OBJECTIVES

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 engineering groups at RCA.

●

To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions.

●

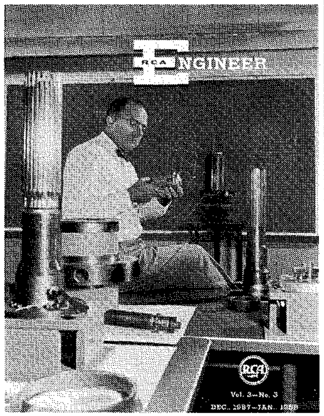
To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field.

●

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.



OUR COVER

This issue's cover shows Dr. Lloyd P. Garner, Manager of Power Tube Development and Applications at the Electron Tube Division's Lancaster Plant, seated among various component parts of several large power and super-power transmitting tubes developed under his direction.

PROFESSIONAL DEVELOPMENT

The engineer who has the combination of a sound theoretical background and practical experience will obtain a considerable degree of personal satisfaction, advancement and accomplishment in engineering.

The fields of engineering are expanding at such a rapid rate that the engineer must, of necessity, continue an effective educational program. Pursuit of such a plan will (1) keep the engineer in step with advances in theory (2) benefit him in his chosen and allied fields (3) keep him mentally inquisitive and alert, and (4) provide him a foundation for future growth.

However, knowledge, even though coupled with technical skill and experience, is not sufficient for the full development of the engineer as a well qualified professional man. There are responsibilities to join and support his technical society, to be active in industry committee work, to be aware as an individual of the integration of his work into the overall efforts of his associates and the company . . . and to have an interest in community and cultural activities.

Professional Development is to a large degree a personal matter. Friends, family, associates and the Company do make their contributions, but in the long run it is up to the individual engineer to plan and carry out his own Professional Development.

D. F. Schm
Vice Preside
Product Engineeri
Radio Corporation of Ameri

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VOL. 3, NO. 3 • DEC. 1957 - JAN. 1958

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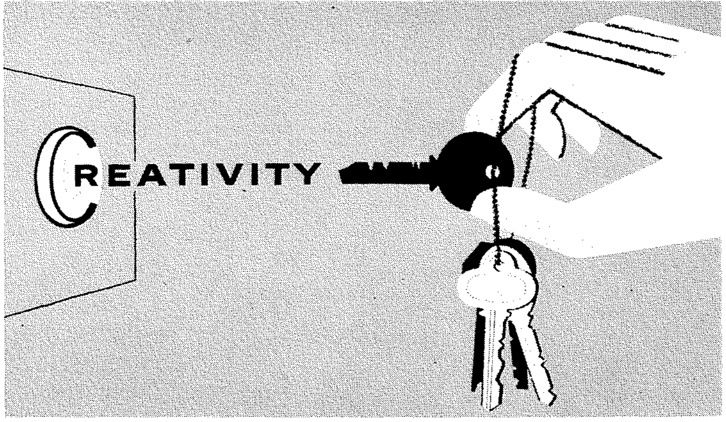
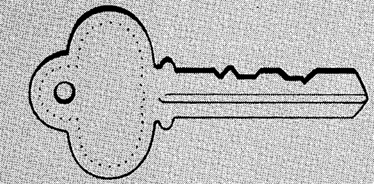


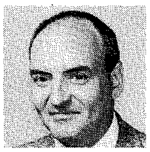
WILL YOUR KEY UNLOCK THIS DOOR?

(Part I of a Series on the Subject of Creativity)

By now, Mr. RCA Engineer has been exposed in one fashion or another to such terms as: Creative Thinking, Creative Engineering, Applied Imagination, Brainstorming, and a host of others based on the same subject. Several articles on Creativity have been published in the RCA ENGINEER (see bibliography), reflecting the thinking and activities of various groups at RCA. A Research Program was conducted in the TV Division and Color Kinescope Engineering at Lancaster. In addition, the RCA Engineering Training Committee has completed a basic training outline covering creativity.

To help "sparkplug" the Series on Creativity, initial plans were made by committee members shown here, l. to r.: D. G. Garvin, Lancaster; J. F. Hirlinger, Harrison; P. C. Farbro, Camden; Dr. H. J. Woll, Camden; J. J. Newman, Camden; L. H. Good, Camden; C. M. Sinnet, Cherry Hill; and G. W. King, Moorestown.





MY THOUGHTS ON MOTIVATION

By

R. H. Peterson

Mechanical Engineering
Defense Electronic Prod.
Moorestown, N. J.

The motivation for creativity is fundamentally that of dissatisfaction. This can be dissatisfaction of one's self, of others or with conditions. At times creativity stems from a recognized need, which is merely another way of stating a condition of dissatisfaction. Likewise yearning for the new and different is merely a change of emphasis but still implies dissatisfaction. Ambition may be considered a motive for creativity, which is governed by nervous state or emotional drive, and here again is another form of implied dissatisfaction.

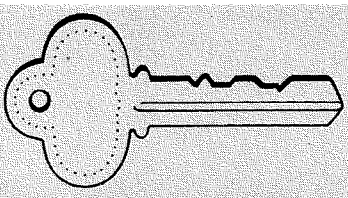
A PROVEN NEED

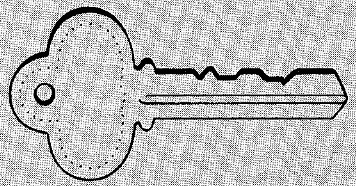
By

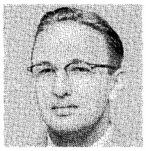
Edward Kornstein

Special Systems and
Development Engineering
Defense Electronic Prod.
Camden, N. J.

Creativity has individual meaning and a different expression for everyone. To me, incentive is the major part of the creative process. The requirement of fulfilling a proven need is a paramount necessity. It supplies me the incentive to start the creative process. Often the first stumbling block is to be *convinced that the need is real* and that all conventional approaches have been investigated. When this is established, incentive automatically increases. Next step is to search one's background and experience for similar situations no matter how remote the similarity. If no solution is forthcoming and the desire and incentive still remain, the problem drops one level to the "if" stage. For example, "If we could do such and such, then we could find a solution to the problem." The entire process is now re-directed to the "if" problem. Some problems require several such levels of Creativity before the final solution. As long as incentive is maintained and aided by a proper atmosphere, Creativity is fostered. *Mr. Kornstein is at Boston U. under privileges of a David Sarnoff Fellowship—Ed.*







A "DUD" OR A PROFIT?

By

G. E. Crosby

Tube Division
Lancaster, Pa.

In product development Creativity is a means to an end; the difference between a competitive product and one that excels; the difference between mediocrity and big success, the difference between a "dud" and a profit.

Even the experienced engineer can learn to be more creative. Somehow he must use his experience, but, at the same time, remove mental blocks so that his thinking is uninhibited by the past.

Creativity is not confined to an engineer with a problem. A wealth of ideas are available from associates. One cannot be expert in everything—so discuss a problem, accept and evaluate suggestions, and incorporate new thoughts into a product. Swallowing the ego and refining another's creative thought is as important as being creative within. Developing a new product is our task—being creative is a means to that product.

WHY THIS SERIES?

Concurrent with Industry's interest in Creativity, numerous definitions came into being which tend to confuse us. Techniques such as Brainstorming, check lists and attribute listings have their place, but by no means give us any understanding of the total concept of creative abilities. These have been supported and criticized by individuals and groups who have not given serious thought to the subject. The Committee and the RCA ENGINEER want to go beyond a superficial treatment!

WHY A COMMITTEE?

The Editors asked a few people in RCA who are interested in the subject of Creativity to assist in developing this series. As a result, the following general areas of interest are suggested as being applicable: (1) Environment, (2) Motivation, (3) Training, (4) Knowledge, (5) Evaluation, (6) Problem Statement, (7) Ideation and (8) Application.

Although it was agreed that these are important areas, the Committee Members were in accord that *the list should be used only as a guide.* It is preferred that statements prepared by engineers be wholly unaffected by preconceived notions or established opinions.

Another function of the Committee is to serve as a "screening" board to select the most provocative statements for publication. It is hoped that readers will be able to make use of knowledge gained from these expressions.

If you have a thought on this subject, submit it to your nearest Editorial Representative, whose name is shown on the inside back cover (please try to limit your statement to 150 words or less).

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Editor's Note: Because of reader interest, we are publishing, starting with this issue, the feelings of RCA engineers on the subject of Creativity. To do this, we have enlisted the help of the Committee pictured on this page, as well as the assistance of our Editorial Representatives in all areas of the Company. Statements appearing in this series on Creativity represent the engineers' personal views, uncolored by the abundance of "expert" opinion available on the subject. We hope you will find these expressions thought provoking and interesting. Submit your ideas on the subject to your nearest Editorial Representative!

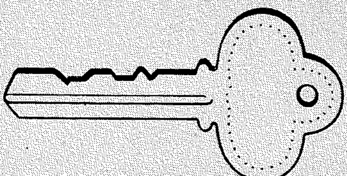
MYSTERIOUS OR MEDIOCRE

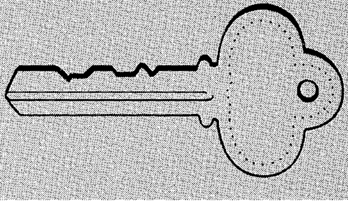
By

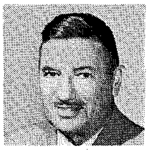
Dr. Ivan H. Sublette

Special Systems and Development Eng.
Defense Electronic Prod.
Camden, N. J.

The truly scientific aspects of the problem of understanding human creativity are essentially identical to the task of describing a machine that could duplicate the unique functions of the human brain. To determine the real progress that has been achieved, therefore, we should examine the success scientists have met in the theory and construction of automata. We find that artificial brains, even in theory, are incompetent creators, and are known for the quantity, rather than the quality, of their ideas. This condition is reflected in mediocrity of contemporary theories on human creativity or "applied imagination". Future studies should greatly increase our understanding of creativity. But the human spirit will always consign to the realm of the mediocre any creative principle that is not mysterious or that could be realized in a robot. Where human interests are concerned, theories of Creativity must die when proved true. *Mr. Sublette recently received his Doctorate at U. of P., (Vol. 3, No. 2)—Ed.*







CREATIVITY? . . . REALLY?

By

Simeon Tourshou, Mgr.

Product Development
B & W Television Engr.
RCA Victor
Television Div.
Cherry Hill, N. J.

The appeal of this word stems from a premise that Creativity, fundamentally, is good. Frankensteins, golden calves, and atomic firecrackers presumably do not contradict the lasting good in the heritage of man. But can we be sure? Though endowed by the Creator with the finest instrument of discernment, we have not yet learned to read His instructions enclosed in its very substance. As students of electronics we may be closest to understanding the processes and the parameters of assertion, which govern our destinies, but who can say that this understanding should not be a major goal?

As yet we haven't outgrown our fascination for gadgets, and a clear sense of direction seems lacking, except as spawned by self-righteousness and its captive conscience. Our ears still are cocked to promptings of the ego: create, brother, create, no matter what, just create. *Mr. Tourshou is author of two articles in the RCA ENGINEER, Vol. 1, No. 2 and Vol. 2, No. 3—Ed.*

UNDERSTANDING THE PROBLEM

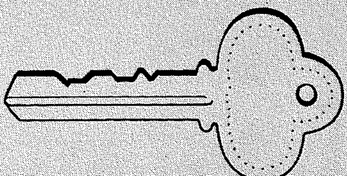
By

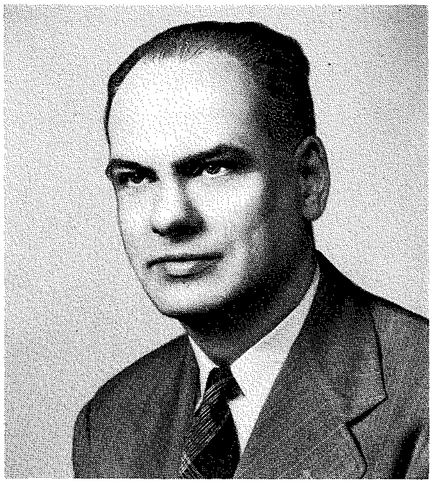
M. M. Mandelkehr

Systems Engineering
Defense Electronic Prod.
Moorestown, N. J.

A major problem facing management today is obtaining the best performance from creative personnel. The trend has been to allow greater freedom which results very often in an atmosphere of confusion and uncertainty.

The major factor that cripples creativeness is *lack of understanding of the problem.* The creative person is too often overestimated in his ability to formulate problems and establish the framework for his ideas to be built onto. Frequently, excellent ideas have been produced with no application to the problem. Not only is time and money wasted, but morale suffers when results of creative efforts go down the drain. A great deal of emphasis should be placed on: (1) establishing the problem, (2) breaking it into factors that may be considered separately, and (3) establishing the procedures by which it can be attacked so that reasonable results can be obtained.





WILLIAM N. PARKER, Staff Engineer, Power Tubes, received his BSEE from the University of Illinois in 1928. In 1929 Mr. Parker was employed by Western Television Corp., where he was associated with the development of mechanical television equipment. Following several months as Chief Engineer of broadcast station XENT, Mr. Parker returned to television development at Philco in 1934 where he pioneered in television transmitters. During World War II, Mr. Parker was with the U. S. Government Army-Navy Expediting Production Agency. He joined RCA in 1943 and has been associated with development of super-power and high-power uhf tubes at Lancaster.

Mr. Parker served as Manager of Large Power Tube Development for two years prior to December, 1955, when he was appointed Staff Engineer. He is the holder of 15 U. S. Patents. Mr. Parker belongs to Eta Kappa Nu, Sigma Tau, Sigma Xi, Pi Mu Epsilon, and is a Senior Member, IRE.

SUPER-POWER TUBE ENGINEERING

by **W. N. PARKER**

Power-Tube Engineering
Electron Tube Division
Lancaster, Pa.

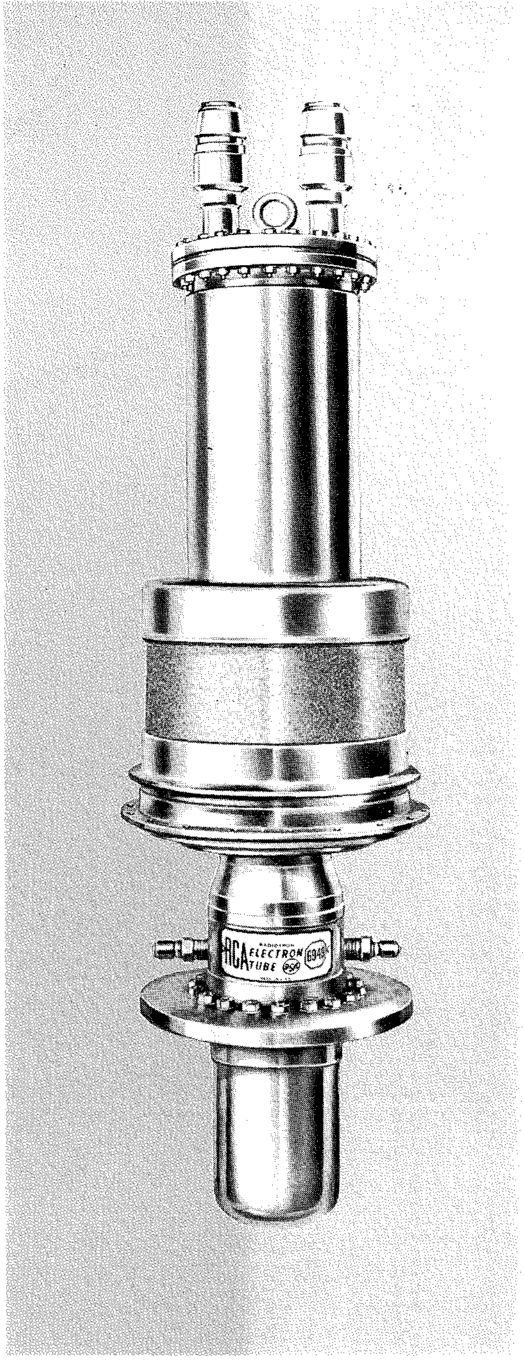
One of the most startling advances in electronics' technology is the development of super-power tubes. These tubes make possible the generation of unprecedented levels of power at higher and higher frequencies. Several types are now offered to industry by the RCA Electron Tube Division for use in super-power applications in which the "megawatt" is the nominal unit of power.

A separate research group was created at RCA in 1937 to develop electron-tube concepts for super-power generation. A new activity for super-power tubes was established in the manufacturing plant at Lancaster, Pennsylvania in 1943, and a separate building and facilities were provided in 1947. These facilities have been continuously expanded in step with the growing needs for high-power, high-frequency generation and new super-power tube designs. The successful development of such tube designs has been possible because of the long-range policies of RCA management, the interest of industry and government agencies, and the efforts of each individual member of the super-power-tube activity.

EARLY WORK

The foundation for super-power tubes was laid in the work done by L. P. Garner and Dr. P. T. Smith under the guidance of Dr. V. K. Zworykin in 1937. The specific objective at that time was to develop a 50-kilowatt cw power tube operating at a frequency of 100 megacycles per second. One of the tubes developed to meet this objective was a metal envelope twin triode employing built-in neutralizing which could be adjusted during operation. An equivalent twin tetrode utilizing internal neutralization was the forerunner of the 5-kilowatt RCA 8D21 which was instrumental in launching VHF-TV broadcasting immediately following World War II.

Even before the war ended several far-sighted individuals, such as the late I. R. Baker, envisioned future needs for tremendous amounts of radio-frequency power for industrial and high-power broadcasting needs. It was felt that super-power broadcasting was relatively imminent and tubes capable of delivering at least one-million watts output would be required. Since the development of such tubes could not happen over night, it was decided that work should be started immediately. Accordingly, Dr. Zworykin called Garner and asked him to head up the development group. As the story goes, the 'phone call took place late at night and Lloyd Garner later said he was too sleepy to say "no" to such a formidable undertaking. The activity was located in Lancaster because of the space available and because it would be near other power-tube engineering activities for ready exchange of techniques and facilities. It was further felt that any such tubes developed at Lancaster would probably require the development facilities for manufacturing.



"TUBE-CIRCUIT" CONCEPT

The Advanced Development Group started in February, 1943, when the author joined Garner at Lancaster. Two basic ground rules were quickly agreed upon, which apply as well today as they did then. The first rule was that a relentless endeavor would be pursued toward achieving more power at higher frequencies. The second rule was that the "tube-circuit" concept would be held to at all times. It was realized that the electronically active portion of the tube was merely one element, even though a vital one, in an over-all system whose objective was the efficient conversion of d-c electric power into radio-frequency power. A good tube design would result only if the circuit aspects of the system were kept in mind constantly.

The importance of this concept is obvious in high-frequency tubes because the electrical length of the active elements of the tube and connecting leads may become an appreciable part of the total electrical circuit. However, it is just as important in lower-frequency high-power tubes because the inductance of tube leads must be minimized to pass the extremely high currents involved. It is also desirable that super-power tubes be tested and evaluated by the same group that designs them so that operating problems will be faced squarely and suitable corrective measures will be taken.

"HIGH-POWER" PHILOSOPHY

Because a one-megawatt tube represents an increase in power of about one order of magnitude over earlier high-power tubes, it was first necessary to develop some concept of what one megawatt really means. This power is equivalent to the output of a 1350-horsepower aircraft engine operating at full load. A megawatt tube based on conventional power-tube design would probably be just as bulky as this aircraft engine, and would probably not operate at frequencies above a few hundred kilocycles per second. To achieve a greater power concentration and a more compact device, it was decided to build the tube as an array of units, each designed for optimum performance, in a manner similar to the individual winding slots in a large electrical machine or the individual blades of a huge steam turbine. It was estimated that approximately 96 such units, each five or six inches long, arranged in a cylindrical array about six inches in diameter should achieve the desired one-megawatt cw output.

UNIT CONSTRUCTION

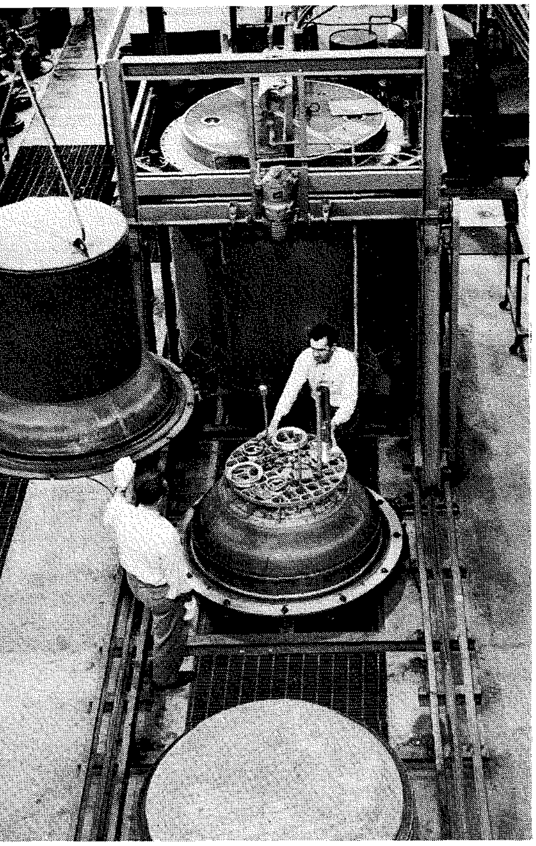
Unit triode tests were made on a structure comprising a single full-length cathode and a pair of full-length grids. These parts were mounted with a suitable anode in a demountable high-vacuum system and the unit was subjected to full voltage and current to test the electrical performance under full-power space-charge conditions. The average power was limited by the use of one-microsecond test pulses. Finally, an electron-optical system was developed in which 95 per cent of the electrons reached the anode, where they could be utilized to furnish useful output. This figure compares to a value of about 60 per cent for conventional electron-tube structures utilizing the same conditions of equal positive grid and anode voltages. This new beam-forming structure was even more effective in the reduction of grid-current absorption, which was decreased from 30 per cent to 5 per cent. This lower grid-current absorption results in less grid heating and greater power gain and power output.

Tests on the unit triodes showed that the high-quality electrical performance was obtained only under the following conditions: (1) the emitting surfaces of the cathode must be flat so that the electrons are emitted in a narrow beam path; (2) the control grids must have sharp, smooth corners to influence the electron beams properly and (3) the cathodes, control electrodes, and beam-forming electrodes must be precisely located and aligned, preferably within one-thousandth of an inch. Furthermore, this accurate alignment must be maintained for many thousands of hours of operation in spite of the fact that the grids and cathodes operate at temperatures above the melting point of many commonly used metals.

A view of a portion of the extensive parts fabrication facilities at Lancaster.

NEW CONSTRUCTION TECHNIQUES

Literally dozens of new techniques were developed for use in super-power tubes. For example, the cathodes are trapezoidal rods of thoriated tungsten having enlarged heads at either end. These precisely shaped heads hook into "v"-grooves in copper supports which position the cathodes and supply heating current for them. Because the cathodes can be mounted in the "v"-grooves at any time, pre-processing operations such



Large hydrogen furnace speeds super-power tube fabrication. In brazing operations, tube structures, held by fixtures, are placed under the large bell which is then filled with hydrogen to keep the parts clean. The furnace enclosure is heated to 2000°F to fire the parts.

A dramatic view of a portion of the immense power supply facilities. Regulated voltage from 2 kilovolts to 40 kilovolts can be obtained. One unit, a grid-controlled rectifier, supplies up to 4 megawatts of continuous d-c power. Another rectifier supplies up to 5 megawatts continuous d-c power operating up to a maximum voltage of 40 KV. Each rectifier features a provision to switch voltages under test.

A view of the super-power tube assembly area, called the "white room." Temperature, humidity and dust are carefully controlled to insure constant conditions for tube assembly.

as carburization and straightening can be completed before the cathodes are mounted in the finished tube. A short constriction is provided between the body of the cathode and the enlarged head to increase the electrical and thermal resistance so that substantially uniform temperature is insured over the entire length of the cathode body.

The cathodes are rolled from centerless-ground thoriated-tungsten rods. Long lengths of rods are carefully straightened, cut to shorter lengths, and then formed into finished cathodes in a series of punch-press operations. During these operations, the "brittle" tungsten is white hot and is in a non-oxidizing atmosphere. The grid rods are formed in a similar manner, but are made of pure tungsten.

A natural question which arose concerning the feasibility of the hook-in cathode mounting was whether it would pass 50 amperes or more of heating current without welding fast. Early doubts were quickly dispelled by tests on a round tungsten wire bent into a hook and inserted in a hole drilled in a copper block. There was no sparking, local heating, or tendency to stick.

Thermal expansion of cathodes and grids is accommodated by the use of a pantographic tensioning device for each individual cathode and grid which makes one of the "v"-groove mountings movable in the longitudinal direction. Bowing of the filaments during expansion and contraction is avoided by a combination of the "hinge" action of the head in the "v"-groove and the relatively small amount of "rocking" action inherent in the pantographic device. The pantographic members comprise a stack of thin strips bonded together at each end for a precisely determined length. The bonding process is accomplished by low-temperature gold-to-copper solid diffusion. In the case of the cathode pantograph, foil-like copper laminations are used for utmost flexibility and current-carrying capacity. After diffusion, the bonded ends appear to be one solid block of copper under metallurgical examination.

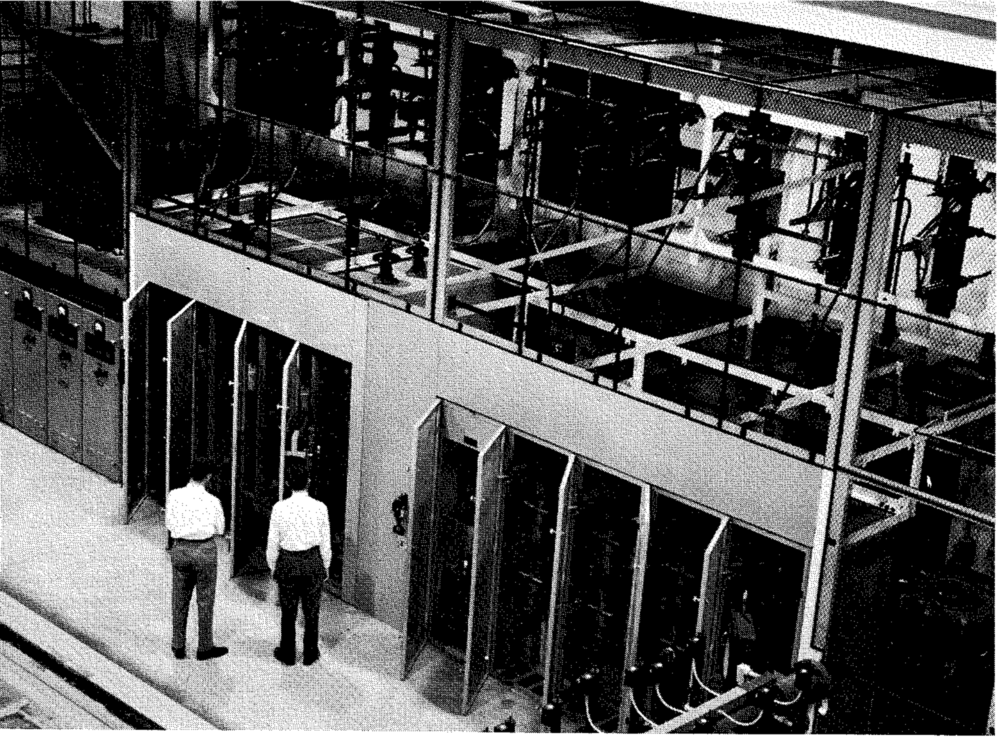
48-ELEMENT TRIODE

A "model" triode was built to evaluate the performance of the unit triode under radio-frequency conditions and to determine the number of beam-forming units needed to achieve the one-megawatt goal. This "model" triode used 48 basic units having a beam-forming-electrode diameter of about three inches, which was the smallest size consistent with good filament pantograph design. This size also permitted use of copper anodes having an inner diameter of four inches, Kovar sheet, and glass cylinders on hand for making conventional power tubes. The copper beam-forming cylinder located inside the cylindrical cathode array was water-cooled to minimize mechanical deformation and misalignments due to thermal expansion.

In order to expedite engineering development changes, the enclosing vacuum-envelope was made of precision ground insulating spools joined together by demountable copper-gasket seals. The insulating spools were formed of two hardened-steel-flanges joined to opposite ends of a glass tube by strong Kovar seals. Bolts of special steel between adjoining flanges maintained vacuum-tight sealing pressure on the copper gaskets.

"Tube-circuit" aspects of this "model" triode were well conserved because the "leads" to the three electrodes were actually conducting surfaces extending continuously around the tube periphery. Consequently, paths having extremely low radio-frequency impedance were provided between the active electronic structure and external circuitry. This "model" triode later became the commercial RCA-5831, which is rated conservatively at 500 kilowatts cw output, but will easily develop one megawatt of power when an anode voltage of 20,000 volts is used.

The story of the RCA-5831 is an



interesting example of the manner in which plans and objectives may change during a long-term development. As the first "model" triode was being built, the Engineering Products Division at Camden was bidding on a contract for a one-megawatt very-low-frequency transmitter for the U. S. Navy. The Camden engineers became enthusiastic about the possible use of this tube for the new super-power transmitter, and asked the Electron Tube Division to develop this size of tube instead of the larger tube originally visualized for one megawatt super-power broadcast service. Evaluation tests proved the 48-element triode to be satisfactory, and the U. S. Navy became the first customer for super-power tubes when they purchased RCA-5831's for their new "Jim Creek" transmitter. Original tubes built for this transmitter in 1949 are still in service after some tens of thousands of hours of operation.

The Atomic Energy Commission later ordered a number of RCA-5831 tubes to power a huge linear-accelerator. In this application, each tube developed a power output of about one megawatt as a grounded-grid (cathode-drive) amplifier self-driven from the accelerator cavity.

