming aids have been developed for Multisystem Test Equipment (MTE), Depot Installed Maintenance Automatic Test Equipment (DIMATE), Digital Evaluation Equipment (DEE), and Land Combat Support System (LCSS). These programming aids have: 1) expidited the process of preparing correct equipment test programs, 2) reduced the overall programming costs, and 3) lowered the skill level required to write equipment checkout programs.

Multisystem Test Equipment (MTE)

An assembler program and a simulator program were written for MTE. The assembler program allows the engineer to use: 1) mnemonic references for both instructions and data, 2) symbolic references to memory locations, permitting instructions and data locations to be independent of their eventual memory assignment, and 3) pseudo-operations that define the assembler's internal bookkeeping operations.

The assembler also has a macrocommand feature to simplify the generation of frequently used test functions. By merely specifying the parameters required, and using the name of any previously defined macrofunction, the assembler program will produce the required MTE digital code.

The simulator program performs the many functions (computer operations, stimulus, measurement, and switching) of the MTE system. It verifies the correctness of the code produced by the assembler and provides an off-line method for checking the test program. In addition to checking the legality of the assembler output, the simulator program checks the compatibility between stimuli and measurement programming and MTE functions, performs programmed arithmetic functions, allows the results of each test comparison to be determined (either by a numeric value or by a HI, LO, GO indication), and performs various program-debugging routines such as program traces and memory dumps.

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Digital Evaluation Equipment (DEE)

An assembly program was written for the DEE system. Of significance is the simplification of switching words permitted by the use of macro-instructions.

DIMATE

A compiler program and a simulator program were written for DIMATE. The DIMATE compiler permits engineering users with various technical skill levels in engineering and programming to generate accurate test programs and debug them quickly. The compiler allows the test engineer to write the program directly in a source language that he understands, automatically converting his specification to DIMATE's digital code. Since the source language allows both highly skilled engineers and relatively unskilled test technicians to write test programs, there is a wide range of potential users of the compiler, and the training normally required to use the compiler is reduced.

The DIMATE compiler source language consists of engineering expressions arranged in tabular format. Since the tabular structure provides a framework into which test parameters can be inserted, procedures are stated simply. Programming conventions are implicit in the structure of the table, and the test engineer programs his requirements in a format and vocabulary that are natural to him. The compiler vocabulary and format provides a basic language structure oriented toward the user's background and his associated task requirements, without forcing him to rely on unfamiliar terms. Since specialized programming notation is not required, the test program in compiler source language becomes final user documentation.

The compiler language functions can be divided into three groups: a basic group of test functions for the relatively untrained user, and two groups of functions which require greater programming skill or engineering knowledge to use properly. These latter two groups act as an *overlay* and are not required to perform the basic equipment tests.

The relatively unskilled user is expected to use only the basic test processes to write his test program; he will:

1) Connect and disconnect stimulus and measuring devices.
2) Establish proper time delays.
3) Generate stimulus signals and perform measurements.
4) Evaluate measured values against specified limits.
5) Branch (change test sequence) based upon the results of a measured comparison.
6) Print the measurement results.

The compiler statements for these functions form the primary language used to specify DIMATE test operations. This primary language is comprehensive and permits all output stimulus signals and input measurements to be selected. Each statement defines the selected stimulus to be applied to the UUT, the selected measurement to be performed and the DIMATE connection points.

The more skilled user, who is interested in programming his test more efficiently, can use internal program branching and subroutine linkages. Internal test program control is achieved by the programmer through conditional jumps based on the state of internal program indicators. The compiler language permits both open and closed subroutines. A section of the program can be defined by the programmer as an open subroutine while predefined computational subroutines allow arithmetic functions of either a single measurement or several measurements to be evaluated.

The highly skilled user can intentionally violate the DIMATE system rules by making direct reference to each stimulus and measurement subsystem (as in the MTE assembler). This feature is considered beyond the capability of the normal user, because coding in machine language of the DIMATE computer requires skill in applying both engineering and programming techniques.

In addition to the test program output, the compiler produces a from-to wire list based on the engineer's source language statements.

The simulator program for DIMATE was an extension of the MTE simulator. With the DIMATE simulator, debugging for the most part has become an off-line operation, with the result that the availability of the test system is increased and the unit cost of UUT testing is reduced.

The simulation program provides a reference for the entire system, i.e., compiler, test program, and the DIMATE equipment. Verifying (on the simulator) the test programs produced by the compiler has certified the correctness of the compiler's processing. Because the simulation program represents the DIMATE system's characteristics, any problems that arise on a verified test program during validation are easily isolated and reconciled.

As a consequence, the simulation program is the primary verification tool for the test engineer. The level of simulation is sufficiently thorough to eliminate the need for validating (on the DIMATE system) any NO-GO path which has been previously verified. Only the basic GO path of the test program must be validated to ensure consistency between the simulator and the test system.

Land Combat Support System (LCSS)

A program that combines the functions of an assembler and simulator program has been written for LCSS. The program, entitled ASEIP (Assembler Static Error Inspection Program), provides an automatic means of preparing a verified program on paper tape in the proper format. This tape can be used directly as input to the LCSS-controller-controlled system. The program contains the following features:

1) Test engineers can use a symbolic language to write their programs.
2) Commonly used test functions are available as macrocommands.
3) Key-punch operators use the test engineer's format, eliminating data retranscription.
4) Paper tape output is in field data code in the required format.
5) The paper tape output is automatically checked for punching errors.
6) The program is updated without having the entire test program resubmitted.
7) Debugging routines have been incorporated.
8) Static error check of the test program is made for legal instructions and switching commands.

FUTURE PLANS

A *universal* test equipment compiler is currently under consideration. It is planned to program this compiler in a standard computer language so that it can be used on many medium- to large-scale computers. This compiler will be designed so that it can be easily adapted (with only minor modifications) to produce programs (in the required digital code) for a wide range of ATE systems. As a consequence of this design: 1) the user will not have to be retrained as he acquires new test systems, and 2) test program routines written for one test system may be *reused* on other test systems without recoding.

BENSON H. SCHEFF received his BA degree in Mathematics from Oberlin College in 1951 and his MA in Mathematical Statistics from Columbia University in 1952. After working as a programming analyst with the National Security Agency, he participated in computer applications research at Massachusetts Institute of Technology. He joined RCA in 1959 and was assigned to diverse programming projects. He developed advanced programming concepts for and is presently assisting in the logical design of a military digital computer. As project engineer for the development of a compiler and a simulator program for the DIMATE System, he was involved with the source language and design of the compiler. He is currently Leader, Technical Staff, responsible for developing the software for an aerospace computer.

VISTA

System Design of a Proposed Direct-to-Home TV Satellite Experiment

Dr. R. B. MARSTEN, Mgr.
Spacecraft Electronics

and

S. GUBIN, Mgr.
Systems Engineering II

Astro-Electronics Division
Princeton, N.J.

VISTA is a proposed telecasting satellite experiment for relay of UHF broadcasts from a synchronous-orbit satellite direct to unmodified home receivers equipped with minimal antenna additions (under $50 cost). It provides Class II pictures to areas of significant population density, and is conceived as a serious forerunner of operational satellite telecasting. The system design is within present state-of-the-art, with launch possible by 1969-70. Spacecraft transmitter stabilization is two-step, with fine-beam control by a sequential-lobing tracker whose error signals give controlled warp of a long boom. Multiport feed is carried on the boom (f/d = 0.44). Thermal control is conductive, and the power amplifier has four highly derated tubes working into a three-bridge diplexer. Included is pulse modulation for sync only, and a unique high-voltage solar array. The spacecraft antenna is a ribbed, unfurlable array with less than 0.3-dB maximum gain loss at 800 MHz; it could receive from any point in the U.S. while its transmitting beam axis is directed at any other point in the U.S.

In 1961 our national capability in space communications was concentrated on the development of small satellites, in order to prove the feasibility of intercontinental communications using such satellites. A particular objective of one of these, RELAY (developed and built for NASA by the RCA Astro-Electronics Division, Princeton, N.J.), was to demonstrate transmission of standard television broadcast material. RELAY had a transmitter power level of about 11 watts and was designed to work with large ground systems having antenna diameters of 60 to 85 feet and noise temperatures of about 40°K. Although successful in its mission, this satellite did not address the problem of television broadcasting from space *directly* to home receivers.

BASIC PARAMETERS

Television broadcasting over large areas was recognized as a fruitful application of space technology as early as 1960. Initial parametric studies at RCA were based on providing superior picture quality directly into a home receiver with a maximum antenna dimension of about 3 feet.[1] While requiring a low-noise, high-sensitivity front-end amplifier, the home receiver was to be otherwise unchanged from its existing form for receiving stan-

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Final manuscript received June 3, 1966

This paper was also presented at the AIAA Communications Satellite Systems Conference at Washington, D.C., May 2-4, 1966 (AIAA Paper No. 66-309).

S. GUBIN received a BS and MS in Electrical Engineering from Yale University in 1929 and 1931. Mr. Gubin has had 20 years of experience at RCA in product design, systems engineering, and engineering management in the broad fields of communications, radar, and navigation systems. Mr. Gubin joined the Astro-Electronics Division in 1963 as Manager in the Spacecraft Electronics System Engineering Activity. His responsibilities have included the electronic subsystems design of current lunar programs, including the Lunar Orbiter video and telemetry communications link design, the Surveyor Lunar Roving Vehicle electronic systems design including the camera, command/control, telemetry and communications subsystems, and the Molab electronic subsystem design. Prior to joining the Astro-Electronics Division, he was a member of the technical staff of the RCA Advanced Military Systems group where he studied satellite communication systems. Some of this work was recently published in "Telecommunication Satellites" edited by K. W. Gatland. Prior to this assignment he was Manager of Tactical and Instrumentation Radar Systems Projects at the RCA Missile and Surface Radar Division. Mr. Gubin has a number of patents in the field of communications. He is a member of IEEE, a past chairman of the Philadelphia section, IEEE.

DR. R. B. MARSTEN received the SB and SM in Electrical Communications in 1946 from the Massachusetts Institute of Technology, and the PhD in Electrical Engineering from the University of Pennsylvania in 1951. He has had an extensive and unique career in several major fields of engineering electronics applications, embracing some 19 years of activity. Dr. Marsten has been with the Astro-Electronics Division since 1961. At that time, he was assigned the overall management responsibility for the Spacecraft Electronics Department on space-related communications, command and control, telemetry, signal processing and recording systems and subsystems. In 1964, this responsibility was expanded to include spacecraft camera systems and equipments. His department has contributed extensively to the Tiros, Relay, Ranger, Sert, Nimbus, and Lunar Orbiter programs. Since receiving his first degree in 1946, Dr. Marsten has worked as a research assistant, consultant engineer and university professor. While associated with the Allen B. DuMont Laboratories, Polarad Electronics Corp., and Air Associates, his work was concentrated in the areas of microwave, communications, and display design and development. Upon joining RCA in 1956, he participated in a wide variety of successful programs in sophisticated radar design, and integration and application of advanced electronic techniques. Dr. Marsten is an associate fellow of the AIAA, and a senior member of the IEEE.

dard TV broadcasts. Study results for a vestigial-sideband system predicted a peak power level of about 107 kW per channel for the spacecraft transmitter, providing coverage over an area of 1.6 million square miles. This area, about half the area of the continental United States, is also about equal to the area of the Indian subcontinent of Asia. Had the 1960-1962 study yielded more practical power requirements for the spacecraft transmitter, satellite television broadcasting operations would then have been shown feasible.

Recent advances in our space capability have renewed interest in such space telecasting. RCA studies in 1965, based on reduced coverage and projected improvements in home receiver design, have shown that a more realistic transmitter power level for the broadcasting spacecraft is about 3 kW per channel. Table I compares the system parameters of the 1960-1962 studies and of the 1965 studies. A spacecraft having a 3-kW average transmitter power and a parabolic antenna of 50-foot diameter, stationed at synchronous altitude, can provide single-channel coverage over an area of 0.35 million square miles at the equator. Neglecting longitudinal squint, the coverage area increases to 0.51 million square miles at 40° latitudes. Fig. 1 shows the effect of increasing latitude on the area coverable by the antenna beamwidth. The increase of the target area seen by the antenna beam is caused by the earth's curvature, which results in an elongation of the north-south axis of the coverage area. The elongation is inversely proportional to cos ($\lambda + \theta$), where λ is the latitude and θ is the (squint) angle between the beam axis and the local vertical for a synchronous, equatorial-orbit satellite; S' represents the area normal to the beam axis within the 3-dB limit, while S is the projection of that area on the Earth's surface. The effect of squint can readily be seen. The situation shown in Fig. 1 and described here neglects longitudinal squint. The effect of longitudinal squint is similar, elongating the east-west axis of the coverage area.

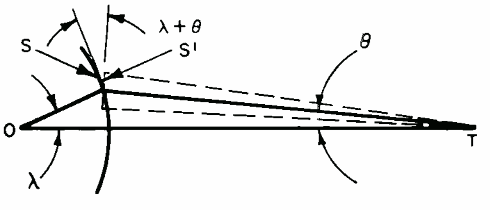


Fig. 1—Effect of latitude on ground coverage.

A conventional UHF home receiver could receive broadcasts from this 3-kW spacecraft when equipped with a UHF antenna having a gain of 19 dB and feeding a transistor booster amplifier with a 30-dB gain and 4-dB noise figure. The antenna dimensions, for reception of broadcasts at a frequency of 800 MHz (channel *69*), need not exceed 1.5 meters for an equivalent paraboloid to meet these requirements. The receiving antenna (a 12-element, 4-layer yagi) and booster amplifier could now be manufactured in large quantities, at retail prices of about $50 to $75 installed.

For this price, the home TV set would receive a picture of "Class-II" quality, a picture noticeably superior to that deemed acceptable by most viewers. In more precise terms, a Class-II picture is characterized by a signal-to-noise ratio *(SNR)* of 36 dB. Studies of viewer rating of picture quality have attempted to place this relatively subjective parameter on a reasonable basis for performance evaluation. The generally accepted results,[1] seen in Figs. 2 and 3, show that 70% of all viewers rate a picture of 30-dB *SNR* passable or better, while 30% of all viewers consider it "fine". The average observer appears content with a picture quality of about 30-dB *SNR*, which is provided in the current design after loss of a 3-dB power budget margin at the beam edge.

TABLE I — Comparison of System Parameters

	1960-62 Studies	1965 Vista Studies	Power Saving (dB)
f_c, Channel Frequency, MHz	800	800	
D_r, Diameter of Receiver Antenna, m	1	1.5	3.5
D_t, Diameter of Transmitter Antenna, ft	30	50	4.2
Coverage, square miles	1.6 x 10^6	0.5 x 10^6	
Modulation	VSB-AM	VSB-AM	
Black-White RMS Noise, dB	36.0	36.0	
Margin, dB	6.0	3.0	3.0
Receiver Noise Figure, dB	6.0	4.1	1.9
Preamplifier Gain, dB	0	30	
Effective Line Loss, dB	2	0	2.0
Gain Loss and Polarization Loss, dB	0	0.6	—0.6
Peak Power, kW	107	4.3	14.0
Video Average Power, kW		2.6	
Audio Average Power, kW		0.4	
Total Average Power, kW		3.0	

This satellite, VisTa (*Vis*ual-*Ta*lking), has been proposed as an experiment by RCA. Its parameters are given in Table I, and its achievement is entirely within the capability of today's space technology. If detailed design studies could begin in 1966, launch could occur in 1969 or 1970. The economics of this application of space technology thus could be established by 1970, since the objective of the proposed VisTa experiment is to demonstrate reliable, long-lived telecasting by satellite over areas of significant population density—as a serious forerunner of operational telecasting by spacecraft.

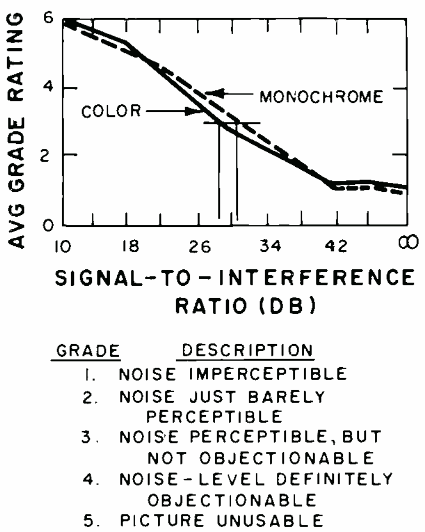


Fig. 2—Picture grade as a function of carrier-to-noise ratio for the mean observer; interference is random noise.

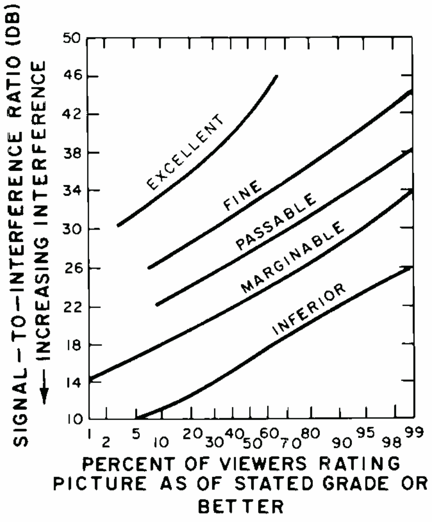


Fig. 3—Distribution of observers' picture ratings as a function of carrier-to-noise ratio; interference is random noise.

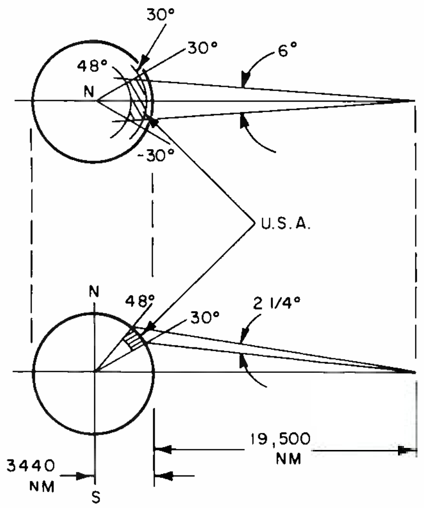


Fig. 4—Coverage geometry.

THE PROPOSED VISTA EXPERIMENT: SINGLE-CHANNEL SPACECRAFT TELECASTING

A meaningful experiment in spacecraft telecasting must satisfy certain constraints similar to those imposed on operational telecasting systems.[2] Principal among these are:

1) the ability to operate with contemporary home receivers having UHF tuners without requiring internal modification to those receivers;
2) the ability to provide virtually continuous broadcast service throughout the coverage area and over the broadcast service day; and
3) the ability to provide reliable broadcast service over sufficiently long periods to be economically attractive.

The preliminary design proposed for the VisTa spacecraft satisfies these constraints; however, as studies of the general broadcast service satellite problem continue, specific VisTa parameters may change. The design basis for the VisTa spacecraft system is as follows:

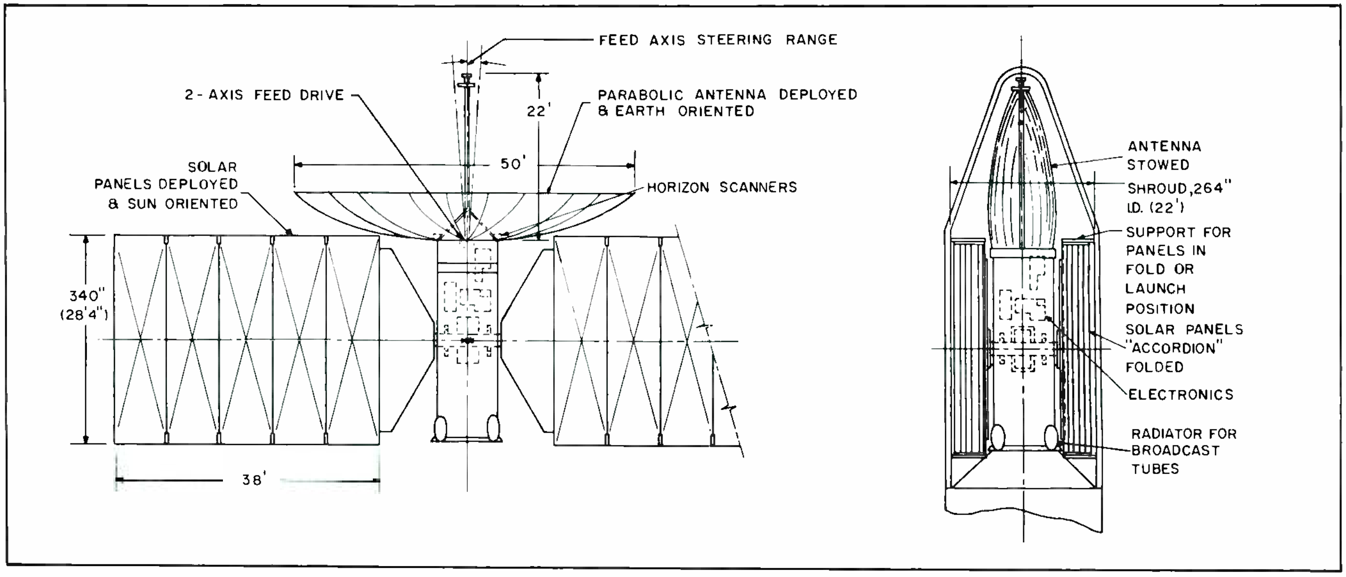
1) A separate home antenna for spacecraft use is anticipated. As stated earlier, the antenna is equipped with a low-noise, transistor preamplifier at the transmission-line input.
2) One of the upper UHF channels (e.g., 69, at 800 MHz) will be used for the down link. The up link may also be at UHF, but choice of up-link frequency is less critical.
3) Spacecraft design is to be within the capability of current space technology.
4) One-channel coverage of the Boston-Washington area is a minimum requirement. Preferably, the spacecraft down-link beam should be pointable to various areas within the spacecraft field of view.
5) Home instrument receivers having UHF tuners are to be used without internal modification.
6) Spacecraft design must provide a mean time to failure (MTTF) of 10 years, with 90% probability of survival in space for at least one year. Further, there must be no wearout of any kind to limit satellite life to less than two years.

The first two requirements, coupled with the need for economic attractiveness to the homeowner, imply a synchronous equatorial orbit for the spacecraft; otherwise, the home installation would need a search-and-track capability, which is an unreasonable requirement. Design within the capability of present space technology and at the same time within the payload capability of economically reasonable boosters implies a solar-oriented photovoltaic array for the power system. To satisfy the coverage requirement, a lightweight, erectable antenna with steerable feed is employed. A beamwidth of about 1¾° by 1¾° is used to cover the continental United States in four steps; from synchronous altitude, the angular spread required for this is about 2¼° in latitude by 6° in longitude. Fig. 4 shows the coverage geometry. The Boston-Washington area lies within the area covered by the spacecraft antenna beamwidth.

Complete continental coverage is obtainable by a combination of coarse and fine control. Coarse beam pointing in increments of 2° is obtained by attitude control of the spacecraft. Vernier-beam pointing is provided by a servo-controlled feed-boom drive, which moves the feed off focus by a small angle. For an angular offset of only a few beamwidths, gain loss in a parabolic antenna is negligible and the sidelobe increase is not serious. In VisTa, the maximum angular offset of the feed will be less than 1.7 beamwidths. The servo error signal input is obtained by a monopulse lobe-comparison method using coded beacon signals from the ground.

Alternative possibilities exist for coarse stabilization. One method, called *stabilite*, uses a single inertial wheel.[3] With stabilite, the overall spacecraft is despun and depends upon the gyroscopic stiffness of the spinning inertia wheel for yaw and roll stabilization. Pitch-axis stabilization is obtained from a servo-controlled motor drive. The sensor in this case is the same microwave beacon used for vernier control of the antenna feed. The other scheme for stabilization uses cold-gas jets in a limit-cycle mode. Its disadvantage, compared with Stabilite, is the limited system life inherent in a finite allowable volume of cold gas. While this stabilization means could be satisfactory for an experiment of limited lifetime, it may well give way to the stabilite for operational designs having over 5-year lifetimes since the latter is not thus limited.

Fig. 5—VISTA satellite configuration.



All detailed designs at component, subsystem, and system levels were subjected to reliability analysis to assure the 10-year MTTF in space. Optimism for two-year survival is provided by experience and data from RELAY I and II spacecraft, both of which operated successfully for more than two years in orbit, as well as by the continuing experience with the spacecraft in the TIROS series, many of which have reached two years of successful operation in orbit. These spacecraft demonstrate performance well beyond their design life specifications.

Results of the VISTA system studies to date are summarized in Table II. The table is intended to indicate a system in which optimization for signal design, cost effectiveness, reliability, and subsystem characteristic tradeoffs are not complete. Some problem areas common to the VISTA system and an operational spacecraft televising system are highlighted by Table II.

The values in Table II for power-amplifier output and power-source generating capability point to a problem for operational telecasting. The 3-kW power amplifier and the 12-kW high-voltage solar-array power subsystem are within present RCA capability to design, develop, and manufacture. Multiple-channel coverage in an operational mode implies linearly increasing power requirements with the number of channels. Other features of the system, such as signal processing designs, may offer tradeoff possibilities which can reduce the per-channel power-amplifier output requirement. This tradeoff could increase the economic attraction of operational spacecraft telecasting systems.

Further power reductions may be realized by increases in antenna size. Though apparently modest, an increase in size of the erectable parabola from 50 feet to 60 feet is accompanied by a reduction in power-amplifier requirements to 2.0 kW. This increase in size appears to be feasible. As multiple channels are added for operational telecasting, multiple feeds with narrower antenna beamwidths become attractive.

VISTA SPACECRAFT DESIGN

Fig. 5 shows the VISTA spacecraft deployed (on the left) and stowed in a SATURN 1B shroud (on the right). Major features of the spacecraft are indicated.

The antenna is a 10-foot-diameter fine-mesh ribbed paraboloid, which is intended for erection in space.[5] Fig. 6 shows deployment stages of this type antenna. Gain and efficiency, for a given diameter in wavelengths, depend upon the number of ribs. Weight of the antenna and movable feed sub-system in VISTA is 482 lb.

Studies of unfurlable, ribbed, parabolic antennas have shown that rib and mesh-saddle effect errors are relatively constant over the range of focal-distance-to-diameter ratios (f/d) between 0.35 and 0.6. Deviation from true paraboloidal shape caused by these errors produces a "gain loss" in the unfurlable antenna. Fig. 7 shows the number of ribs required as a function of reflector diameter in wavelengths for three different values of gain loss. Fig. 8 shows antenna gain as a function of reflector diameter in wavelengths for various number of ribs. The maximum useful gain for a given number of ribs occurs when the contour errors cause a gain loss of 3 dB at the operating frequency. The curves demonstrate the need for more ribs to hold the same gain loss as the antenna

TABLE II — VisTa Characteristics

Ground TV Transmitter
  Channel 62
  10 kW
  28-ft. parabola

Ground Beacon Transmitter
  Channel 83
  100 W
  10-ft. parabola
  Bandwidth, 100 Hz

Transponder
  Translate video and sound separately
  Demodulate sync
  Channel 69 (down)

Modulator
  Audio and video
  Class-B linear sync
  High-level plate moduation

Power Ampifier
  Video, 4 tubes with 3-bridge diplexer
  10% audio power
  3.0-kW average radiated power

Attitude Control
  All cold gas jets, 2 year life
  Reaction wheels or momentum wheel for extended mission
  Accuracy, ±1°
  Sensors: Sun, Earth, and one star microwave beacon

Power Source
  Oriented array of silicon cells
  12 kW
  Pantograph deployment
  Power transmission: wind up
  Voltage: high (direct to PA plate)

Command and Telemetry
  Antenna, omnidirectional
  Modulation, PCM-FM
  Frequencies, Telemetry: 136-137 MHz
    Command: 120-150 MHz

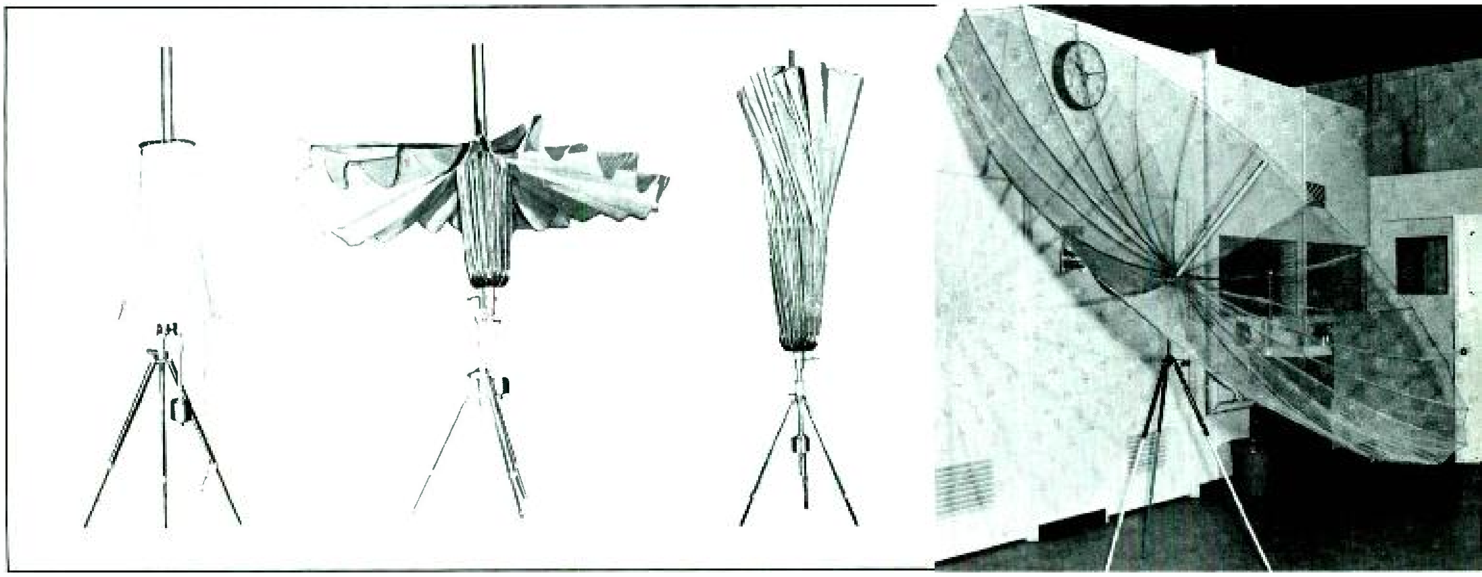
Spacecraft Antenna
  50-ft. parabola
  30 ribs
  Focal length-to-diameter ratio (f/d) = 0.44
  5-dipole feed, mechanically steered

Vernier Beam Control
  "Monopulse" tracker
  Servo controlled feed
  Accuracy, ±0.2°

Thermal Control
  Four aluminum radiators, approx. 32 sq. ft. area each
  Radiators fixed directly to power amplifier anodes

Home Receiving System
  Unmodified receiver
  Antenna gain, 19 dB
  NF of antenna-mounted preamp, 4 dB
  Gain of antenna-mounted preamp, 30 dB (2-stage)
  S/N, black-white to RMS, 36 dB at center of transmit beam

Fig. 6—Experimental antenna, deployment stages.



diameter or operating frequency is increased. Since the ribs are the major factor in antenna weight, the gain loss and number of ribs (30) have been determined in tradeoff studies.

The solar array consists of two assemblies of panels accordion-pleat-folded in stowage. These can be extended either by pantograph or by extensible boom. When deployed, the panels must be controlled to remain essentially perpendicular to the sun. Because of the 23° angle between the equatorial and ecliptic planes, this cannot be done without providing two degrees of freedom for the controlled motion of the panels. If this is not done, the maximum alignment error between the sun line and the normal to the panels will be 23°, and the incident energy on the panels in this case will be reduced by the cosine of that angle, or to 92% of its desired value. In the interest of simplicity and reliability, the array has been sized accordingly larger and a single degree of freedom provided for its controlled motion. To eliminate slip rings or microwave rotary joints from the spacecraft design, a cable wrap-up is employed. Since the rotation rate of the array is slow, wrap-up does not present a severe problem. In operation, it will be necessary to program the array back through the 360° wind-up angle daily. This can be done without serious programming outages, possibly in the early morning hours between 3:00 and 4:30 AM.

Comparisons of high-current and high-voltage solar array subsystems favor the choice of high-voltage for VisTa, since 70% of the total load power in the spacecraft is required at high voltage for the power amplifier. The high-voltage system eliminates the need for high-current low-voltage-to-high-voltage converter, thus increasing overall power subsystem efficiency and reducing weight. A further weight reduction can be realized in the bus bars, which no longer need to carry heavy currents. The power subsystem includes, in addition to the high-voltage solar array, voltage converters for the low-voltage equipment in the spacecraft, array output regulators and low-load batteries, and charge-control electronics for operation during the cable unwinding period. The weight of the entire subsystem, including deployment drive and cable mechanisms, is 1,580 lb. The weight of the equivalent low-voltage power subsystem would be 1,900 lb.

Recent surveys of space power subsystem capabilities and extrapolations of work now in progress point to 20-kW or even 40-kW solar array subsystems as practically realizable for 1975 flight hardware. For 1968-1969, it is practical to design 12-kW arrays. These use 8-mil-thick silicon cells which have a 2-cm x 2-cm area with both contacts on the cell rear face and a 10% to 11% conversion efficiency. With 3-mil-thick glass covers for thermal control and protection from low-energy particles, flight hardware arrays on honeycomb paddles would provide 15 to 20 watts per pound.

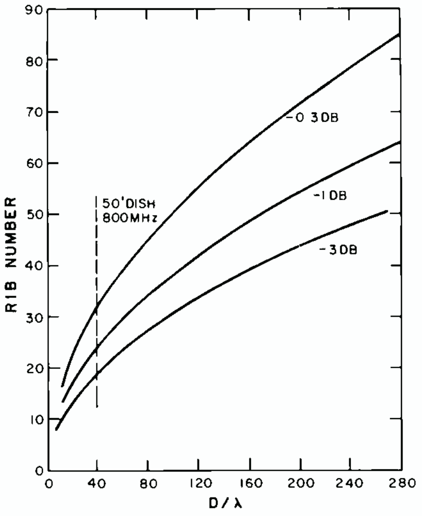


Fig. 7—Number of ribs versus gain loss for various reflector diameter-to-wavelength ratios.

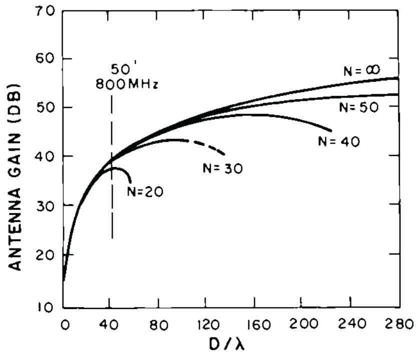


Fig. 8—Antenna gain versus diameter-to-wavelength ratio for various numbers of ribs.