Continuing electron-optical studies resulted in the development of a new triode concept known as the shielded-grid triode, or more commonly, shielded-triode. A grounded shielding electrode was interposed between the grid and plate electrodes, thereby minimizing the feedback capacitance. This internal shielding permitted a system of electronic configuration such that a triode tube could be operated at high frequencies in grounded-cathode (grid-driven) service without neutralization. The RCA 6949 is the culmination of the work on the shielded-grid concept. This generic class of tube is providing radio-frequency power for the giant Bevatron and HILAC atom-smashers at the University of California. More recently, the Signal Corps has announced the use of this tube in its "World Spanner" short-wave transmitters.

CERAMIC SEALS

The radial compression ceramic seals[1] used on many RCA super-power tubes were developed to meet the need for low-loss vacuum-seals suitable for operation in the UHF range. Conventional glass-to-metal seals became too hot even when forced-air cooling was used. The radial compression seal remains relatively cool because there is direct contact between the high-conductivity copper conductors and the insulating member without the presence of intermediate high-resistance oxides or other semiconductor layers. The necessary mechanical compressive force is obtained from hoop-tension in the strong metal band into which the ceramic insulator is pushed. The resulting radial compressive force is localized in a narrow region so that the unit stress is sufficient to cause plastic flow of the metal and thus provide a vacuum-tight seal. An unusually strong aluminum-oxide ceramic is the base for the insulating member. The metal cup or band is usually made of copper-plated high-strength tool steel or Inconel alloy.

A different form of the compression seal is used in a new developmental UHF triode. In this tube, the vacuum envelope is formed by a series of alternate metal and ceramic rings interspersed by copper gaskets which form the vacuum seals. The necessary axial compressive force to maintain the vacuum seals is supplied by a bolt in the center of the tube. This center bolt is a heat-treated steel rod, having a diameter of about one inch and a length of approximately eight inches. The required stress causes this rod to stretch elastically approximately $\frac{1}{64}$ of one inch to maintain the vacuum seals during high-temperature bake-out and subsequent operations.

DOUBLE-ENDED CONSTRUCTION

This developmental triode is a "double-ended" tube, i.e., both input and output-circuit terminals are located at both ends of the tube. This construction permits higher power output to be obtained at higher frequencies because the electrical length of the active structure may be twice that feasible with conventional tubes. For example, a conventional single-ended tube designed for operation at 1000 megacycles has an active length of less than one inch. If, figuratively speaking, the tops of two such tubes are cut off and the tubes are butted, a double-ended tube is formed having twice the power capability of one single-ended tube. Elimination of the "dead-head" capacitance of the inside end of the single-tube structure results in further improvement. Other design features of this double-ended tube are covered in detail in an article by J. R. Fendley.[2]

The use of double-ended construction in another developmental tube more than doubles its maximum op-

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[1] Described in the article entitled "Development of the Radial Compression Seal" by I. E. Martin and A. C. Tunis.

[2] Described in the article entitled "A 100 Kilowatt UHF Triode" by J. R. Fendley.

erating frequency. This super-power shielded-triode is capable of delivering an output of hundreds of kilowatts at operating frequencies higher than 200 megacycles.

The double-ended circuit principle is also being used in a more powerful developmental triode which can deliver peak power outputs of 5 to 10 megawatts at 500 megacycles under pulse conditions, with an average power of several hundred kilowatts. This new tube employs 96 individual triode sections. It also uses radial compression vacuum seals on the 11-inch-diameter ceramic output insulators.

UHF TETRODES

A number of unconventional tube techniques have been developed for application in UHF tetrodes. For example, the RCA 6181, a one-kilowatt UHF tetrode[3] employs one-piece copper control grids and screen grids made by the Uniskan extrusion process,[4] which comprises a simple rolling operation followed by an acid etch. In the RCA-6448, the anode is located at the center and cathodes are arranged in a circular array facing inward. This 15-kilowatt UHF tetrode[5] also employs unit electronic structures, hook-in cathodes, and water cooling of internal structural supporting members and electrodes.

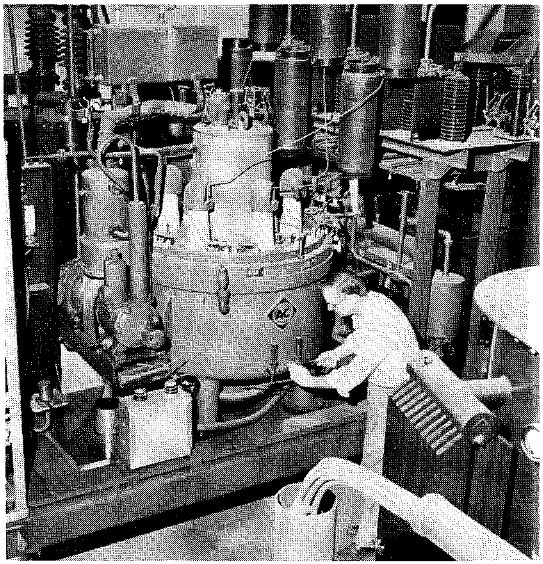
An improved version of the 6448, the RCA-6806, is capable of twice as much output. A developmental tube of the same family is designed to operate at frequencies up to at least 900 megacycles in pulsed amplified service. It can deliver 200-kilowatt pulses of several milliseconds duration in UHF applications.

All of the tubes discussed thus far use directly heated thoriated-tungsten cathodes. For high-power radar applications using pulse lengths up to at least 10 microseconds, a tube employing an oxide-coated cathode has been developed.

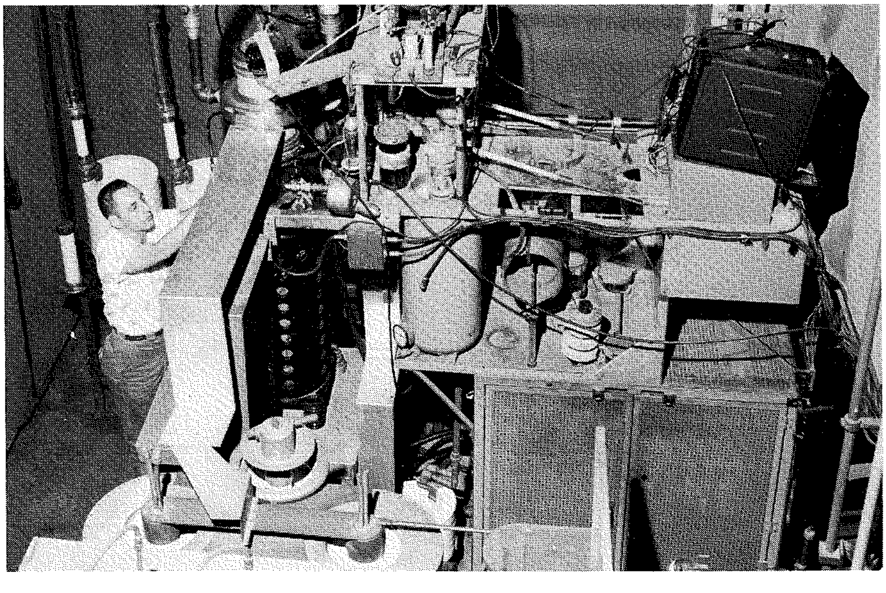
This tube, the RCA-6952, can deliver an output of 750 kilowatts in high-gain pulsed radar UHF amplifiers. The cathode employs a matrix-oxide type of emitting surface on a directly-heated base metal.

MECHANICAL LABORATORY

Extensive facilities have been built up over the years to develop, evaluate, and manufacture super-power tubes. An important facility is the fine machine shop, more properly called a "mechanical laboratory," which is manned by skilled craftsmen who cooperate with the tube-design engineers in their efforts at practical creativity. The precision mechanical techniques developed have formed the foundation of successful super-power tubes. The processing and high-vacuum techniques used by super-power tubes represent a considerable advance in the art. Facilities developed for testing multi-megawatt tubes are believed to be the only ones of their kind in the world. Two huge power supplies which have been installed for supplying plate power to the test sets have continuous power ratings of two and five megawatts, respectively. Several complete television transmitters are also available for testing of the uhf television types.



A super-power mercury-pool rectifier is adjusted by technician C. S. Geiger in the test activity.



One of the test cages in the super-power tube activity is shown with technician George Hockenbrocht making final adjustments on a tube under test.

ACKNOWLEDGEMENT

The numerous features and techniques incorporated in super-power tubes represent the contributions of many capable and hard-working engineers, technicians, and craftsmen, all working together as a team. Their products have found applications in a wide variety of services, evidence that the super-power tube age has arrived.

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[3] W. P. Bennett and H. F. Kazanowski, "One-Kilowatt Tetrode for UHF Transmitters," Proc. IRE, Vol. 41, p. 13, January, 1953.

[4] W. N. Parker, "Dull-Press Extrusion Cuts Cost of Thin-Wall Parts," Iron Age, March, 1953.

[5] W. P. Bennett, "A 15-kw Beam Power Tube for UHF Service," RCA Engineer, Vol. I No. 1, June-July, 1955.

DEVELOPMENT OF THE RADIAL COMPRESSION SEAL

By
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Electron Tube Division
Lancaster, Pa.

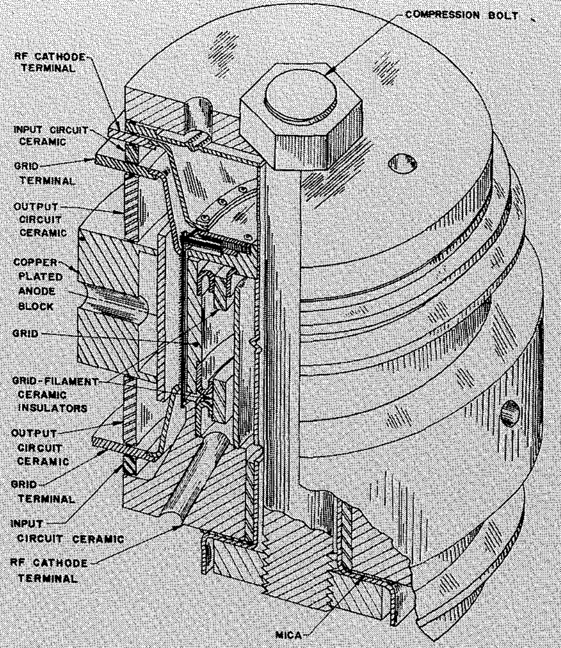

Fig. 1—Isometric view of a 100-KW UHF TV triode

THE ENVELOPE OF an electron tube is the vacuum-tight enclosure surrounding the internal elements. It serves four basic functions: 1) as a barrier against the atmosphere, 2) as an insulator for the various voltages required by each element, 3) as a passageway for the r-f energy through its "windows," and 4) as a structural member. The relative importance of each function depends upon the type of tube and its application. In most receiving tubes the main function of the envelope is to serve as a vacuum enclosure; however, as power and frequency increase, the other functions assume greater importance. In superpower tubes, the tube and envelope contain a major portion of the circuit, and as such, place stringent demands upon the tube designer.

SEAL AND WINDOW REQUIREMENTS

Glass, which until fairly recently had served as the only material for insulation and window in the envelopes, has several disadvantages. *First,* it is comparatively fragile and fractures easily when subjected to thermal or mechanical impact. *Second,* matched expansion alloys are required at the glass-to-metal seals to avoid destructive stresses. These alloys are extremely poor thermal conductors and may present heat-transfer problems at high power. *Third,* the glass-to-metal joint presents a high-resistance interface to the high-frequency currents passing through the "window." *Fourth,* the dielectric loss within the glass becomes excessive at high frequencies and at high power. Its poor thermal conductivity cannot carry the resultant heat away rapidly enough and the glass "sucks in" due to softening.

It is to overcome these limitations that the metal-to-ceramic radial compression seal has been developed. This seal is mechanically executed between ceramic and metal and requires no high temperatures or evidenced chemical reactions. Through its use the following advantages are gained. 1) Because high-strength alumina ceramics are used, an extremely rugged assembly results. 2) This strength plus the elasticity of the metal member greatly reduces the need for matched expansion alloys. 3) The ceramic has very low dielectric loss and a much higher thermal conductivity than glass. 4) The ceramic-to-metal joint presents a pure metallic interface to the r-f currents.

EARLY USE OF CERAMICS

The early technique of making metal-to-ceramic seals consisted of sintering molybdenum or tungsten powders on the ceramic at a temperature of approximately 1400 degrees Centigrade, and later brazing a metal support to the coated ceramic. In large sizes, high-temperature firings result in a severe distortion of parts, and the tube designer is confronted with the problem of stresses resulting from differing thermal-expansion ratios of components. Moreover, high-loss interface, which is a result of the metalized ceramic coating, has been found by previous investigations at the University of Illinois* to have a resistance equivalent to that of Nichrome. This high resistance can cause seal heating during tube operation with a resulting loss of power. It is obvious that a seal with a pure metallic interface was desirable.

AXIAL COMPRESSION

The first attempt to make a purely mechanical seal that did not involve heating or a high-loss interface utilized high-strength alumina ceramic rings and metal flanges of the same physical dimensions stacked alternately on a tube, with small copper gaskets between them. Steel studs were used to supply the necessary force, and vacuum seals were attempted. Valuable information was obtained from this venture, but the need to simplify envelope construction was apparent, because 1) massive steel back-up rings were necessary for the uniform loading of the ceramic, and 2) the time-consuming stud-tightening procedure presented a severe assembly problem.

A method of using one stud through the center of the envelope structure to supply the force for the seals was soon

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* Electrical Losses in Ceramic to Metal Seals; E. W. Ernst and O. T. Puol; Electrical Engineering Research Laboratory; University of Illinois.

Fig. 2—A. C. Tunis is shown with two ceramic-to-metal seals. On the left is a coaxial seal and on the right is a O.D. assembly

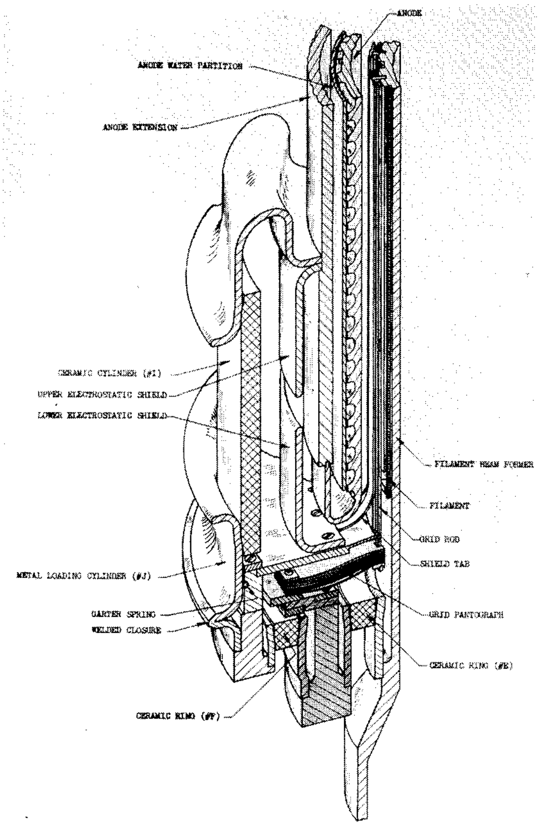

Fig. 3—Cross-section of a super-power shielded-grid beam triode

conceived. This method greatly simplified the entire design problems, and, for the most part, high-conductivity copper flanges were substituted for the steel flanges. This structure was considerably more attractive for a practical tube design. The developmental UHF triode† shown in Fig. 1, which utilizes this axial compression structure, presents a simplicity of envelope construction never before possible in super-power-tube types.

However, the center stud of the axial compression seal prevented adaptation of this seal to conventional super-power tube structures. For this reason it was thought desirable to replace the stud with radial force members which would be an integral part of the seal. This method consists of pressing a steel band on a ceramic so that the radial forces produce the vacuum seal.

RADIAL COMPRESSION

The radial compression seal may take two basic forms; the coaxial assembly or the outer-diameter assembly. Fig. 2 is a photograph of both types placed side by side. The coaxial assembly on the left consists of a seal on both the inner and outer diameters of a ceramic ring with the forces balanced so that the ceramic is always in compression. The O.D. assembly consists of seals on the outside diameter of both ends of a ceramic cylinder. Both seals are incorporated in the super-power shielded-grid beam triode shown in Fig. 3 in cross-section. The output ceramic in Fig. 3 has an 8.36-inch outside diameter; a tube currently under development employs a 10-inch outside diameter cylinder.

In Fig. 4 an outer-diameter seal is illustrated and the primary sealing forces are shown. It can be seen on the left side of the figure that the outside diameter of the ceramic is larger than the inside diameter of the metal. The seal is made by an initial force, which may be as high as 20 tons applied along the axis of the seal members; this wedging action then creates the radial sealing forces, F_r, as the interference fit deforms both metal and ceramic.

From a close-up view of the seal, in Fig. 5, it can be seen that force F_r is confined to a relatively narrow area of contact near the top of the taper. This high stress concentration creates plasticity in the copper plating, which fills or spans the ceramic surface irregularities so that a vacuum seal results. Although seals have been made without copper plating, high surface conductivity and greater reliability is achieved if copper or a similar ductile metal is used as an interface.

EXPANSION AND ELASTICITY

The choice of materials is important because their mechanical properties must serve a definite function. The force members must not only maintain force on the ductile interface at room temperature, but throughout the temperature cycling required in processing and tube operation.

Fortunately, the high-alumina ceramics have very good electrical properties and their mechanical properties are the best available to date. They have a compressive limit above 250,000 p.s.i., which is stronger than that of many steels. Unfortunately, the ceramic has a low expansion rate, and metals with a matched expansion rate have very low thermal conductivity and a low strength. It can be shown, however, that the elasticity of the metal can be made to compensate for the expansion differential. Although this factor permits the use of a high-thermal-conductive metal such as beryllium copper in this particular application, a high-hot-strength tool steel was used for the metal rings.

The use of the elasticity to compensate for expansion differential during the temperature cycle might be understood more easily by visualizing two series springs in compression, one spring representing the ceramic elasticity, the other that of the metal. Consider the case in which the ring of high-expansion material, the metal, has the larger diameter (see Fig. 3). It then can be seen that the sealing force decreases as the temperature increases. Obviously the stored compression must be greater than the strain reduction resulting from expansion mismatch and temperature range. The requirements can be determined from:

$$S_c + S_m - \Delta T \, \Delta C = S_b$$

$$S_c = \frac{P_c}{E_c} \text{ and } S_m = \frac{P_m}{E_m}$$

where:

S_c = Unit elastic strain in the ceramic in inches per inch.
S_m = Unit elastic strain in the metal in inches per inch.
E_c = Young's modulus of ceramic in p.s.i.
E_m = Young's modulus of the metal in p.s.i.
ΔT = Temperature difference in degrees Centigrade.

I. E. MARTIN, Engineer in the Large Power Tube Development Activity at Lancaster, received his BS in EE from Tulane University in 1950. He joined the Radio Corporation of America in 1950. Mr. Martin is a member of Tau Beta Pi.

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† See "A 100-KW UHF Triode" by J. R. Fendley in this issue.

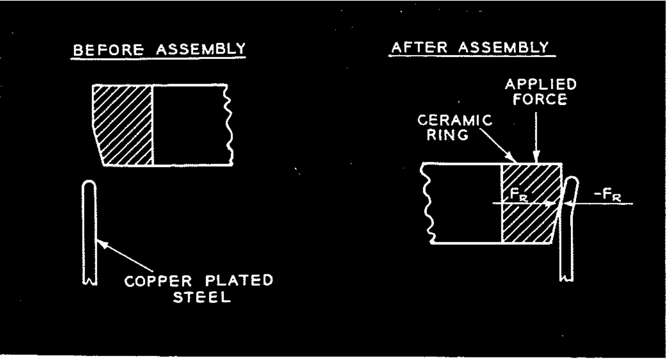


Fig. 4—A radial compression seal

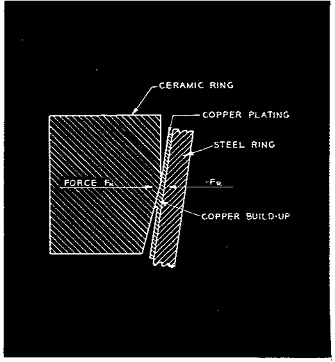


Fig. 5—An enlarged cross-section of a radial compression seal

ΔC = Expansion difference.
S_b = Min. value of strain in inches per inch.
P_o = Elastic stress of the ceramic in p.s.i.
P_m = Elastic stress of the metal in p.s.i.

These equations show that the higher the strains, with their resultant stresses, the greater the permissible mismatch in expansions.

It should be emphasized here that only elastic strains are being considered; the plastic strains can be used to increase the tolerances on parts, but serve no function during the temperature cycle.

STRESS

The stress condition within the members requires careful consideration, particularly in cylinders where the radial strain results in longitudinal as well as other stresses. These relationships can be obtained in any good stress-analysis handbook such as *Roark's Formulas for Stress and Strain.*‡ Even though tensile stresses are not as critical with high-alumina ceramics as with most other ceramics, it is still desirable to avoid them. The stress due to longitudinal bending of a cylinder can be particularly bothersome, and it may reach a maximum an inch or more away from the point of contact. However, all of these stresses can be minimized through the proper choice of parameters.

Once the materials have been chosen, the primary stresses, circumferential tension and compression, can be put in the form of the curves shown in Fig. 6. This family of curves can be made by equating the expressions for the radial forces.

$$\frac{K_c}{4\sqrt{l-r_c^2}}\,E_c(\Delta R_c)\left(\frac{t_c}{R_c}\right)^{3/2} = \frac{K_m}{4\sqrt{l-r_m^2}}\,E_m(\Delta R_m)\left(\frac{t_m}{R_m}\right)^{3/2}$$

where:

Subscript *c* denotes values for the ceramics,

Subscript *m* denotes values for the metal,

Units are in pound and inches.

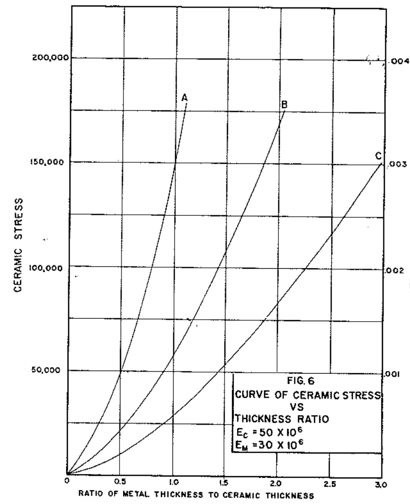
E = Young's Modulus
t = Wall thickness
R = Mean radius
r = Poisson's ratio
K = constant (dependent on locus or position of loading)

Manipulation produces the following expression:

$$\frac{S_c}{S_m} = \frac{E_c(\Delta R_c)}{E_m(\Delta R_m)} = \frac{K_m}{K_c}\,4\sqrt{\frac{l-r_c}{l-r_m}}\left(\frac{R_c}{R_m}\right)^{1/2}\left(\frac{t_m}{t_c}\right)^{3/2}$$

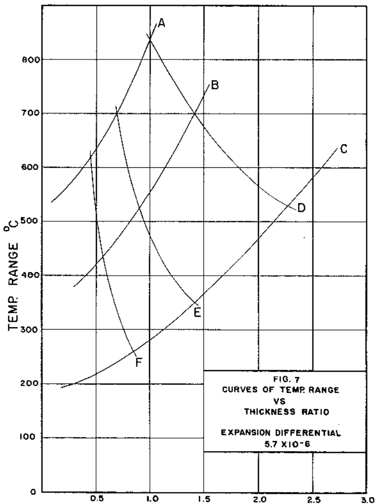
For each stress condition in the metal, therefore, a curve is obtained relating the ceramic stress to the ratio of thicknesses. Usually the stress conditions of the metal can be approximated from the strength of the metal and the interference between the members, so that a thickness ratio can be selected which will maintain a safe level of ceramic stresses.

An additional family of curves can be plotted from these stress curves if the expansion differential is known. These curves are given in Fig. 7. With these curves and a knowledge of the stress condition of the metal, the approximate temperature range can be determined from the thickness ratio.



CURVE	STRESS IN METAL P_M	STRAIN IN METAL S_M
A	150,000	.005
B	60,000	.002
C	30,000	.001

Fig. 6—Curve of ceramic stress vs. thickness ratio



CURVE	STRESS IN METAL P_M	STRAIN IN METAL S_M
A	90,000	.003
B	60,000	.002
C	30,000	.001
CURVE	STRESS IN CERAMIC P_C	STRAIN IN CERAMIC S_C
D	100,000	.002
E	50,000	.001
F	25,000	.0005

Fig. 7—Curves of temperature range vs. thickness ratio

CONCLUSION

The radial compression seal described has provided a very useful building block for the construction of super-power tubes, and can be used for other applications requiring a metal-to-ceramic joint. The seal is rugged, presents a pure metallic interface to r-f currents, and utilizes a high-thermal-conductivity ceramic which has a very low dielectric loss. The seal is accomplished at room temperature by purely mechanical means, requiring only a hydraulic press. Reproducibility during manufacture is relatively easy to achieve.

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‡ *Formulas for Stress and Strain*, 2nd Edition, Roark, Raymond J., McGraw Hill Publishing Company, 1943.

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A DEVELOPMENTAL 100-KILOWATT UHF TRIODE

by

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Large Power Tube Development
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IN RECENT YEARS, the growth of uhf television broadcasting has emphasized the demand for tubes capable of delivering power outputs in the order of 100 kilowatts at frequencies above 500 megacycles per second. Although the use of long-transit-time devices such as klystrons and magnetrons was considered for such applications, experiments showed that a high-power grid-controlled tube was not only feasible, but advantageous in most respects.

DESIGN CONSIDERATIONS

The basic design selected to satisfy the power and frequency requirements of uhf broadcasting was a high-mu triode in which the grid and grid terminals form an internal shield between the plate and the cathode. This design can be used without neutralization in "grounded-grid" circuits, in which the input signal is inserted in the space between cathode and grid terminals and the power is taken out from the space between plate and grid terminals. Connections are made to the resonant coaxial cavities through low-inductance terminal rings.

JAMES R. FENDLEY, JR. graduated from St. Mary's University, San Antonio, Texas, in 1952. He received a B.A. degree with Major in English. After serving two years as an artillery officer, he returned to St. Mary's for courses in physics and mathematics. In September, 1955, he joined RCA as a specialized trainee. Since January, 1956, he has worked at Lancaster in Large Power Tube Development.

A double-ended construction was considered desirable so that voltage maxima could be located at or near the center of the electronic structure (active length) of the tube. Fig. 1 shows r-f voltage and current standing-wave patterns for both single-ended and double-ended tube-and-circuit combinations. When a double-ended tube and circuit are used, the fundamental resonance in the desired TEM mode is a half-wave length rather than a quarter-wave length. Consequently, the active region of the tube can be made several times longer than that of the single-ended tube, and unit-area heat-dissipation and emission requirements are reduced accordingly.

Heat-dissipation and emission requirements are also dependent on the size or area of the tube and hence are a function of tube diameter. An increase in the diameter is advantageous at least until the circumference approaches the wavelength. If the circumference equals or exceeds the wavelength, the preservation of electrical circular symmetry may become a problem because modes other than the desired TEM mode may be excited.

DESCRIPTION OF TUBE

A developmental uhf triode incorporating the basic design principles discussed above is shown in Fig. 2 and in cross-section in Fig. 3. This tube is designed to deliver a power output of 75 to 100 kilowatts at frequencies up to 900 megacycles. The electronic structure of the tube is slightly more than two inches long, and the average diameter is about three and one-half inches. The two identical grid terminals, which are symmetrically located with the r-f output ceramic insulators and the plate between them, have a diameter of 5.6 inches. On the far side of each grid terminal, away from the center plane of the tube, are the r-f input insulators. The two r-f cathode terminals, which are situated beyond the input insulators, have a diameter somewhat smaller than that of the grid terminals.

As shown in Fig. 2, the output wave space of the tube is symmetrical about the mid-plane of the plate. At the r-f input terminals, however, some departure from symmetry is made so that both filament connections may be located at one end of the tube. The concentric filament terminals also carry liquid in and out of the tube to cool the grid and the cathode supporting structure.

The electronic structure of this developmental triode is shown in the exploded view of Fig. 4. The grid-cathode assembly is shown at the bottom of the photograph, then the r-f input insulator, the grid terminal, the r-f output insulator, the envelope vacuum-seal gasket, and at the top the plate assembly with its water fittings.

In this tube, 48 unit triodes are arranged in a circular formation suitable for coaxial circuitry. A close-up view of the grid-cathode assembly is shown in Fig. 5. Each of the thoriated-tungsten cathode ribbons is suspended in a slot milled in the copper "grid block" which forms the support structure for all the units. The one-piece tungsten grid is wound around this

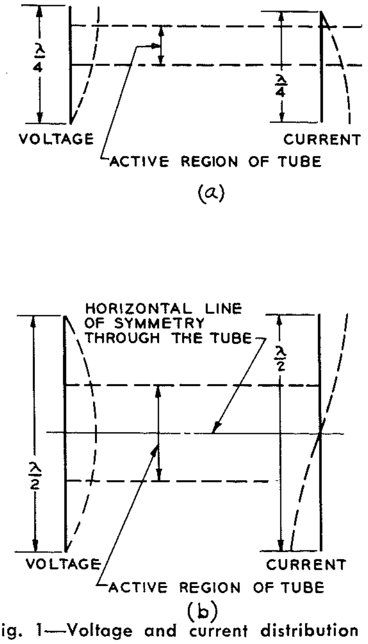

Fig. 1—Voltage and current distribution patterns for (a) single-ended and (b) double-ended tube-and-circuit combinations.