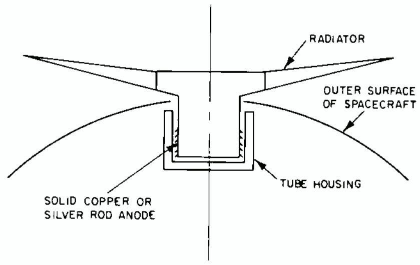


Fig. 9—Thermal model of power transmitter tube.

In VisTa, the power amplifier tubes would be mechanically modified versions of reliable RCA tetrodes, either the normally liquid-cooled 6806 or the normally air-cooled 8501. The mechanical modification consists of replacing the normal cooling systems with thermal radiators. These, indicated in Fig. 5, are shown in more detail in Fig. 9. Connection to the anode may be either with solid copper, as in Fig. 9, or through a heat pipe. If solid copper is used, the radiator will have a major axis of about 4 feet, a minor axis of about 2½ feet, and will weigh about 30 lb. Four power-amplifier tubes, appropriately derated for the limitations of this conventional cooling system, are required for the transmitter. Increases in power-amplifier tube power level are passed on proportionately to the radiator area in order to handle the increased dissipation requirements. Weight and size limitations, as well as thermal limitations on power-tube design, make this approach to increasing channel capacity unpromising. The situation can be relieved with heat-piping techniques, which offer equivalent thermal conductivity several thousand times that of solid copper.

The heat pipe[4] is a closed hollow tube containing a liquid and a wick, as shown in Fig. 10. Liquid is evaporated at the hot (anode) end of the pipe and condenses at the cold (radiator) end. Condensate is returned to the hot end by capillarity of the wick. Since a saturated liquid-vapor equilibrium exists within the pipe, there is only a small temperature difference between evaporating and condensing surfaces. Recent work at RCA has demonstrated the transfer of 2,500 watts of thermal energy along a 2-foot length of ⅝-inch-diameter molybdenum heat pipe at 1,200°C with a temperature differential of less than 5°C. Results have shown that the input heat can be concentrated in a small area and delivered to a large area with flux transformation ratios as high as 12:1. The greatly improved efficiency of heat transfer from power-amplifier anode to thermal radiator provided by the heat pipe should remove the limitations on power and channel capacity presently imposed by conventional conduction connections to the radiator.

A weight summary for the VisTa spacecraft is given in Table III. Since VisTa is a single-channel telecasting spacecraft, it is clear that substantial weight improvements, or new techniques implying lighter weight, or both, will be required in the design of multiple-channel telecasting spacecraft. The weight is limited by available booster capability, and at present the Titan III-C launch vehicle aided by a solid apogee kick motor in the payload can place only

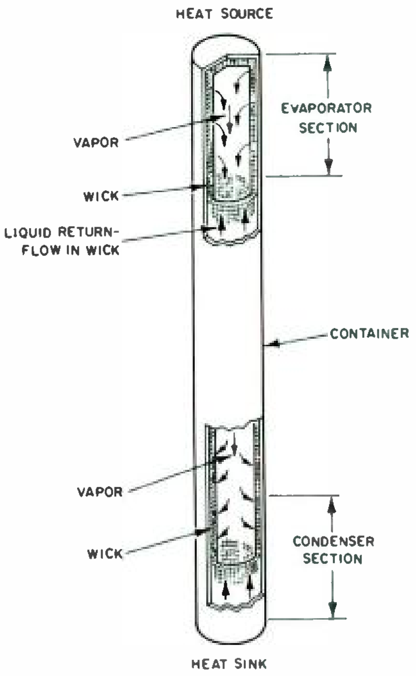


Fig. 10—The Grover heat pipe.

3,500 lb. in a synchronous, equatorial orbit.

For slightly heavier designs, a Titan III-C, Centaur combination has been suggested. This combination would have the ability to place an 8,000-lb. payload in synchronous, equatorial orbit when aided with an apogee kick motor. While the combination is not now being worked on, the gap between Titan III-C and Saturn 5 implied by possible cancellation of Saturn I-B Centaur make some similar vehicle combination of intermediate capability a necessity if payloads of the order of 6,000 to 8,000 lb. are to become a reality. This appears necessary to the multiple-channel telecasting application.

CONCLUSIONS

The primary objective of the VisTa design is to facilitate a meaningful, direct-to-home, space telecasting experiment in the present decade. Selection of spacecraft system specifications to be compatible with unmodified, standard, broadcast receivers and minimal additions to the home antenna make this feasible and practical. Technological modifications which would improve the link performance could result in wider geographic coverage or lower spacecraft transmitter power per TV channel. For operational spacecraft telecasting, the incorporation of signal processing to permit reduction of the power amplifier level becomes attractive indeed. One possible approach recognizes that conventional transmission of television program material is based on providing power over a substantially wider bandwidth than the receiver will accept. If this excess power is not transmitted, the signal can still be shaped to accommodate the receiver. This is shown in Fig. 11, where conventional transmission and receiver filtering are shown under *receiver attenuation*. Placing a receiver-attenuation type of filter in the spacecraft repeater reduces the transmitted power, while the viewer would only have to retune the receiver. Two evident problems with this approach are the loss of some high-frequency signal components, which may present difficulty with color pictures, and increased attenuation of the audio signal. Appropriate filter design can overcome the latter problem relatively easily. But any approach to signal processing changes must accommodate color transmission and must provide proper scaling for the carrier in the receiver since it contains luminance information. Because of this, different approaches to signal processing are under consideration. Each has different aspects of filtering and picture reproduction to be investigated, and any one may lead to substantial per-channel power reductions in the spacecraft. But any advances which increase the attraction of direct-to-home space telecasting must accommodate color and must not require changes in receiver design which make existing receivers obsolete or increase the consumer cost of new ones appreciably.

The VisTa experiment is practical and feasible whether or not signal processing changes are developed for the space telecasting application. Advances in technology required to progress from an experimental to an operational system have not been found to depend upon such changes. Should signal processing advances be found which do fit the system application, their principal effect will be to increase the economic attraction which is already apparent.[1,2]

TABLE III — VisTa Weight Summary

Spacecraft Subsystem	Weight (lb)
Structure:	535
Thermal radiators	
Truss or monocoque structure	
Power Subsystem:	1,580
Solar cells and panel electrical equipment	
Substrate	
Deployment drive	
Miscellaneous hardware	
Power Conditioning Equipment	
Storage batteries	
Antenna:	482
Attitude Control and Stabilization:	145
Control gas	
Tankage, jets	
Gyros and sensors	
Electronic equipment:	705
PA, driver tubes, and circuits	
Transistor circuitry	
Plumbing	
TOTAL	3,447

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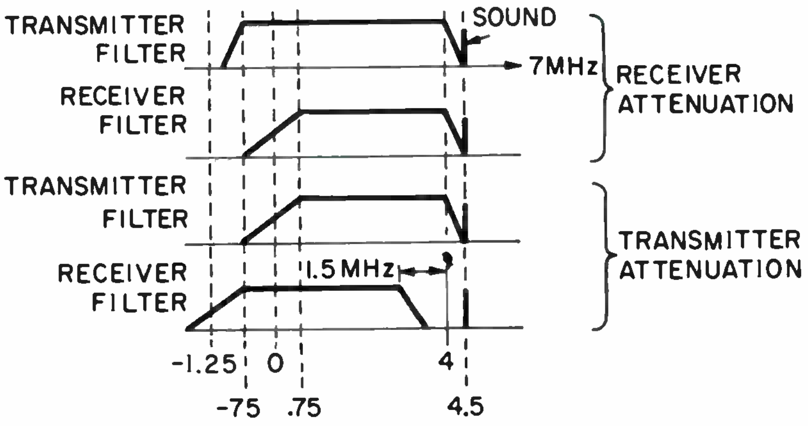

Fig. 11—Receiver filter.

TECHNICAL PAPERS

Acceptance or Rejection?

Journal editors and conference program chairmen, who must review technical papers sent to them and say "accept" or "reject," are influenced by a number of factors. By understanding their viewpoint and some of the processes involved, authors of technical papers can gain insight into the reception their work may receive. To promote such understanding, this article is written from the viewpoint of a professional-society journal editor.

DAVID B. DOBSON, Administrator
Technical Publications
Aerospace Systems Division, DEP, Burlington, Mass.

What determines the fate of the paper you submit to a technical journal or professional meeting? What standards of measurement do the reviewers apply? Examination of the editorial review process may remove some of the mystery that seems to surround acceptance of technical papers. If you take the trouble to understand the editorial viewpoint, you are better equipped to write a paper of high quality—one that will be more readily accepted.

The mechanics of technical writing is the subject of many comprehensive texts and articles (see Bibliography); therefore, no attempt is made here to deal with that aspect. Instead, we will look at what is in store for your manuscript at the "receiving end," where the journal staff or conference committee must critically review and evaluate it. Will they mark it *accept*, or *reject?*

THE EDITOR'S ACTIONS

After the journal editor or conference program chairman receives your paper and records the "manuscript received" date and other basic administrative data, your paper usually will be put aside for reading in turn with the many others he is handling—unless he has been waiting especially for yours. Later, when the editor picks it up for initial review, he notes the title, abstract, introduction, and conclusion in detail, spot-reading the body text as needed to grasp the content. If the editor feels that your contribution is worthwhile and deserving of further consideration, he will route the text and copies of the illustrations with a paper review form (see Fig. 1) to selected reviewers. This first step may involve from one week to one month, depending on how busy the editor is.

The information indicated in Fig. 1 is in effect a good check list for every author—for it shows the criteria by which a paper is actually judged.

The reviewers independently take the time necessary to carefully study your paper and provide their comments via the review form. Remember that at this point the reviewers and editor represent the readers; their basic test is: *Does your article disseminate information that is novel or presented in a new light, and that our readers are seeking?* Most such reviewers are *not* on the full-time journal editorial staff. They usually serve in this capacity on a volunteer, "labor-of-love" basis, and may often be senior technical authorities in a given field. Some are more prompt than others in completing their reviews, and anywhere from two weeks to two months or more may be involved in this step.

The reviewers' comments are weighed carefully by the editor as he evaluates their various impressions and recommendations. Based on these comments and recommendations, his personal knowledge of each reviewer, and his own final review, the editor will reach a decision and notify you. Although the editor may assume you are a technical authority, he will not accept your paper unless he believes the subject will be of value and interest to his audience. This basic truth emphasizes the need for the author to clarify the *significance* of his work—ideally in the introductory text.

If the paper is accepted, the editor's letter will usually be quite short, and may contain further instructions. When your paper is not acceptable, he may return it to you with constructive comments on how to make it acceptable, or possibly with a statement to the effect that it is better suited for use by another journal or conference. Sometimes within a large professional society (e.g., the IEEE), various editors exchange papers directly, notifying the author of the movement from journal to journal by a copy of the transfer letter.

If your paper is rejected, don't be discouraged; try to understand why, and what the editor is saying. By working with *his reasons* for rejection, you are applying helpful advice that may result either in his or another editor's acceptance of your revised effort or perhaps of another, future paper.

CONFERENCE PAPERS

Papers are selected for technical conferences by similar methods, with a few changes required by the different end use. One of the most demanding ques-

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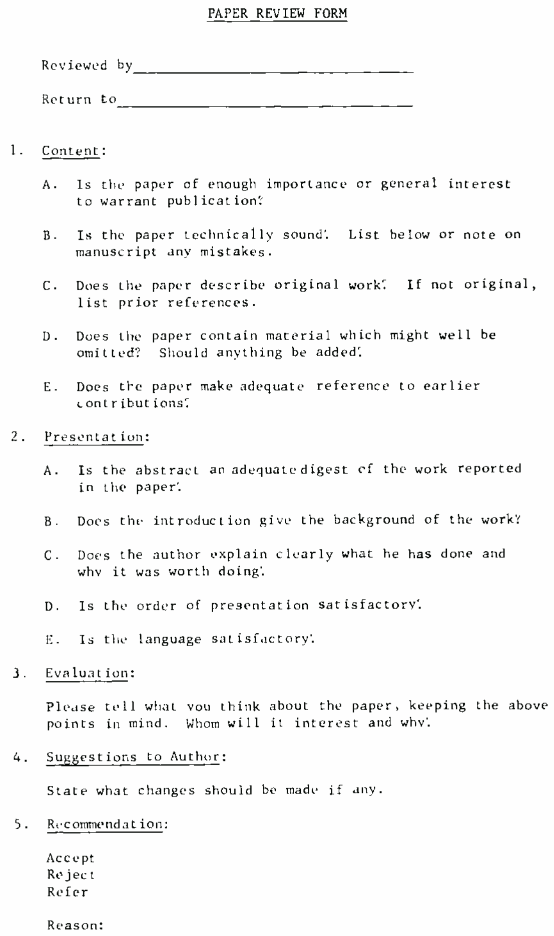
Final manuscript received June 7, 1966.

DAVID B. DOBSON received the BEE degree from Rensselaer Polytechnic Institute in 1952. He then participated in development of high-powered audio amplifying systems for the Signal Corps Engineering Labs and in the application of electronic equipment to psychological warfare as a member of the Psychological Warfare Board at (now) the Special Warfare Center, Ft. Bragg, N.C. At RCA, Mr. Dobson has engaged in engineering work on fire control radars and associated test equipment. He then became engaged in the engineering application of RCA Systems Support products to new areas; such test equipment programs include HAWK, MPTE, DEE, APATS, DIMATE, and PTS. In 1963, he became responsible for reporting on all ATE programs including multisystem test equipment (MTE) and the first phases of land combat support systems (LCSS). He is now Administrator, Technical Publications for the Aerospace Systems Division where he coordinates technical writing and reporting, new business activities within engineering, and Divisional press relations. He is a Senior Member of IEEE and serves on several technical committees. Mr. Dobson served as conference record chairman for several international conferences, as guest editor of 1962 IRE Transactions on Military Electronics, Editor of the IEEE Transactions on Aerospace, and is now Executive Editor, IEEE Transactions on Aerospace and Electronics Systems. He is an associate member of the Aviation/Space Writers Association, a member of the Society of American Military Engineers, and of the American Ordnance Association.



PAPER REVIEW FORM

Reviewed by______________________________

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1. Content:
    - A. Is the paper of enough importance or general interest to warrant publication?
    - B. Is the paper technically sound? List below or note on manuscript any mistakes.
    - C. Does the paper describe original work? If not original, list prior references.
    - D. Does the paper contain material which might well be omitted? Should anything be added?
    - E. Does the paper make adequate reference to earlier contributions?
2. Presentation:
    - A. Is the abstract an adequate digest of the work reported in the paper?
    - B. Does the introduction give the background of the work?
    - C. Does the author explain clearly what he has done and why it was worth doing?
    - D. Is the order of presentation satisfactory?
    - E. Is the language satisfactory?
3. Evaluation:

    Please tell what you think about the paper, keeping the above points in mind. Whom will it interest and why?
4. Suggestions to Author:

    State what changes should be made if any.
5. Recommendation:

    Accept
    Reject
    Refer

    Reason:

Fig. 1—A paper review questionnaire used by the *IEEE Transactions on Aerospace and Electronics Systems*. Some journals use a questionnaire form that also involves a numericol ranking for each review factor.

tions to be answered during a conference committee review is: *Is this paper (or abstract, if abstracts are called for) written especially for us, or is it also being sent to other conferences?*

The conference program chairman will, with the advice of his reviewers, try to ascertain whether your material fits within the theme of the conference. With the advice of his committee, he must arrange the program in a tentative order, sometimes modifying or changing it to fit available subject material.

The program chairman, having made a preliminary arrangement of the technical program, notifies the authors (if complete papers were not required) that their abstracts are approved, and to prepare their papers. Generally, this review process is rather prompt, since the reviewers involved are concentrating their efforts on *that* particular conference, and must make timely decisions to firm up the program.

But, at this point (when you receive a "go-ahead" based on your abstract) do *not* assume that the paper can be presented without additional effort on your part.

The conference must always be prepared for authors dropping out, knowing that many engineers don't start writing until the abstract is approved. There are usually about 60 days from first notification for you to finish your writing, get necessary clearances and approvals, and submit the completed paper. If you miss any stated milestones, the conference has a reason for turning you down. Be sure to: 1) mail the paper by or ahead of the due date, 2) conform to your abstract, and 3) guarantee that your paper is completely cleared for presentation *and* for publication, if it is to appear in a printed conference record.

One sure way to improve your chance of acceptance is to write your entire paper, have it cleared and approved, and submit it—complete—in response to the initial call for papers. Seldom is anyone turned down who submits good material and goes to this much trouble; it is proof of your serious interest in the conference. One disadvantage, however, of completing your material well in advance of the conference is the possible reduction in its timeliness. You (as the authority responsible for the paper) and the conference committee (as the authorities responsible for the program) will have to weigh how important this is in individual cases. Another way of getting more consideration of your paper is to submit it through a known conference contact.

WAYS TO GAIN ACCEPTANCE

A good understanding of the problems and objectives of the editor or conference chairman is essential to gain acceptance of your talk or paper.

Understanding the Audience

Place yourself in the position of the editor who receives a technically sound, carefully organized paper, obviously beamed to the exact technical field covered by his journal, and complete with novel items of special interest to the journal's readers. *How can he resist?* Such a paper makes the editor's job easier and eliminates correspondence, phone calls, and missed opportunities.

When you have decided to submit your work for consideration by a particular journal, study the journal format and then mold technical material to the interest of the magazine. *Space Aeronautics*, for example, has far different format and requirements than those of the *Journal of the American Physical Society*.

To some degree (depending on the journal), an editor looks to a "stable" of proven authors and recognized experts who can produce especially good or special-purpose papers such as critical reviews, state-of-the-art reports, tutorial material, etc. Similarly, each conference technical chairman has his own list of outstanding people that can be called upon to round-out a program. By showing interest and ambition, and by following established journal or conference needs carefully, it is possible to establish yourself as such an author of proven capability.