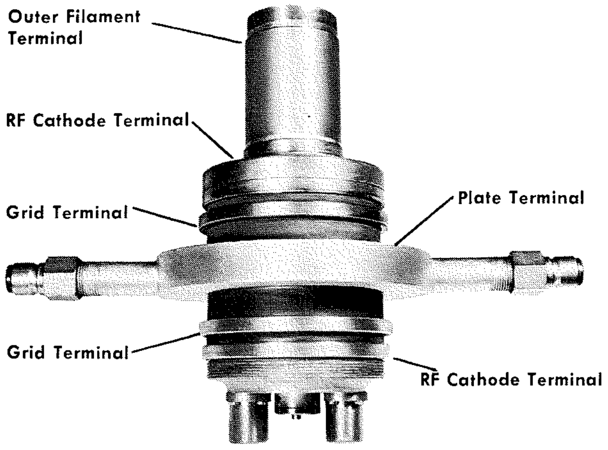

Fig. 2 — Photograph of developmental uhf triode.

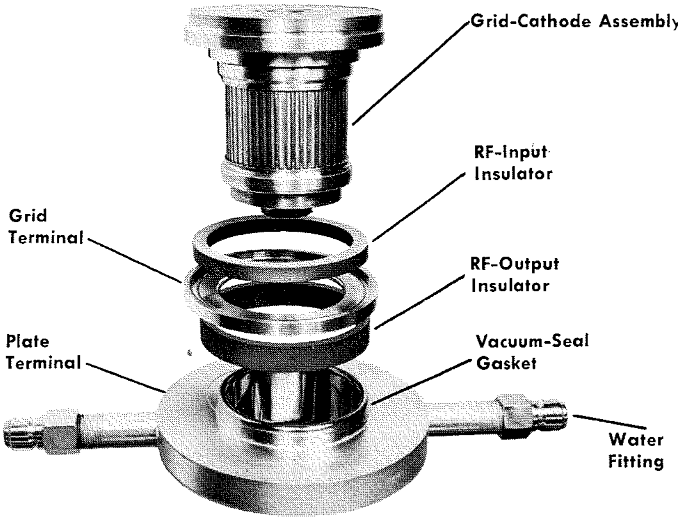

Fig. 4—Exploded view of developmental uhf triode.

grid block in intimate contact with its integral fins. The grid wire, which has a diameter of 0.0033 inch, is wound at a pitch of 72 turns per inch, providing approximately 14000 thermal-conduction paths from the grid to the liquid-cooled copper block. This grid design effectively overcomes the problems of excessive grid temperature or grid dissipation.

Because the cooling liquid for the grid-cathode assembly flows across the grid-cathode mount insulators, as shown in Fig. 3, a non-electrolyte liquid must be used to avoid electrolytic damage when grid-bias voltage is applied.

CATHODE DESIGN FEATURES

The ribbon-type cathodes used in this developmental triode have a trapezoidal cross section. Like the cathodes used in other RCA super-power tubes, they incorporate "lead corrections" which compensate for heat-conduction losses to the cathode-support structure. As shown in Fig. 6, part of the cross section is clipped off at each end of the cathode to raise the resistance at the ends and provide a nearly flat temperature distribution across the active length at the operating temperature.

The use of this "lead-correction" technique is possible because each cathode is pre-processed before insertion in the grid-cathode mount. Consequently, no "flashing" of the cathodes at high temperature is required after the cathodes are installed, and there is no danger of burnout at the lead corrections.

During processing, each cathode is carburized; i.e., a layer of tungsten carbide is formed on the surface. Various tungsten-carbide structures and methods for obtaining them have been discussed by Horsting.[1] The correlation between carbide structure and emission has been reported by Harbaugh.[2] When the processing is controlled so that the carbide is of the proper laminar structure, the cathodes provide up to three amperes electron emission current per square centimeter without "activation" as soon as they are raised to the operating temperature of 2000 degrees Kelvin.

Because the cathodes are pre-processed at temperatures much higher than normal operating temperature, units having weak crystal structure are eliminated before tube assembly. As a result, the completed tubes are more apt to give dependable performance. Super-power tubes using carburized thoriated-tungsten cathodes have had service lives exceeding 20,000 hours. Life experience and life predictions for carburized thoriated tungsten have been discussed by Ayer.[3]

CERAMIC SEALS

The envelope of the developmental tube employs ceramic-to-metal compression seals of the axial type.[4] Required sealing forces are provided by a tensioned center bolt. Copper or silver-plated copper gaskets are pressed directly against high-alumina-content ceramics, forming a high-vacuum seal without the use of high-temperature metalizing and brazing processes. This type of seal effects an abrupt transition from a good conductor to a good insulator, thus avoiding an interface which might have objectionable r-f resistance.

More conventional metalized ceramics are used for internal insulators within the grid-cathode mount. Because the surfaces of the grid-cathode mount are machined to close tolerances after these internal ceramic-to-metal seals are brazed, high-temperature-brazing distortions do not significantly affect the important grid-cathode spacing.

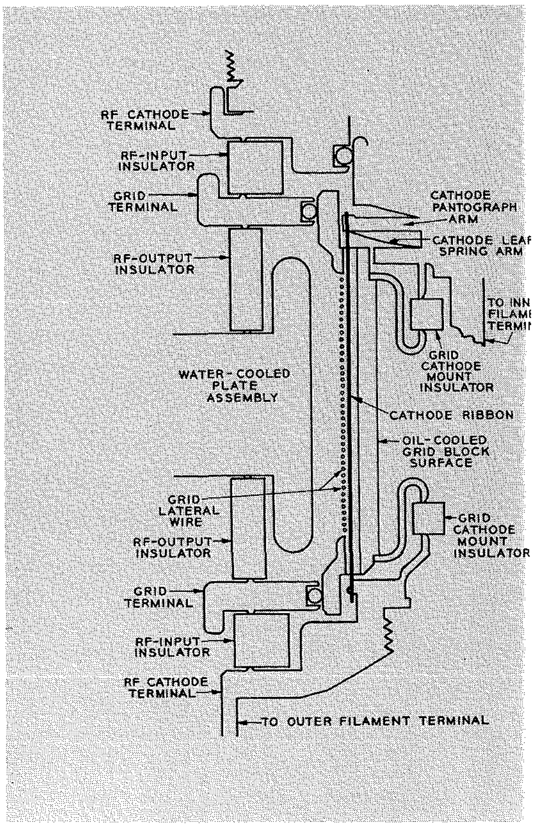

Fig. 3—Cross-section diagram of developmental uhf triode.

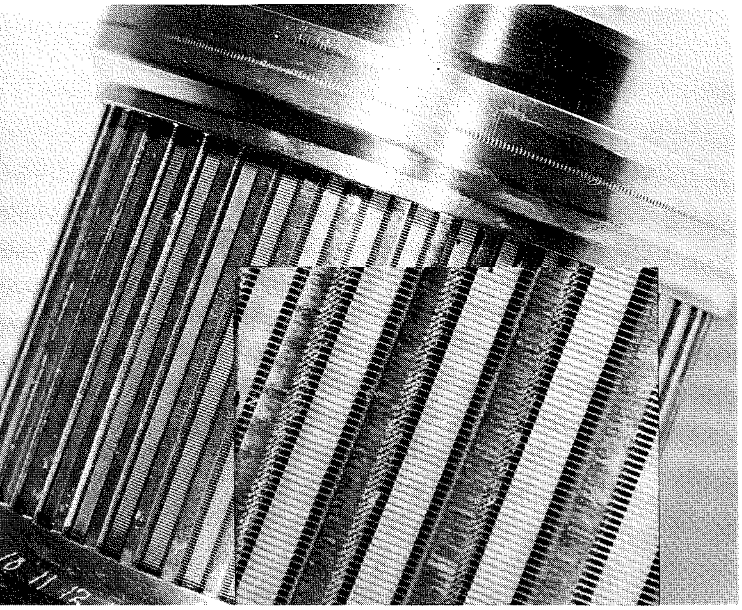

Fig. 5—Close-up view of grid-cathode assembly.

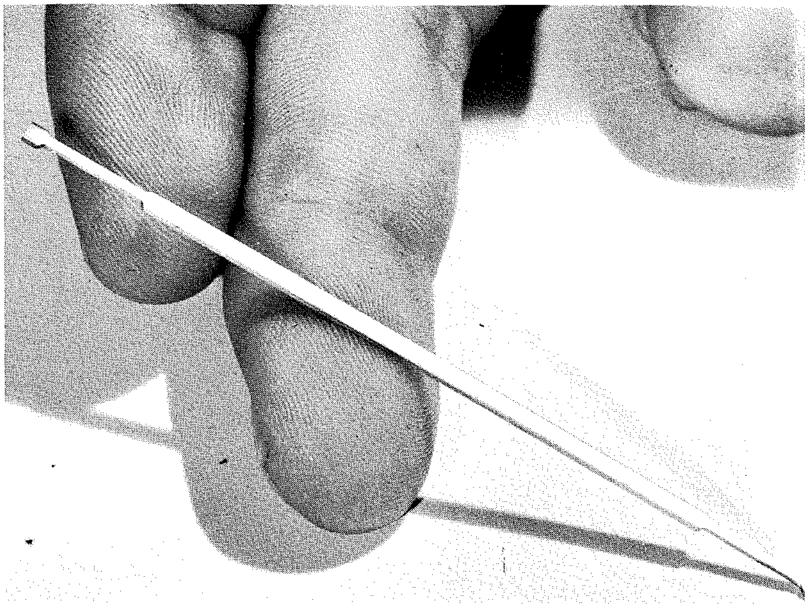

Fig. 6—Ribbon-type thoriated-tungsten cathode used in developmental triode.

TUBE PERFORMANCE

An experimental power amplifier using this developmental triode has delivered continuous power of 110 kilowatts at 540 megacycles and 60 kilowatts at 820 megacycles. Tube-and-circuit development for the amplifier were carried out simultaneously by the Broadcast Transmitter activity at Camden and the Power Tube Engineering activity at Lancaster.

ACKNOWLEDGMENT

The author wishes to acknowledge the contributions of numerous RCA engineers and development personnel to the project which resulted in the developmental uhf triode described in this paper. He does not wish to imply that the developments reported are his own.

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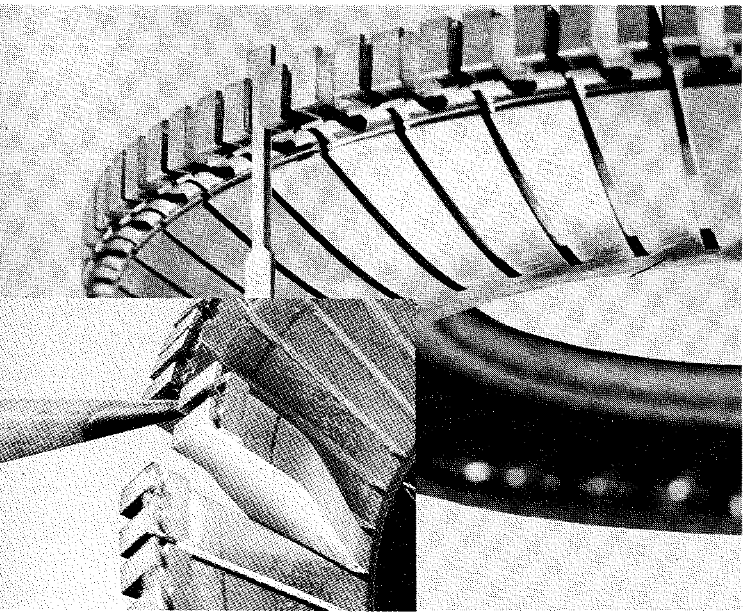
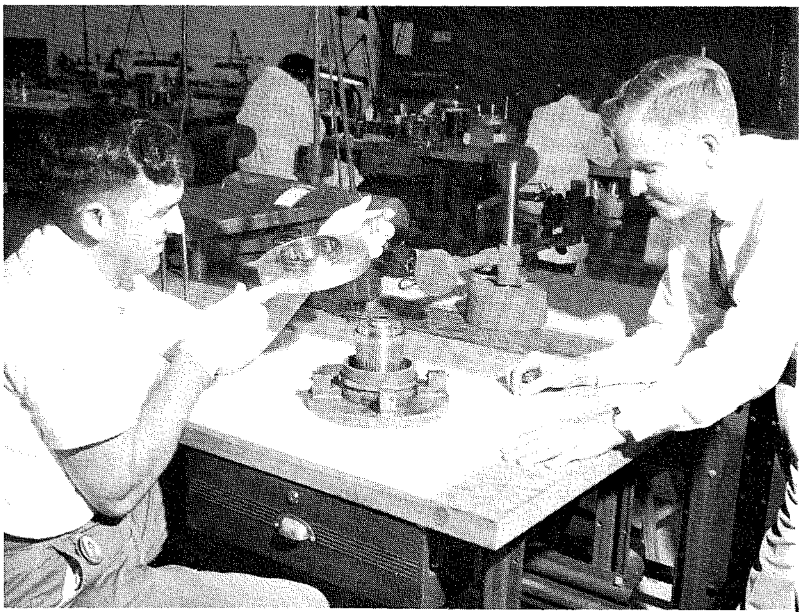
A. A close-up of a cathode inserted in its slot in the pantograph assembly. Notice the leaf-spring with its two "helper" springs, which maintains tension on the cathode. The inset shows the cathode pantograph with one arm deflected far beyond normal operating range. Notice how closely parallel the top surfaces remain. The pantograph has fifty-four chrome-copper laminations, held together by the solid diffusion of gold plating on alternate laminations.



B. Author watches progress of a developmental UHF triode "stack" as experimental tube builder, Veryl Herr, readies anode assembly.



By

LESLIE L. KOROS and M. WILLIAM DURIS
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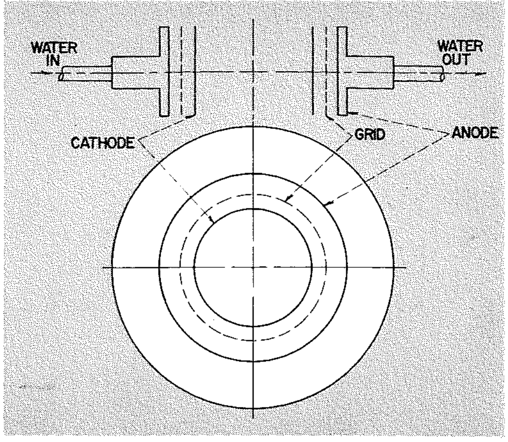

Fig. 1—Simplified Representation of the 100-kw, Double Ended Triode.

A 100-KW UHF AMPLIFIER*

Early in 1953 the RCA-6448 UHF beam power tube[1] and the TTU-12A broadcast television transmitter[2] development reached a goal of 15 KW visual power output in the ultra-high-frequency television band. This was the highest power obtained at ultra-high frequencies with a grid-controlled tube up to that time. The TTU-12A transmitter was rated for operation at 12.5 KW, peak-of-sync power, and together with a 20-gain antenna was capable of an effective radiated power (ERP) in excess of 200 KW. FCC rules, at the end of the freeze, permitted an ERP of 1000 KW. In order to reach this power level, elements of the TTU-12A transmitter were utilized to parallel two RCA-6448 tubes for a visual power of 25 KW[3], and one RCA-6448 tube for a sound power level of approximately 12.5 kilowatts. This combination, together with a 40-gain antenna system[4] permitted attainment of the 1-megawatt objective, and the first installation at WBRE-TV in Wilkes-Barre, Pennsylvania went on the air at the end of 1954. By incorporating design changes, the power handling capability of the RCA-6448 was considerably increased. This resulted in a new high-power tube, designated RCA-6806, capable of a peak-of-sync power output in excess of 25 KW. Thus, it became possible to achieve 1-megawatt of ERP with one RCA-6806 in the visual side of the RCA TTU-25B transmitter which was developed to use this new tube.

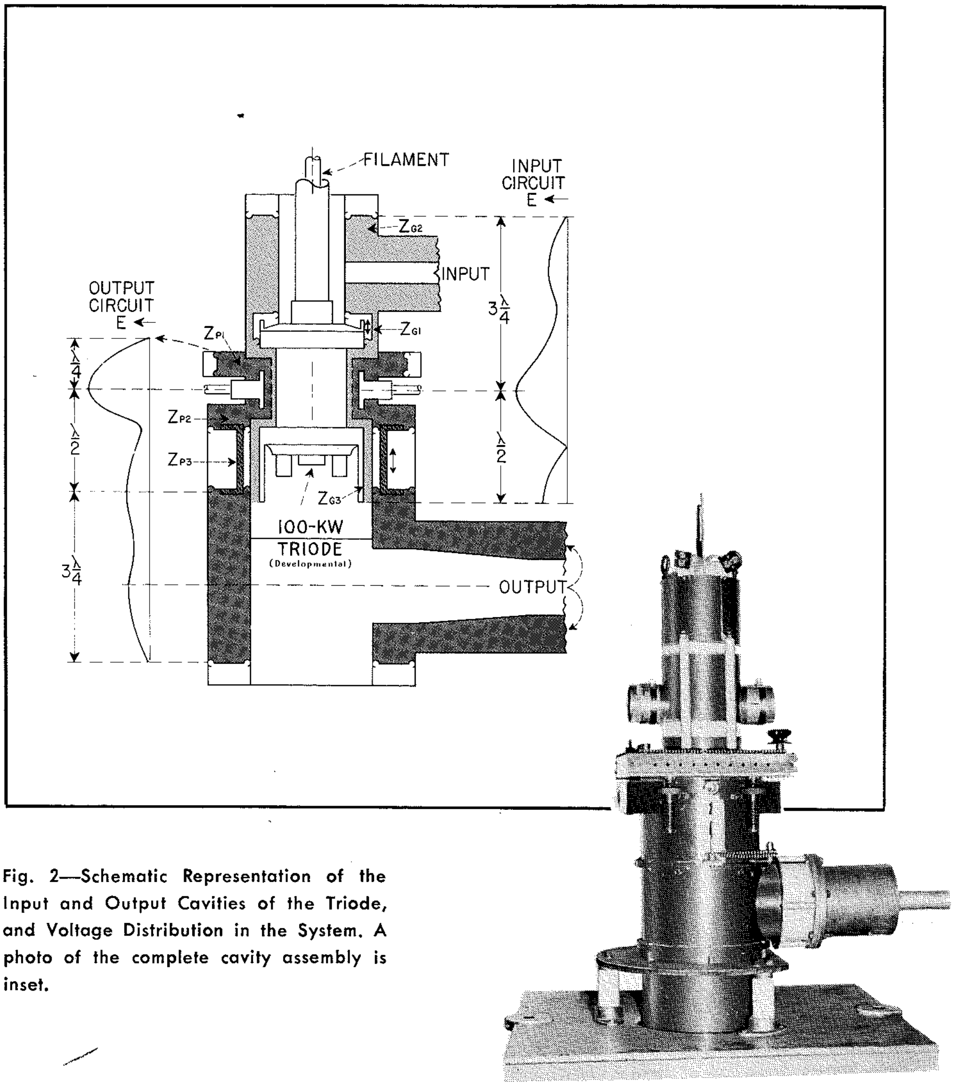

Fig. 2—Schematic Representation of the Input and Output Cavities of the Triode, and Voltage Distribution in the System. A photo of the complete cavity assembly is inset.

STILL HIGHER POWER NEEDED

It was predicted even before 1953, as a result of propagation studies[5], that much higher powers would be required for effective utilization of UHF for TV broadcasting. This prediction was substantiated by field experience in early UHF-TV installations and a program was begun to develop systems capable of still higher power output. The transmitter power output target was set at 50 KW, and the Electron Tube Division began the development of a tube for this purpose. Development of companion circuitry was carried out by Broadcast Transmitter Engineering, IEP.

100-KW TUBE—A COORDINATED EFFORT

Development of the tube and circuit progressed simultaneously with the objective of a higher power television transmitter. Fortunately, the concept

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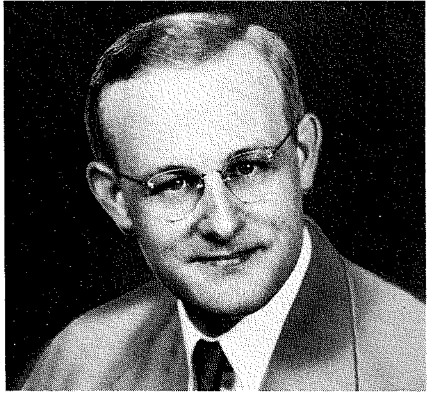
*Incorporated in a paper entitled "Developments in High-Power UHF Television", by J. E. Young, L. L. Koros and I. E. Martin, presented at IRE National Convention, N. Y. City, March 18-21, 1957.

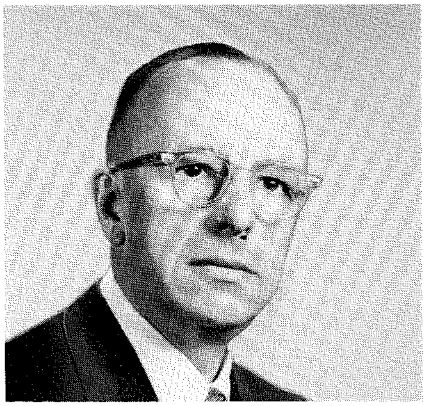


LESLIE L. KOROS received his Engineering degree from Royal Joseph Technical University, Budapest. In 1925, he joined a European associate of the I. T. & T. Co., and in 1932 became Managing Director of Stabilovolt Company within the same organization.

Mr. Koros joined RCA Victor Argentina Co. in Buenos Aires in 1943, as Chief Design Engineer of the Transmitter and Engineering Products Dept. In 1948 Mr. Koros transferred to Camden, and was in charge of developmental UHF transmitter projects using frequency controlled magnetrons, klystrons and grid-controlled tubes. He is Leader, Circuit Development, Broadcast Transmitter Engineering.

Mr. Koros is the author of 19 papers, has been granted more than 100 patents in different countries, and is a Senior Member of I.R.E.

M. WILLIAM DURIS received his B.S. degree from the University of Pittsburgh in 1952 and shortly thereafter joined RCA. Since his assignment to the Broadcast Engineering Group, his work has been in connection with UHF Broadcast Transmitters. He has done design work on the TTU-12A, TTU-25A, TTU-25B, and the 100-KW, UHF class B linear amplifier.



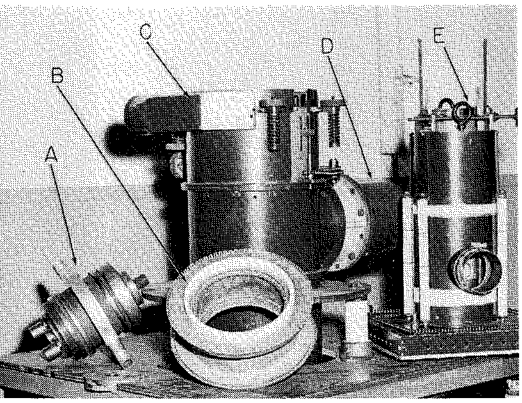


Fig. 3—Components of the Power Amplifier, (A) Double Ended Triode, (B) The Sliding Low Impedance Plate Tuning Section, (C) The Loaded Plate Cavity, (D) The 6"-75 ohm Output Line of the Plate Cavity, (E) The Excited Grid Cavity and the Unloaded Plate Cavity.

of the tube was based on a large margin of safety over the 50-kw transmitter power level which had been set with an ERP of 2 or 3 megawatts in mind. The need for still higher power became obvious as more UHF field experience was accumulated. When the FCC increased the permissible power level of UHF transmission to 5 megawatts, ERP, the power reserve built into the tube immediately became useful. Early in 1956 a transmitter built around the developmental tube was used in a test with an RCA 46-gain antenna. During this test a maximum ERP in excess of 8 megawatts was achieved. This high, peak-of-sync power was obtained by temporarily overloading the amplifier. However, no failures occurred.

The results obtained during this combined circuit-tube development and evaluation program have demonstrated that devices of this type can be used for a wide variety of high-power UHF applications. Among these are frequency modulated multiplex transmission, single-sideband transmission, or pulse transmission for radar services. Emission at this high-power level should be useful for long distance scatter communication. An experimental high-power, broadband amplifier for UHF has been constructed and can be refined into a product design for commercial or defense projects.

INPUT AND OUTPUT CIRCUITS

The construction of the double-ended triode is described by J. R. Fendley†, and some aspects of cavity design are described here. In the simplified sketch of Fig. 1, note that the tube anode is of annular construction with a water inlet and outlet pipe spaced 180° apart. The grid and cathode structures are cylindrical and located within the anode. The anode water cooling connections are shown in Fig. 1, but the internal cathode cooling path of the tube and the vacuum envelope are omitted. A double-ended tube requires two output and two input resonators, one for each end of the tube. Ideal operating conditions are attained when the r-f voltage has a maximum value occurring at the horizontal symmetry line in the grid-cathode and grid-anode resonators. The horizontal symmetry plane is at the water pipes in Fig. 1. Two plate cavities and two grid cavities are fitted to the tube for symmetrical operation.

CAVITY SYSTEM DESCRIBED

The principle of the cavity system used during development is presented in Fig. 2, which (in oversimplified form) contains all the important components except the d-c blocking condensers. Voltage distribution in the cavities and tube is shown qualitatively. The input and output circuits are indicated in a different gray tone in Fig. 2, with maximum input voltage at the center of the tube. Electrical grid-cavity length, from tube center to the short-circuiting plunger, is three-quarters of a wavelength. The cavity consists of a coaxial transmission line section of low impedance, Z_{G1}, and a high-impedance coaxial line section, Z_{G2}. Tuning is achieved by changing the effective length of Z_{G1}. An annular metal slug with contact fingers on both ends is the movable tuning element in the input. At the upper cavity end, a short-circuiting plunger terminates the coaxial input network; the position of the plunger controls input matching. In the 800-mc frequency region, the low-impedance section, Z_{G1}, is removed, and the tuning is controlled by the short-circuiting plunger. An additional matching device is inserted in the input line at this frequency region.

The lower grid cavity is a half-wavelength resonator, open circuited at the end of the Z_{G3} section. The internal plate cavity opening is relatively small in diameter, thus no radiation takes

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†See "Development of 100-KW UHF Triode" this issue by J. R. Fendley.

place at the open end of the grid cavity. The plate-cavity internal tubing acts as a waveguide below cut-off for the carrier frequency‡. The internal tube diameter, however, is not below cut-off for harmonics of the carrier. A metal sheet is applied to prevent harmonic radiation from the open-ended grid cavity.

Fig. 2 shows that the lower grid cavity end is a resonator without external excitation, and the upper grid cavity is an externally driven resonator. A similar philosophy applies to the plate cavity design. The upper plate cavity is an unloaded radial resonator, Z_{P1}, while the lower plate cavity is provided with a transmission line for external loading. The radial resonator was designed with a relatively high surge impedance and is tuned with four short-circuiting segments. The lower plate cavity consists of a coaxial high surge impedance transmission line section, Z_{P2}, and a very-low-impedance section, Z_{P3}. The Z_{P3} section is a teflon-filled coaxial transmission line. The impedances of Z_{P2} and Z_{P3} determine the output voltage at the end of the Z_{P3} section. Plate cavity tuning is accomplished by sliding Z_{P3} section into proper position.

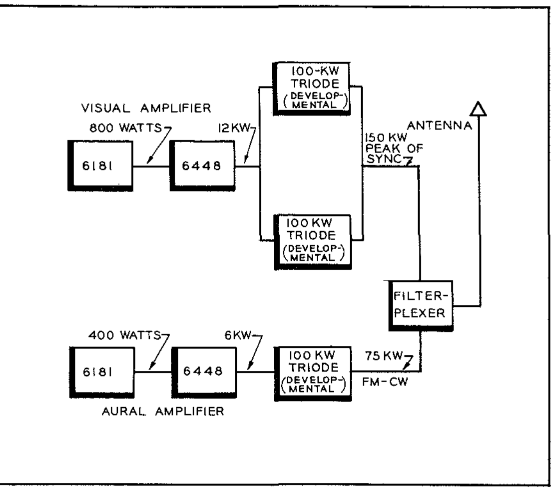

Fig. 4—Power-Tube Block Diagram for a Five Megawatt ERP UHF Television Transmitter.

The position of the short-circuiting plunger at the bottom of the plate cavity affects the resistance seen by the tube output, but has little effect on the resonant frequency of the cavity. The plunger acts as a bandwidth control.

In television transmitters, the application of a "trombone line" is advantageous in the input to improve the amplitude response at higher video frequencies. A good match of the input line can only be effected near carrier frequency. For side-band frequencies, a certain standing-wave ratio exists. By adjusting the input line length, several db of grid peaking is possible to give a flat overall frequency response.

For special applications, it may be required that the grid cavity bandwidth be considerably increased, for example to 20 mc, where the exciter line length becomes less important, since a reasonably good match occurs at sideband frequencies. In such cases, a swamping resistor can be applied in parallel with the grid cavity (see inset of Fig. 2). The grid cavity has two transmission line connections, one for r-f drive and the other for swamping. The radial plate cavity is located below the cavity, and the loaded plate cavity is at the bottom of the assembly. Fig. 3 photo shows the main components of the amplifier stage with the double-ended triode removed.

OPERATING CONDITIONS

Before applying power to the UHF high-power amplifier, certain preliminary adjustments are necessary by the "cold-probe" method. The two plate and two grid cavities must be resonated at the operating frequency to obtain a maximum voltage at the tube center. Also, the plate bandwidth should be adjusted to 10 mc, as measured at the —3 db points.

In the experimental transmitter, the driver for the 100-KW amplifier was the TTU-12A, a 12.5-KW, UHF television transmitter. The 12.5-KW stage was driven by the TTU-1B, 1-KW, UHF television transmitter[6]. The RCA-6181 tetrode in the TTU-1B visual transmitter is series cathode modulated. The TTU-12A utilizes an RCA 6448 beam power tube as a linear Class B, r-f amplifier. Both the TTU-1B and TTU-12A were used with about 10 mc plate cavity bandwidth when operated for picture transmission. The overall frequency response from the modulated stage up to the 100-KW power output was flat within one-half db over a 5-mc bandwidth. The specifications for monochrome and color transmission can be easily met with this transmitter. The phase versus amplitude distortion at the color subcarrier frequency is within a few degrees when the plate cavity of the amplifier is tuned exactly to the carrier frequency. The linearity requirements for color transmission will be satisfied when an RCA TA-9A stabilizing amplifier is used for the video input.

Test operation of the amplifier at 540 mc resulted in 110 KW-CW and in 80-KW peak-of-sync power. At 820 mc 60 KW-CW and 75 KW peak-of-sync power was obtained.

FUTURE PLANS

Fig. 4 block diagram shows the projected TTU-150A television transmitter for producing 5 megawatts ERP. Two 100-kw triodes would be operated in parallel for the picture transmitter to produce 150 KW peak of sync power, and a single triode used to deliver 75 KW of frequency modulated aural power. With this transmitter power, and a 50-gain antenna, the maximum ERP permitted by FCC can easily be obtained.

Several other projects are also under consideration to utilize the power amplifier for communication purposes. The discussion of those applications is, however, beyond the scope of this article.

ACKNOWLEDGEMENTS

The development project was actively supported by T. J. Boerner, J. B. Coleman, V. E. Trouant and J. E. Young. Circuit design and development was done with the cooperation of T. Douma, W. A. Novajovsky, and E. H. Potter of Broadcast Transmitter Engineering.

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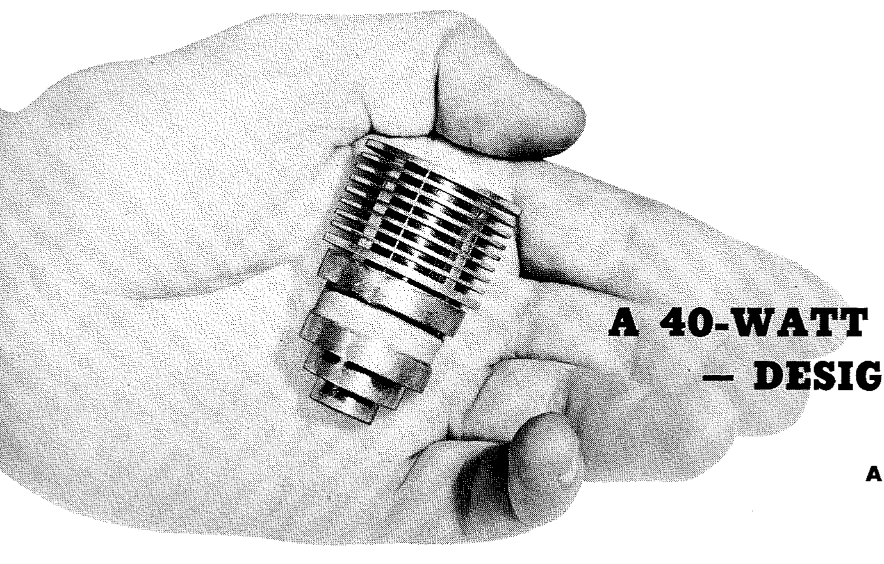
‡The open-circuited, grid cavity construction was suggested by M. V. Hoover, RCA Electron Tube Division, Lancaster.



A 40-WATT UHF BEAM POWER TUBE — DESIGN AND APPLICATION

by

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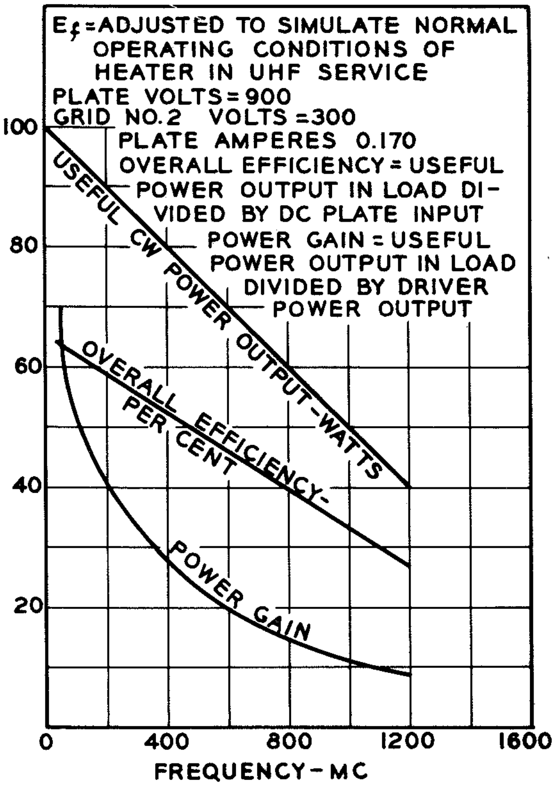

Fig. 1—Typical Performance Characteristics of Type 6816 in Class C Telegraphy or Class C FM Telephony Amplifier Service

THE INCREASED EMPHASIS by the Military Air and Surface Forces on compact, high-power electronic equipment capable of meeting increasing environmental requirements has necessitated the development of many new tube types. The RCA-6816 UHF Beam Power Tube is one such type. Occupying only two cubic inches of space it is capable of delivering 40 watts of useful power at 1200 megacycles, and an even higher power output at lower frequencies, as illustrated in Fig. 1. Its high power gain makes possible further reductions in over-all equipment size by substantially reducing the number of driver stages required. The electrical performance of the 6816 is coupled with a mechanical construction which assures reliable operation under extreme environmental conditions, and which is adaptable to economical and reproducible manufacturing techniques.

DESIGN FEATURES

Several unique structural features which make this performance possible are shown in the cross-sectional view of the 6816 given in Fig. 2. The stacked metal-and-ceramic envelope utilizes butt seals with their advantages of high strength and close tolerances. This design allows high processing temperatures with consequent improved outgassing, and permits tube operation at seal temperatures up to 250 degrees centigrade.

If the advantages of a metal-and-ceramic envelope are to be fully utilized, the internal elements of the tube must be designed to have good thermal and mechanical properties. In the 6816, the control grid (grid-No. 1), the screen grid (grid-No. 2), and the plate are formed of either copper or copper alloy, and have no welds or parts of low thermal conductivity to block the heat flow. Thus, operation at a seal temperature of 250 degrees centigrade need not be compromised by grid-emission problems due to excessive temperature rise in the electrode structure. The cathode is fabricated from a single sheet of nickel alloy to prevent mechanical distortion due to welds and differential expansions. This one piece construction gives low-inductance, low-loss electrical paths to the active elements and results in greatly improved uhf performance as compared to that of more conventional designs.

The coaxial construction of the 6816 permits the incorporation of these attractive electrical and environmental properties without sacrificing reliability and life. Grid-No. 1-to-cathode spacing is twice as great as in comparable parallel-plane structures, and cathode-current density is reduced by a factor of two. This conservative design has resulted in a tube having a high degree of reliability and a long life.

The electrical ratings of the 6816* follow a similar conservative pattern. Typical characteristics and class C telegraphy ratings are shown in Table I. These parameters are controlled in production not only by the conventional static characteristic tests, gas tests, peak-emission tests, and grid-emission tests, but also by a 400-megacycle amplifier test to control high-frequency power gain. Life tests at full rated seal temperatures and input are also conducted in 400-megacycle amplifiers.

COOLING TECHNIQUES

The cooling necessary for the 6816 can be accomplished in a number of ways. Normally, it is unnecessary to supply any cooling air to the heater, cathode, control-grid, or screen-grid seals because the connectors used will conduct away enough heat to prevent the temperature of the tube elements from exceeding 250 degrees Centigrade. This feature permits the tube to be operated under standby condi-

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* A companion tube, the RCA-6884, is identical to the RCA-6816 except for its heater rating of 26.5 volts.

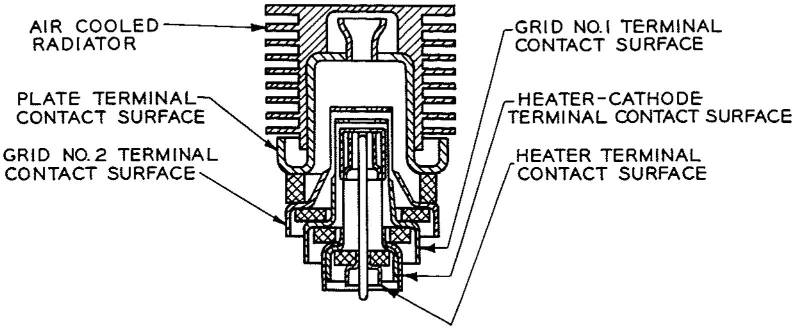
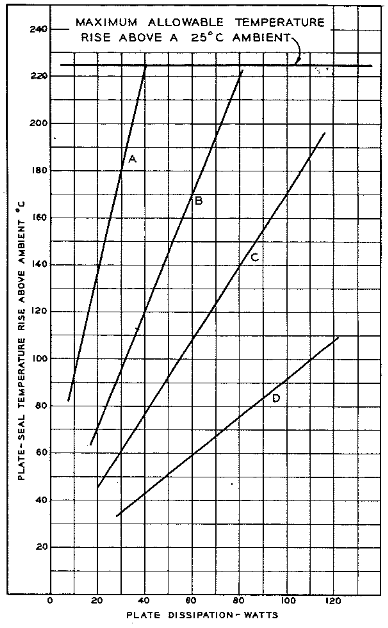


Fig. 2—Cross-Sectional View of Tube Structure



A. No Forced Air. Conduction and Convection cooling from a 500mc strip line designed to optimize its cooling properties.

B. Free Delivery Forced Air cooling. 10 cfm from a 1″ x 1½″ orifice located 1¼″ from the radiator.

C. Forced Air cooling. 10 cfm through the recommended radiator cowling. Less than 0.1″ of water pressure drop.

D. No Forced Air. Conduction cooling through Beryllia Ceramic insulators to chassis. A point on the chassis 3″ from the tube socket was maintained at ambient temperature.

Fig. 3—Typical Cooling Requirements for RCA-6816

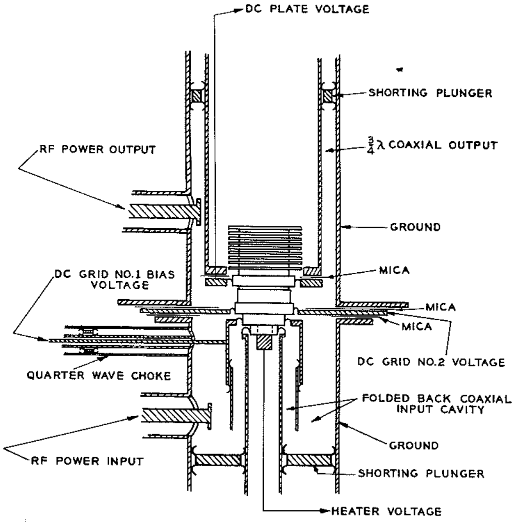


Fig. 4 — 1200-Megacycle Amplifier Circuit for RCA-6816

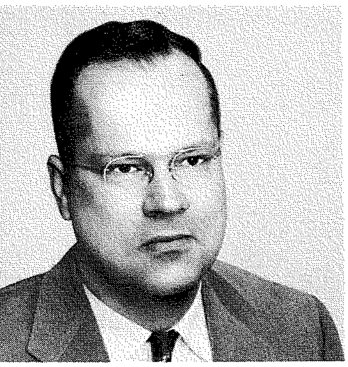
tions without the added power drain of a blower. However, operation at high ambient temperatures or with connectors having very light contacts may require that some air be circulated past these seals.

The plate is normally cooled by air passing through the radiator. Typical air requirements are shown in curves B and C of Fig. 3. Because of the high seal-temperature rating of the 6816, however, it is possible to eliminate forced-air cooling entirely in many applications by the use of "heat-sink" techniques. Curve A of Fig. 3 is for a typical example of such an application. Here, a 500-megacycle, quarter-wave, strip-line having a surface area of 13 square inches is bypassed at the ground end so that it serves as the "heat-sink." Forty watts can be dissipated continuously at the plate without exceeding the seal-temperature ratings, and 80 watts can be dissipated with a duty cycle of one minute "on," five minutes "off."

The results of an even better ex-

Table I—Typical Characteristics and Class C Telegraphy Ratings

Electrical: **GENERAL DATA**		
Heater, for Unipotential Cathode:		
Voltage (AC or DC)	6.3 ± 10%	volts
Current	2.1	amp
Minimum heating time	60	sec
Mu-Factor, Grid No. 2 to Grid No. 1 for plate volts = 1000, grid-No. 2 volts = 300, and plate ma = 100	16	
Direct Interelectrode Capacitances:		
Grid No. 1 to plate	0.085 max.	μμf
Grid No. 1 to cathode & heater	14	μμf
Plate to cathode & heater	0.015 max.	μμf
Grid No. 1 to grid No. 2	17	μμf
Grid No. 2 to plate	6	μμf
Grid No. 2 to cathode & heater	0.5 max.	μμf
RF POWER AMPLIFIER & OSCILLATOR—Class C Telegraphy and RF POWER AMPLIFIER—Class C FM Telephony		
Maximum CCS Ratings, Absolute Values:		
DC Plate Voltage	1000 max.	volts
DC Grid-No. 2 (Screen) Voltage	300 max.	volts
DC Grid-No. 1 (Control-Grid) Voltage	—175 max.	volts
DC Plate Current	180 max.	ma
DC Grid-No. 1 Current	30 max.	ma
Plate Input	180 max.	watts
Grid-No. 2 Input	4.5 max.	watts
Plate Dissipation	115 max.	watts



ARTHUR P. SWEET, Engineering Leader in the Power Tube Applications Activity, Industrial Tube Products at Lancaster, received his BS in EE from the Michigan College of Mining and Technology in 1943. That same year he joined the RCA Tube Plant at Harrison as a Power Tube Development Engineer. In 1951 he was appointed Engineering Leader, Small Power Tube Design, and in 1954 transferred to his present job as Engineering Leader, Applications. Mr. Sweet is a member of the IRE. He is now serving as chairman of the JETEC Committee on High Power Vacuum Tubes.

ROBERT E. BYRAM received the BS degree in EE from Massachusetts Institute of Technology in 1949, and took graduate courses in physics at Franklin and Marshall College, Lancaster, Pa.

Six years of employment at the research laboratories of the Electro-Metallurgical Corporation were followed by three years of service in the U.S. Air Force. While at MIT, he was employed by the Servomechanism Laboratory there. He joined RCA in July, 1949, as a vacuum tube design engineer in small power tubes, and since 1954 has been engaged in application work on small and large power tubes and gas tubes.

Mr. Byram is a member of Sigma Xi.

Table II—Performance Characteristics of RCA-6816 in Several Applications

	1200-Megacycle Amplifier		400-to-1200 Megacycle Tripler		Parallel-line Amplifier		400-Megacycle Coaxial Amplifier	Units
					200 mc	400 mc		
DC Plate Voltage	900	1000	700	1000	400	400	900	volts
DC Grid No. 2 Voltage	300	300	300	300	175	175	300	volts
DC Grid No. 1 Voltage	—22	—52	—130	—160	—7.7	—7.7	—30	volts
DC Plate Current	170	178	149	140	147	175	170	ma
DC Grid No. 2 Current	1	2.5	$\sim$0	$\sim$0	15	15	1	ma
DC Grid No. 1 Current	4	12	13	13.5	10	10	10	ma
RF Driving Power	5	20	5.1	8.5	1	1.5	3	watts
RF Power Output	40	75	16.8	22	29	21	80	watts
Power Gain	8.0	3.75	3.3	2.7	29	14	26.6	
Overall Efficiency	26	42	16	16	49	30	52	per cent

ample of this "heat-sink" cooling technique are shown in Curve D of Fig. 3. In this case, six ½-inch-diameter beryllia spacers, each ½-inch long, are used to support and insulate the plate connector from the chassis. The heat is conducted through these insulators to the chassis. This technique allows the tube to be operated within a dust- or moisture-tight enclosure. Thus, the equipment designer is given wide latitude in optimizing his space requirements, environmental conditions, and electrical performance.

1200-MEGACYCLE AMPLIFIER PERFORMANCE

The 6816 has been operated as a "straight-through" amplifier at 1200-megacycles, and as a frequency tripler with 400-megacycle input and 1200-megacycle output. In both applications, a folded-back, coaxial input circuit is used. Details of this type of input circuit are given in Fig. 4, which shows the complete 1200-megacycle amplifier. The folded-back line is connected between grid-No. 2 and grid-No. 1 at one end, and between grid No. 1 and cathode at the other end. The r-f driving power is fed into the grid-No. 1-grid-No. 2 region near a voltage maximum point; consequently, a capacitive probe is used. The length of the grid-No. 1 cylinder, which is common to both halves of the folded-back line, can be adjusted for tuning purposes. The position of the short between the grid-No. 2 cylinder and the cathode cylinder is also adjustable. This short represents an inductive reactance inserted in the line connected between grid-No. 2 and cathode. By adjustment of the position of the short the circuit may be made either regenerative or degenerative. A complete analysis of this type of input circuit may be found in the two references given at the end of this paper.

The d-c grid-No. 1-bias voltage is connected to the grid-No. 1 cylinder near a voltage minimum point, and further r-f isolation of the bias connection is obtained by bringing the bias lead out through a quarter-wave choke.

The output circuit for the 1200-megacycle amplifier is shown as a coaxial line connected between plate and grid-No. 2. This line operates in the three-quarter-wave mode, and the output power is coupled to the load by a capacitive probe inserted near a voltage maximum point.

Two sets of typical operating conditions that have been measured in this 1200-megacycle amplifier circuit are shown in Table II. The d-c grid-No. 1-bias voltage was developed by means of a grid resistor. When the tube is used as an amplifier at 1200 megacycles, 40 watts of useful r-f power output can be obtained with a power gain of eight and an overall plate and circuit efficiency of 26 per cent. With increased grid-No. 1-bias voltage, the overall efficiency is increased to 42 per cent, resulting in an r-f power output of 75 watts at a power gain of 3.75.

1200-MEGACYCLE TRIPLER PERFORMANCE

The circuit used for operation of the 6816 as a tripler from 400 megacycles to 1200 megacycles is shown in Fig. 5. The 400-megacycle input circuit is of the folded-back coaxial type. Included in this input circuit is a low-impedance section which can be moved along the length of the coaxial line between grid-No. 1 and cathode. This low-impedance section allows some adjustment of the electrical length of the grid-No. 1-cathode line without changing its physical length. Thus, the line can be made to have the correct electrical length, without carefully proportioning the characteristic impedances of the two lines in accordance with the relative amounts of foreshortening caused by tube interelectrode capacitances.

The 1200-megacycle output circuit shown for the tripler is a radial cavity. This cavity is tuned by means of a baffle made of thin copper sheet and mounted just below the top of the cavity. Means were provided for moving the baffle up and down inside the radial cavity, thus varying the cavity height and changing its resonant frequency. This radial output cavity was also used on the 1200-megacycle amplifier at various times, and no significant difference in power output or efficiency was observed between it and the three-quarter-wave coaxial cavity. The radial cavity provides a more compact circuit and is useful where tuning over a wide frequency range is not required.

Typical operation of the 6816 as measured in the 400- to 1200-megacycle tripler circuit is also shown in Table II. Nearly 17 watts of 1200-megacycle output power can be obtained with a power gain of 3.3. Driving the tube harder increases output power to 22 watts at a power gain of 2.7. In either case, the over-all plate and circuit efficiency is about 16 per cent.

200- TO 400-MEGACYCLE PERFORMANCE

Table II shows that in a 400-megacycle coaxial amplifier, the 6816 can deliver a useful r-f power output of 80 watts, with a power gain of 26 and an over-all efficiency of 52 per cent. The input circuit used in obtaining these data consists of a quarter-wave coaxial line between grid-No. 1 and grid-No. 2, with the cathode connector brought through the grid-No. 1 fingers to grid-No. 2 at the socket. The output circuit is a conventional quarter-wave coaxial line between grid-No. 2 and plate.

Tests were also made to determine the performance of the 6816 over the range from 200- to 400-megacycles, using a low-cost easily-constructed circuit operating at a low value of plate voltage. The circuit for this application uses flat plates as sections of transmission lines. A sketch of this circuit is shown in Fig. 6. The output circuit consists of a shorted quarter-wave line connected between plate and grid-No. 2. The input circuit, which is also a shorted quarter-wave line, is connected between grid-No. 1 and grid-No. 2. The cathode is tied to grid-No. 2 at r-f by a low inductance connection placed near the tube. The r-f driving power is directly coupled to the input circuit, and a double-stub tuner is used to assist in matching the input circuit and the driver output. The r-f power output is capacitively coupled from a point near the plate of the tube.

When this circuit is operated with a 400-volt plate supply, 20 watts or more of output can easily be obtained over the 200- to 400-megacycle range with a power gain of 10 or greater, as shown in Table II. Thus, in an application where moderate output at low voltages is desired, this circuit can be built easily and inexpensively, and the transmission lines of flat plates lend themselves to various configurations which can be used for automatic tuning.

CONCLUSION

Only a few of the applications of the RCA-6816 have been described here. However, it is obvious that this tube and its companion, the 6884, have many applications in communications, telemetering, navigation, and allied fields. The small size, reliable operation under extreme environmental conditions, and excellent ultra-high-frequency performance should find ready acceptance with the equipment designer who demands superior operation in the face of increasing environmental obstacles.

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2. D. H. Preist, "Coaxial Tetrode as a TV Amplifier at VHF and UHF," Tele-Tech, V. 11 (January, 1952), P. 52.

Fig. 5—400-to1200-Megacycle Tripler Amplifier Circuit for RCA-6816

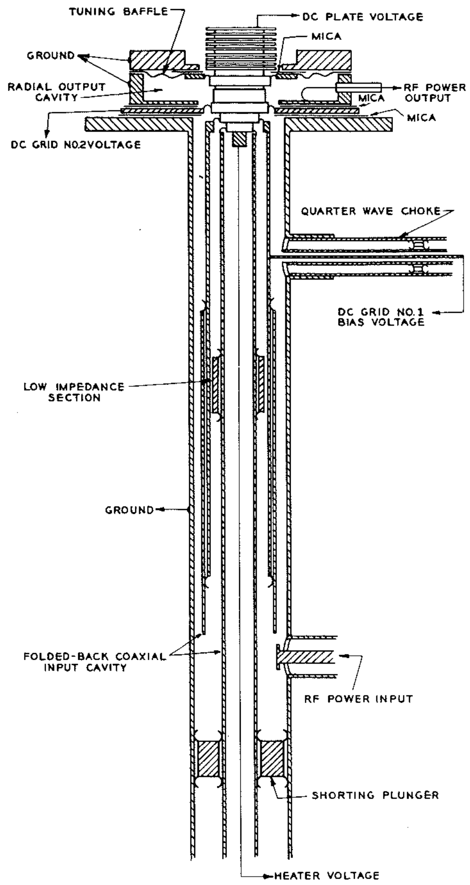
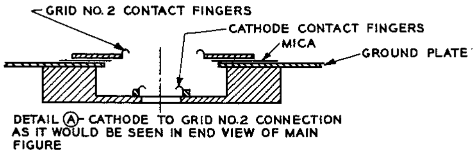
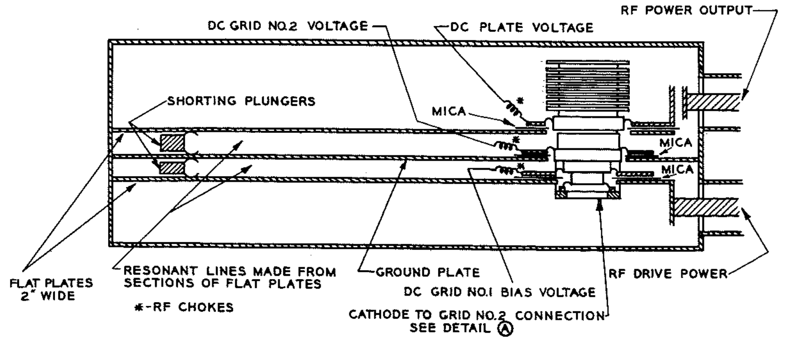
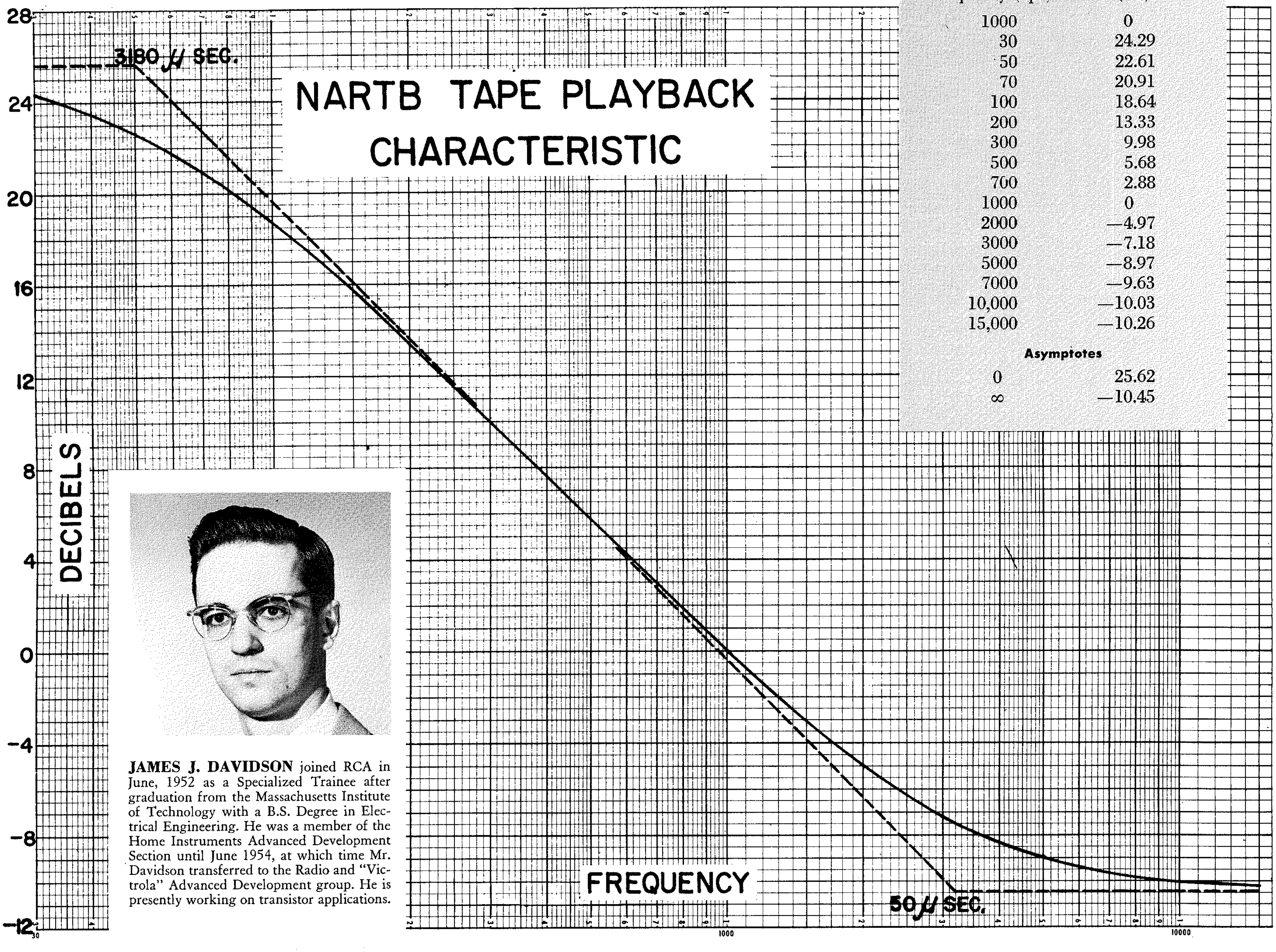


Fig. 6—200-to-400-Megacycle Amplifier Circuit for RCA-6816







NARTB TAPE PLAYBACK CHARACTERISTIC

Frequency (cps)	Relative Response (db)
1000	0
30	24.29
50	22.61
70	20.91
100	18.64
200	13.33
300	9.98
500	5.68
700	2.88
1000	0
2000	—4.97
3000	—7.18
5000	—8.97
7000	—9.63
10,000	—10.03
15,000	—10.26
Asymptotes	
0	25.62
∞	—10.45

JAMES J. DAVIDSON joined RCA in June, 1952 as a Specialized Trainee after graduation from the Massachusetts Institute of Technology with a B.S. Degree in Electrical Engineering. He was a member of the Home Instruments Advanced Development Section until June 1954, at which time Mr. Davidson transferred to the Radio and "Victrola" Advanced Development group. He is presently working on transistor applications.

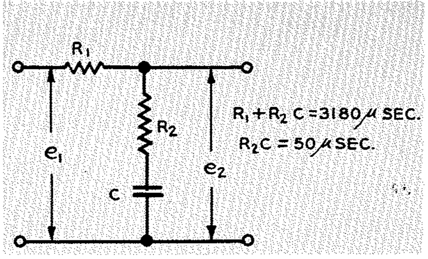


Fig. 2—A circuit which exactly fulfills the requirements of the NARTB tape playback curve.

THE NARTB TAPE PLAYBACK CHARACTERISTIC

By **J. J. DAVIDSON**
Advanced Development Engineering
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In the course of any design work in connection with tape recorders, the engineer is confronted with an equalization problem. As shown in Fig. 1, the unequalized response of a recorder is far from satisfactory for any but the most limited of applications. In determining how best to compensate the associated amplifiers in order to emerge with a more uniform response, several considerations are involved.

1. Overall signal-to-noise ratio of the final signal;
2. Spectral distribution of the incoming signal;
3. Overload capabilities of the system as a function of frequency;
4. Uniformity of equalization, such that a tape made on one machine can be played on another, of different manufacture, with optimum performance.

The first three items indicate a scheme in which most or all of the high-frequency compensation is done in the recording channel, and the low-frequency compensation is done in the playback amplifier. It then remained for the NARTB to adopt a standard curve, with this in mind.

Because of the variations in tape and heads, it was decided to specify only a playback characteristic, postulating an ideal reproduce head. This allows sufficient design latitude to account for deviations in components, but insures compatibility among machines.