Format and Style

It is always good practice to please an editor by following closely the established style of *his* journal. Careful adherence to the journal's handling of paragraph subheadings, symbols, abbreviations, equations, glossaries, figures and captions, and tables will have its positive effect. The use of nonstandard units and the proliferation of unexplained abbreviations and mysterious acryonyms can be very frustrating to the editor.

Make a final review of your paper to assure conformance to the journal requirements. Ensure that your paper treats the subject thoroughly but is not overly long; that it is professionally sophisticated but not abstruse; and that it has technical depth, but is not beyond the understanding of the intended audience.

All illustrations must be carefully prepared for good readability. In journals, illustrations are often reduced to ⅓ or ¼ or more of their original size. If possible, avoid using the *same* original artwork for a slide and for a figure in a printed paper. The criteria for a good slide do not apply across the board to figures. If artwork must do such double duty, plan it even more carefully to make the best compromises. By working with your graphics group you can do much to assure that figures and slides will be effective. Be sure to include succinct, descriptive captions keyed to and marked for each illustration.

Relate Your Paper to Other Literature

Important in gaining the respect of reviewers is a clear indication of how your paper relates to other published literature on the same general topic. You should cite appropriate references, include them in a bibliography at the end of the paper, and explain in the text what their relation to your work is. (Don't just add an *un*explained list of references.) An intelligently prepared bibliography is solid evidence that you are familiar with the literature of the field, and have given it due consideration in the thinking processes that have produced your paper. As much as practical, distinguish between references that you have used directly (e.g., cases where you are using data from other sources) and cases where you are recommending references for additional information (which readers welcome).

Take Particular Care With the Title and Abstract

Your title and abstract have special importance which demands extra attention. First, if it is a conference paper, remember that the title and often the abstract *which you write* will appear on the conference program, and is a factor in stimulating attendance at the conference and in assuring a good audience for *your* paper. Also, your title and abstract for a published paper will be used in abstract journals (e.g., *Engineering Index, International Aerospace Abstracts*, etc.) by which others in the field search for literature. Some indexing activities lean very heavily on examination of the title and abstract (rather than the full text) in preparing subject indexes. Depending on the journal, you may even be asked to add "keywords" to the abstract to guide later indexing.

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THE ORAL PRESENTATION

A paper intended for oral presentation deserves mention, as it is one of the major hurdles facing engineers trying to communicate.

In an oral presentation, the speaker puts ideas across without benefit of a "second chance"—that is, each thought must be clear the *first* time since the audience cannot re-read an unclear section, as in a printed paper. No one really cares whether you are a polished speaker, use gestures, or speak in clearly modulated tones as long as the message gets through to the listener. *Today's most glaring problem is the conference paper read verbatim in its entirety and without benefit of rehearsal.* The drone of such a talk is a sure sleep producer. Many authors have *un*founded fears that the human touch or digressions are nonprofessional; actually, they provide insight into thought processes and may be of great interest to the audience. In short, *discuss* your paper when giving it orally, don't just read the same thing that will be in print in the conference proceedings or in an available hand-out such as a preprint or reprint.

The easy way to keep your talk simple and direct is to try it on associates for reactions. This way you can detect errors in logic before you face your audience and gain insight as to how the talk will be received; and, perhaps, find a better way of saying the same thing. Don't feel that your peers will think less of you for this step; they will respect you for it.

Slides and charts are aids, not crutches; keep them few, simple, legible from the back row, and don't try to put everything on one slide; a clear pencil sketch is better than a professionally drafted but overly detailed schematic.

CONCLUSION

The engineer who takes the time and effort to get his work into print receives just credit for it, even though others may also have contributed to the basic work. Publication credit may be considered analogous to the patent process, in the sense that proof in the form of early publication can have much influence. And, the impression left with the reader or listener by your technical paper affects both your own professional status and RCA's technical reputation.

At the end of the rehearsal of your talk, or upon a last reading of your article before submittal, ask, *What did I say?*, *What did I prove?*, *What did I recommend?* When you stand back and look at your work from the editor's viewpoint, your chances of acceptance are greatly enhanced.

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Engineering and Research NOTES

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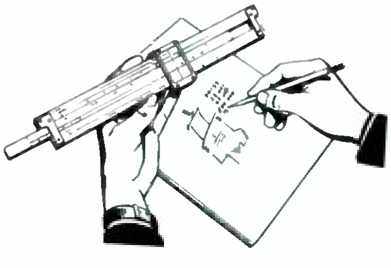


Physical Significance of the Power-Amplification/Bandwidth Product of an Active Device

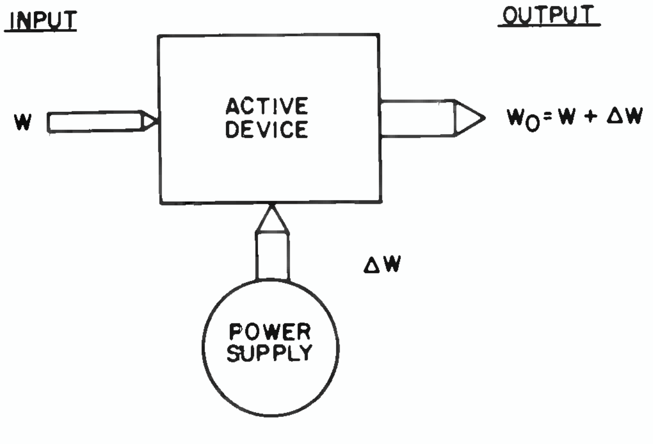
E. O. Johnson
Electronic Components and Devices
Harrison, New Jersey

Final manuscript received June 29, 1966

This *Note* discusses the elementary physical significance of the power-amplification/bandwidth product for an active device. Although the significance of this product may have been pointed out elsewhere, it does not seem to be generally known in the electron-device field, at least in explicit terms. The elementary physical viewpoint presented in this *Note* distinguishes two types of gain-bandwidth product and shows how one type serves as a physical parameter that limits the ultimate performance of a transistor.

A basic function of a system which processes information-bearing electrical signals is the addition of electrical energy to the signal from a power supply.[1] The performance of this function is one of the most important attributes of an active device. A figure of merit for this can be derived from the active device shown in Fig. 1. The device combines an input signal of energy W with a power-supply input of energy ΔW to produce an output signal $W_o = W + \Delta W$; it is assumed that there is no internal energy loss. This process occurs in a time interval ΔT defined here as the interaction time. This time, equivalent to the input-output signal transit time, is important because the information-processing *rate* of a system or device is usually of primary concern.

Fig. 1—Energy flow in an active device.



A reasonable figure of merit M for an active device can be stated as follows:

$$M = \frac{1}{W} \times \frac{\Delta W}{\Delta T}$$

where the normalization factor $1/W$ is introduced so that power-handling devices do not assume undue advantage. This equation can be transformed as follows:

$$M = \frac{1}{W} \times \frac{\Delta W}{\Delta T} = \frac{\Delta W}{W}\,\frac{1}{\Delta T} = \frac{W_o - W}{W}\,\frac{1}{\Delta T} \cong G_p\,\Delta f \tag{1}$$

where G_p represents the power amplification of the device and Δf represents its bandwidth. Eq. 1 describes the elementary physical relation which is the subject of this *Note*. In arriving at this result, it is assumed that the average output/input energy ratio is equal to the corresponding power ratio; also, that base-band conditions apply. The signal energy W may or may not appear in the output circuit depending on the type of device. In this discussion, as well as for most practical cases, W can be ignored in the output signal. Broadly interpreted, Eq. 1 emphasizes that the product of power amplification and bandwidth for an active device is a measure of the *rate* at which power-supply energy is converted to signal energy.

This interpretation distinguishes two types of power-amplification/bandwidth product: the "interaction" type discussed above, which applies to such devices as the grid-controlled vacuum tube and the transistor; and the "response" type, which relates to such devices as the travelling-wave tube, which has appreciable gain over a wide frequency spectrum, but also has a relatively long input-output signal transit time.

In the latter type, a large "response" amplification/bandwidth product (the type normally given in performance specifications for such devices) is achieved at the expense of a long energy interaction time ΔT by clever use of a geometrically and electrically distributed structure.

For example, a typical travelling-wave tube having a specified gain-bandwidth product of a few gigahertz would have a product about one-tenth this value if its performance were evaluated in terms of energy interaction or signal transit time. This difference is not of practical importance in such applications as microwave repeater stations which process commercial television signals. On the other hand, the difference can be, and usually is, of great importance in a high-speed computer where precise coincidence of signals is required after transit along different circuit paths.

In a lumped-circuit type of device such as a grid-controlled vacuum tube or a transistor, the gain-bandwidth product relates quite directly with the energy interaction time. The simple physical notion of the gain-bandwidth product given above leads directly to the physical parameter that limits the ultimate performance of a transistor. In a typical transistor, power-supply energy enters by way of the collector circuit and is added directly to the collector-bound charge carriers which carry the signal. The maximum electrostatic energy that can be added to a carrier per unit length of carrier path is equal to the breakdown field E of the semiconductor material. For germanium and silicon, this field is of the order of 10^5 volts per centimeter.

Furthermore, the maximum velocity that the carrier can attain is limited to the saturated drift velocity v_s, which is of the order of 10^7 centimeters per second for Ge and Si. This maximum velocity is reached at electric fields about one-tenth the value of the breakdown field E.

Therefore, the maximum time rate at which electrostatic energy can be added to the signal carriers in a Ge and Si transistor is given by the parameter Ev_s, which is of the order of 10^{12} volts per second. Accordingly, this parameter should play a key role in defining the performance capabilities and limitations of a transistor; a detailed analysis[2] indeed shows that such is the case. It has also been shown that the quantity Ev_s has a similar basic role in establishing the ultimate performance in other semiconductor devices such as varactors, IMPATT oscillators, and possibly also GUNN oscillators.[3]

In summary, the power-amplification/bandwidth product of an active device is a measure of the rate at which power-supply energy is converted to signal energy. This rate in a transistor is determined by the parameter Ev_s, which is of the order of 10^{12} volts per second for Ge and Si. Certain devices, such as travelling-wave tubes, achieve a large bandwidth product at the expense of a lengthened energy interaction time.

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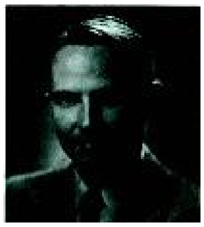
1. See, for example, *IRE Standard 58 IRE 3.S1* for definition of an "active transducer."
2. E. O. Johnson, "Physical Limitations on Frequency and Power Parameters of Transistors, *RCA Review*, Vol. XXVI, June, 1965, pp. 163-177.
3. Personal communication with J. M. Early and B. C. De Loach, Jr., of the Bell Telephone Laboratories.

Improved Accuracy in Reading Graphs



D. J. Blattner, *Electronic Components and Devices, Princeton, New Jersey*

Final manuscript received June 14, 1966.

Speed and accuracy in reading graphs can be improved by use of the handy reference scales shown in Figs. 1 and 2. These scales can be made from a piece of clear plastic film (such as the acetate cover from a report) placed over Figs. 1 and 2 and marked with the sharp end of a compass.

The scale in Fig. 1 is linear; it can be used to divide vertical or horizontal grid lines of a graph (or any line parallel to them) into 5 uniform intervals. The logarithmic scale in Fig. 2 can be used to divide horizontal or vertical grid lines (or any line parallel to them) into intervals that are logarithmically related. Thus, the two scales make it possible to subdivide linear, semi-log, or log-log graphs.

The use of these new tools is illustrated in Figs. 3 and 4 for a sample graph using linear and logarithmic scales. Fig. 3 shows how the linear reference scale of Fig. 1 can be used to determine the maximum gain value as 16.5 dB. Fig. 4 shows how the logarithmic reference scale of Fig. 2 can be used to determine a value of 400 hertz as the frequency for which gain is 15 dB.

If slots are cut in place of the parallel lines, or holes are drilled where the scale lines cross the parallel lines, these handy tools can also be used to lay out graphs to any convenient scale. Other modifications will undoubtedly occur as these devices are used.

Surely the few minutes spent making the scales will pay an enormous return in the efficiency and improved accuracy in reading graphs.

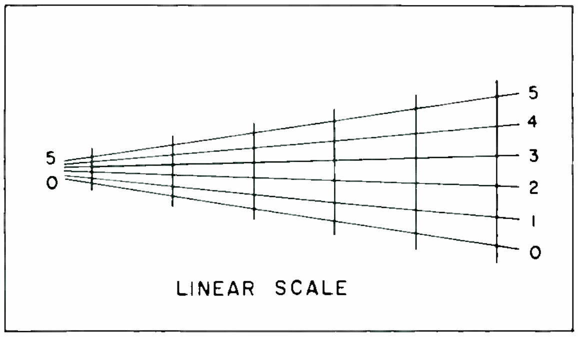


Fig. 1—Layout of a linear reference scale. Each of the parallel vertical lines is divided linearly.

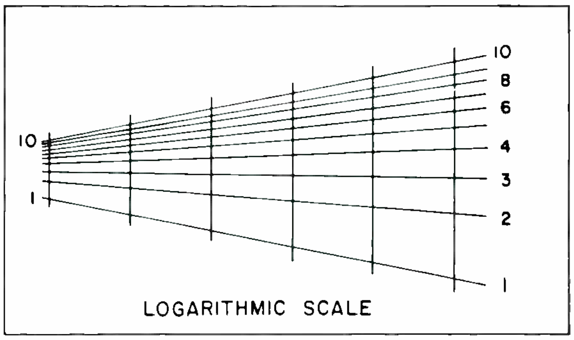


Fig. 2—Layout of a logarithmic reference scale. Each of the parallel vertical lines is divided logarithmically.

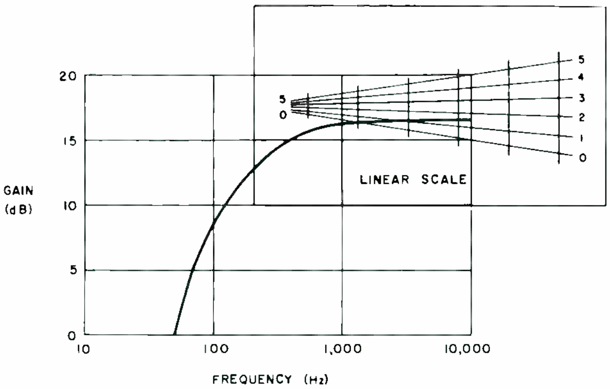


Fig. 3—Use of the linear scale to determine the maximum gain on a typical gain-frequency curve.

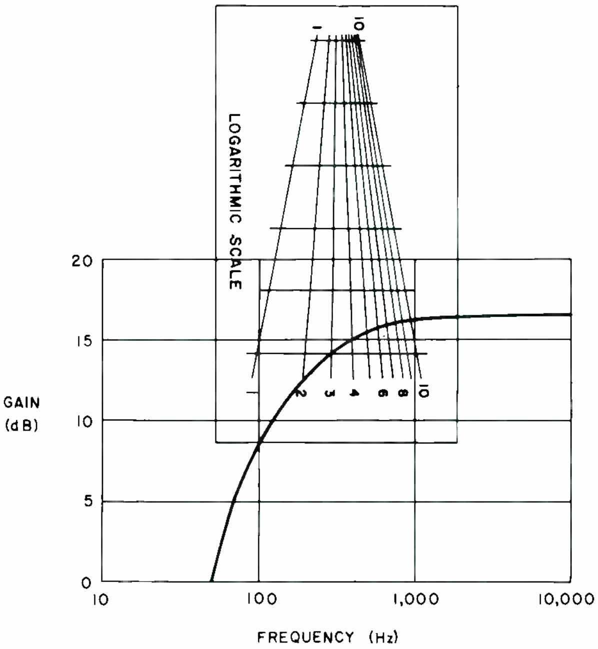


Fig. 4—Use of the logarithmic scale to determine the frequency for which gain is 15 dB.

Coplanar Gunn-Effect Devices

C. T. Wu, *RCA Laboratories,*
Princeton, N.J.

Final manuscript received May 27, 1966.

Theory. A high-frequency current instability in *n*-GaAs was first reported by Gunn.[1] By postulating that the mechanism for the instability is a decrease of mobility when an electron acquires sufficient energy to transfer from the main conduction band valley to a higher energy satellite valley (Fig. 1) it can be shown (Ridley[2]) that a stable bias point in the resultive negative resistance part of the *I-V* curve cannot exist. Instead domains of high and low fields are formed in the crystal and these domains then propagate across the crystal with a transit time of W/V, where W is the thickness of the sample and V is a velocity constant.

Oscillations ranging from 500 MHz to 40 GHz have been observed by several workers at RCA Laboratories (L. Norton, J. J. Thomas, D. Thomson). These microwave oscillations were obtained by using samples of different thickness and it is believed that the devices were operating in the fundamental transit time mode.

In a sandwich type device (contacts on opposite faces of GaAs crystal), the heat generated in the sample is conducted to the heat sink through the two faces and these areas are usually quite small. To provide for a better transfer of heat through a larger area, a coplanar structure can be used. This structure is similar to the MOS structure.

The gate electrode in the MOS transistor is used to modulate the conductivity of the channel by changing the charge distribution. This scheme should also give some degree of control for the coplanar Gunn device, as mentioned in the conclusion.

For a gap that is small compared with the thickness, the static potential distribution is:

$$V(X,Y) = \frac{V_o}{2} + \frac{V_o}{\pi}\sin^{-1}\frac{1}{2a}\left(\sqrt{(X+a)^2+Y^2} - \sqrt{(X-a)^2+Y^2}\right)$$

It is expected that only a layer near the surface will have sufficient field to cause current instability while the remaining bulk acts as a shunt to the Gunn diode and also as a leakage path for the bias. Clearly it would be advantageous to remove this shunt. If this were done, the remaining sheet of GaAs would be difficult to handle. An alternative approach is to epitaxially grow a thin layer of low resistivity GaAs on a high resistivity substrate. The substrate provides a mechanical support in addition to being a heat sink. Experiments on this epitaxial device seem to indicate a lower threshold field for Gunn oscillations.