The NARTB defines the standard playback characteristic as "... that which results from the superposition of three curves; one that falls with increase of frequency at the rate of 6 db per octave; this curve to be modified at low audio frequencies by a curve that falls with decrease of frequency in conformity with the admittance of a series combination of a capacity and a resistance having a time constant of 3180 microseconds; and this same curve to be modified at high audio frequencies by a curve that rises with increase of frequency in conformity with the admittance of a parallel combination of a capacitance and a resistance having a time constant of 50 microseconds."

Although the present standards specify this characteristic only for a tape speed of 15 inches per second, it is gaining widespread popularity at 7½ inches per second, and will probably become standard at that speed.

This curve can be realized quite simply by the circuit in Fig. 2. It can be shown that this circuit exactly fulfills the requirements set down in the definition. Thus, by solving the equation for the transfer function of the network, the NARTB playback curve can be plotted.

The network transfer function is:

$$T(\omega) = \frac{e_2}{e_1} = \frac{R_2 + \frac{1}{pC}}{R_1 + R_2 + \frac{1}{pC}}$$

$$= \frac{R_2\,pC + 1}{(R_1 + R_2)\,pC + 1}$$

where $p = j\omega = j2\pi f$

A plot of this equation appears on the facing page, and values for discreet frequencies appear in Table I.

DUMMY HEAD

For those working with tape recorders, a dummy head, which simulates the output of a test frequency tape, can be useful. The circuitry for such a device is shown in Fig. 3. Essentially, the unit consists of a shaping network which modifies an oscillator output and drives the head impedance (L_h) with the same signal as would be obtained from moving tape. Indicated values of resistance are approximate, and selection will insure conformity with the NARTB curve.

ACKNOWLEDGEMENT

The author wishes to express his thanks for the work of Mrs. R. A. Johnson, mathematician in RCA Victor Television Division Advanced Development Engineering, in obtaining solution of the transfer equation.

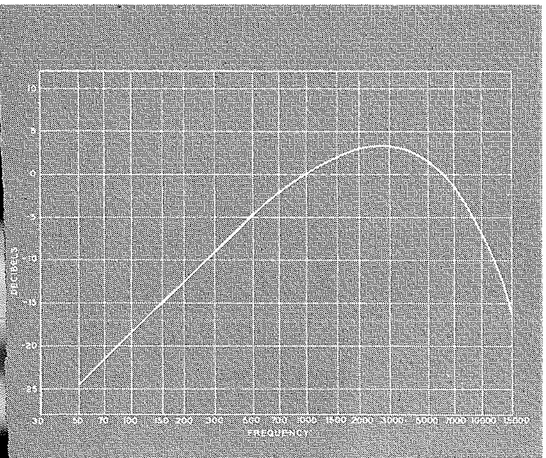

Fig. 1—Overall response of a tape system (record & playback) with no compensation (Tape speed—7½ ips)

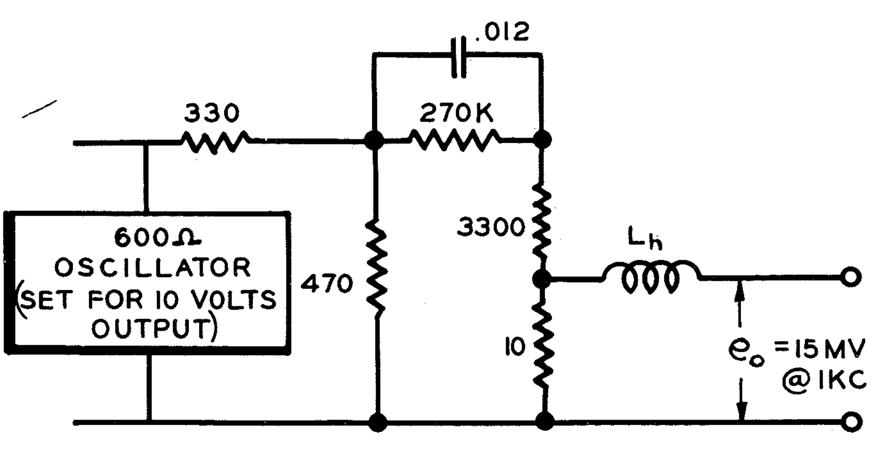

Fig. 3—Circuit for dummy tape playback head.

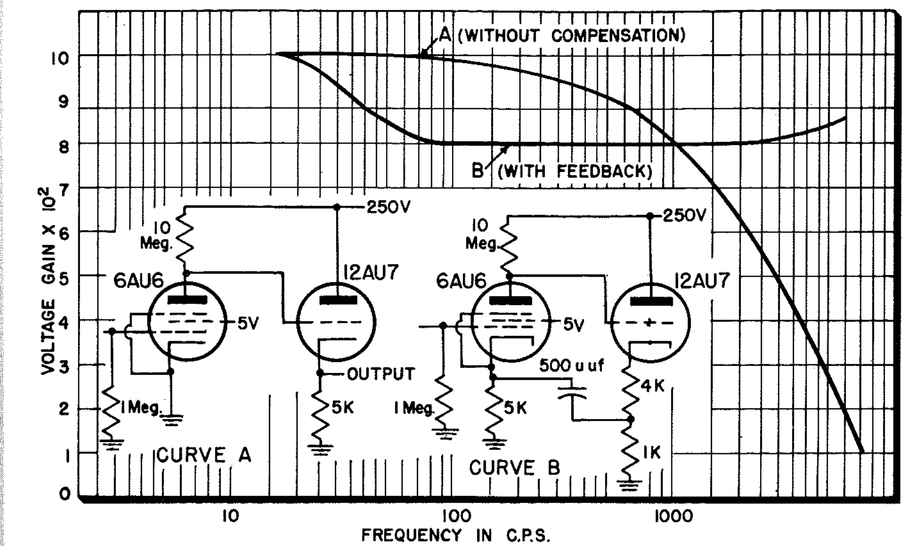

Fig. 1—Starved-pentode amplifier frequency response. A small amount of regeneration extends the audio range.

Control grid, rather than screen grid, is used here as stabilizing source of anode current of the starved-pentode amplifier. Applications of this high-gain circuit include frequency-selective and d-c amplifiers, and frequency meters.

STARVED-PENTODE AMPLIFIERS

by **BERNARD B. BYCER**

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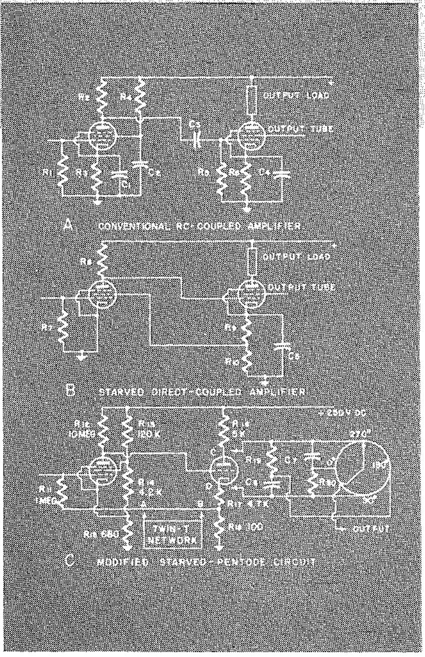
THE OPERATION OF a pentode in low current regions has suggested the name, "Starved-Pentode Amplifiers." This mode of operation permits full realization of pentode performance by matching plate resistance and plate load. Many advantages are thus derived, often yielding results far superior to conventional circuitry. Proper utilization of this circuitry allows the practicing engineer to obtain effective results in reducing the volume and number of required components while increasing circuit performance. For example, the phase shift in a direct coupled amplifier can be held to a minimum. At the same time, a chopper need not be incorporated for circuit stability. With such excellent circuit performance characteristics, the Starved-Pentode Amplifier is a component worthy of attention. It is especially adaptable for use as an operational amplifier and other applications requiring high degeneration together with high base gain.

STARVED-PENTODE FEATURES

The starved-pentode amplifier, with reduced plate and screen voltages and a load resistor greater than one megohm, is capable of achieving gains of the order of 1000 in a single stage. With low plate voltages, cascade coupling does not require attenuating resistors nor V-R tube techniques. All possible gain achieved in one stage can be coupled to the next stage without loss. The high plate load impedance of this circuit makes possible a natural immunity to high-frequency pick-up, transients and surge conditions. However, the useful frequency spectrum of this component is limited to the audio range. In a-c applications utilizing this circuit configuration and pentode characteristics, the amplifier output is insensitive to slight power supply variations. For d-c applications, proper impedance matching is necessary when conversion techniques are not incorporated.

The low current characteristics and excellent stability under small power supply fluctuations permit the utilization of the starved-pentode in portable applications for indication of current, voltage and impedance measurements.

Fig. 2—Modified circuit uses control, rather than screen, grid as plate current stabilizer.



BASIC CIRCUIT

In the basic starved-pentode amplifier, the screen grid is utilized to stabilize anode current (Fig. 2-B). It is preferred that all voltage sources for the tube elements have low internal impedances and are regulated. The inherent characteristics of a starved-operated tube also require some means of stabilizing the anode current, and a means of extracting the information from the high output impedance. This necessitates the use of an additional tube which serves two purposes:

1. A stabilizing medium
2. An impedance transformation

Since a second tube is required, the circuit then becomes a starved-pentode amplifier/cathode-follower combina-

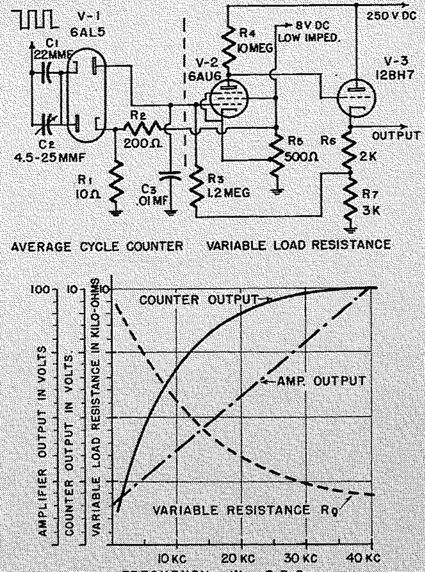


Fig. 3—Input impedance variation is used to advantage in frequency counting circuits.

tion. The stabilization of the starved-pentode anode current is basic. The plate voltage of the pentode at quiescence is made slightly higher in order to operate the cathode follower. Before proper operating conditions can be established, the correct amount of negative feedback must be obtained for stabilization. The cathode and either the control grid or screen grid are operated at predetermined controlled voltages unaffected by their currents. Operation with self-bias is difficult. Therefore, cathode voltage, derived from a low impedance and low voltage source, must be used as bias (Fig. 3).

A complete comparative analysis of the conventional R-C coupled amplifier (Fig. 2-A) and the fundamental direct coupled starved-pentode amplifier (Fig. 2-B) has been fully described in another publication.[1]

The underlying principle of how a pentode can be employed to yield this additional gain is as follows: the pentode no longer acts as a constant current source but acts as a voltage amplifier. The gain of the current is dependent on the amplification factor, μ, ($\mu = g_m \cdot R_p$).

Operation in the low current region reduces the value of g_m appreciably. Correspondingly, the screen grid voltage is reduced and has considerable control over the electron flow passing its grid structure on the way to the plate. The plate resistance of the tube increases as the screen voltage is reduced.

The rate of increase of plate resistance exceeds the reduction in g_m so that μ increases in value. A maximum value of μ occurs and trails off when the rate of reduction of g_m exceeds R_p. This peak value of μ extends over a narrow range of plate current. Besides the frequency range limitation, the starved-pentode amplifier has a narrow grid operating range. The grid bias must therefore be positioned properly by adjusting the existing voltages at the other terminals of the tube. The fact that the input must be small is not a problem in circuitry.

DESIGN CONSIDERATIONS

Preferably, a set of curves should be taken of the particular tube over the desired range of currents under consideration and the range of input. From here, conventional load line techniques are permissible and good results can be obtained. A relatively large negative voltage may exist at the grid of the tube and must be taken into consideration when establishing the quiescent point of operation. Elimination of any grid current is desirable, but in practical d-c circuit applications may be unobtainable. The input signal, where a choice exists, should be a negative-going signal. Here the plate is "bottomed" at zero input and the cathode follower operates at its lowest power dissipation.

APPLICATIONS

The tube characteristic curves for the 6AU6 were obtained by using the appropriate current and voltmeter ranges. These curves are shown as Figs. 4, 5 and 6 and were used for an averaging cycle counter circuit described later in the article. In evaluating the starved-pentode as a low-frequency amplifier, an additional tube was used as a cathode follower so that the output could be measured across a low impedance. To prevent any degeneration in the basic starved-pentode circuit the cathode and grid resistors were connected to ground while the plate supply was 250 volts. The screen was not tapped on the cathode of the following stage as shown in Fig. 2-B, but adjusted to permit maximum a-c output. The control grid voltage (—0.7 volts) was insufficient to prevent plate current saturation and the anode voltage dropped to zero. With the proper adjusted screen grid voltage (5 volts d-c) and the greatest signal input of .02 rms volts, the frequency response of the amplifier is shown in Fig. 1. A small amount of regeneration was introduced to show how the audio range could be extended.

In evaluating a single stage some interesting characteristics are apparent. In basic a-c operations, the starved-pentode cathode follower may use either grid or screen grid for plate current stabilization.

The average current of both tubes is not altered and the d-c operating voltages remains fairly constant. In d-c applications, using the screen grid as the stabilizing source of the starved-pentode, some difficulty of maintaining starved-operation is encountered (Fig. 2-B). As a d-c amplifier (increasing negative signal) the plate voltage increases in the positive direction as does the cathode follower voltage. The net result is the plate voltage of the starved-pentode reaches an upper limit and the screen grid voltage follows to such a value that the pentode is no longer in a starved-operation condition. A modification of the same basic starved-pentode operation (Fig. 2-B) is shown in Fig. 3 and a complete analysis is given in detail. In the basic circuit, the negative contact potential at the grid supplies the necessary bias for operation and cathode is at ground. The screen grid of the basic circuit (Fig. 2-B) is the source of stabilization. The modified circuit has the control grid acting as the plate current stabilizer. The cathode voltage is adjusted to supply the proper bias of operation and to control the existing grid current. The screen grid voltage is optimized for maximum grid swing. When the cathode and screen grid voltages are optimized with proper feedback through the grid circuit, large screen grid voltage variations such as ±20% change has little effect on the starved-pentode operation. This does not hold true for the cathode voltage. A higher ratio of stability is achieved by using the control grid as a plate current stabilizer, than using the screen grid of the basic circuit of Fig. 2-B.

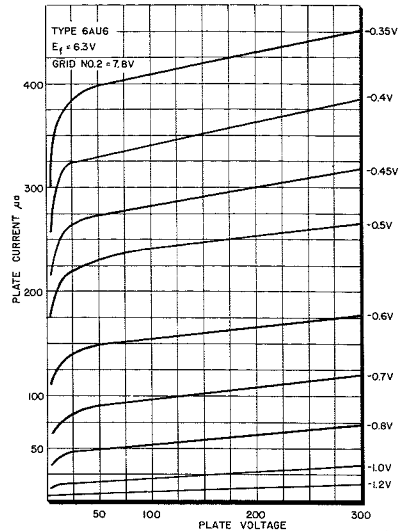


Fig. 4

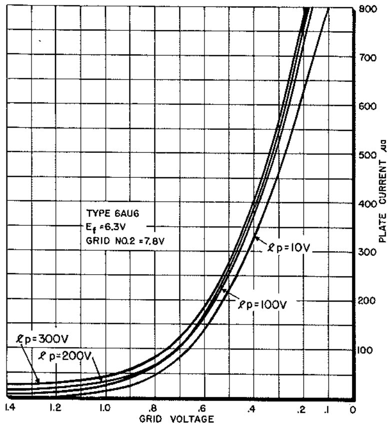


Fig. 5

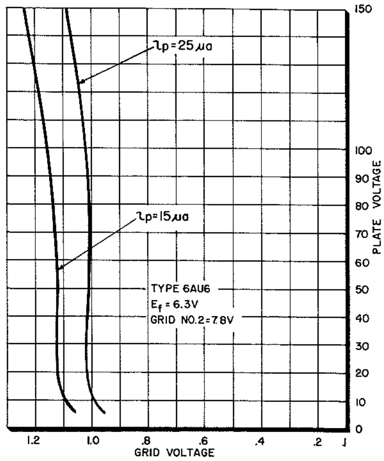
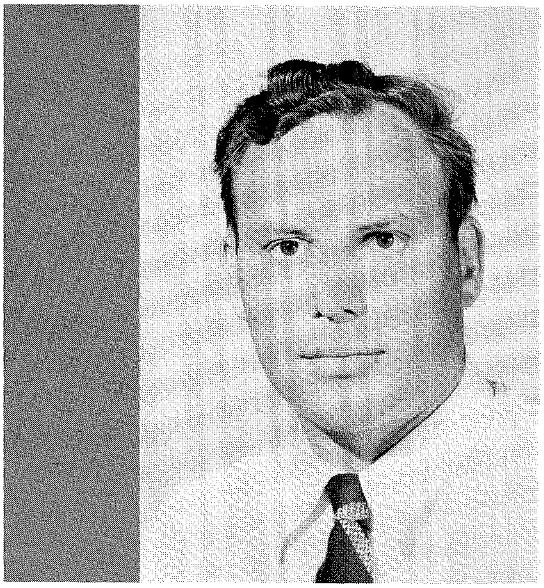


Fig. 6

Figs. 4, 5, and 6—Tube characteristic curves for the 6AU6 used for the averaging cycle counter circuit.

The modified circuit of Fig. 3 differs considerably from the basic starved-pentode circuit. Here, the starved-pentode is used to amplify a d-c signal employing drastic degenerative feedback for stabilization. The d-c potential existing at the grid of the pentode will affect the preceding tubes and measures are necessary to control this condition as shown in Fig. 3. The input impedance varies according to the input signal. Hence, the starved-pentode presents a varying load and varying feedback attenuation as a function of input magnitude. These features of the starved-pentode are used to advantage in achieving a linear counter output. The circuit applications are numerous as frequency meters, counter discriminators, etc. The formulas written below are presented to show that the input impedance when properly utilized in this fashion afford excellent results. The formulas shown from equation 1 through 4 may be found in electronic handbooks. Equation 1 is the formula for the output of an "averaging cycle-rate counter." The term "fT" (frequency × time constant) in the denominator prevents the output from rising linearly. The formulas have been developed below with the idea of reducing this value without altering the remainder of this equation. Equation 2 states that the applied signal of V-2 (Fig. 3) is composed of two sources; one is the output of the counter, and the second is the negative feedback voltage through R_3. This resistor serves as part of the discharge resistor of the counter in addition to being the feedback loop. The resistance between the control grid and ground of the starved-pentode and the counter capacitors (C-1 and C-2) form the time constant of the counter. The negative feedback loop holds the drift down to a minimum. Since the internal plate resistance over the range varies, a ratio of it to the plate load is stated. This permits the internal plate resistance of the starved-pentode to assume any value up to 50 megohms. The gain of the combination starved-pentode cathode follower stage is approximately 400. In the counter formula, the resistive load that exists between the pentode control grid and ground attenuates the feedback voltage at V-2. By substituting, in equation 6 for resistor R_g, K_1 is introduced as a fraction less than 1 and varies throughout the frequency range, decreasing in value. On the basis of current flow through R_3 and the voltage at the grid of V-2 to ground, the resistive component was found to be approximately 93,000 ohms at 1kc, decreasing to 20,000 ohms at 40kc. The resistive component between control grid and ground of the pentode changes by 5 to 1 over the frequency range of 40 to 1. If the linear portion of the counter output is two-thirds of the final registered output, the frequency range without feedback is 1kc to 11kc. With feedback as shown, the frequency is extended beyond 50kc with the same degree of linearity and in the same ratio as the input impedance variation. If K_1 were to approach zero, a perfectly linear counter would be possible. This result is unobtainable for two reasons:



1. K_1 and R_3 are related such that their product is finite in equation 7.
2. Increasing R_3 also increases the negative voltage developed at the grid of the pentode.

$$e_1 = \frac{EfT}{1 + fT} \qquad (1)$$

where e_1 is the counter tube output voltage, E is the applied voltage to the counter, f is the frequency, T equals $(C_1 + C_2)R_g$, where R_g is the input resistance of the starved-pentode combination.

$$e_2 = e_1 + K_1 B e_o \qquad (2)$$

where e_2 is the grid to cathode voltage of V-2, K_1 is the attenuation of feedback voltage, B is the feedback ratio, and e_o is the output voltage from cathode to ground of V-3.

$$e_3 = \frac{-e_3 \mu_2 R_4}{r_{p2} + R_4} \qquad (3)$$

where e_3 is the grid to ground voltage applied to V-3, μ_2 is the amplification factor of starved-pentode V-2, r_{p2} is the internal plate resistance of V-2.

$$e_o = \frac{e_3 \mu_3 (R_6 + R_7)}{r_{p3} + (1 + \mu_3)\ (R_6 + R_7)} \qquad (4)$$

where r_{p3} is the internal plate resistance of V-3, and μ_3 is the amplification factor of V-3.

By substitution, equation (1) becomes

$$e_1 = e_o \left[K_1 B + \left[\frac{r_{p3} + (1 + \mu_3)\ (R_6 + R_7)}{\mu_3 (R_6 + R_7)} \right] \left[\frac{r_{p2} + R_4}{\mu_2 R_4} \right] \right] = \frac{EfT}{1 + fT} \qquad (5)$$

assuming $R_6 + R_7 = r_{p3}$,

and $a_1 = \dfrac{r_{p2}}{R_4}$

where $0 < a_1 > 5$, then

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plifiers, pulsed AGC systems, sweep systems and
tory on television. His work included video am-
components along with patent disclosures covering these subjects.

Since 1949, his work has consisted of Airborne Electronics in navigational instruments and computer work with ferrites. Mr. Bycer joined RCA in May 1956 and is engaged in the Data Handling Group at Moorestown.

Mr. Bycer has several publications and patents filed to his credit. He is a senior member of the I.R.E.

$$\left.\frac{(R_6 + R_7) + (1 + \mu_3)\ (R_6 + R_7)}{\mu_3 (R_6 + R_7)}\right|_{\mu_3 \gg 2} \doteq 1$$

$$\left.\frac{(a_1 + 1)}{\mu_2 R_4}\right|_{\mu_2 > 6} \doteq 0$$

equation (5) reduces to

$$-e_o K_1 B = \frac{Ef(C_1 + C_2) R_g}{1 + f(C_1 + C_2) R_g}$$

$$-e_o = \frac{1}{K_1 B} \left[\frac{Ef(C_1 + C_2) R_g}{1 + Ef(C_1 + C_2) R_g} \right] \qquad (6)$$

but R_g is the effective resistance from grid to ground of V-2 and attenuation of feedback is

$$K_1 = \frac{R_g}{R_3}, \text{ where } R_3 > R_g$$

so that

$$e_o = \left[\frac{Ef(C_1 + C_2) R_3}{1 + K_1 (C_1 + C_2) R_3} \right] \left[-\frac{1}{B} \right]. \qquad (7)$$

Here, the output voltage is controlled by $1/B$ as would be expected with a negative feedback amplifier. The range of linearity is increased by maintaining the denominator nearly equal to one over this range.

The modified starved-pentode circuit shown in Fig. 2-C has many possibilities and some interesting characteristics. The bleeder (R_{13}, R_{14}, and R_{15}) across the power supply is designed to optimize the screen and cathode voltages for the existing d-c voltage at the control grid. No bypass capacitor is used. This slight amount of degeneration reduces the harmonic content in the output. As an audio amplifier, this type of circuit has good response up to 10kc and serves as a high gain amplifier with push-pull output. With a power supply of 250 volts, and $R_{13} = 120\text{K}$, $R_{14} = 4.2\text{K}$, $R_{15} = 680$ ohms as bleeder resistances, the voltage gain was 800 with a plate load of 10 megohms. The value of R_{11} was 1 megohm with the conditions that $R_{17} = 4.7\text{K}$, $R_{18} = 100$ ohms and $R_{16} = 5\text{K}$. The output tube used for this data was triode unit of a 12AU7. These values were obtained by optimizing first for B^+ supply variation and then for filament voltage variation. The power supply design center was 250 volts d-c and was varied over a range of 220 to 300 volts d-c for the pentode only. With a minus 12% to a plus 20% B^+ variation, the a-c output across the cathode follower (12AU7) changed ±2.5% for a 30 cps sine wave. The filament voltage was varied over a range of 5.5 a-c volts to 7.0 volts a-c with negligible change in the output. The circuit is free from drift and exceptionally immune to microphonics when subject to vibration. As a frequency selective amplifier, a twin-"T"-network can be inserted to points A and B of Fig. 2-C. A direct coupled starved-pentode amplifier, affords high gain permitting a larger ratio of effective negative feedback than the usual R-C coupled amplifiers. High ratios of negative feedback without phase rotation and regeneration components make this circuit an excellent frequency selective network. By adding a phase shifting device at points C and D the utility of this circuit can be augmented for phase detection with a desirable simplicity in circuitry.

CONCLUSION

The starved-pentode, with high gain and good stability can reduce and in many cases simplify existing electronic equipment. It may be used as a variable mu tube, altering the degree of starvation as desired. Its ability to distinguish between changes in voltage, current, and impedance makes it an excellent regulating device.

In summarizing this type of circuitry, applications of audio and servo amplifiers, phase detectors, average cycle meters, ph meters, pulse type counters, operational amplifiers are but a few of the ultimate uses of this component. The versatility lies in the fact that the output can function with a-c input, d-c input, or a combination of both. The output can be push-pull or single ended.

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HOW TO PLAN A BIZMAC INSTALLATION

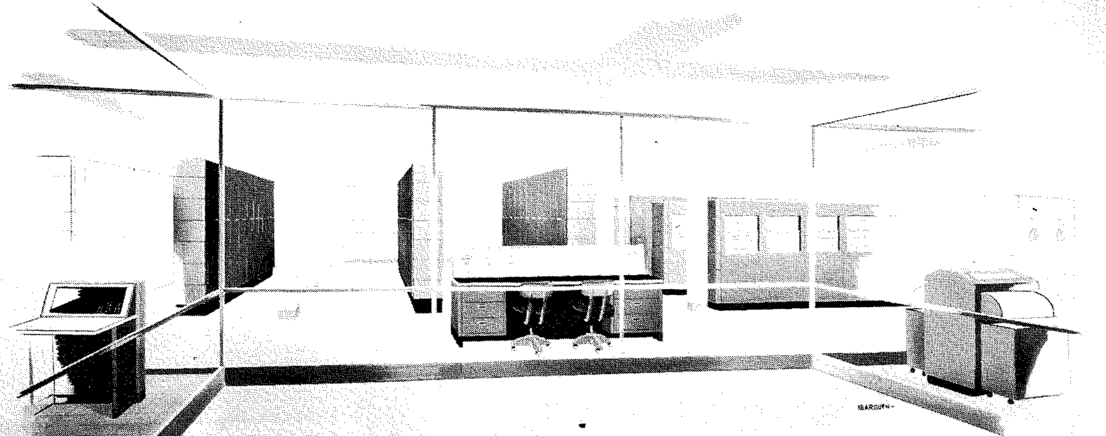


Fig. 1—Artist's conception of a typical BIZMAC installation.

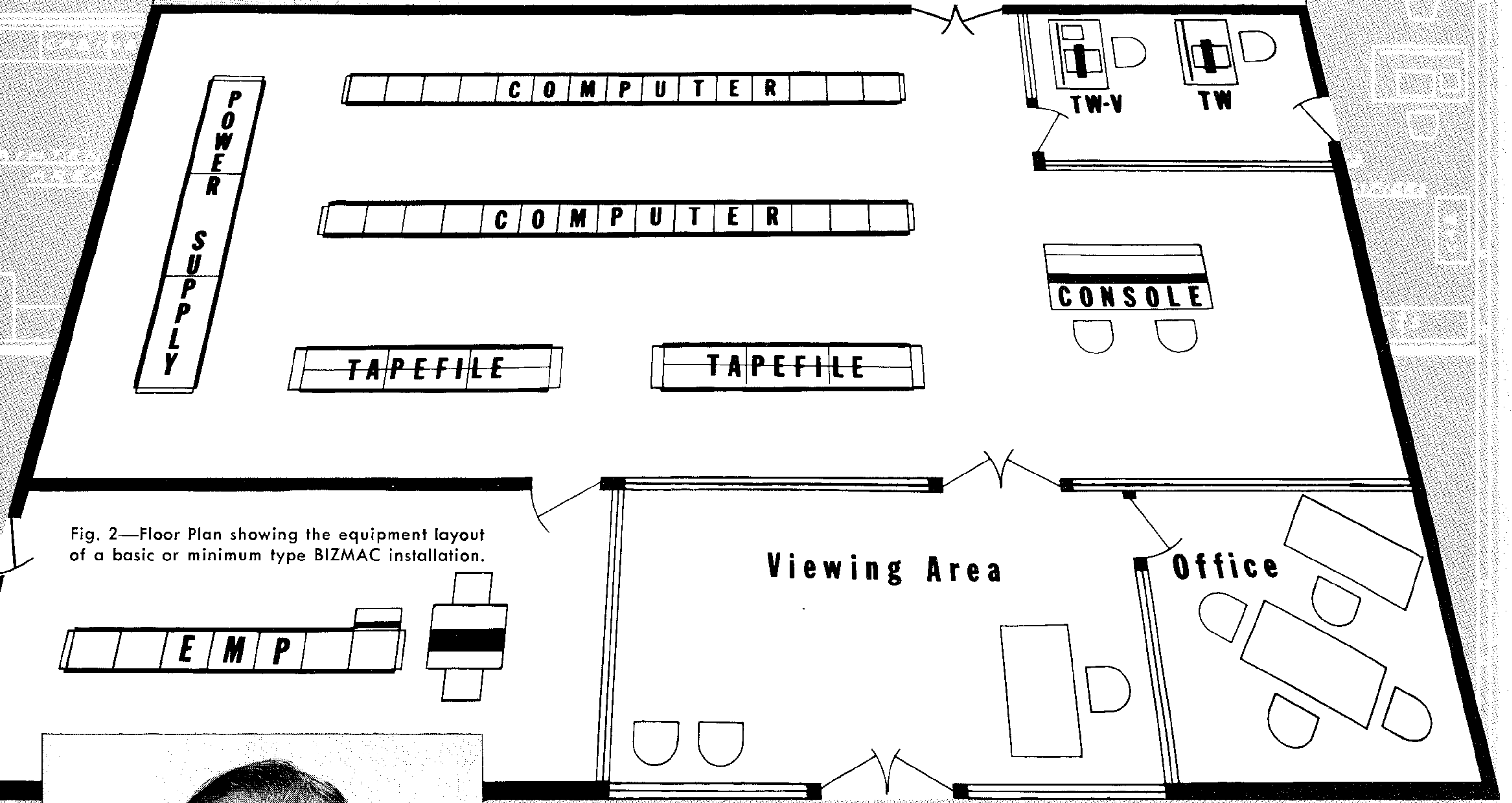
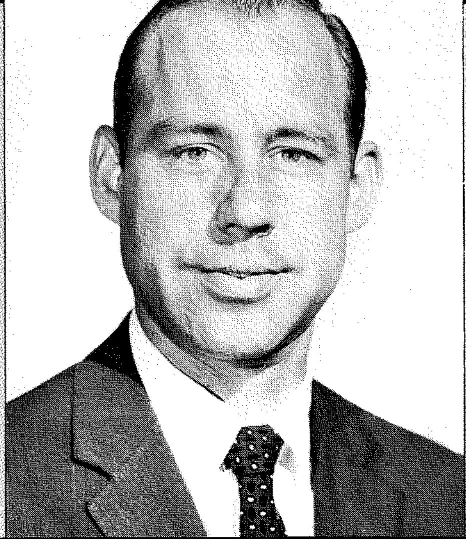


Fig. 2—Floor Plan showing the equipment layout of a basic or minimum type BIZMAC installation.