Two types of coplanar devices were constructed. One was made from bulk grown GaAs and the other type made use of epitaxially grown material.

Device Fabrication. The coplanar bulk device was prepared by lapping GaAs wafers to 4 mils in thickness. Tin for contacts was then evaporated on the surface through a beryllium copper mask with the desired gap size. The wafer was then alloyed in a furnace to produce ohmic contacts.

It was found that for surfaces lapped using a coarse abrasive the tin diffused into the gaps because of capillary action during alloying. These samples were noisy and failed to give coherent oscillations. Better success resulted when the surface was polished either by a 5% bromine in methanol solution or by mechanical polish with an alumina abrasive prior to evaporation.

The epitaxial device was made by growing a ½-mil-thick layer of $n = 5 \times 10^{15}/\mathrm{cm}^3$ ($\sim 5\Omega$-cm) GaAs on top of a compensated 2000 Ω-cm GaAs substrate ~20 mils thick. Ohmic contacts were made using the same evaporating process described above and then the wafer was sawed into sticks ~10 mils wide. The resistance of the samples is:

$$R = \frac{\rho\tau}{W}\left[\left(\frac{\tau}{a}\right) - \tfrac{1}{6}\left(\frac{\tau}{a}\right)^3\right]^{-1}$$

Results. The GaAs wafer samples have a resistance in the range of 30 to 150 ohms and are operated by pulsing with a 30-ms pulse from a 50-ohm line. The peak power is ~5mW for all the frequencies listed in Table I.

For all the samples tested, the electric field required to cause oscillations was higher than the expected 2,000 to 3,000 V/cm in the sandwich type geometry. It was also found that the frequency of oscillation for a given gap size was about 20% lower than that of a sandwich device having the same thickness as the coplanar device gap width. A comparison of the results is shown in Table I.

TABLE I—Comparison of Results

Type	Gap Size, mil	Average Field, V/cm	Fundamental Frequency, GHz
Bulk	4	8500	0.8
	3	11500	1.1
Epitaxy	3	6000	1.0
Sandwich	4	3000	1.0
(Expected)	3	3000	1.3

For the coplanar device it is important for the gaps to be parallel. Localized regions of high field intensity will destroy the coherency because the high field domain will nucleate non-uniformly. Fig. 2 shows a typical burnt sample that failed to oscillate coherently. It can be seen that spikes of burnt surface extend from the contacts, indicating a localized field. This field is believed to be the reason that samples with a rough surface failed to oscillate coherently.

Conclusions and Recommendations. Compared to the sandwich device the coplanar device is advantageous in that it is easier to fabricate; ohmic contacts have to be made only on one side of the GaAs instead of both sides as in the sandwich devices. By having a substrate as in the epitaxial layer device, we can fabricate monolithic integrated microwave circuits. It seems worthwhile to explore the possibility of connecting the diodes in parallel on the same chip to increase the power output as has been done with transistors.

The Gunn effect devices typically have low efficiency because of the high bias voltage necessary for the formation of a high-field domain. The voltage required to maintain the domain once the domain is formed is lower than the voltage necessary to nucleate one. Therefore, it is natural to ask whether we can bias the diode just sufficiently to maintain the domain and induce the formation of domains by, for example, a third electrode. In the coplanar device, the geometry seems favorable. A gate electrode can be added near the source electrode through a thin insulating layer. By applying a voltage between the source and gate electrodes, a relatively high field will result near the semiconductor surface. If a domain can be nucleated this way then it will propagate across the sample by the drift field that exists between the source and drain. The possibility of inducing nucleation of domains through a high impedance control electrode is worth investigating.

Acknowledgments I wish to sincerely thank J. Dienst for his guidance in preparing this article, B. Robinson for his help in the physics, I. J. Hegyi for growing the epitaxy samples, D. Thomson for his "know-how" in putting on the ohmic contacts, and also A. Matzelle for sawing up the samples.

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Fig. 2—A 3-mil-gap device, showing burnt-out regions due to localized high field. (About 1000 X).

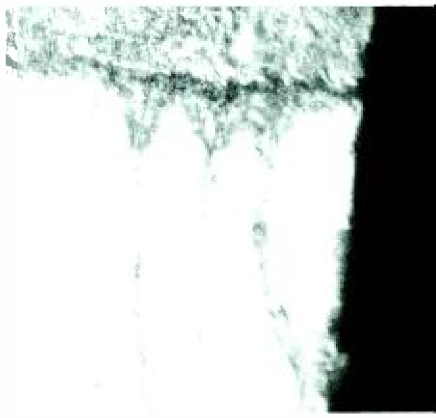
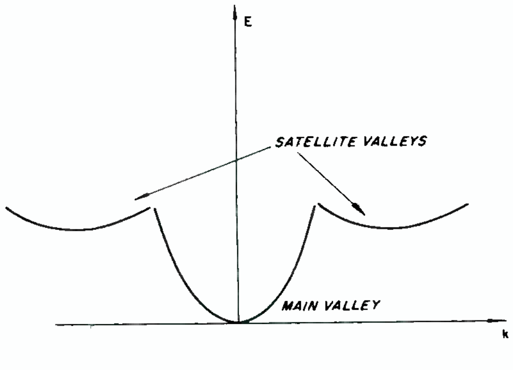
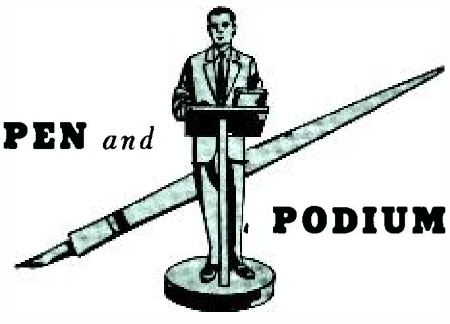


Fig. 1—Energy vs. wave vector for GaAs. The upper valleys have electrons with heavier mass and lower mobility than the main valley.





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AUTHOR INDEX

Subject listed opposite each author's name indicates where complete citation to his paper may be found in the subject index. Where an author has more than one paper, his name is repeated for each.

PRODUCT ENGINEERING (STAFF)

RESEARCH AND ENGINEERING (STAFF)

COMMUNICATIONS' SYSTEMS DIVISION

BROADCAST AND COMMUNICATIONS PRODUCTS DIVISION

MISSILE AND SURFACE RADAR DIVISION

DEFENSE MICROELECTRONICS

AEROSPACE SYSTEMS DIVISION

ASTRO-ELECTRONICS DIVISION

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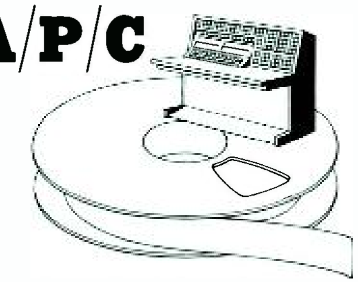
APPLIED RESEARCH

DEP STAFF

RCA LABORATORIES

S/C/A/P/C

Scientific
Computer
Applications
Program
Catalog



Data sheets added to SCAPC are published when received from R. Gildea, ASD, Burlington, who coordinates SCAPC. Data sheets contain an abstract describing the program and its status. The following engineers maintain SCAPC data sheets for reference.

AEDH	R. Goerss, AED, Prin., N.J.	EDPS	L. Stuart, EDP, Cher. Hill, N.J.
ASDB	J. L. Richmond, ASD, Burl., Mass.	LABS	R. W. Klopfenstein, RCA Labs, Princeton, N.J.
BCDM	F. M. Brock, Broadcast Microwave Eng., Cam., N.J.	M&SR	R. Faust, M&SR Div., Mrstn., N.J.
CSDC	H. Jacobowitz, CSD, Cam., N.J.	VICM	G. Payette, RCA Victor Co., Ltd., Montreal, Can.
DEPA	R. D. Smith, Appl. Res., Cam. N.J.	WCDV	A. E. Cressey, West Coast Div., Van Nuys, Calif.
EDPP	S. Heiss, EDP, W. Palm Beach, Fla.		

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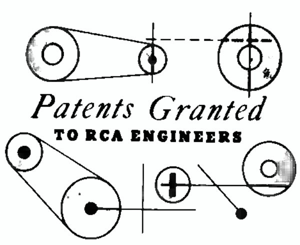

Patents Granted
TO RCA ENGINEERS

As Reported By RCA Domestic
Patents, Princeton

RCA LABORATORIES

Alkaline Earth Halide Divalent Dysprosium Laser Materials—P. N. Yocom, M. Kestigian, G. J. Goldsmith (Labs, Pr) *U.S. Pat. 3,243,381*, March 29, 1966 (assigned to U.S. Gov't.)

Laser Multiplex Communication System—A. R. Moore (Labs, Pr) *U.S. Pat. 3,256,443*, June 14, 1966

Circuit for Substantially Eliminating Oscillator Frequency Variations with Supply Voltage Changes—K. W. Angel (Labs, Pr) *U.S. Pat. 3,256,496*, June 14, 1966

Semiconductor Device Enclosures—C. W. Mueller (Labs, Pr) *U.S. Pat. 3,257,588*, June 21, 1966

Color Television Receiver—G. L. Beers (Labs, Pr) *U.S. Pat. 3,258,526*, June 28, 1966

Index Signal Generation—R. D. Thompson (Labs, Pr) *U.S. Pat. 3,258,527*, June 28, 1966

High Density Plasma Generator—G. A. Swartz (Labs, Pr) *U.S. Pat. 3,258,633*, June 28, 1966

Electron Beam Convergence Apparatus—W. F. Deitz (Labs, Pr) *U.S. Pat. 3,258,642*, June 28, 1966

Light Emitting Display Panels—J. A. Rajchman (Labs, Pr) *U.S. Pat. 3,258,644*, June 28, 1966

Solid State Device with Gate Electrode on Thin Insulative Film—P. K. Weimer (Labs, Pr) *U.S. Pat. 3,258,663*, June 28, 1966

Low-Noise Electron Guns—A. L. Eichenbaum (Labs, Pr) *U.S. Pat. 3,255,376*, June 7, 1966

Character Generator Having Stored Control Signals—W. D. Houghton (Labs, Pr) *U.S. Pat. 3,255,444*, June 7, 1966

Apparatus for and Method of Emitting Particles—J. M. Hammer (Labs, Pr) *U.S. Pat. 3,253,402*, May 31, 1966

Pulse Sequence Generator—P. K. Weimer (Labs, Pr) *U.S. Pat. 3,252,009*, May 17, 1966

Pickup Tube Having a Photoconductive Target of Enlarged Crystal Structure—F. Van Loon Shallcross (Labs, Pr) *U.S. Pat. 3,252,029*, May 17, 1966

Connections in Multilayer Circuits and Method of Making Same—H. R. Beelitz, H. F. Schnitzler (Labs, Pr) *U.S. Pat. 3,250,848*, May 10, 1966

Logic Circuits—S. R. Hofstein (Labs, Pr) *U.S. Pat. 3,250,917*, May 10, 1966

Solid State Devices Utilizing A Metal Between Two Semiconductor Materials—A. Rose (Labs, Pr) *U.S. Pat. 3,250,966*, May 10, 1966

Solid State Triode—A. Rose (Labs, Pr) *U.S. Pat. 3,250,967*, May 10, 1966

Binary Comparator—H. Weinstein (Labs, Pr) *U.S. Pat. 3,251,035*, May 10, 1966

Method of Making Magnetic Ferrite Sheet with Imbedded Conductors—R. L. Noack (Labs, Pr) *U.S. Pat. 3,247,573*, Apr. 26, 1966

Variable Density Layers of Particles and Method of Preparing Them—P. J. Messineo (Labs, Pr) *U.S. Pat. 3,248,218*, Apr. 26, 1966

Apparatus for Measuring Positive and Negative Ion Currents in the Atmosphere—A. Streib, C. W. Hansell (Labs, Pr) *U.S. Pat. 3,248,644*, Apr. 26, 1966

Permanent Storage Type Memory—M. H. Lewin (Labs, Pr) *U.S. Pat. 3,248,711*, Apr. 26, 1966

FM Multiplex Stereo Radio Signal Receivers—J. O. Schroeder (Labs, Pr) *U.S. Pat. 3,249,697*, May 3, 1966

Logic Circuit—H. S. Miiller (Labs, Pr) *U.S. Pat. 3,249,765*, May 3, 1966

Cryotron—C. M. Wine (Labs, Pr) *U.S. Pat. 3,249,768*, May 3, 1966

Pulse Generator—J. R. Burns, J. J. Amodei (Labs, Pr) *U.S. Pat. 3,249,772*, May 3, 1966

High Frequency Negative Resistance Circuit Including a Voltage Controlled, Negative Resistance Device—D. E. Nelson (Labs, Pr) *U.S. Pat. 3,253,233*, May 24, 1966

Electroluminescent Device for Producing Images—B. Kazan (Labs, Pr) *U.S. Pat. 3,247,389*, April 19, 1966

Electroluminescent Device—B. Kazan (Labs, Pr) *U.S. Pat. 3,247,390*, April 19, 1966

Modulators for Light Radiation Employing Carrier Injection—J. I. Pankove (Labs, Pr) *U.S. Pat. 3,246,159*, April 12, 1966

Electroluminescent Device Having a Field-Effect Transistor Addressing System—Te Ning Chin (Labs, Pr) *U.S. Pat. 3,246,162*, April 12, 1966

Signal Translating Circuit Employing Insulated-Gate Field Effect Transistors Coupled Through a Common Semiconductor Substrate—R. S. Silver (Labs, Pr) *U.S. Pat 3,246,173*, April 12, 1966

Oscillator Circuit with Series Connected Negactive Resistance Elements for Enhanced Power Output—H. S. Sommers, Jr. (Labs, Pr) *U.S. Pat. 3,246,256*, April 12, 1966

Content Addressed Memory—M. H. Lewin (Labs, Pr) *U.S. Pat. 3,245,052*, April 5, 1966

Toner Feed—R. R. Ulary (Labs, Pr) *U.S. Pat. 3,242,902*, March 29, 1966

Space-Charge Neutralized Electron Gun—A. L. Eichenbaum (Labs, Pr) *U.S. Pat 3,243,640*, March 29, 1966

Semiconductor Circuits Exhibiting N-Shaped Transconductance Characteristic Utilizing Unipolar Field Effect and Bipolar Transistors—P. Schnitzler (Labs, Pr) *U.S. Pat. 3,243,732*, March 29, 1966

Superconductive Associative Memory Systems—M. W. Green (Labs, Pr) *U.S. Pat. 3,243,785*, March 29, 1966

Rectifying Devices—H. S. Sommers, Jr. (Labs, Pr) *U.S. Pat. 3,242,016*, March 22, 1966

Nonlinear Tunnel Resistor and Method of Manufacture—J. T. Wallmark (Labs, Pr) *U.S. Pat. 3,242,389*, March 22, 1966

Variable Velocity Halftone Facsimile System—M. Artzt (Labs, Pr) *U.S. Pat 3,229,033*, Jan. 11, 1966 (assigned to U.S. Gov't.)

ELECTRONIC COMPONENTS AND DEVICES

Method of Measuring the Thermal Resistance of a Semiconductor Device by Providing a Stabilized Temperature Difference Between the Case and a PN Junction Therein and Thereafter Obtaining Measurements of a Temperature Sensitive Parameter—P. A. Peckover (ECD, Som) *U.S. Pat. 3,253,221*, May 24, 1966

Annular Saw and Tension Means—J. V. Wiseman (ECD, Findlay) *U.S. Pat. 3,247,837*, Apr. 26, 1966

Tuning System for a Magnetron Oscillator Utilizing Differential Transformer Controls—M. Fromer (ECD, Hr) *U.S. Pat. 3,248,665*, Apr. 26, 1966

Non-linear Analog to Digital Converter—R. W. Sonnenfeldt (ECD, Natick) *U.S. Pat. 3,248,726*, Apr. 26, 1966

Electron Tube and Method of Making the Same—J. W. Gaylord (ECD, Lanc) *U.S. Pat. 3,251,641*, May 17, 1966

Logic Circuit Employing Transistor Means Whereby Steady State Power Dissipation is Minimized—B. Zuk (ECD, Som) *U.S. Pat. 3,252,011*, May 17, 1966

Electron Discharge Device and Method of Making the Same—C. E. Doner (ECD, Lanc) *U.S. Pat. 3,252,043*, May 17, 1966

Cathode Ray Tube Gun Having Nested Electrode Assembly—R. H. Hughes (ECD, Lanc) *U.S. Pat. 3,254,251*, May 31, 1966

Method of Forming Semiconductor Junction—D. W. Flatley, H. W. Becke, D. Stolnitz (ECD, Som) *U.S. Pat. 3,255,056*, June 7, 1966

Electron Gun Having Grid-Accelerator and Grid-Cathode Insulator Rod Supports—R. C. Paull (ECD, Marion) *U.S. Pat. 3,258,627*, June 28, 1966

Packaging—T. W. Kisor (ECD, Som) U.S. *Pat. 3,256,982*, June 21, 1966

Solid State Microwave Amplifier with Power Source of Same Frequency as Input—F. Sterzer (ECD, Pr) *U.S. Pat. 3,230,390*, Jan. 18, 1966 (assigned to U.S. Gov't.)