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Mr. Lipinski joined RCA in 1954 and was assigned to BIZMAC Engineering during the final planning and installation of the first BIZMAC System for the Ordnance Tank Automotive Command in Detroit, Michigan. He planned and developed facilities of the second BIZMAC System for the Associated Merchandising Corp. at Higbee Company in Cleveland, O.—following the installation to completion as RCA Resident Engineering Observer. He has now completed preliminary plans and specifications for installing two large-scale systems for Travelers and New York Life Insurance Companies.

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LARGE DATA PROCESSING systems with central control, especially those using more than one computer, require new planning considerations, and an appreciation of the processing concepts of massive amounts of data. The size and complexity of most data processing systems point up the fact that installation planning has become an important phase in engineering. To do this planning well in advance of equipment delivery, will repay both customer and planning engineer with a system arrangement that can be more easily, efficiently and economically installed and operated. There are several factors affecting every installation . . . and each one must be evaluated before equipment units can be set up.

SITE CONSIDERATIONS

Among the factors affecting site selection are suitable space, accessibility to data processed, convenience to facilities, and budgetary limitations. Perhaps the most important of these is the selection of an installation site that is close to the source of data processed, and in a location where main working areas are not disturbed. Hallways, doors and elevators must allow passage of the largest unit of equipment. Although these factors are also applicable to most other equipment installations, the purpose of this paper is to present a brief yet specific evaluation of a BIZMAC System installation.

FLOOR SPACE

Sufficient floor area should be planned to assure adequate space for equipment, free traffic movement, and comfort of programming personnel. An area approximately 25% of that allotted for the main equipment should be provided as a work area for maintenance personnel, and the nearby storage of system files, operating supplies and spare parts. Provision of a little extra space in this area will facilitate future expansion.

CEILING HEIGHT

It is recommended that a ceiling height of 11 feet, 6 inches be provided to assure easy access to air supply ducts and interconnecting wiring across the top of the installation. Although it is possible to "get by" in an area with a lower ceiling, it may necessitate installation of air supply ducts and interconnecting wiring on another floor level. A room with less than a nine-foot ceiling may create drafts, resulting in discomfort to operating personnel.

FLOOR LOADING

BIZMAC equipment can be placed on any floor which is capable of supporting a load of 100 pounds-per-square foot. Most office buildings have floors that easily meet BIZMAC equipment loading requirements with an adequate factor-of-safety. Such floors are designed and built to accommodate concentrated loads over far larger areas than those actually occupied by the equipment.

AIR CONDITIONING AND POWER

To assure optimum performance of the BIZMAC System, temperature must be maintained within relatively narrow limits. Such control is achieved by introducing forced-cooled air (55 degrees F) at the bottom of each rack unit, passing the air through the units and out the top into the room. The BIZMAC System (Fig. 2) has about fifty equipment racks and requires close to 26 tons of refrigeration.

In addition to providing cooling air to the equipment, the air conditioning system should provide cooling air directly into the room. Here, through turbulance, it mixes with air circulated through the equipment. Not less than 80% of this air should be recirculated.

Power input requirements of a BIZMAC installation will vary in accordance with the size of the equipment installation and the amount of air conditioning and auxiliary equipment. Adequate power must be supplied, in the case of the Fig. 2 installation, 67 KW. This power should be obtained from a 208-volt, 3-phase, 4-wire source with a line drop of not more than 2% and a slow line voltage variation not exceeding ±10%.

COSTS AND EQUIPMENT LAYOUT

Important to both customer and engineer is the consideration of economy. Budget limitations require the location of equipment in available space at the lowest reasonable cost. Placement of equipment where it can be demonstrated to visitors may be another determining factor in the final cost and location of equipment.

Fig. 1 shows an artist's sketch of a BIZMAC installation. The Computer with its console appears in the center. At the left is the System Central through which interconnections are made to the input-output and data handling units and the Tapefile. At the far right are Tapefiles and at near right is the Electro-Mechanical Printer for high-speed, page-printing output.

The planning for such an installation must be a joint effort between the installation-planning engineer and customer. The customer must provide space based on certain minimum requirements of the system. He must also decide whether demonstration of the equipment in operation is desirable. Experience indicates that personnel gathering information for feeding the data processing system, or those using the processed output, are deeply interested in the system operation. However, space considerations and accessibility to work will be more important in the overall evaluation of system layout than accessibility for demonstrations, or aesthetic considerations.

Fig. 2 shows a "minimum" equipment layout of a basic BIZMAC installation fed by input keyboard machines located in a separate room. Information to be fed into the computing system is transcribed onto punched paper tape in the BIZMAC Code by a Tapewriter (TW) and checked by the Tapewriter-Verifier (TW-V). Information is entered from paper tape through the Computer Console onto magnetic tape in the Tapefile. The Computer then draws upon information in the Tapefile, processes it and returns it to the Tapefile. The Electro-Mechanical Printer (EMP) produces printed pages at high speed from information on magnetic tape in the Tapefile. In Fig. 2 a reception room has been provided where the entire system operation may be observed.

CONCLUSION

Even a minimum system such as that of Fig. 2 requires careful planning. This basic "minimum" system occupies a little over 2,000 square feet of floor space, contains five types of equipment and has a total complement of 18 devices. Other systems may occupy up to 20,000 square feet of floor space and have a total of 220 devices. As may be seen from the foregoing, the planning of any installation is exacting and requires the concerted efforts of a number of experienced engineers.

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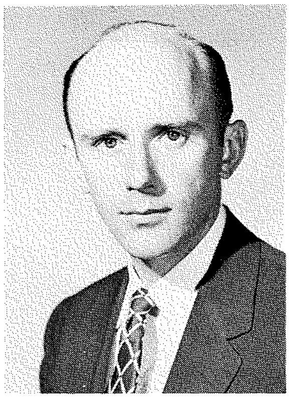

Editor's Note: No attempt is made by the author to include all the various and sundry treatments of servo design. On the contrary, to simplify the presentation, this article is confined to the familiar, frequency-response method of evaluating audio amplifiers, and its relation to linear servo amplifier design.

SERVOMECHANISM PRINCIPLES AND APPLICATIONS

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As ENGINEERS, the field of Servomechanisms is of great importance to us. Servo devices are the hearts and brains of automatic machines, and have recently entered numerous phases of electronics.

We are familiar with many regulation and control systems. One example is the human body which contains a great number of individual regulating processes. Some of them act slowly, such as the stomach which requires several hours before a feedback signal indicates hunger. Others respond more rapidly such as the eye which reacts quickly to changes in light intensity. Consider the accurate regulation system by which the temperature of the body is held constant regardless of ambient temperature. Whatever the process, there are three important quantities to be considered:

(1) Desired or Controlled Output
(2) The Reference or Input
(3) Function of Difference Between Output and Input, or Actuating Error Signal.

Notice that regulation systems and control systems have been referred to indiscriminately. Another word, servomechanism, has recently taken their place. Many definitions have been applied to these terms but none appears to be completely accurate or sufficiently inclusive. They all fall into the general category of feedback control systems in which the difference between a *reference input* and some function of a *controlled output* is used to supply an *actuating error* signal to the control elements. The amplified error signal drives the control elements so as to reduce the difference between the reference input and the controlled variable. If system gain is sufficiently high, and of the proper phase, the error signal will approach zero.

FEEDBACK CONTROL ANALYSIS

Fig. 1 is a block diagram of a simplified feedback control system. If at any frequency, the gain and phase shift of the control elements is $A\underline{/\theta}$, and the transfer function of the feedback element is $\beta\underline{/\phi}$, the "open loop" gain of the system is defined as:

$$\frac{B}{E} = (A\underline{/\theta})\ (\beta\underline{/\phi})$$

and the closed loop transfer function is:

$$\frac{C}{R} = \frac{A\underline{/\theta}}{1 + A\underline{/\theta}\,\beta\underline{/\phi}}$$

The similarity of the function to that of a feedback amplifier is apparent.

There was evidently little communication at first between the people developing feedback amplifiers, regulation systems, and servomechanisms, since each field developed its own language to say the same thing. The work of Bode, Nyquist, Nichols, Brown, and Hall is now being used collectively to solve control problems encountered in today's complex systems. Recent work includes ways of solving nonlinear systems and reducing noise.

One of the most important tools for the solution of servo problems is the LaPlace Transform, used in the application of transfer functions to the study of the time variation of the output of a circuit, mechanism, or system subjected to a time-varying input. As an example of the use of transfer functions, consider a d-c amplifier with finite frequency response as shown in Fig 2. The transfer function is:

$$\frac{E_{OUT}}{E_{IN}} = \frac{K}{(p/\omega_1 + 1)\ (p/\omega_2 + 1)}$$

K represents the magnitude of the d-c gain. It can be shown[3, 4] that the terms in the denominator describe the variation of gain with frequency, if $j\omega$ is substituted for p. The transient response may be found directly by LaPlace transform techniques.

The steady-state gain vs. frequency curve can be plotted by inspection of the transfer function. This curve is

GLOSSARY OF TERMS

TRANSFER FUNCTION: Expression for gain and phase relation of output and input in LaPlace Form: $\frac{K(p/\omega_1 + 1)\ (p/\omega_2 + 1)\ \ldots}{(p/\omega_3 + 1)\ (p/\omega_4 + 1)\ \ldots}$

where: p is the operator for $j\omega$ for sinusoidal inputs, and ω_1 and ω_2 are **Lead,** and ω_3 and ω_4 are **Lag** corners.

Lead-Lag Network: $\frac{K(p/\omega_1 + 1)}{(p/\omega_3 + 1)}$ where $\omega_1 < \omega_3$.

Lag-Lead Network: $\frac{K(p/\omega_1 + 1)}{(p/\omega_3 + 1)}$ where $\omega_1 > \omega_3$.

frequently referred to as a Bode diagram. For a value of $\omega = \omega_1$ the gain is reduced to .707K, or in terms of db, the gain has been reduced by 3 db. For values of ω greater than ω_1 but less than ω_2, the gain curve can be approximated by a straight line on semi-log paper sloping at —6 db per octave. At the value $\omega = \omega_2$ an additional 3 db attenuation occurs (note dotted line) and above ω_2 the gain curve is again approximated by a straight line and decreases at 12 db per octave. Phase shift vs. frequency curve is shown by the dashed line.

In addition to describing the slopes in terms of db per octave, they are frequently quoted in terms of db per decade and of slopes of 1, 2, etc., where a slope of 1 is equal to 6 db/octave or 20 db/decade. On the straight line approximation, the points at which the slopes break are frequently called corners. If the corner results in decreased gain as the frequency increases, it is called a lag corner. A corner which results in more positive slope is a lead corner.

From the transfer function, it is seen that the phase shift contributed by each corner adds to the total phase angle at any frequency. The phase angle for a single lag corner starts at zero at d-c, becomes —45° at the corner frequency, and finally approaches —90° asymptotically. In this d-c amplifier there are two lag corners (see resulting phase shift in Fig. 2).

STABILITY

With this brief introduction we can now consider the analysis of various types of servomechanisms but first we must consider the problem of stability. Basically, feedback control systems provide accurate outputs by continuously correcting any errors which exist. However, this corrective action can give rise to unstable operation when the control elements contain a large amount of amplification and significant delays in the response time. This causes large sustained oscillations which may be dangerous when a large amount of power is being controlled. To obtain a system which recovers rapidly and smoothly from transients or severe disturbances, it is necessary to have an adequate margin of stability. It becomes apparent that the requirements of stability and high accuracy tend to be mutually incompatible. Time delays, or lag corners that are not significant for low-gain systems may cause instability in high-gain systems. Since many time delays are part of control elements that cannot be changed, anticipation or lead corners are used to compensate for inherent time delays.

TYPE ZERO SYSTEM

Having considered some of the important means for analyzing a servomechanism, let us look at the various types of control systems. *A type 0 (zero) system* is one requiring a constant actuating error signal for a constant value of the controlled output. A Bode Plot of a type 0 system has a slope of zero at d.c. and over the frequency range in which control is desired. Most regulator systems are of this type, including such common items as a regulated power supply. The open loop transfer function in the plot of Fig. 3 has the form:

$$\frac{B}{E} = \frac{K}{(p/\omega_1 + 1)\ (p/\omega_2 + 1)}$$

To insure adequate stability, the unity gain or zero db line should cross the open loop gain plot where it has a —1 slope, that is, between ω_1 and ω_2. Here, the phase shift is no greater than 135°, and the system will be very stable. To increase d-c gain further, a lead-lag network may be used in the control element.

ANTICIPATION NETWORK

Fig. 4 shows an RC lead-lag network having a transfer function of

$$\frac{E_{OUT}}{E_{IN}} = \frac{\omega_3}{\omega_4}\left[\frac{(p/\omega_3 + 1)}{(p/\omega_4 + 1)}\right]$$

This is used to obtain the required anticipation by providing a lead corner to cancel one of the lag corners in the original system. Fig. 5 shows the result of adding a lead-lag network.

If $\omega_3 = \omega_2$ and $\omega_4 = 10\omega_3$, then the second corner has moved up in frequency by one decade. The gain can now be increased by 20 db resulting in the same degree of stability. However, an additional 20 db of gain is required to make up for the insertion loss due to the term ω_3/ω_4 in the compensating network. Thus a total of 40-db gain is added to the amplifier in the control element.

TYPE 1 SYSTEM

In a Type 1 System a constant actuating error signal is required for a con-

Fig. 1—A simplified feedback control system containing control elements, a feedback element, and a summing point. The minus sign indicates negative feedback or a phase shift of 180°.

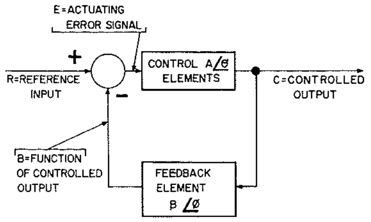


Fig. 2—Plot of gain (solid line) and phase shift (dashed line) vs. frequency for a d-c amplifier with finite frequency response.

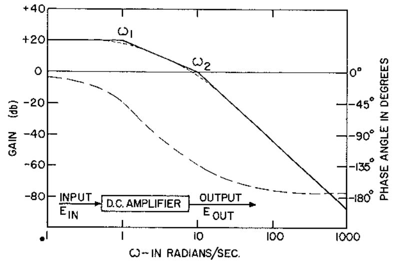


Fig. 3—Plot of open-loop gain vs. frequency for a type zero system.

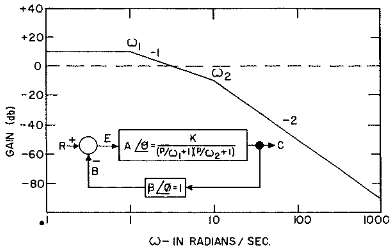


Fig. 4—Leading phase shift and positive slope of gain curve produced by a lead-lag network.

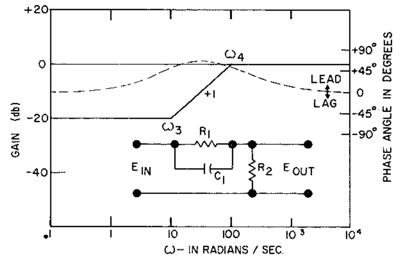


Fig. 5—Increased response and gain made possible by the addition of a lead-lag network to the original system (Fig. 3).

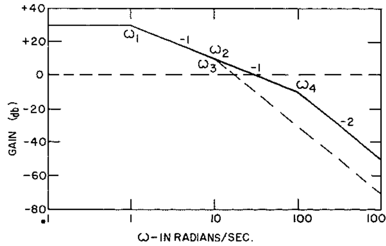


Fig. 6—Plot of open-loop gain and phase shift of a type 1 system, which includes a motor in the control element and a potentiometer for the feedback element. The low-frequency gain and phase characteristic is caused by the integrating action of the motor.

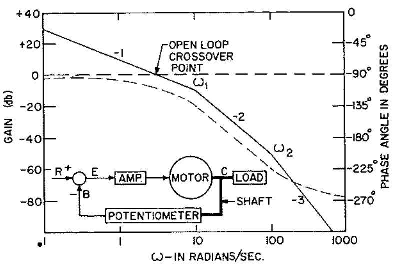


Fig. 7—The open-loop gain and phase shift of a type 2 system are shown by the solid lines. The dashed lines represent the addition of lead-lag network.

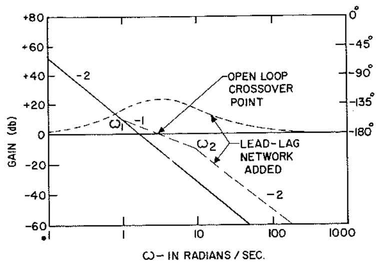


Fig. 8—Block diagram of a control system utilizing rate feedback from a tachometer in an inner loop (within dashed lines).

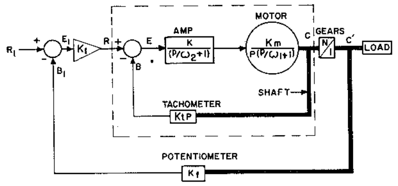
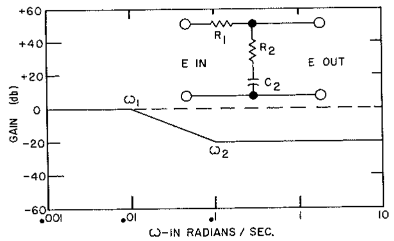


Fig. 9—Gain vs. Frequency for lag-lead network. Corner frequencies are:

$$\omega_1 = \frac{1}{C_2(R_1 + R_2)} \text{ and } \omega_2 = \frac{1}{R_2 C_2}$$



stant rate of change of the controlled output. The Bode Plot of a Type 1 system starts with a —1 slope at d.c. and continues at —1 within the frequency range of interest (See Fig. 6). The open loop transfer function is:

$$\frac{B}{E} = \frac{K}{p(p/\omega_1 + 1)\ (p/\omega_2 + 1)}$$

The same requirements for stability exist as in the Type 0 system, that is, the crossover point of the gain curve and zero db should be on the —1 portion of the curve. Such a system is represented by a motor driving a shaft with a position take-off element for feed-back. The motor transfer function is basically $K_m/p(p/\omega_1+1)$ where K_m is the gain, the term $1/p$ is due to the fact that a motor output is in Radians/second/per volt of input, and the lag term $1/(p/\omega_1 + 1)$ is determined by the torque and inertia of the motor and load. A lead network placed in the control element portion of the loop will permit the use of a higher gain while meeting stability requirements.

TYPE 2 SYSTEM

A Type 2 system is one in which a constant error signal is required to produce a constant acceleration of the controlled output. The system has a —2 slope and 180° phase shift from d.c. through the frequencies of interest.

From the Bode plot in Fig. 7, there is no portion of the solid line curve crossing the zero db line with an associated phase shift of less than 180°. Therefore, to provide stability, a lead network must be inserted in the frequency range of the crossover point to obtain less than 180° phase shift at unity gain. This leads to a marginally stable system when gain increases or decreases.

MULTI-LOOP SYSTEMS

Although the systems discussed so far provide solutions for many problems, *multi-loop systems* are often required. For example, a Type 1 system with a motor would frequently require a lead network to obtain a sufficiently accurate servo. However, the corner frequency of the motor is a function of the torque constant and may vary considerably. Also the gain is usually non-linear and reduces the possibility of obtaining an optimum system. A tachometer providing an output voltage proportional to angular velocity can be used in an inner loop (see Fig. 8).

The transfer function of the tachometer is $K_t p$ and the loop transfer function for the inner loop becomes:

OPEN LOOP

$$\frac{B}{E} = \frac{K_s}{(p/\omega_1 + 1)\ (p/\omega_2 + 1)}$$

Where $K_s = K_A K_t$, & $K_A = K K_m$

CLOSED LOOP

$$\frac{C}{R} = \frac{K_A}{(K_s + 1)\ p\ [D_1 + D_2 + 1]}$$

where:

$D_1 = p^2/(K_s + 1)\ \omega_1\omega_2$

$D_2 = (\omega_1 + \omega_2)\ p/(K_s + 1)\ \omega_1\omega_2$

Closed Loop with $K_s > 10$: $C/R =$

$$\frac{1}{K_t p \left[\frac{p^2}{K_s\ \omega_1\omega_2} + \frac{(\omega_1 + \omega_2)p}{K_s\ \omega_1\omega_2} + 1 \right]}$$

Thus the product of the lag corners of the closed loop system have been moved higher in frequency. The closed inner loop transfer function can be approximated at low frequencies by $1/K_t P$, which would be the transfer function of an idealized motor. The open loop transfer func-

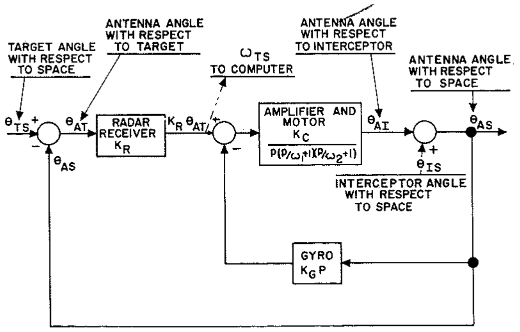


Fig. 10—Simplified block diagram of the tracking and stabilization loops of a typical Airborne Fire Control System.

tion at low frequencies for the outer loop of Fig. 8 then becomes:

$$\frac{B_1}{E_1} = \frac{K_1 K_p}{K_t p}$$

Since the gain of the closed inner loop is relatively independent of the motor gain and since the corner frequencies have been increased, the gain can be increased to produce a stable Type 1 servo with a gain higher than that possible without the tachometer feedback.

INTEGRAL NETWORK

Another method of obtaining a higher gain at low frequencies utilizes a lag-lead or integral network. Such a network and its transfer functions are shown in Fig. 9. If the lag-lead network is added at a frequency sufficiently below the crossover point of a Type 1 system, the low-frequency gain may be increased without affecting loop stability. This results in a compromise system between a Type 1 and Type 2 and is frequently used.

AIRBORNE FIRE CONTROL APPLICATION

As an illustration of how some of the servo techniques are used in an Airborne Fire Control System, consider Fig. 10. One of the problems is to track a target with a radar system. Since the radar antenna is mounted in a moving aircraft, it is necessary not only to follow the movements of the target but also to stabilize against the motion of the aircraft in which the antenna is mounted. Two loops are frequently employed in the servo system. The inner loop is referred to as the space stabilization loop. The error sensing device used to detect movement of the antenna in space is a gyro. The torque output on the output axis of a gyro is proportional to the rate of change of angle about the input axis. Thus, if a spring is used to restrain the motion of the output axis, the angle of rotation of the output axis is proportional to the rate of change of angular position of the radar antenna on which the gyro is mounted. The transfer function of the feedback element or "rate gyro" can be represented by $K_G p$. It has the units of volts/radian/second when a potentiometer is attached to the output shaft.

The control elements consist of an amplifier and a motor, which can be represented by:

$$\frac{K_c}{p\,(p/\omega_1 + 1)\;(p/\omega_2 + 1)}$$

The open loop transfer function of the stabilization loop then becomes:

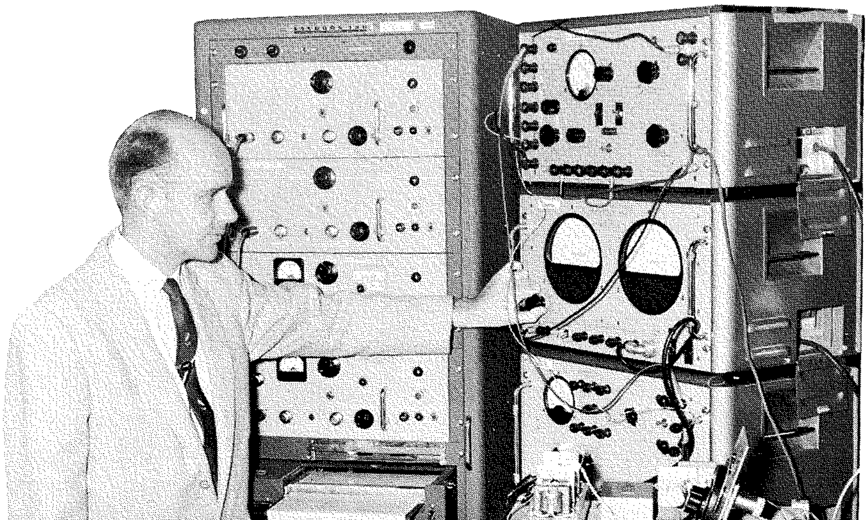
$$\frac{K_c\, K_G}{(p/\omega_1 + 1)\;(p/\omega_2 + 1)}$$

The errors introduced by the aircraft's own motion in space will be reduced by the value of the open-loop gain at frequencies below the cross-over point much the way audio amplifier hum is reduced by use of feedback.

Of course, this only applies about one axis. If the antenna is free to move about two or three axes, then duplicate control systems must exist for each degree of freedom.

The outer loop of the Fire Control Tracking System includes the Radar Receiver. In a typical system, the antenna pattern is caused to rotate about an axis displaced by a small angle (approximately one-half the beam width of the antenna), thus describing a narrow cone in space. By using synchronous demodulators, which receive a reference signal that is of the same frequency as the conical motion of the r-f beam, a signal can be obtained which indicates the "up direction" by one polarity of d-c output voltage and "down direction" by the other polarity. Thus, the antenna can act as a position error sensing device similar to a potentiometer with units of volts-per-radian. The outer loop can then be closed and its open-loop transfer function is $K_R/K_G p$ (a Type 1 system).

R. H. Aires, author, is shown in an Airborne Fire Control Laboratory during engineering tests. The Test set-up from l to r: 4-channel Sanborn Recorder, Solatron Servo Analyzer, and Instrument Servo in foreground.



Since this is a Type 1 system, it has a constant error for a constant rate of change of the controlled output, which in this case is the position of the antenna in space Since the radar receiver transfer function is constant, the voltage at the receiver output is proportional to the error in the position angle in space. When the outer loop is closed, the receiver output is proportional to the angular velocity of the target in space by definition of the Type 1 system. This is a quantity useful in the Fire Control Computer to predict the required lead angle for armament.

APPLICATIONS ARE DIVERSIFIED

There are many servo applications in an Airborne Fire Control System:

(1) Radar Receiver AGC System
(2) The Range Tracking System
(3) Instrument or Follow-up Servos which repeat the readings of other sensitive instruments
(4) The Autopilot System
(5) Servos for Computation

Some engineers get the impression that the application of servos is limited to large motors, amplidynes or other rotating equipment. Actually there are at least two servo systems in your TV sets, the AGC and the horizontal-frequency-control system. Of course, you are all aware of the many servo processes within both digital and analog computers. These are only a sample of the many uses for servo systems which will influence the future progress of Electronics.

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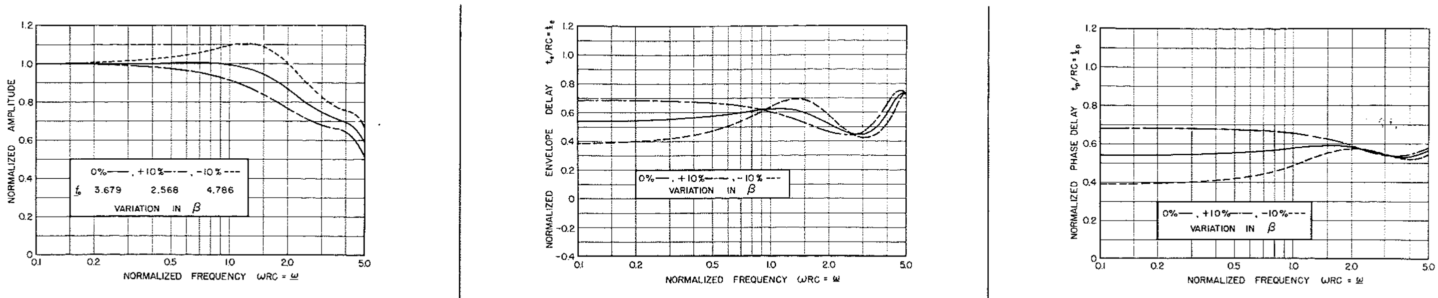
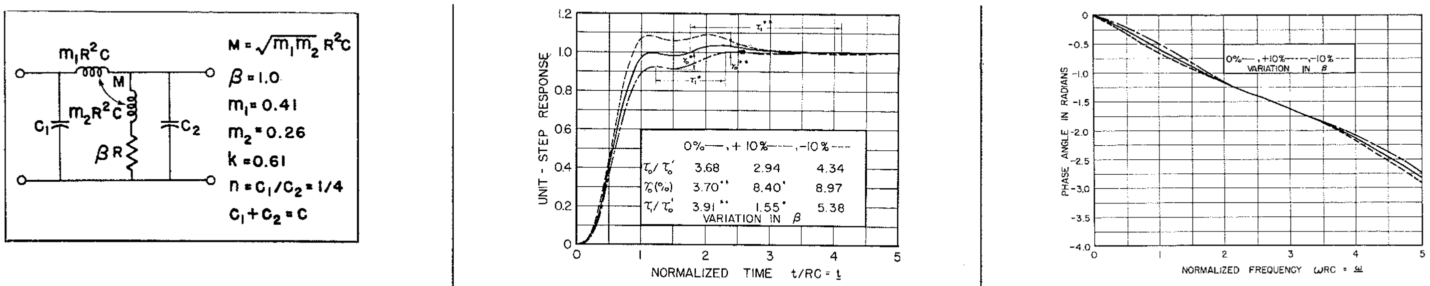


(a)

Peaking Circuit

(e)

ENGINEERING APPLICATIONS FOR COMPUTERS



(b)

(c)

(d)

Fig. 1, a, b, c, d & e—Steady-State and Transient Characteristics for Mutually-Coupled Peaking Circuit.

by

ROSEMARY A. JOHNSON

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TODAY ELECTRONIC COMPUTERS perform many engineering calculations which were previously considered impossible because of their length.

Electronic computers are either analog or digital. An analog computer measures continuously, while a digital computer counts by units. Prototype of the analog machine is the slide rule or automobile odometer. The analog consists of summing amplifiers, differentiating and integrating circuits and feedback loops. The digital computer works on the principle of the abacus or mechanical calculator by counting electrical impulses.[1] Multiplication or division is accomplished by making use of repeated addition or repeated subtraction.

Speed—A large machine like the recent Naval Ordnance Research Calculator NORC (IBM) can do the following:

In One Second it can "read" or "write" more than 70,000 digits from or onto magnetic tape. This "writing" is as fast as 14,000 typists working at one time.

In One Day it can perform as many operations as 1,000 people calculating all their lives, without a machine error. Hundreds of millions of operations per day.

In 31 Millionths of One Second it can multiply two 13-digit numbers and automatically place the decimal point correctly in the answer.

The IBM 650 at the David Sarnoff Research Center, using a floating-point interpretive programming system, can execute a multiplication in 67.2 μs; square root in 206 μs; evaluate the transient response of a network from the ratio of two polynomials in six minutes.

Important Features—Some of the important characteristics of electronic computers are:

1. High speed at which arithmetic operations are performed.
2. Ability to retain information in an internal memory, which information is readily accessible to the machine for computation.
3. Ability to modify its own problem instruction as a function of the partial results obtained. For instance, if one were to compute the sine integral

$$Si(x) = \int_0^x \frac{\sin u}{u}\, du \qquad (1)$$

   and as an approximation used a power series when $0 \leq x \leq 1$ and an asymptotic series when $1 < x < \infty$, the machine, unaided by manual control, will compute the argument (x) and choose the series which gives the best approximation.
4. Ability to detect its own errors through the use of redundant number systems.
5. Ability to prepare tabulations of results in many different forms, adjustable as needed.

One other advantage which is not always explicitly mentioned is that libraries of standard programs can be set up so that problems which fall in some standard categories can be solved quite readily by simply referring to previous work. Routines available at the David Sarnoff Research Center will be treated later in more detail.

PURPOSE OF THE PROGRAM

A program usually starts with a flow chart, which is simply a connected description of the logical steps that are to be performed to derive the output from the given input information. Programming a fast machine is similar to writing instructions for ten thousand people who will work ten years without any further instruction from you. One has to foresee any difficulties they will run into.

A human calculator does a tremendous amount of work without knowing he does it. It is done automatically and includes keeping track of the decimal point, writing information in the proper column, rounding off, solving the right problem, stopping when the results are obtained, avoiding division by zero, etc. Programming is essentially the preparation of a set of instructions in a form which provides every step normally done by a human calculator. This includes the machine instructions and proper utilization of the input and output mechanisms. Instructions in the program must include such things as what data to select from those available in the memory for a solution of each part of the problem, and the printing arrangement of the results.

The system instructions must give the following information: (1) What to do, (2) where to get the data to do it with, and (3) where to store the result. In modern machines these instruction words are stored in the memory, just as the data are stored, and the machine is called a stored program calculator. The memory is broken up into many small areas like a sheet of paper marked off in rows and columns. Each area is identified by an address. To tell the machine to pick up an instruction or a word of data from the memory, the address of the memory location where that word is stored is given. It is customary to put instructions in one general region of storage and data in another.[2]

WHAT TYPES OF PROBLEMS CAN BE HANDLED

Now, most of you are probably wondering, "You have given us general information concerning computers, but what can it do for me? What type of problems can I solve?" Anything that can be expressed mathematically in closed form with standard functions or that can be approximated by a power series, asymptotic series, etc., can be handled by a computer. Have you ever looked at an equation and said, "Well, I might just as well stop now. This thing would take a week or two to evaluate on a desk calculator, and I want more than just one case." This is the type of problem that can be solved on the computer. For instance, a theoretical group at Cherry Hill was just recently approached with a problem in electromagnetic fields. The function to be evaluated was

$$A(z) = \int_{a_2}^{b_2} dy \int_{a_1}^{b_1} f(x, y, z)\, dx$$

The magnitude of this problem was staggering when considered in terms of the desk calculator. It took the problem proposer and the programmer, working together, four days to solve for one value of z on the desk calculator and the problem required approximately 31 values of z. The time involved would be approximately 1.5 work years on a desk calculator. The IBM 650 required 36 minutes to evaluate each z.

A problem does not have to be stated in complex mathematical notation before it can be evaluated by a computer. Many problems that are just a combination of elementary transcendental functions such as sine, cosine, exponential, log, can be evaluated very neatly. Problems are particularly suitable to programming if the constants or parameters of it might assume many different values. For example, the following network analysis was done at Cherry Hill on the 650. Consider the following network:

The loop equations are given by

$$-\frac{i}{pC_1} + i_1\left[\beta R + p(L_1 + L_2 + 2M) + \frac{1}{pC_1}\right] - i_2\Big[\beta R + p(L_2 + M)\Big] = 0 \qquad (2)$$

$$-i_1\Big[\beta R + p(L_2 + M)\Big] + i_2\left[\beta R + pL_2 + \frac{1}{pC_2}\right] = 0 \qquad (3)$$

After equations (2) and (3) are solved for i_2, the output voltage e_2 is found to be

$$e_2 = i_2\frac{1}{pC_2} = \frac{[\beta R + p(L_2 + M]\, i}{\{p^4C_1C_2(L_1L_2 - M^2) + p^3C_1C_2\beta RL_1 + p^2[L_2C_2 + C_1(L_1 + L_2 + 2M)] + p\beta R(C_1 + C_2) + 1\}} \qquad (4)$$

By a series of substitutions[3] in equation (4), the transfer function can be written as

$$Z(p) = \frac{a_1p + a_0}{p^4 + b_3p^3 + b_2p^2 + b_1p + a_0} \qquad (5)$$

where, pRC has been changed to p and,

$$a_0 = \frac{(n+1)^2}{m_1m_2n(1-k^2)};\ L_1 = m_1R^2C$$

$$a_1 = \frac{a_0}{\beta}(m_2 + k\sqrt{m_1m_2});\ L_2 = m_2R^2C$$

$$b_1 = \beta a_0\ ;\ m = k\sqrt{L_1L_2}$$

$$b_2 = a_0\left[m_2 + \frac{m_1n}{n+1} + \frac{2nk\sqrt{m_1m_2}}{n+1}\right]$$

$$b_3 = \frac{a_0m_1n\beta}{(n+1)^2};\ n = C_1/C_2;\ C = C_1 + C_2$$

Interpretive subroutines have been compiled for the IBM 650 which evaluate the steady state characteristics; that is, the amplitude, phase, envelope delay, and the phase delay, and the transient characteristics for this network. The only information which must be supplied by the engineer to the programmer is the transfer characteristic such as equation (5) and the values of the parameters to compute he coefficients of the transfer characteristic. This enabled the engineer to observe the sensitivity of the characteristics to a change in the circuit parameters without any laborious calculations on his part. See Fig. 1 for the curves of this network.

The following time factors are based on one set of circuit constants for 50 values of the variable of the function. The IBM 650 calculator takes approximately six minutes to evaluate all the steady-state characteristics; it takes approximately 5-7 minutes to evaluate the unit-step response and it requires approximately 7-10 minutes to evaluate the response of a network to a suddenly-applied sine wave.

These subroutines have the following limitations: Let the order of the transfer characteristic be the same as the highest powered p term of the denominator of the transfer characteristic.

(a) the steady state characteristics can be found for a 2nd, 3rd, 4th, . . ., 12th order transfer characteristic.
(b) the unit-step response can be found for a third, fourth, or fifth order transfer characteristic only.
(c) the response of a suddenly-applied sine wave to a fourth order filter only.

Routines are also available at the David Sarnoff Research Center which can

(a) extract the real and complex roots of a polynomial

$$f(z) = a_0z^n + a_1z^{n-1} + a_2z^{n-2} + \ldots + a_n = 0 \quad (6)$$

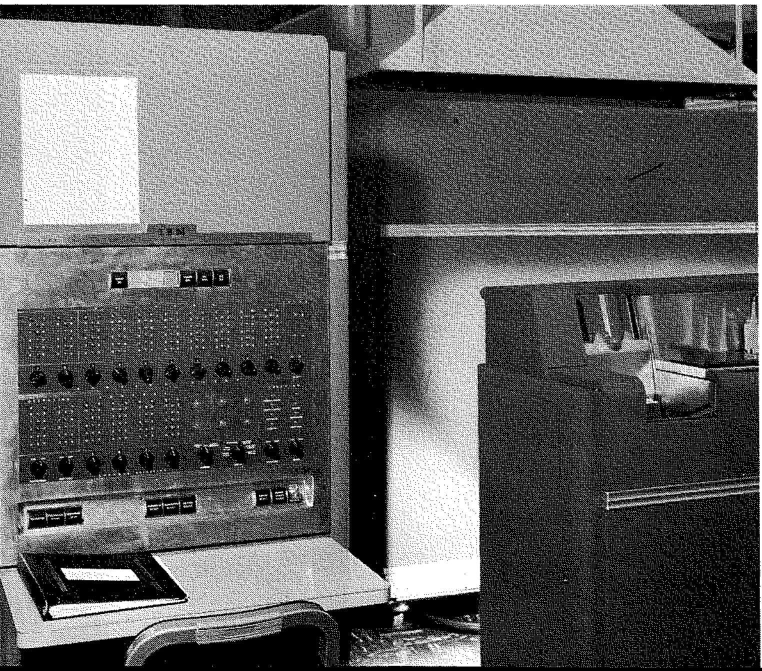
where $3 \leq n \leq 24$. The engineer need only supply the values of the coefficients or the parameters to compute them. The time required for a seventh-order polynomial is approximately three and one-half minutes,
(b) solution of a system of n first order ordinary differential equations, $n < 30$,
(c) perform multiple numerical integration,
(d) locate roots of a function of one real variable,
(e) compute Bessel functions J_0, J_1, I_0, I_1, K_0, K_1, Y_0 and Y_1 for real arguments,
(f) solve a system of n simultaneous linear equations.

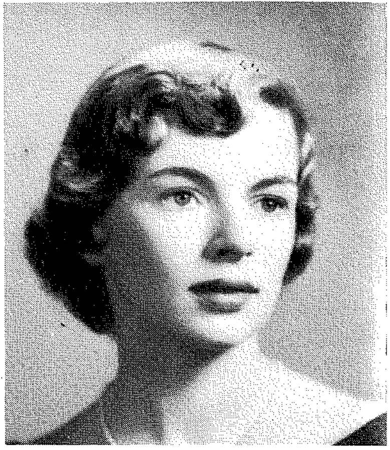
LIMITATIONS OF THE MACHINE

A computer performs no miracles; it merely creates the illusion of doing so. As is usually true when any new machine or device comes along, there is a tendency to exaggerate its capabilities on the part of those presenting information to the public, and many of the engineering articles have this "salesmanship" quality. As a result, the uninitiated gets a distorted viewpoint of new developments. I refer to statements about "Machines That Think," "Giant Brains," "Ability to Out-Think the Scientist Who Built Them," and other misleading suggestions which infer the machines are endowed with intellect or reason. This is far from true. They are in reality nothing more than glorified desk calculators. They receive their operating stimulus from electrical impulses produced when a contact is made through a hole in a piece of paper, or when a magnetized spot passes under a reading head rather than from a manual push on a keyboard. But such machines have opened new roads to scientific progress by enabling the solution of such problems as coordinated weather prediction, complex space navigation equations, structural vibration analysis, complex thermal distribution studies, etc.

It may be that the deciding factor in the present race for power will be the enormous advantage our scientists gain by having these powerful mathematical machines available.[4]

Fig. 2—View of IBM Type 650 Magnetic Drum Data Processing Machine.





ROSEMARY JOHNSON came to RCA in July 1954 directly upon graduation from Immaculata College where she received her BS in Math. Until January of this year, when she left the Company, Mrs. Johnson was employed in the Advanced Development Section of the TV Division. Much of her time was spent at the Princeton Laboratories where she did programming for their IBM 650 Computer.

CONCLUSION

In conclusion, we should like to stress to every engineer the fact that computer facilities are at your disposal. If you are engaged in work that involves the numerical solutions of formulas, then here is an opportunity for you provided by RCA. If you have problems that would increase the range of your work but that you hesitate to solve because of the time involved, then reconsider them in the light of computing.

ACKNOWLEDGEMENTS

The author wishes to express her appreciation for the invaluable aid and cooperation of Mr. Robert Serrell and Mr. T. Murakami in writing this paper.

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4. See reference 2, p. 12.

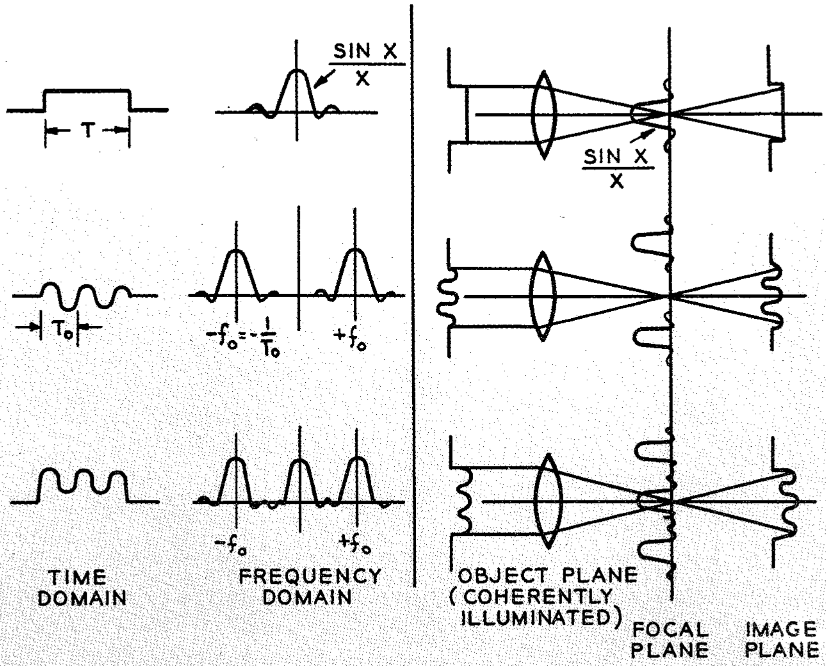

Fig. 1 — Electrical and Optical Analogy

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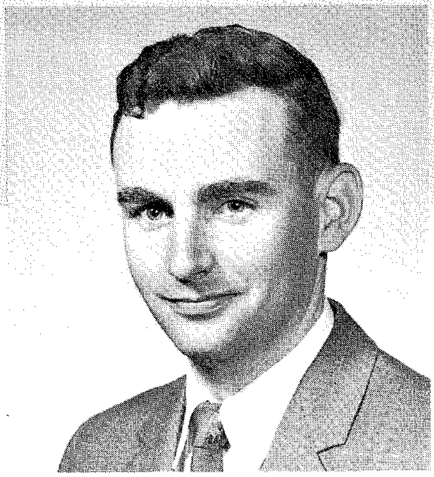

OPTICAL SPATIAL FILTERING

By **DONALD L. AMORT**

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RAPID FOURIER ANALYSES of complex waveforms or computation of antenna patterns are easily attainable through the use of optical filters. For example, near-perfect low-frequency, narrow-band filters can be designed, with equivalent bandwidths of fractions of a cycle.

In recent years a new insight has been brought to the field of optics by the use of the analogy between optical system theory and electrical communication theory. The work of Otto Schade[1] in evaluating optical systems in terms of equivalent frequency response[1] has created an increase of interest in optics by electronic engineers, resulting in wider application of optical systems. This article is about a major application of optics, that of employing optical principles to solve problems of filtering . . . previously accomplished only with electrical or mechanical networks. A rigorous theoretical treatment of the optical-electrical analogy can be found in the literature.[2] However, this article gives a simple explanation of the basic principles and illustrates a few functional applications for those not already acquainted with them.

THE OPTICAL-ELECTRICAL ANALOGY

It is well known in circuit theory that the Fourier transform of a single pulse yields the distribution of amplitudes as a function of frequency. The amplitude of the spectrum of a single pulse is sin x/x centered about zero frequency, as shown in Fig. 1. The width of the spectrum is inversely proportional to the period of the pulse. If the signal is a sine wave of frequency (f_o), modulated by a single pulse, the resulting spectrum is the same width and shape as the spectrum of the d-c pulse, but now it is centered around plus and minus f_o. The spectrum of the sum of a number of time functions is equal to the sum of the individual spectra for a linear system.

A very exact analogy exists in optics. Diffraction theory shows that a slit, uniformly illuminated with collimated monochromatic light, produces the amplitude pattern sin x/x at the focal plane of a lens. If a ruling consisting of parallel opaque and transparent strips is placed over the aperture, the diffraction pattern consists of a central spectrum and symmetrically spaced spectra of the first and higher

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[1] National Bureau of Standards Symposium on Optical Image Evaluation (NBS Circular No. 526)—"A New System of Measuring and Specifying Image Definition," by Dr. O. H. Schade.

[2] "Selected Topics in Optics and Communication Theory," O'Neill, Edward L., Boston University Optical Research Laboratory, Summer 1956.

orders. The distance separating the line of the first order spectrum is given approximately by the relationship

$$S = F\lambda/d,$$

where F is the focal length of the lens, λ is the wavelength of the monochromatic light, and d is the spacing of the ruled lines.

The spacing d corresponds directly to the period of a square wave in the electrical case. As the spacing decreases, the spectral lines shift in the same manner that the spectrum of an electrical square wave shifts in frequency as the period decreases. It can also be shown that the Fourier spectrum of any complex amplitude distribution of an aperture occurs at the focal plane.[2]

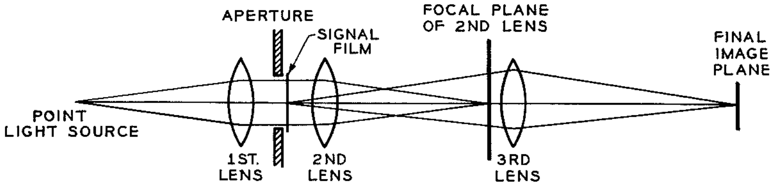

Fig. 2 — Optical configuration for spatial filtering

OPTICAL FILTERING

In order to utilize the principles of optical filtering, it is necessary that the signal be stored in the form of variation in the transmission characteristic of photographic film or a material with similar properties. In many cases, the signal is already stored in this manner, as in the case of photographs. Other types of signals can be recorded on film by photographing a cathode ray tube that is intensity modulated with the signal, or by using other types of light modulators.

The basic configuration of the optical system for performing filtering operations on a signal, shown in Fig. 2, consists of a monochromatic light point source, a lens to collimate the light, the signal film, a second lens to form the spectrum at its focal plane, and a third lens to form the final image of the signal film. A proper mask introduced in the focal plane can select the spatial Fourier components that are desired in the final image and suppress the others.

OTHER APPLICATIONS

Another application, that of sharpening the edges of a photographic image, can be accomplished by placing a small opaque spot at the axis of the focal plane. The spot decreases the "d-c components" and permits the remaining higher spatial frequency components to be reformed into an image with sharp edges. An example of the signal output image with edges sharpened by this means is shown in Fig. 3. A mathematical analysis of this type of filtering shows that the double lines are to be expected, but that they can be controlled by the size of the spot and the weighting of its relative opacity from center to circumference.

This general type of filtering is useful for image enhancement of photographs and has been applied to aerial reconnaissance. Within RCA these techniques have also been applied to the pre-enhancement of kinescope recordings by the Optical Engineering Group, DEP Special Systems and Development, headed up by D. J. Parker. The filtering was done to emphasize the high-frequency components in the film record and attenuate the lows so that after passing through subsequent parts of the system, the total response of the image would be more nearly uniform. The results from this have been very encouraging.

An *optical band-pass filter* can also be used to attenuate certain components; i.e., noise, or unwanted detail and to permit only a desired band of frequencies to constitute the final image. The effectiveness of a low-pass filter in removing unwanted lines from the signal is illustrated in Fig. 4.

Comb filters and other types of matched filters can easily be made. A simple method consists of positioning pinholes at the proper places in opaque material. A more exact filter may be made by exposing a piece of film at the focal plane to the spectrum of the desired signal. The positive transparency of a film so exposed is a filter that will attenuate noise and only permit passage of the spectral components present in the signal. An example of comb filtering is shown in Fig. 5.

Because the spatial spectrum is two dimensional, it is possible to separate signals aligned in a particular direction by orienting the spatial filter in the proper direction. If two rulings are placed in the aperture, at a given angle to each other, the spectra will lie at the same angle relative to each other. In Fig. 6 is the spectra of two rulings at right angles. Selection of either spectrum set will give an output that is the ruling that produced the selected spectrum.

Scanning the spectrum with a phototube equipped with a pinhole will give a measure of the power spectrum of the aperture illumination. This is useful for obtaining antenna patterns and can also be used in the analysis of complex waveforms.

Only a few of the many practical applications of optical filtering have been suggested here. Other types of operations readily performed by optics and of interest to engineers are multiplication accomplished by imaging one spatial function through another, and implementation of complicated cross correlations by using cylindrical lenses to perform integration.[3] In general, optical systems can constitute simple and accurate computers that are capable of performing many operations. Often, the exploitation of such systems by engineers will result in savings of time and money.

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[3] Goade, H. H., and Machol, R. E., "Systems Engineering," McGraw-Hill, New York, 1957; p268.

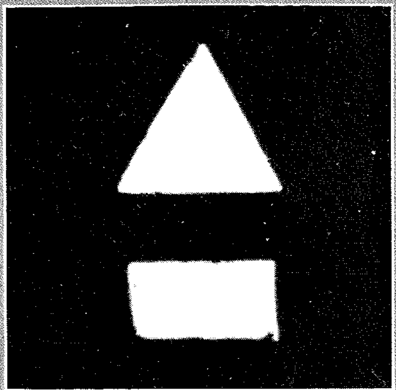


Fig. 3a — Signal before filtering

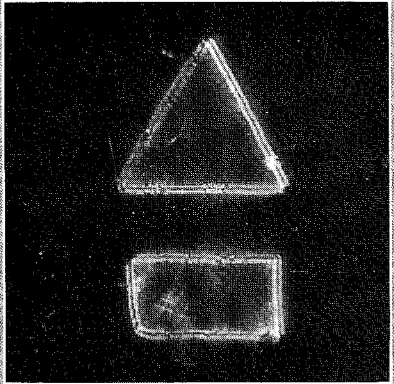


Fig. 3b — Signal with edges sharpened

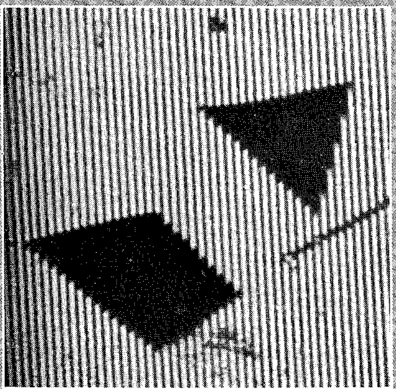


Fig. 4a — Signal and unwanted lines before filtering

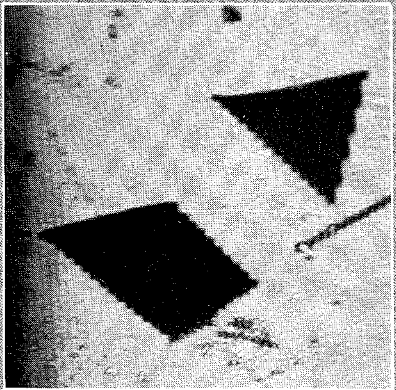


Fig. 4b — Signal with lines filtered out

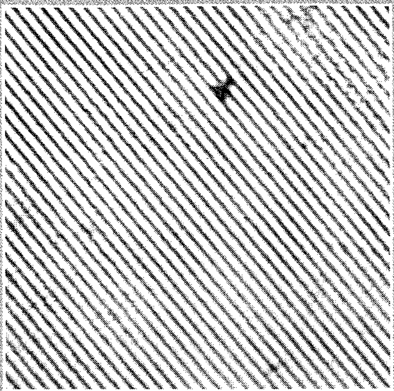


Fig. 5a — Desired signal

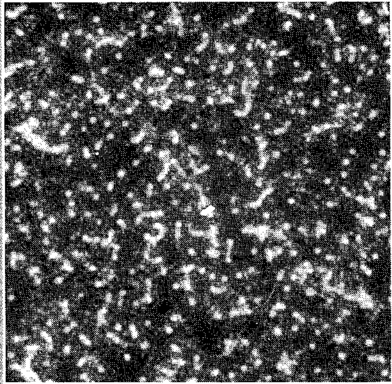


Fig. 5b — Noise

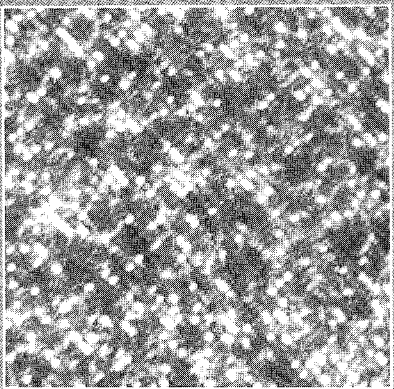


Fig. 5c — Signal combined with noise

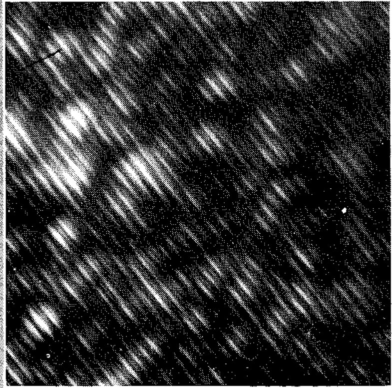


Fig. 5d — Signal recovered by comb filtering

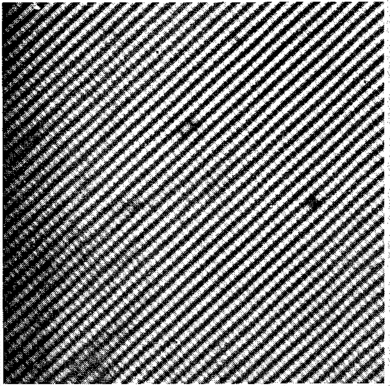


Figure 6

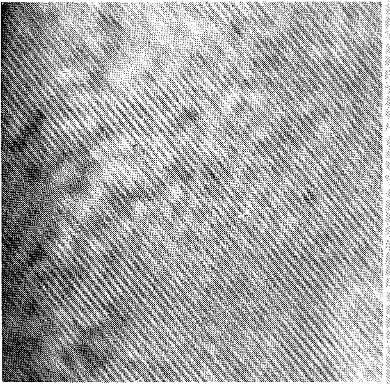


Figure 6

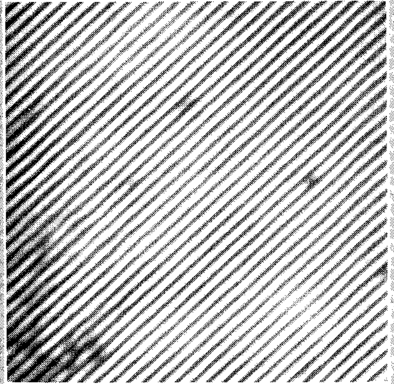


Figure 6

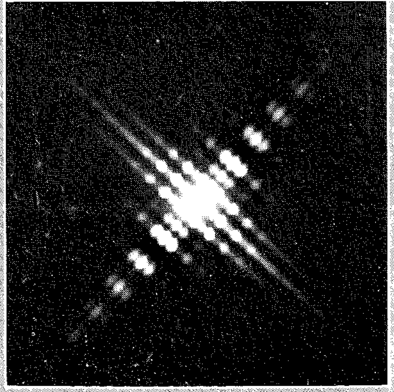
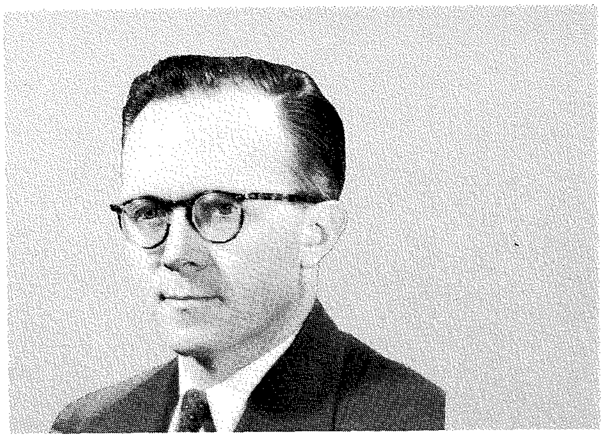


Fig. 6 — Spectra of two rulings at right angles are shown in above four illustrations

SOLAR BATTERIES FOR ELECTRONIC EQUIPMENT

ERNEST G. LINDER was awarded the Ph.D. degree by Cornell University in 1931, and the M.S. and B.A. by the University of Iowa in 1927 and 1925 respectively. He served as instructor at the California Institute of Technology 1927-28, was Detroit Edison Research Associate at Cornell 1928-31, was a member of the Research Division of the RCA Manufacturing Company 1932-41, and since 1941 he has been with the RCA Laboratories, where he is now Administrator for the Electronic Research Laboratory. Dr. Linder has research experience, publications and patents in the fields of thermoelectricity, photoelectricity, crystals, electrical discharges in gases, mass-spectrography, microwave tubes, microwave propagation, electron physics, radar, semiconductors, nuclear and solar batteries. He is a Fellow of the American Physical Society, Sigma Xi, and a Fellow of the Institute of Radio Engineers.



by

Dr. E. G. LINDER

RCA Laboratories, Princeton, N. J.