Semiconductor Devices—W. M. Triggs, M. A. Blumenfeld (ECD, Som) *U.S. Pat. 3,241,931*, March 22, 1966

Electron Mounting Structure of a High Frequency Electron Tube—F. J. Pilas (ECD, Hr) *U.S. Pat. 3,242,373*, March 22, 1966

Photosensitive Cathode with Closely Adjacent Light-Diffusing Layer—F. A. Helvy, R. M. Matheson (ECD, Lanc) *U.S. Pat. 3,243,626*, March 29, 1966

Photocathode on Beveled End Plate of Electron Tube—B. H. Vine (ECD, Lanc) *U.S. Pat. 3,243,627*, March 29, 1966

Electron Multiplier with Curved Resistive Secondary Emissive Coating—R. M. Matheson (ECD, Lanc) *U.S. Pat. 3,243,628*, March 29, 1966

Storage Tube with Secondary Emissive Storage Grid—D. W. Roe (ECD, Lanc) *U.S. Pat. 3,243,644*, March 29, 1966

Method of Manufacturing a Heater—F. H. Thaler (ECD, Hr) *U.S. Pat. 3,245,132*, April 12, 1966

Electronic Timing System for Automatic Machine Operations—G. D. Hanchett (ECD, Som) *U.S. Pat. 3,246,182*, April 12, 1966

Assemblies of Magnetic Elements—A. J. Erikson (ECD, Needham) *U.S. Pat. 3,247,496*, April 19, 1966

RCA VICTOR INSTRUMENTS

Amplitude Dependent Zero Shift Reduction for Frequency Discriminators—G. F. Rogers (HI, Indpls) *U.S. Pat. 3,256,489*, June 14, 1966

Electron Beam Convergence Apparatus—E. Lemke (HI, Indpls) *U.S. Pat. 3,258,643*, June 28, 1966

Symmetrical Clipping Circuit Employing Transistor Saturation and Diode Clamping—G. F. Rogers, F. A. Barton (HI, Indpls) *U.S. Pat. 3,254,241*, May 31, 1966

Automatic Gain Control Circuit for Amplifiers—D. J. Carlson (HI, Indpls) *U.S. Pat. 3,254,306*, May 31, 1966

Color Television Receiver Kinescope Master Bias Arrangement—T. C. Jobe, P. E. Crookshanks (HI, Indpls) *U.S. Pat. 3,251,931*, May 17, 1966

Multiband Tunable Circuit—D. J. Carlson (HI, Indpls) *U.S. Pat. 3,252,095*, May 17, 1966

Multiband Tunable Circuit—D. J. Carlson (HI, Indpls) *U.S. Pat. 3,252,096*, May 17, 1966

Magnetic Recording and Reproducing Apparatus—D. R. Andrews (HI, Indpls) *U.S. Pat. 3,248,066*, Apr. 26, 1966

Spring Retaining Clip—W. T. Bell (HI, Indpls) *U.S. Pat. 3,252,679*, May 24, 1966

Wideband Stabilized Amplifier—D. J. Carlson (HI, Indpls) *U.S. Pat. 3,253,229*, May 24, 1966

DEFENSE ELECTRONIC PRODUCTS

Threshold Circuits—B. Rabinovici, C. A. Renton (CSD, NY) *U.S. Pat. 3,253,113*, May 24, 1966

Current Steering Logic Circuit Employing Negative Resistance Devices in the Output Networks of the Amplifying Devices—E. C. Cornish (AppRes, Cam) *U.S. Pat. 3,253,165*, May 24, 1966

Fluid Supported Transducer with Laterally Stressed Resilient Flexible Diaphragm—H. Silver (MSR, Mrstn) *U.S. Pat. 3,249,701*, May 3, 1966

Data Processing Apparatus—W. A. Helbig, W. E. Woods (WCD, Van Nuys) *U.S. Pat. 3,249,746*, May 3, 1966

Information Handling Apparatus—E. D. Simshauser (CSD, Cam) *U.S. Pat. 3,249,923*, May 3, 1966

Magnetic Recording System—T. R. Mayhew (AppRes, Cam) *U.S. Pat. 3,248,717*, Apr. 26, 1966

Electrical Neuron Circuits—E. P. McGrogan, Jr. (AppRes, Cam) *U.S. Pat. 3,250,918*, May 10, 1966

System Which Includes Means for Automatically Checking Connections During the Wiring of Electrical Equipment—L. J. Cronkite, P. G. Lawrence (WCD, Van Nuys) *U.S. Pat. 3,250,992*, May 10, 1966

Data Processing System—L. L. Rakoczi, W. J. Gesek (CSD, Cam) *U.S. Pat. 3,251,038*, May 10, 1966

Negative Resistance Circuits Utilizing Tunnel Resistor—C. R. Pendred (AppRes, Cam) *U.S. Pat. 3,252,005*, May 17, 1966

Current Steering Logic Circuits Having Negative Resistance Diodes Connected in the Output Biasing Network of the Amplifying Devices—M. Cooperman (AppRes, Cam) *U.S. Pat. 3,254,238*, May 31, 1966

Flip-Flop Having Jam Transfer Feature—G. P. Chamberlin (AppRes, Cam) *U.S. Pat. 3,254,239*, May 31, 1966

Memory Sense Amplifier Having A High Speed Memory—T. R. Mayhew (AppRes, Cam) *U.S. Pat. 3,254,305*, May 31, 1966

Bidirectional Selfresetting Overload Slip Clutch—J. C. Spracklin, G. M. Robinson (MSR, Mrstn) *U.S. Pat. 3,251,200*, May 17, 1966 (assigned to U.S. Gov't.)

Frequency Synthesizer—H. A. Robinson (CSD, Cam) *U.S. Pat. 3,249,887*, May 3, 1966 (assigned to U.S. Gov't.)

ELECTRONIC DATA PROCESSING

Tape Handling Apparatus—W. W. Deighton, A. G. Caprio (EDP, Cam) *U.S. Pat. 3,254,854*, June 7, 1966

Tape Handling Apparatus—G. V. Jacoby (EDP, Cam) *U.S. Pat. 3,250,480*, May 10, 1966

Pulse Generator Employing Serially Connected Delay Lines—A. Turecki (EDP, Fla.) *U.S. Pat. 3,248,657*, Apr. 26, 1966

Data Processing—L. L. Rakoczi, J. W. Figueroa (EDP, Cam) *U.S. Pat. 3,242,349*, March 22, 1966

Data Processing System—L. L. Rakoczi (EDP, Cam) *U.S. Pat. 3,242,464*, March 22, 1966

Data Processing System—E. Gloates, L. L. Rakoczi (EDP, Cam) *U.S. Pat. 3,242,465*, March 22, 1966

Synchronizing Arrangement—J. V. Fayer, G. Spector (EDP, Cam) *U.S. Pat. 3,243,665*, March 29, 1966

Pulse Delay Circuits—E. J. Daigle, Jr. (EDP, Cam) *U.S. Pat. 3,244,907*, April 5, 1966

Circuits Including a Flip-Flop and a Delay for Generating Two Pulses—A. Turecki (EDP, Fla.) *U.S. Pat. 3,244,985*, April 5, 1966

Electrical Circuit—R. H. Jenkins (EDP, Cam) *U.S. Pat. 3,247,363*, April 19, 1966

BROADCAST AND COMMUNICATIONS PRODUCTS DIVISION

Pulse Code Generator System—G. A. Lucchi (BCD, Los Angeles) *U.S. Pat. 3,253,278*, May 24, 1966

Reader Employing Optical Fibers—B. R. Clay, V. F. Ryan, Jr. (BCD, Cam) *U.S. Pat. 3,249,692*, May 3, 1966

Electronic Motor Control Servo System—W. J. Derenbecher, Jr. (BCD, Cam) *U.S. Pat. 3,252,067*, May 17, 1966

Combined Tuning and Stabilization Means for Cavity Resonators—W. C. Painter (BCD, Meadow Lands) *U.S. Pat. 3,252,116*, May 17, 1966

Reel Spindle—A. E. Jackson (BCD, Cam) *U.S. Pat. 3,253,796*, May 31, 1966

Alignment of Television Camera—S. L. Bendell, R. A. Dischert, W. J. Cosgrove, H. N. Kozanowski (BCD, Cam) *U.S. Pat. 3,255,304*, June 7, 1966

PROFESSIONAL MEETINGS

DATES *and* DEADLINES

Be sure deadlines are met—consult your Technical Publications Administrator or your Editorial Representative for the lead time necessary to obtain RCA approvals (and government approvals, if applicable). Remember, abstracts and manuscripts must be so approved BEFORE sending them to the meeting committee.

Meetings

SEPT. 4-10, 1966: **2nd Int'l Congress of Biophysics**, IEEE, G-EMB-IOPAB, Vienna, Austria. **Prog. Info.:** Mrs. E. Weidenhaus, Wiener Medizinische Akademie, Wien, IX, Alserstrase 4, Vienna, Austria.

SEPT. 20-22, 1966: **8th Conf. on Tube Techniques**, IEEE, United Engineering Center, N.Y.C. **Prog. Info.:** R. J. Bondley, Gen'l Electric Co., Schenectady, N.Y.

SEPT. 22-24, 1966: **16th IEEE Broadcast Symp.**, IEEE, G-B, Mayflower Hotel, Wash., D.C. **Prog. Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

SEPT. 23-24, 1966: **14th Annual Cedar Rapids Communication Symp.**, Cedar Rapids, Iowa. **Prog. Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

SEPT. 25-28, 1966: **1st Nat'l Conf. on Non-Conventional Energy Conversion Applications**, ASME, AIAA, AIChE, IEEE, International Hotel, Los Angeles, Calif. **Prog. Info.:** R. E. Henderson, The Allison Co., Indpls., Ind.

SEPT. 26-27, 1966: **14th Joint Engrg. Management Conference**, IEEE, G-EM et al., Statler-Hilton Hotel, Washington, D.C. **Prog. Info.:** Homer Sarasohn, IBM, Armonk, N.Y.

OCT. 3-5, 1966: **Nat'l Electronics Conf.**, IEEE, et al., McCormick Place, Chicago, Ill. **Prog. Info.:** Nat'l Elect. Conf., 228 N. LaSalle St., Chicago 1, Ill.

OCT. 3-5, 1966: **Aerospace & Electronic Systems Conv.**, IEEE, G-AES, Sheraton Park Hotel, Wash., D.C. **Prog. Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y.

OCT. 3-5, 1966: **5th Symp. on Discrete Adaptive Processes**, IEEE, G-IT, G-SSC, G-AC, McCormick Place, Chicago, Illinois. **Prog. Info.:** K. S. Fu, School of Elec. Engineering, Purdue Univ., Lafayette, Ind.

OCT. 5-7, 1966: **Allerton Conf. on Circuits & System Theory**, IEEE, G-CT, Univ. of Ill., Conf. Center Univ. of Illinois, Monticello, Ill. **Prog. Info.:** Prof. W. R. Perkins, Dept. of EE, Univ. of Ill., Urbana, Ill.

OCT. 9-14, 1966: **Fall Mtg., The Electrochemical Soc.**, Phila., Pa. **Prog. Info.:** Chas. Moore, The Electrochemical Soc., 30 E. 42nd St., N.Y., N.Y. 10017.

OCT. 12-15, 1966: **Ultrasonic Symp.**, IEEE, G-SU; **Prog. Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

OCT. 13-14, 1966: **4th Canadian Symp. on Communications**, IEEE, Region 7; Queen Elizabeth Hotel, Montreal, Canada. **Prog. Info.:** Prof. G. W. Farrell, McGill Univ., 805 Sherbrooke St., W. Montreal, Canada.

OCT. 13-14, 1966: **Stat. Theory of Signal Detection in Communication & Control Systems**, IEEE Sec. & Nechr, Tchn. Gesellschaft: Darmstadt, F. R. Germany. **Prog. Info.:** H. H. Burghoff, 6 Frankfort 70, Stresemann Allee 21 VDE Haus, F. R. Germany.

OCT. 17-18, 1966: **Systems Science & Cybernetics Conf.**, IEEE, G-SSC; Intl. Inn, Wash., D.C. **Prog. Info.:** M. D. Rubin, The Mitre Corp., P.O. Box 208, Bedford, Mass.

OCT. 18-21, 1966: **13th Nuclear Science Symp.**, IEEE, G-NS; Statler Hilton, Boston, Mass. **Prog. Info.:** J. E. Coleman, U.S. Natl. Bureau of Standards, Wash., D.C.

OCT. 24-27, 1966: **21st Ann. ISA Conf. & Exhibit.** Hotel New Yorker & Statler Hilton Hotel, Coliseum, N.Y., N.Y. **Prog. Info.:** Conf. Prog. Coordinator, c/o ISA Headquarters, 530 William Penn Place, Pittsburgh.

OCT. 26-28, 1966: **Electron Devices Mtg.**, IEEE, G-ED, Sheraton Park Hotel, Wash., D.C. **Prog. Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

OCT. 26-28, 1966: **7th Symp. on Switching & Automata Theory**, IEEE, Computer Group, Univ. of Calif.; Univ. of Calif., Berkeley, Calif. **Prog. Info.:** D. E. Muller, Math Dept., Univ. of Ill., Urbana, Ill.

NOV. 2-4, 1966: **N. E. Research & Eng. Mtg. (NEREM)** IEEE, Region 1; Boston, Mass. **Prog. Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

NOV. 2-5, 1966: **Thermionic Conversion Spec. Conf.**, IEEE, G-ED, Shamrock Hilton Hotel, Houston, Texas. **Prog. Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

NOV. 7-9, 1966: **Symp. on Automatic Support Sys. for Advanced Maintainability**, IEEE, St. Louis Sec., Colony Motor Inn, Clayton, Missouri. **Prog. Info.:** D. L. Reed, P.O. Box 4124, St. Louis, Missouri 63136.

NOV. 8-10, 1966: **Fall Joint Computer Conf.**, IEEE, AFIPS (IEE-ACM), Brooks Hall, Civic Ctr., San Francisco, Calif. **Prog. Info.:** AFIPS Headquarters, 211 E. 43rd St., N.Y., N.Y.

NOV. 9-11, 1966: **Intl. Conf. on Automatic Operation & Control of Broadcast Equipment**, IEEE, Region 8, IEE, IERE, London, Eng. **Prog. Info.:** IEEE Headqtrs., 345 E. 47th St., N.Y., N.Y. 10017.

NOV. 14-17, 1966: **19th Engrg. in Medicine & Biology Conf.**, IEEE, G-EMB, ISA, ASME, Sheraton-Palace Hotel, San Francisco, Calif. **Prog. Info.:** D. H. LeCroissette, Jet Prop. Lab., Calif. Inst. of Technology, Pasadena, Calif.

NOV. 15-17, 1966: **Electric Welding Conf.**, IEEE, G-IGA, Rackham Bldg., Eng. Society of Detroit, Detroit, Mich **Prog. Info.:** M. Zucker, Myron Zucker Eng. Co., 708 W. Long Lake Road, Bloomfield Hills, Mich.

NOV. 15-18, 1966: **12th Conf. on Magnet & Mag. Matls.**, IEEE-G-MAG, et al., Sheraton Park Hotel, Wash., D.C. **Prog. Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

Call for Papers

JAN 9-11, 1967: **Electrical & Electronic Meas. Test Instrument Conf. (EEMTIC)**, IEEE Ottawa Sec., Ottawa, Ontario, Canada. **Deadline: 9/1/66** TO: J. H. Bradley, Material Command, Canadian Forces Base, Rockcliffe, Ottawa, Ontario.

JAN. 29-FEB. 3, 1967: **IEEE Winter Power Mtg.**, IEEE, G-P, Statler-Hilton Hotel, N.Y. **Deadline: 10/31/66** TO: E. C. Day, IEEE, 345 E. 47th St., N.Y., N.Y. 10017.

FEB. 15-17, 1967: **Int'l Solid State Circuits Conf.**, IEEE, G-CT, Phila. Sec., Univ. of Penn. Sheraton Hotel, Phila., Penna. **Deadline Info.:** J. S. Mayo, Bell Tel. Labs., Rm. 3F332, Holmdel, N.J.

MAR. 1-3, 1967: **2nd Particle Accelerator Conf.**, IEEE, G-NS et al., Shoreham Hotel, Wash., D.C. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

MAR, 20-24, 1967: **IEEE Int'l Conv. & Exhibition**, All Groups & TAB Comms., Coliseum & N.Y. Hilton Hotel, N.Y., N.Y. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

APR. 5-7, 1967: **Int'l Magnetics Conf. (INTERMAG)**, IEEE, G-MAG, Shoreham Hotel, Wash., D.C. **Deadline Info.:** R. F. Elfant, IBM, Yorktown Hgts., N.Y.

APR. 18-19, 1967: **Electronics & Instrumentation Conf. & Exhibition**, IEEE Cincinnati Sec., ISA, Carousel Inn, Cincinnati Gardens, Cincinnati, Ohio. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

APR. 18-20, 1967: **Spring Joint Computer Conf.**, IEEE, AFIPS, Chalfonte-Haddon Hall, Atlantic City, N.J. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

APR. 19-21, 1967: **Southwestern IEEE Conf. & Elec. Exhibition (SWIEEECO)**, IEEE Region 5, Dallas Memorial Auditorium, Dallas, Texas. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

APR. 19-22, 1967: **Semiconductor Device Research Conf.**, IEEE Region 8 et al., Bad Nauheim, Germany. **Deadline: 12/15/66** TO: Prof. W. J. Kleen, 8 Munchen 8 (F. R. Germany) Balanstr. 73 (Abstract).

MAY 3-5, 1967: **Joint Parts, Materials & Packaging Conf.** (formerly the **Electronic Components Conf.)**, IEEE, G-PMP, EIA, Marriott Motor Hotel, Washington, D.C., **Deadline Info.:** C. K. Morehouse, Globe Union Inc., Box 591, Milwaukee, Wisc., 53201.

MAY 15-17, 1967: **IEEE Aerospace Elec. Conv. (NAECON)**, IEEE Dayton Sec., G-AES, Dayton, Ohio. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

MAY 16-18, 1967: **Nat'l Telemetering Conf.**, IEEE, AIAA, ISA, San Francisco Hilton Hotel, San Francisco, Calif. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

MAY 18-19, 1967: **10th Midwest Symp. on Circuit Theory**, IEEE, G-CT & Purdue Univ., Purdue Univ., Lafayette, Ind. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

MAY 22-24, 1967: **Frequency Generation & Control for Radio Systems**, IEEE, Savoy Place, London Eng. **Deadline:** (Synopsis) **8/31/66** TO: J. L. Regan, IEE, Savoy Place, London, W.C. 2, Eng.

MAY 22-25, 1967: **Spring URSI-IEEE Mtg.**, URSI-IEEE, Ottawa, Ontario, Canada. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

MAY, 1967: **Int'l Symp. on Microwave Theory & Techniques**, IEEE, G-MTT, Boston, Mass. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

JUNE 5-9, 1967: **Joint Automatic Control Conference**, IEEE, AACC, Univ. of Penna., Phila., Penna. **Deadline Info.:** IEEE Headquarters, 345 E. 47th St., N.Y., N.Y. 10017.

JUNE 12-14, 1967: **IEEE Int'l Communications Conf.**, IEEE G-Com. Tech. Twin Cities Sect., Radisson Hotel, Minneapolis, Minn. **Deadline Info.:** R. J. Collins, Univ. of Minnesota, Dept. of E. E., Minneapolis, Minn. 55455.

JUNE 19-21, 1967: **San Diego Symp. for Biomedical Engrg.**, IEEE, U.S. Naval Hospital et al., San Diego, Calif. **Deadline:** (Abstract) **4/12/67** TO: D. L. Franklin, Scripps Clinic & Res. Foundation, LaJolla, Calif.

JULY 9-14, 1967: **Summer Power Mtg.**, IEEE G-P, Portland Hilton Hotel, Portland, Oregon. **Deadline: 4/10/67** TO: E. C. Day, IEEE, 345 E. 47th St., N.Y., N.Y. 10017.

AUG. 22-25, 1967: **Western Electronic Show & Convention (WESCON)**, IEEE-WEMA, Cow Palace, San Francisco, Calif. **Deadline:** (Abstract) **5/15/67** TO: IEEE, 345 E. 47th St., N.Y., N.Y. 10017.

SEPT. 11-15, 1967: **Int'l Symp. on Info. Theory**, IEEE, G-IT, Athens, Greece, **Deadline: 5/1/67** TO: IEEE, 345 E. 47th St., N.Y., N.Y. 10017.

SEPT. 13-14, 1967: **8th Biennial Elec. Heating Conf.**, IEEE, G-IGA, Statler Hilton Hotel, Detroit, Mich. **Deadline:** (Abstract) **12/29/66** TO: IEEE, 345 E. 47th St., N.Y., N.Y. 10017.

SEPT. 24-28, 1967: **Joint Power Generation Conf.**, IEEE, G-P et al., ASME, Statler Hilton Hotel, Detroit, Mich. **Deadline: 4/1/67** TO: IEEE, 345 E. 47th St., N.Y., N.Y. 10017.

Engineering NEWS *and* HIGHLIGHTS

WENDELL C. MORRISON APPOINTED DIRECTOR OF PRODUCT ENGINEERING

Wendell C. Morrison has been appointed Director, Product Engineering, by **D. F. Schmit,** Staff Vice President, Product Engineering. Mr. Morrison had been Chief Engineer of the RCA Broadcast and Communications Products Division.

Reporting to Mr. Morrison are the following Product Engineering Staff Activities: **W. O. Hadlock,** Mgr., RCA Staff Technical Publications (which includes the RCA ENGINEER); **G. A. Keissling,** Mgr., Product Engineering Professional Development; and **J. W. Wentworth,** Mgr., Current Concepts in Science and Engineering (CCSE) Program. Mr. Morrison reports to Mr. Schmit, as do the following: **H. E. Schock, Jr.,** Administrator, General Quality Control; **J. P. Veatch,** Director, RCA Frequency Bureau; and **S. H. Watson,** Mgr., Standardizing.

W. C. Morrison

Mr. Morrison joined RCA in 1940 after receiving his BSEE and MSEE from the State University of Iowa. He was a member of the Technical Staff of RCA Laboratories, Princeton, N. J., for 15 years, engaged in development work in such fields as UHF-TV transmitters, antenna pattern calculators, and color TV terminal and test equipment. In 1957, he became a Staff Engineer for the former RCA Industrial Electronic Products organization, and, in 1959, was promoted to Manager, Engineering Plans and Services. Two years later, Mr. Morrison was designated Assistant to the Chief Defense Engineer of RCA Defense Electronic Products. In 1963, he was appointed Chief Engineer of the Broadcast and Communications Products Division. The Institute of Electrical and Electronics Engineers named Mr. Morrison a *Fellow* in 1963 for "*significant contributions to the fields of VHF, UHF and color television.*" He is also a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

WALTER NAMED GSD CHIEF ENGINEER

Gerard O. Walter has been appointed Chief Engineer of the RCA Graphic Systems Division, Princeton, N. J. He reports to **Stanley W. Cochran,** Division Vice President and General Manager. Mr. Walter succeeds **Dr. N. I. Korman,** who has been named Director, Medical Electronics Plans and Programs, RCA New Business Programs, Princeton.

Prior to joining GSD a Manager, Product Engineering, in 1965, Mr. Walter had been: R&D Leader with Mergenthaler Linotype; Technical Director, Standard Camera Corporation; and Manager, Advanced Development Engineering, Remington Division, Sperry Rand.

A native of Vienna, Austria, Mr. Walter studied mechanical engineering at St. John's University, Lvov, Poland. He received basic and advanced degrees in mechanical engineering and applied physics from the Institute of Technology, Zurich, Switzerland. He continued his graduate and postgraduate studies at the New York University School of Physics. He was an Assistant Professor at the New York Institute of Optics and also taught in other schools. Mr. Walter is the author of books on applied optics, photography and physical research technology. He holds patents in the field of automated typesetting, optical tooling, and data retrieval technology.

NEW RECORD LABEL ESTABLISHED

A new record label, *COLGEMS,* has been announced by Columbia Pictures Corp., Screen Gems, Inc., and the RCA Victor Record Division. This is the first time RCA Victor has entered into such an arrangement with another record company.

INGLIS HEADS NEW BCD DEPARTMENT

Consolidation of engineering and merchandising activities for major products in a newly created department headed by **Andrew F. Inglis,** a Division Vice President, has been announced by the RCA Broadcast and Communications Products Division. Mr. Inglis for the past three and one-half years had been Division Vice President, Communications Products Operations, at BCD's Meadow Lands, Pa., facility. The new department brings together engineering of broadcast, communications and microwave products and scientific instruments, and engineering administration; merchandising of broadcast studio and transmitting equipment, and sales support and services for all BCD product lines.

MSR, SEER, AND CSD ENGINEER-AUTHORS HONORED

Approximately 90 RCA engineers from MSR, SEER, and CSD who had presented or published articles during 1965 were honored recently at two separate receptions. The MSR and SEER groups attended a reception held in Cherry Hill. The other reception was held in New York for engineers from the Advanced Communications Laboratory of the Communications Systems Division.

A. N. CURTISS AND T. H. MITCHELL RECEIVE AFCEA SERVICE AWARDS

Arthur N. Curtiss, Director of Administration, RCA Labs, and **Thompson H. Mitchell,** Chairman of the Executive Committee, RCA Communications, Inc., were honored recently by the Armed Forces Communications and Electronics Association with Meritorious Service Awards. They were the only civilians to receive such awards this year.

RCA AND HOFFMANN-LA ROCHE TO COLLABORATE ON MEDICAL ELECTRONICS

RCA and Hoffmann-La Roche, Inc., of Nutley, N. J., have agreed to collaborate in the development, production, and marketing of new and advanced medical devices, to be designed and manufactured by RCA and marketed by Hoffmann-La Roche.

Dr. N. I. Korman, formerly Chief Engineer, RCA Graphic Systems Division, has been appointed Director, Medical Electronics Plans and Programs, New Business Programs, Princeton, N. J. He reports to **F. H. Erdman,** Division Vice President, New Business Programs.

Dr. Korman heads the RCA team which will collaborate with a corresponding team from Hoffmann-La Roche. The medical devices will be of an electronic, electrochemical, and electromechanical nature which can measure and/or influence biological processes and can be used as aids for human and/or animal investigation, diagnosis, prosthesis, surgery, and therapy.

Assisting Dr. Korman are three Administrators, Medical Electronics—**J. M. McCulley, F. J. Herrman,** and **P. Snyder.** In addition, **L. E. Flory,** a Fellow of the Technical Staff of RCA Laboratories, will be a Consultant. **R. C. Bitting,** Manager, Financial Planning, on the Staff of the Executive Vice President and Controller, will assist the team on a part-time basis in its overall planning.

Initial efforts will involve a study to formulate an effective program to develop understanding of present and anticipated technology that can be applied to medical needs and to determine the feasibility and practicality of various types of products.

Some of the RCA team's work will be done at the Hoffmann-La Roche Laboratories, which can provide extensive animal and human clinical test facilities. After RCA develops prototypes, Hoffmann-La Roche will test them and secure approval by the Food and Drug Administration.

RCA's negotiations for the agreement were conducted by **Mr. Erdman, T. A. Smith,** Executive Vice President, Corporate Planning, and **L. F. Jones,** Manager, Engineering, for the New Business Programs activity.

M. GOLDMAN AWARDED SLOAN FELLOWSHIP

Max Goldman, CSD, Camden, has been awarded a Sloan Fellowship in Executive Development at the MIT School of Industrial Management. Mr. Goldman started with RCA in 1955 as an engineer on the TALOS system. In 1964, he was appointed to his present position as Manager, AUTODIN Program. He received his BSEE from CCNY in 1947, and his MSEE from Brooklyn Polytechnic Institute in 1954.

DR. RAJCHMAN NAMED TO ENGINEERING ACADEMY

Dr. Jan Rajchman, Director of the Computer Research Laboratory, RCA Labs, Princeton, has been elected to the National Academy of Engineering for his contributions to computer technology. He is one of 27 new members recently named to the Academy, which now has a total membership of 95. The Academy, founded in 1964, advises the government, on request, on matters of science and technology. Dr. Rajchman was also recently named to the Electrical Engineering Advisory Committee of the Newark College of Engineering.

NINE ENGINEERS RECEIVE "TECHNICAL EXCELLENCE AWARDS" AT MSR

The Missile and Surface Radar Division, Moorestown, N. J., has presented *Technical Excellence Awards* to nine engineers for their achievements during the first quarter of 1966. The men and their areas of achievement are: **S. Abbott**—*redefinition of standardization requirements;* **H. B. Boardman**—*design concept for a range tracker with several novel features;* **S. B. Kreitzberg**—*concepts for display subsystem;* **E. G. May**—*mathematical analysis techniques for array radar transmitter;* **R. J. McCurdy**—*developing a programmable clock;* **T. Murakami**—*mathematical and analytical work on multiple offset FM carriers;* **M. Ratliff**—*body-centered data display technique;* **G. J. Rogers**—*hydrostatic bearing;* **W. L. Watkins**—*techniques for modifying instrumentation radars in the field.*

AVIATION DEPT. RECEIVES AWARD

The Aviation Equipment Dept. of the RCA West Coast Division received the annual award of the Aviation Electronics Association "*in recognition of outstanding contributions to general aviation electronics for the year 1965*" at the Association's annual meeting in Reading, Pa.

RECORD DIVISION OPENS NEW ENGINEERING LABORATORY

The new Engineering Laboratory of the RCA Record Division in Indianapolis was officially opened recently by **D. F. Schmit**, Staff Vice President, Product Engineering. The new laboratory is a one-story brick building with a center rectangle housing the cafeteria and service laboratories separated by four connecting corridors from the outer periphery offices, conference rooms, and precision laboratories. The nearly 30,000 square feet of floor space is devoted to all engineering and development phases of disc and tape record products.

RCA SERVICE CO. TO RUN JOB CORPS CENTERS

The RCA Service Company has been awarded a contract for the operation of a new Job Corps Center for Women near Hazleton, Pa. The RCA Service Company previously received a contract to operate a 1,700-man Job Corps Center at Sparta, Wisconsin.

DR. BLOOM TO STUDY ABROAD UNDER RCA LABS PROGRAM

Dr. Stanley Bloom, RCA Labs, will spend a year studying and doing research at the University of Cambridge in England. He is the ninth RCA scientist to be offered such an opportunity under an RCA Labs program established in 1954.

DEGREES GRANTED

G. Noel, RCA Labs	MA, Physics, Temple University
A. M. Monsen, RCA Labs	BS, Elec. Engineering, Newark College of Engineering
A. S. Clorfeine, RCA Labs	Ph.D., Electrical Eng., Carnegie Institute of Tech.
R. W. Cohen, RCA Labs	Ph.D., Physics, Rutgers University
J. F. Dienst, RCA Labs	Ph.D., Electrical Eng., Rutgers University
T. F. Dwyer, RCA Labs	Ph.D., Electrical Eng., Princeton University
N. Feldstein, RCA Labs	Ph.D., Physical Chemistry, New York University
R. M. Williams, RCA Labs	Ph.D., Electrical Eng., University of Penn.
R. C. Blosser, RCA Labs	MS, Electrical Eng., Princeton University
L. N. Dworsky, RCA Labs	MS, Electrical Eng., Princeton University
J. T. Grabowski, RCA Labs	MS, Electrical Eng., University of Penn.
E. A. Miller, RCA Labs	MS, Chemistry, Drexel Institute of Tech.
R. S. Rosenblum, RCA Labs	MS, Electrical Eng., Polytechnic Institute of Brooklyn
E. C. Ross, RCA Labs	MS, Electrical Eng., Princeton University
H. Y. S. Tang, RCA Labs	MS, Electrical Eng., Columbia University
J. S. Hadjilogiou, RCA Labs	BS, Electrical Eng., Polytechnic Institute of Brooklyn
C. I. Brodsky, RCA Labs	LL.B., MBA, Law Business Administration, N. Y. University
I. Rappaport, RCA Labs	LL.B., Law, George Washington University
D. H. Parks, Home Instruments	MSEE, Purdue University
J. E. Blanford, RCA Ser. Co.	Assoc. Degree, Eng., Brevard Engineering College
F. J. Tuck, RCA Ser. Co.	Assoc. Degree, Eng., Brevard Engineering College
L. H. Bancroft, RCA Ser. Co.	BSEE, Brevard Engineering College
D. S. Bistarkey, RCA Ser. Co.	BSEE, Brevard Engineering College
F. L. LeMosy, RCA Ser. Co.	BSEE, Brevard Engineering College
K. R. Clark, RCA Ser. Co.	BS, Mathematics, Brevard Engineering College
J. A. Paddock, RCA Ser. Co.	MSEE, Brevard Engineering College
J. J. Pex, RCA Ser. Co.	MSEE, Brevard Engineering College
T. H. Murdock, RCA Ser. Co.	MS, Mathematics, Brevard Engineering College
G. E. Simoneaux, RCA Ser. Co.	MS, Mathematics, Brevard Engineering College
K. E. Forry, RCA Ser. Co.	MS, Operations Research, Brevard Engineering College
H. L. Smith, RCA Ser. Co.	MS, Operations Research, Brevard Engineering College
J. S. Brodie, ASD	MBA, Boston University
W. W. Barrow, Jr., ASD	MBA, Northeastern University
W. T. Ackermann, ECD	MS, Management Engineering, Newark College of Engineering
D. J. Dempsey, MSR	MEE, Villanova University
A. Gulino, MSR	BSIE, LaSalle College
J. Brumbaugh, MSR	MEE, Villanova University
J. S. Degnan, MSR	MEE, Villanova University
R. Fink, MSR	BS, Elec-Physics, LaSalle College
R. Hoffman, MSR	BSEE, Drexel Institute of Technology
A. Klamo, MSR	MEE, Villanova University
H. Ravitch, MSR	MA, Statistics, University of Pennsylvania
W. Scaglione, MSR	BS, Indus. Admin., Drexel Institute of Technology
R. St. John, MSR	MSEE, Drexel Institute of Technology
F. L. Lanphear, MSR	MEE, Villanova University
R. F. Hamilton, MSR	MSME, Drexel Institute of Technology
A. A. Raguckas, MSR	BSME, Drexel Institute of Technology
W. K. Pehlert, Jr., MSR	Ph.D., University of Pennsylvania

GRAPHIC SYSTEMS DIVISION ANNOUNCES AUTOMATED SYSTEMS

An electronic type composition system, capable of setting the entire text for a newspaper page in two minutes by video and computer techniques, has been announced by the RCA Graphic Systems Division, Princeton, N. J. The *Videocomp Model 70/820* is the first commercially available typesetter to employ all electronic character generation.

The second system, *Colorscan II*, is an electronic color separation device, which can scan color transparencies and break them down into the four color separations required for full color reproduction. Both these products, which will be marketed by RCA, are produced by Firma Dr.-Ing. Rudolf Hell, of Kiel, West Germany. Dr. Hell is an internationally known expert in electronic equipment for the graphics industry.

Videocomp and Colorscan II represent the first phase of a broad product program by the Graphic Systems Division, which was formed in 1965 to specialize in advanced electronic products for the printing industry.

Videocomp a "metal-less" typesetter, utilizes a computer memory to store up to four type fonts ranging in size from 5 to 24 points. Under program control, it generates text at rates up to 600 characters a second, and writes it with an electron beam on the face of a high resolution cathode ray tube. The characters on the tube are exposed through a precision lens directly onto sensitized film or paper for subsequent printing by offset, letterpress, or gravure processes. Original copy is fed into a computer, which hyphenates and justifies the text and produces an output tape. This is read electronically by the Videocomp, which calls from its memory the proper characters in desired type font and size.

Colorscan II solves many of the cost and time problems involved in color printing, producing faster and more consistent quality than present camera and filtering methods.

NEW BCD DEPARTMENT TO MARKET EDUCATIONAL-TRAINING EQUIPMENT

A new department for application of electronic products to education and related fields has been announced by the RCA Broadcast and Communications Products Division. The new Instructional and Scientific Department is headed by **Adron M. Miller**, who has been named a Division Vice President. He formerly was Manager, Broadcast Merchandising Operations, for BCD. The department will centralize marketing for educational fields of complete TV systems, including 2,500 MHz equipment, TV cameras, audio and video tape recorders, electron microscopes, learning laboratories, motion picture recording and projection equipment, etc. Based in Camden, it will draw its products from the Camden engineering and manufacturing facilities as well as from those at Meadow Lands, Pa., and Burbank, Calif.

AED BUILDS NEW NIMBUS UNITS

AED, which provided the advanced TV cameras and other equipment aboard Nimbus II, is now building a power system for the next Nimbus—an advanced version of the one in Nimbus II—and a new centralized data recording and transmission system, called the High Data Rate Storage System (HDRSS). The HDRSS will store both analog and digital signals on a five-track, two-speed tape recorder.

. . . PROMOTIONS . . .

to Engineering Leader & Manager

As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parentheses.

Missile & Surface Radar Division

A. D. Korbin: from Cl. "AA" Eng. to *Ldr., Systems Engrg.* (S. G. Miller, Mrstn.)

Communications Systems Division

A. I. Krell: from AA Eng. to *Ldr., Des & Dev Eng.* (Dr. Guenther, Camden)

R. S. Lawton: from Ldr., Des. & Dev. Eng. to *Mgr., Communications Equip. Projects* (E. Kalkman, Camden)

S. M. Tucker: from Ldr., Des. & Dev. Eng. to *Mgr., Communications Equip. Projects* (T. Genetta, Camden)

J. T. Smith: from Engr. Projects Coordination to *Ldr., Projects Administration* (J. B. Cecil, Mrstn.)

A. J. Barrett: from Mgr., Mfg. Engrg. Services to *Superintendent, Assembly* (G. L. McCormick, Camden)

L. E. Potter: from Ldr., Des. & Dev. Engineers to *Adm., Test Equipment* (B. V. Dale, Camden)

Astro-Electronics Division

H. C. Lawrence: from Mgr., Data Transmission to *Mgr., Spacecraft Electronics* (A. J. Vaughan, Princeton)

P. B. Lazovick: from Eng. to *Ldr., Engineers* (R. Callais, Princeton)

H. H. Rickert: from Senior Eng. to *Ldr., Engineers* (H. C. Lawrence, Princeton)

B. Stewart: from Eng. to *Ldr., Engineers* (J. E. Keigler, Princeton)

Aerospace Systems Division

R. W. Foster: from Proj. Eng. Specialist to *Ldr., Eng. Specialist* (I. C. Akerblom, Burlington)

A. Sinkinson: from Engrg. Scientist to *Adm., Design Standard Engrg.* (J. S. Furnstahl, Burlington)

Electronic Components and Devices

H. R. Snow: from Resident Eng. to *Adm., Cost Reduction* (W. Brown, Harrison)

F. G. Hammersand: Senior Eng., Product Dev. to *Engrg. Ldr., Product Dev.* (Mgr., Super Power Tube Oper.)

R. E. Benway: from Sen. Eng. to *Mgr., Design and Standardizing* (D. J. Ransom, Marion)

R. W. Osborn: from Eng., Prod. Dev. to *Mgr., Design and Standardizing* (D. J. Ransom, Marion)

R. L. Leigh: from Sen. Eng., Prod. Dev. to *Engrg. Ldr., Prod. Dev.* (C. T. Lattimer, Marion)

R. E. Salveter: from Sen. Eng., Prod. Dev. to *Engrg. Ldr., Prod. Dev.* (C. T. Lattimer, Marion)

J. A. Stankey: from Sen. Eng., Prod. Dev. to *Engrg. Ldr., Prod. Dev.* (C. T. Lattimer, Marion)

E. Slaney: from Member, Tech. Staff to *Ldr., Technical Staff* (Mgr., Applications & Design Engrg., Needham)

J. Rodriguez: from Member, Technical Staff to *Ldr., Technical Staff* (Mgr., Memory Systems Engrg., Needham)

A. R. Visco: from Industrial Eng. to *Mgr., Industrial Engrg.* (Mgr., Manufacturing Standards, Needham)

RCA Service Company

J. F. Byrne: from Eng. to *Ldr., Eng.* (T. J. Barry, Alexandria, Virginia)

J. J. Pex: from Eng. to *Ldr., Engineers* (J. T. Painter, Cocoa Beach, Florida)

Electronic Data Processing

H. P. Cichon: from Ldr., Des. & Dev. Engineers to *Adm., Test Equip.*

RCA LABS APPOINTS FOUR STAFF VICE PRESIDENTS AND THREE LABORATORY DIRECTORS IN STAFF REALIGNMENT

Appointment of four Staff Vice Presidents and three new Laboratory Directors at the RCA Labs, Princeton, N.J., has been announced by **James Hillier,** Vice President, RCA Laboratories.

Heading the list of new appointees is **Humboldt W. Leverenz,** named Staff Vice President, Research and Business Evaluation, a new position. An evaluation group under Mr. Leverenz will provide a continuing source of technical and business guidance.

The other principal appointees are **Ralph S. Holmes,** Staff Vice President, Communications Research; **Harry F. Olson,** Staff Vice President, Acoustical and Electromechanical Research, and **William M. Webster,** Staff Vice President, Materials and Device Research. A principal function of the three executives in their respective areas will be to help establish clearer and more direct relationships between Laboratories groups and major RCA product divisions having common interests. This task is becoming more complex with the increasing diversification of the Corporation.

In addition to the new Staff Vice Presidents, Dr. Hillier announced the appointments of **Kerns H. Powers** as Director, Communications Research Laboratory; **Henry R. Lewis** as Director, Electronic Research Laboratory, and **Fred D. Rosi** as Director, Materials Research Laboratory. Dr. Powers will report to Mr. Holmes, and Drs. Lewis and Rosi to Dr. Webster.

All of the new appointees have long been leading members of the RCA Laboratories technical organization.

Mr. Leverenz, who was Associate Director of RCA Laboratories, is internationally recognized for his basic contributions in the field of luminescent and other electronically active materials. He has been associated with RCA since 1931. Through the 1930's and during World War II, he was responsible for the pioneering development of luminescent phosphors for television and for radar and other electronic displays. During the postwar period he headed the RCA Laboratories program of solid-state materials research, and served as Director of Research for the organization from 1959 until his appointment as Associate Director, RCA Laboratories, in 1961.

Mr. Holmes, formerly Director of the Special Projects Laboratory, has been associated with RCA and its predecessor companies for more than forty years. He is widely known for his contributions to research and development work in television, radar, and communications systems, and from 1959 to 1963 he directed Project PANGLOSS, a large-scale Navy communications project for which RCA was prime contractor.

Dr. Olson, a leading authority in the field of acoustics, joined RCA in 1928 and has headed the corporation's acoustical research activities since 1934. He has pioneered in the development of sound pickup and reproduction systems, and among his many significant inventions is the velocity microphone, which became the standard pickup device for broadcasting and recording. He was honored in 1959 by election to the National Academy of Science.

Dr. Webster is known for his basic contributions in semiconductors and gaseous electronics. He joined RCA Laboratories in 1946 as a specialist in vacuum and solid-state electronics, and served from 1954 to 1959 as Manager of Advanced Development for RCA's Semiconductor and Materials Division, Somerville, N.J. In 1959, he returned to RCA Laboratories as Director of the Electronic Research Laboratory.

Dr. Powers has been associated with RCA Laboratories since 1951 as a specialist in communications research. From 1953 to 1955, he held an Industrial Fellowship in Electronics at the Massachusetts Institute of Technology, and received his Sc.D. degree from MIT in 1956. Since 1959, he has been in charge of communication system studies in connection with a major U.S. Navy project at RCA Laboratories, and until his new appointment he was Technical Director, New Systems, of the Special Projects Laboratory at the David Sarnoff Research Center.

Dr. Lewis, formerly head of the Quantum Electronics Group of the Electronic Research Laboratory at the David Sarnoff Research Center, has been with RCA since 1957. He received his Ph.D. degree from Harvard in 1956 for his study of distortions observed in nuclear resonances using the molecular beam technique, and prior to joining RCA he worked with the Operations Evaluation Group of MIT on various problems in naval warfare. At RCA Laboratories, he has made significant contributions in such areas as the paramagnetic resonance of iron-group and rare earth ions in single crystals, and microwave and optical masers.

Dr. Rosi, who has been an Associate Director of the Materials Research Laboratory at the David Sarnoff Research Center, is recognized as an authority on the metallurgy of semiconductors, and plastic deformation of metal crystals, as well as thermoelectricity. A graduate of Yale University he has been with RCA Laboratories since 1954, heading research in the Semiconductors, Superconductors, and Metals Research group. In 1963, he was one of the recipients of the David Sarnoff Outstanding Team Award in Science, presented for the achievement of germanium-silicon alloys for thermoelectric power generation.

CERF OF RANDOM HOUSE AND SCOTT OF NBC NAMED RCA DIRECTORS

Election of **Bennett Cerf** and **Walter D. Scott** to the RCA Board of Directors has been announced by Chairman **David Sarnoff.** Mr. Cerf is Chairman of the Board and Chief Executive of Random House, Inc., recently acquired by RCA as a wholly owned subsidiary. Mr. Scott has been Chairman of the Board of NBC since April 1 and has been NBC's Chief Executive Officer since Jan. 1, 1966.

As an RCA subsidiary, Random House will continue to function as a separate entity with complete editorial autonomy in the hands of its own Board of Directors. No changes are contemplated in its present personnel and management.

HAWKINS HEADS RCA COMMUNICATIONS

Howard R. Hawkins has been elected President of RCA Communications, Inc. Mr. Hawkins, formerly Executive Vice President of RCA Communications, succeeds **Thompson H. Mitchell** as President. Mr. Mitchell becomes Chairman of the Executive Committee of the Board of Directors. **Charles M. Odorizzi,** a Director and Group Executive Vice President of RCA, was elected Chairman of the Board of RCA Communications.

Mr. Mitchell assumes his new post after almost 40 years of service with RCA Communications, Inc. He was elected Executive Vice President of RCA Communications in 1944 and has been President since 1953. Mr. Hawkins joined RCA Communications in 1946 as its Assistant General Attorney and became General Attorney in 1949; he was elected Vice President and General Attorney in 1951 and Executive Vice President and Director in 1964.

C. Dunaief

NEW ED REPS: C. DUNAIEF FOR DEFENSE MICROELECTRONICS, H. EPSTEIN FOR SEER, AND M. B. ALEXANDER FOR INDUSTRIAL SEMICONDUCTORS

Charles Dunaief has been named RCA ENGINEER Editorial Representative for the Defense Microelectronics engineering group located in Somerville. **Harris Epstein** has been named Ed Rep for the Systems Engineering, Evaluation and Research activity of the Defense Engineering Staff; SEER is located in Moorestown. He replaces **A. Stocker.** Both will service on **Frank Whitmore's** Defense Engineering Editorial Board.

M. B. Alexander has been named Ed Rep for the Industrial Tube and Semiconductor Division of EC&D in Somerville. He replaces **E. F. Breniak,** and will service on **Charley Meyer's** EC&D Editorial Board.

Mr. Dunaief's biography follows; biographies of Mr. Epstein and Mr. Alexander will be published when received.

Charles Dunaief received his BAE from New York University in 1947, and taught physics and thermodynamics at Mohawk College and Cooper Union. He was employed by the Sperry Gyroscope Co. as Leader of an Autopilot equipment group for six years, when he joined GE as a missile electronic equipment consultant. He joined RCA in 1957 as Leader of an airborne communications equipment group in the USAF Time Division Data Link Program. He subsequently was Leader of Systems and Projects groups until he joined ACCD marketing with responsibility for advanced communications sales. Mr. Dunaief was responsible for advanced technique marketing in Applied Research until his assignment to Defense Microelectronics as Staff Engineer to the Manager of DME. He is presently Manager, DME Custom Circuits, and is concerned with development and fabrication of custom circuits using multiple integrated circuits and supplementary microelectronic chips. Mr. Dunaief is a Senior Member of IEEE and has published several papers.

DR. HEIMAN TO GIVE 30-WEEK COURSE IN SEMICONDUCTOR PHYSICS TO SOMERVILLE ENGINEERS

Dr. Fred P. Heiman of RCA Labs will give a special course in *Basic Semiconductor Physics* to EC&D engineers and chemists at Somerville who wish to strengthen their basic physics background in solid-state theory. The course is planned for Wednesdays, 4:45 to 6:35, and will run 30 weeks beginning in September 1966. Among topics in the course are statistical mechanics, band theory, conduction in solids, p-n junction theory, surface physics, and photoconductivity. The course includes homework, exams, and grades. The course will avoid detailed transistor design techniques, and will emphasize general theory and phenomena. This approach should provide a better understanding of present device problems and new device phenomena.—*C. W. Sall.*

RAPPAPORT NAMED CHAIRMAN OF NEW ENERGY-CONVERSION INTERSOCIETY STEERING COMMITTEE

Paul Rappaport, Associate Laboratory Director, Materials Research Laboratory, RCA Labs, has been named Chairman of the Steering Committee of the Intersociety Energy Conversion Engineering Conference (IECEC) for 1966.

The IECEC is a new organization designed to reduce the duplication and proliferation in the number of conferences in the energy conversion field. It comprises energy conversion groups from six professional societies: the American Institute of Astronautics and Aeronautics, the Institute of Electrical and Electronics Engineers, the American Society of Mechanical Engineers, the American Institute of Chemical Engineers, the American Nuclear Society, and the Society of Automotive Engineers. Mr. Rappaport played an active part in the establishment of the new intersociety conference.

The 1966 Intersociety Energy Conversion Engineering Conference, which this year will be under the auspices of the AIAA, will be held in Los Angeles from September 26 to 28.—*C. W. Sall.*

RCA PLANS PUERTO RICAN PLANT

RCA plans to establish a new facility in Juncas (south of San Juan), Puerto Rico, for manufacturing electron guns for color TV picture tubes, to start limited operations during late 1966. The new 25,000-square-foot plant will supplement the manufacture of RCA electron guns in Lancaster, Pa., and Marion, Ind. Employees will be recruited entirely in Puerto Rico, with a limited management staff from other RCA locations. The new operation will be directed by RCA Electronic Components and Devices.

SPECIAL CREDIT TO JIM PARSONS FOR RCA ENGINEER EDITORIAL WORK

From December 1965 to through June 1966, much of the job of putting out the RCA ENGINEER was ably handled by **Jim Parsons,** who served as assistant editor for that six-month stint on a temporary assignment from his regular RCA Service Company duties. Jim did a truly outstanding job in handling some 100 technical papers involved with Vols. 11-5 through 12-2. He deserves much credit for his professional approach in quickly phasing into these editorial duties and applying his abilities toward maintaining the editorial and technical excellence so important to the RCA ENGINEER. Jim performed this task during the temporary absence of **Ed Jennings,** Associate Editor, who was on a special assignment. The Editors, the Advisory Board, and the Editorial Representatives all express their gratitude for the especially competent manner in which he carried out this assignment.

W. O. Hadlock, Editor.

NBC TO ASSIST SOUTH VIETNAM IN ESTABLISHING 4-STATION TV NETWORK

NBC International will assist South Vietnam in establishing a four-station national television network. NBC International will supply managerial, technical and engineering services to the Vietnam Ministry of Information, which will control the network, and will train Vietnamese to take over the stations. The government plans to use its national network for school and adult education programs, as well as for cultural and informational purposes. The project is being coordinated by the Joint U. S. Public Affairs Office (JUSPAO) in Saigon and the U.S. Information Agency in Washington.

NBC International has helped 15 other foreign governments establish national television networks, the latest of which are Nigeria and Saudi Arabia.

The network system will replace and expand the television broadcasts made since last February from two U.S. Navy transmitter-equipped C-121s, flying over the Saigon area. The planes transmit Vietnamese government programs and American TV programs daily.

Main facilities of the national network will be in Saigon, with that station scheduled to go on the air about October 15 of this year. A second station is planned for Can Tho, southwest of Saigon, to begin broadcasting about December 15. The two other stations will go into operation next spring and summer.

The Saigon TV Center will consist of a 300-foot transmitter tower with 80-foot antenna; a building housing two 25,000 RCA transmitters, each with an effective radiated power of 300,000 watts, and two other buildings for studio and administrative offices. The transmitters should be able to cover a 40-mile radius. The transmitter at Can Tho also will be 25,000 watts, while the two other stations will be equipped with 5,000-watt transmitters for coverage of 25-mile radii.

Most of the viewing of the plane-transmitted programs in the Saigon area is on TV sets placed at public locations in villages and hamlets. So popular has the Vietnamese programming been to date that sometimes 1,000 persons will gather around one television set.

A network also is planned for the U.S. Armed Forces. It will use one of the two transmitters in Saigon, but in other locations will have separate facilities.

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RCA ENGINEER

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