THERE HAS BEEN A notable increase in interest in solar batteries* during the past several years. This has arisen mainly through remarkable improvements which make these devices, for the first time, appear to be potential sources of energy of a practical sort. For example, solar batteries have now been made which will convert sunlight into electrical energy with an overall efficiency of about 14 per cent. This is comparable to the overall efficiency of some types of small internal combustion engines.

It is evident that the solar battery is not far from a competing position, insofar as efficiency is concerned. Furthermore, there is the broader aspect of future energy sources for mankind, and the possible exhaustion of coal and oil supplies about 200 years from now. These are reasons for a serious interest in solar batteries. However, this paper is concerned with applications to electronic equipment, and here we are dealing with a more immediate possibility. The use of solar batteries for power in the milliwatt range can be discussed as a practical matter today.

We can obtain a perspective of the status of the solar battery by taking a quick preliminary look at its origin and earlier development. This takes us back over 100 years to 1839 when the first photovoltaic cell appears to have been discovered by Becquerel[1]. He noticed that an electromotive force was generated when light fell on one of a pair of electrodes immersed in an electrolyte. This was a wet type of cell. The first dry photovoltaic cell was discovered by Adams and Day[2], who observed the effect in selenium about forty years later in 1876. However, the practical application of this cell was delayed until its rediscovery almost simultaneously by Lange[3] in 1930 and Bergmann[4] in 1931. The cuprous oxide type of cell was discovered by Grondahl and Geiger[5] in the early 1920's and further developed by Lange[6] and Schottky[7] in 1930. Thus about 100 years elapsed between the first discovery of the photovoltaic effect and its first practical application. Selenium cells have now been used commercially for many years, principally as light meters and for the operation of relays. They have not been used extensively as solar batteries, probably because of their low efficiency.

The more recent types of photovoltaic cells are of considerably higher efficiency. Their development may be considered as an outgrowth of the extensive work on transistors, and semiconductors in general, which has expanded prominently during the past few years.

These more recent types of cells make use of a special type of barrier layer between two semiconductors known as a p-n junction. The older selenium and cuprous oxide cells used metal-semiconductor junctions. Another and perhaps more important difference is that the new cells use single-crystal materials, whereas the old ones were polycrystalline.

OPERATION OF A SOLAR BATTERY

A simplified sketch showing the principal elements of one of the new-type cells is illustrated in Fig. 1. Here is shown a cross section of a wafer of semiconductor material, taken as n-type. Its upper surface is treated by diffusion or alloying so that it contains a small amount of doping material, making it p-type. This layer is thin enough so that light may penetrate to within a diffusion length of the junction. Output leads are connected to the p- and n-type sections.

The p-n junction is the most important part of this cell, and the element where the conversion of radiant energy to electricity actually takes place. Such a junction is illustrated in Fig. 2. An internal potential difference, similar to a contact potential difference, exists in such a junction. The potential distribution is shown by the dashed line. The valence band is shown at the bottom. By far the greater fraction of the electrons in the semiconductor resides in this and lower bands. At the top is shown the con-

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*Strictly speaking, these devices are solar "converters" and not "batteries"; however, the latter term has been employed here because of common usage.

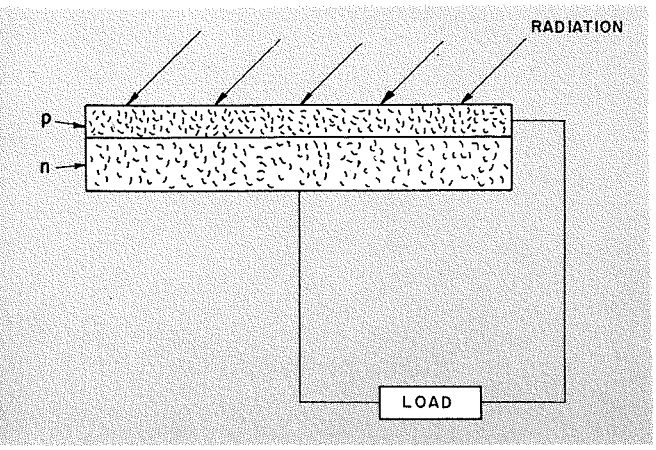


Fig. 1—Principal Parts of a Solar Battery.

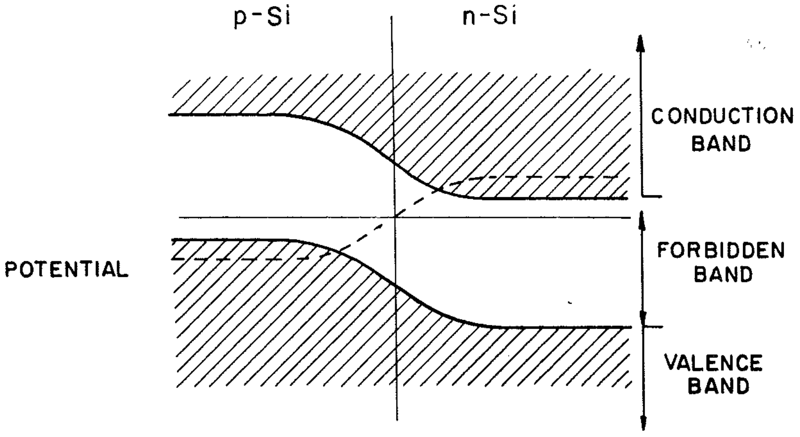
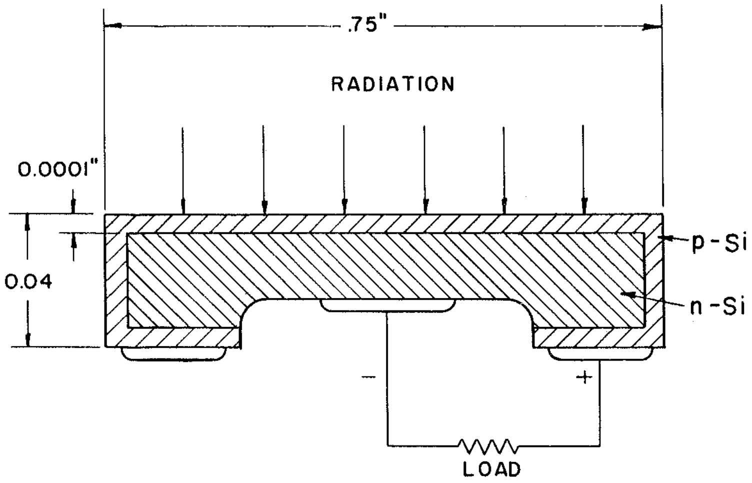


Fig. 2—Energy Bands in a p-n Junction.

Fig. 3—Cross-sectional View Showing Constructional Details of Silicon Solar Battery.



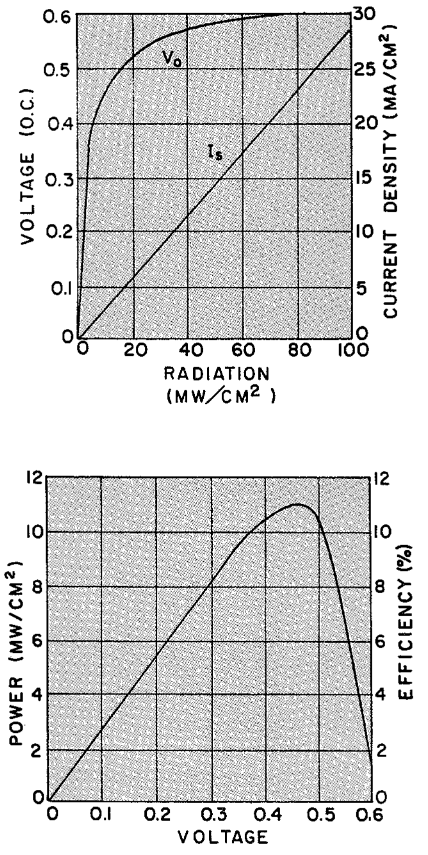


Fig. 4—Typical Curves Showing Current, Voltage and Power Relations of Silicon Solar Battery.

duction band. The number of electrons in the conduction band, or holes in the valence band, may be increased by raising the temperature or by exposing the semiconductor to suitable radiation, such as light or nuclear radiation. Between the valence and conduction bands is the forbidden band where free electrons or holes may not reside, as prescribed by the laws of quantum mechanics. The width of this band determines important properties of the material. If the width is zero, the material is a metal. If it is about one electron volt, the material is a semiconductor. If it is more than several electron volts, the material is an insulator. In the case of solar batteries, the width usually lies between one and two electron volts.

In operation, light raises some electrons to the conduction band, leaving positive holes in the valence band. Under the action of the internal electric field, these electrons move to the right, and the holes to the left, thus producing an electric current in an attached circuit.

Junctions of this type are capable of converting many types of radiant energy into electricity, including visible light, ultraviolet light, x-rays, and nuclear radiations such as alpha, beta and gamma rays. As a matter of fact, the junctions will operate with any type of radiation capable of creating free electrons and holes in the semiconductor. The main criterion is that the quantum energy of the radiation equal or exceed the energy of the forbidden band gap. When such devices are operated with solar light, they are called "solar batteries"; when operated with nuclear radiation, they are called "atomic batteries." However, they are basically similar devices.

In 1954 there was an outburst of activity on devices of this type. In January of that year, the Radio Corporation of America announced an experimental cell of this type. However, operation with nuclear radiation was emphasized, and the device was called an atomic battery. RCA work with visible light will be discussed later. In April, the Bell Telephone Laboratories released information on a similar device used as a solar battery. In July, articles appeared describing work on the photovoltaic effect at the General

Electric Company's Knolls Laboratory. And, in October, work at the Wright Air Development Center was published describing their type of battery. It appears that 1954 was a big year for solar batteries.

A typical construction of a silicon solar is shown in Fig. 3. It consists of a disc of n-type silicon about three-fourths of an inch in diameter and 0.040 inches thick. By heating in the presence of a gas containing boron, the boron diffuses into the silicon to a depth determined by time and temperature, forming a p-type layer. The junction so formed is usually at a depth of about 0.0001 inches. A small area of the p-layer is removed so that contact to the n-silicon may be made. A second contact is made directly to the p-layer.

A typical set of current-voltage curves[8] for this cell is shown in Fig. 4. The open-circuit voltage V_o is shown in the left-hand part of the figure, plotted as a function of the sunlight intensity. The value 100 mw/cm² corresponds to full sunlight at the earth's surface in the vicinity of New York. In the same figure, the short-circuit current I_s also is shown. The voltage rises logarithmically, and the current linearly, in accordance with theory. In the right-hand part of the figure the power output and efficiency are shown for full sunlight (100 mw/cm²), for a varying voltage due to variation of the load resistance. A maximum efficiency of 11 per cent is shown, although similar batteries have now been made with as high as 14 per cent efficiency.

At the RCA Laboratories, work has been in progress under a U. S. Signal Engineering Laboratories' contract. This investigation has been carried on principally by Paul Rappaport[9], J. J. Loferski[9, 10], and D. A. Jenny[9]. Its purpose is to study new materials for solar converters. Materials used formerly, apparently have been selected largely on the basis of accident or availability. Now an attempt is being made to have a scientific evaluation and selection. The specific aim is to find a semiconductor for use in a photovoltaic cell which will convert solar energy into electricity with the highest possible efficiency. The existence of such an optimum material results from the optical absorption which determines what fraction of the solar spectrum will be used, and the rectifying properties of the p-n junction which govern the conversion to electricity. Although the efficiency depends upon most of the parameters of the semiconductor it turns out that the forbidden band gap energy is one of the most important. As the band gap increases, the voltage generated increases, but the current decreases since less of the spectral energy is absorbed. Hence, the efficiency and power pass through a maximum. A mathematical analysis has been made to determine the optimum band gap. It has been found that absorption by atmospheric gases and water vapor modify the solar spectrum and shift the optimum energy gap between the limits 1.2 to 1.6 ev. This effect is shown in Fig. 5. Here *m* is the effective number of atmospheres through which the sun's rays pass. This is a function of the position of the sun. The quantity *w* is the number of centimeters of precipitable water in the atmosphere.

These efficiency data do not take into consideration various energy losses such as those due to light reflection from the surface, hole-electron recombination, and internal resistive losses. Hence the experimental efficiency values are lower than the theoretical. The highest observed value so far reported is 14 per cent.

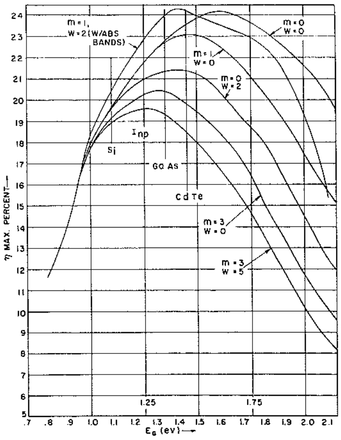


Fig. 5—Maximum Efficiency vs. Energy Gap for Different Atmospheric Conditions.

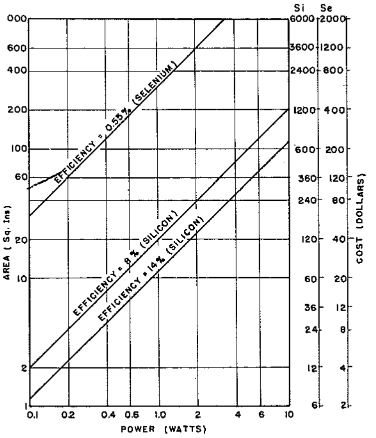


Fig. 6—Approximate Size and Cost of Some Commercial Solar Batteries. (The cost varies considerably with size and quantity.)

As a result of this analysis, the experimental program at RCA, has been directed at an experimental study of InP, GaAs, and CdTe. The work at present is concerned with the production of these comparatively new materials in the form of crystals large enough for testing, and having the proper electrical resistivity, and carrier lifetime. The technologies of p-n junction formation, and ohmic contact production also are being studied. The best efficiency obtained to date is 6.5% with GaAs, but this is not thought to be the maximum value.

ELECTRONIC APPLICATIONS

Electronic and other applications await only an adequate supply of solar batteries at a cost competitive with that of other types of batteries. Although selenium photovoltaic cells have been sold commercially for many years, they do not appear to have been used for power generation, but only as component parts of light meters, relay operators, etc. Recently, however, several concerns have advertised solar batteries for general application. Both selenium and silicon types are available. Information on some commercially available batteries is given in Fig. 6. (Only the 8% Si type is available commercially). Here it is seen that the efficiency of the Se type is lower than that of the Si by a factor of about 16, so that 16 times the area is required. However, the cost per unit area is lower for selenium by a factor of about three.

A comparison between the cost of power from solar cells and that from LeClanche dry cells may be of interest. Two cents per watt-hour may be taken as an average figure for D-size cells. For solar cells the data of Fig. 6 may be used. Assuming 8 per cent efficiency, taking the present cost of about $120 per one-watt capacity, and assuming operation at an average of one-sixth full power, it is found that to be competitive cost-wise with LeClanche cells, a solar cell must last about four years. This gives a rough comparison, but for accuracy each application should be analyzed individually.

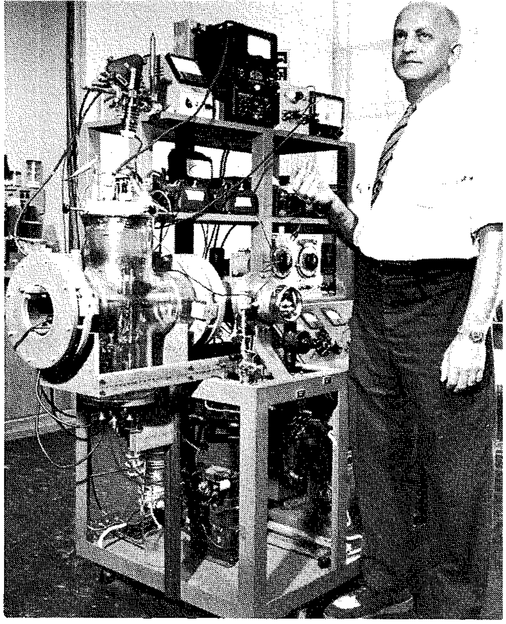


Fig. 8—Equipment for Evaporating Thin-Film Photovoltaic Devices. L. Pensak is Shown With a Sample Experimental Device in His Hand.

Fig. 7—(Courtesy Hoffman Solar Division) A 400-Cell Solar Battery, Which Produces About Ten Watts of Power.

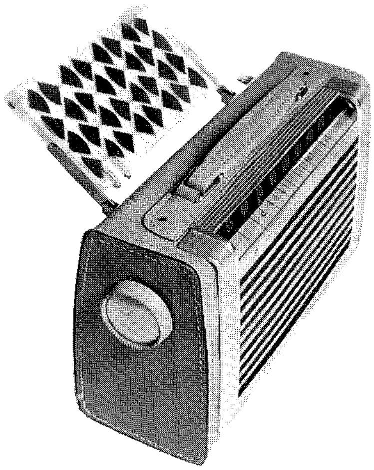


Fig. 9—An RCA Portable, Transistorized Radio Modified for Solar Battery Operation.

A reduction in cost is very necessary for wide-spread applications. For power in the range of over a few watts, it is presently necessary to construct batteries of many small cells connected together (See Fig. 7). This is obviously costly. An RCA Laboratories project was undertaken with cost reduction in mind. It is believed that if the use of large-areas of highly purified semiconductor crystals could be avoided the cost could be greatly reduced. Research is in progress by L. Pensak, on techniques using the evaporation of thin films of semiconductor, see Fig. 8. Encouraging results have been obtained.

Solar batteries are especially promising for use with transistorized equipment, where the low-power requirements of the transistor are compatible with the capabilities of such batteries. A typical application is shown in Fig. 9, where an RCA transistorized portable radio is shown as modified for operation with a solar battery consisting of 32 silicon cells connected in series.

A particularly intriguing application is that of a power supply for an artificial earth satellite. Here the requirements are for long life, small size, light weight, ruggedness and reliability, all of which are well met by solar batteries. Another requirement in this application is that the complex, high-energy radiation of outer space shall not damage the battery. Radiation damage tests were made at RCA Laboratories, under the above mentioned Signal Engineering Laboratories' contract, by P. Rappaport and J. J. Loferski, to determine the extent of damage by ultra-violet light, x-rays, electrons, protons, and alpha particles. No important effects were found for radiation intensities such as are encountered above the atmosphere.

CONCLUSIONS

The most significant solar battery development of the past ten years is no doubt the great increase in efficiency—from about ½ per cent to about 14 per cent—a factor of about 28. Further research may yield still greater increases, but already the region has been reached where commercial applications are feasible insofar as efficiency is concerned.

The most important problem yet to be solved is that of reducing cost. Mass production of solar batteries would no doubt reduce costs considerably. Nevertheless, a cheaper fabrication process is needed—possibly one not requiring the use of large areas of highly-purified semiconductor crystal.

Another problem, not mentioned above, but which should be considered, is the development of a simple, cheap storage battery having a life equal to that of the solar battery itself. Although a storage battery is not necessary for all applications, it is required for operation in the absence of adequate light.

It seems quite likely that both the problem of cost and that of storage will receive attention and approach solution during the next few years, and we shall probably see increasing applications of solar batteries to electronic equipment.

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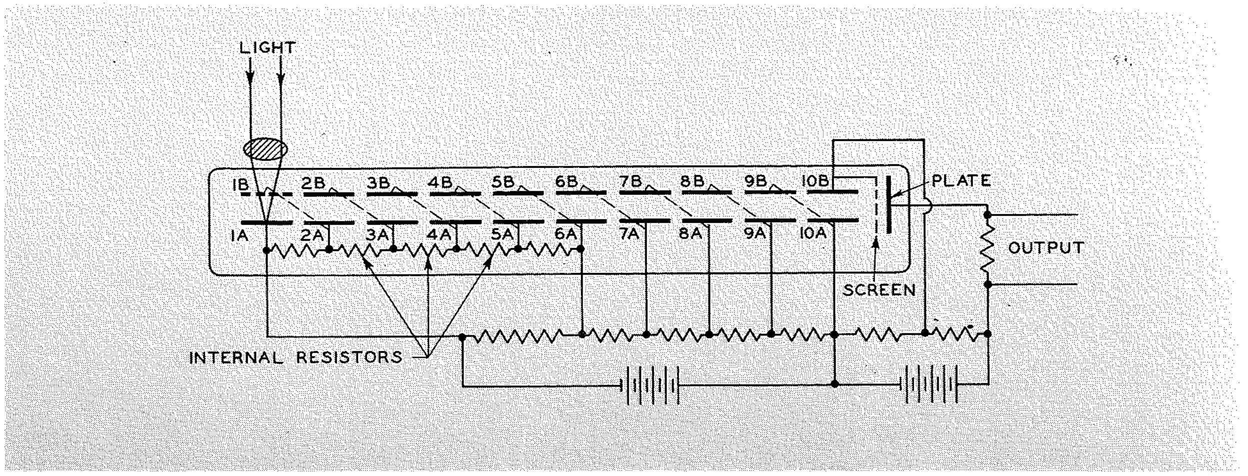

THE MULTIPLIER PHOTOTUBE

by **Dr. R. W. ENGSTROM**

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Electron Tube Division, Lancaster, Pennsylvania

DUPLICATION OF THE sensitivity of the dark-adapted eye requires a device capable of detecting or measuring a photocurrent as small as 10^{-18} ampere. The almost impossible problem of utilizing such small currents has been solved by the use of secondary-emission amplification in multiplier phototubes. These sensitive tubes are remarkable for their very high speed of operation which permits resolution of photoevents in 10^{-9} second. This speed is in sharp contrast to the time response of the human eye. The eye readily accepts the relatively low-frequency light pulses of television and movies as a continuous display.

Use of the unusual properties of multiplier phototubes has led to many and varied applications: measurement of starlight, spectral analysis, headlight-dimming control, scintillation counting, and flying-spot pickup. This paper traces some of the historical developments of the multiplier phototube and shows the interaction of the principal applications.

INVENTION

Photoelectricity was demonstrated by Hertz in 1887. He showed that a spark could be made to jump a larger gap when the negative electrode was irradiated with ultraviolet. Although secondary-electron emission has also been known since 1902, the first practical combination of these two effects in a multiplier phototube did not occur until many years later.

From the beginning, RCA engineers have been foremost in developing this new device. A phototube having a single-stage of secondary emission was designed by Iams and Salzberg[1] at RCA in Harrison. This tube had an effective gain of about 6 and was thus the equivalent of a gas-filled phototube without frequency-response limitations. Commercially, the advantages of this single-stage tube did not outweigh the additional cost and circuit complexities.

High gain called for a design having many stages, with secondary electrons directed from one stage to the next. Zworykin, Morton, and Malter[2] ingeniously solved this problem by using crossed electric and magnetic fields. Tubes having as many as twelve dynodes functioned without loss of focus. These experimental tubes were obsoleted by later developments which did not require the use of magnetic fields.

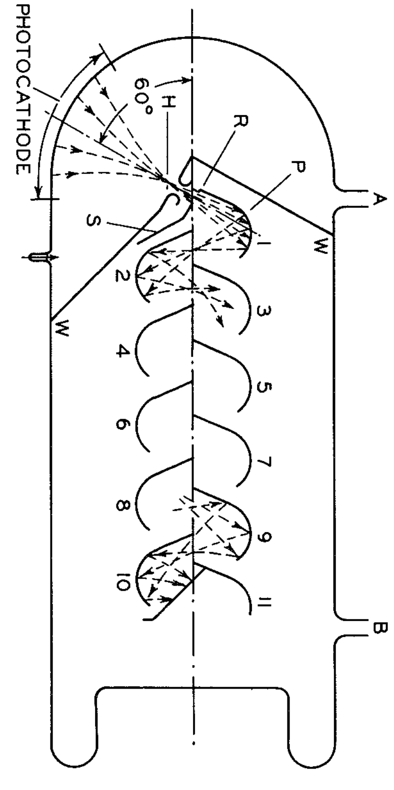

Fig. 2—Diagram Showing Original Linear-Type Dynode Array.

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[1] Iams, H. and Salzberg, B., "The Secondary Emission Phototube," Proc. I.R.E., *23*, pp. 55-64, January 1935.

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Fig. 1—Diagram of Magnetic-focus Type of Multiplier Phototube.

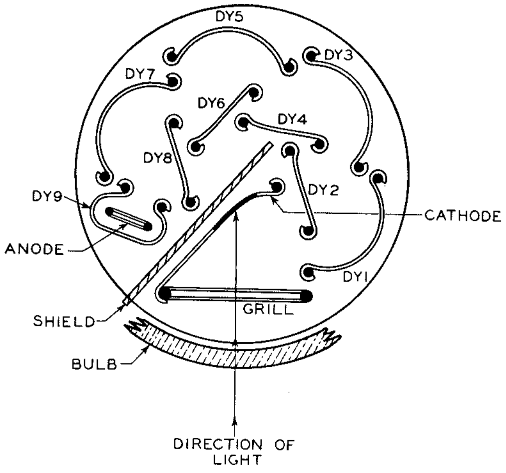

Fig. 3—Diagram Showing Circular-Type Dynode Cage Used in the 931-A.

FIRST COMMERCIAL MULTIPLIER PHOTOTUBE

Zworykin and Rajchman[3], by use of mathematical analysis and mechanical analogues, devised linear and circular-type recurring dynode structures requiring only electrostatic fields. Rajchman and Snyder[4] further developed the circular type of dynode "cage" to permit a more compact arrangement with a larger photocathode. This development led to the first commercial multiplier phototube, the 931.[5] All present-day RCA multiplier phototubes stem from these original circular and linear designs. Much of the early development work on multiplier phototubes was done under the direction of of Dr. A. M. Glover.

APPLICATION PRINCIPLES

In a multiplier phototube such as the 931-A having antimony-cesium dynodes, secondary emission at each stage is 4 to 5 electrons per primary at 100 volts per stage. For 9 stages, therefore, the over-all gain is about 10^6. Aside from convenience, this current gain is important in measuring very small amounts of light because it eliminates circuit-noise problems.

In a vacuum phototube not having secondary-emission amplification, the limit to detection of low-level light is usually set by the Johnson noise of the load (coupling) resistor rather than by the fluctuation of the photocurrent. For example, the rms noise voltage in the load resistor is $(4kTR\triangle f)^{1/2}$, where k is Boltzman's constant, T is the absolute temperature, R is the resistance, and $\triangle f$ is the bandwidth of the observation. For comparison, the shot noise of the photocurrent, i, produces an rms voltage drop across the load resistor of $R(2ei\triangle f)^{1/2}$, where e is the charge of the electron. Usually, the thermal noise of the resistor is larger than the noise inherent in the photocurrent, and the full detection capabilities of the phototube are obscured. However, the Johnson noise voltage increases as $\sqrt{R}$, while the shot-noise voltage developed across the resistor varies directly as R. It is thus evident that an increase in the value of R favors elimination of the Johnson noise component. As the photocurrent becomes smaller, extremely high resistance values (10^{12} ohms and larger) are required. Unfortunately, high resistance leads to problems of leakage and instability, as well as loss of response speed.

In a multiplier phototube the amplification by secondary emission is essentially noise free, and the primary limitation to detection of low-level light is the shot noise of the photocurrent. This characteristic permits detection of much lower light levels with moderate load resistances.

Another advantage of the multiplier phototube is the retention of the high speed inherent in the photoemission process. When the load resistance for a conventional phototube is increased to improve the signal-to-noise ratio, there is an inherent loss in speed associated with the circuit time constant. Because a multiplier phototube has high gain, however, load resistances as small as 100 ohms can be used. Consequently, single photoelectrons may be observed with no time limitation except that due to transit-time spread of electrons through the multiplier phototube.

SCIENTIFIC MEASUREMENTS

Early applications of the multiplier phototube were for scientific measurements and made use of the tube's ability to detect low light levels. In astronomy the highly sensitive multiplier phototubes opened up new avenues of research, permitting measurements with small telescopes that formerly required giant ones. Applications now include stellar photometry, colorimetry, telescope guiding, study of starlight polarization, and observation of variable stars and spectroscopic binaries.

Similarly, in Raman spectroscopy the multiplier phototube became an essential tool. Raman spectra originate from scattering of monochromatic light in a gas or liquid. Multiplier phototubes have made possible rapid, direct measurements of the Raman spectra, outmoding older and inflexible techniques of photography. Practical applications are in the quantitative analysis of organics and in the determination of molecular structure.

DARK NOISE

Because multiplier phototubes eliminate problems of thermal noise in coupling resistors, it is important to know the limitations imposed by the multiplier phototube itself. If there is no light on the cathode, output current is caused only by amplified thermionic emission, leakage, or regenerative effects. The principal noise in

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[3] Zworykin, V. K. and Rajchman, J. A., "The Electrostatic Electron Multiplier," Proc. IRE, *127*, pp. 558-566, September 1939.

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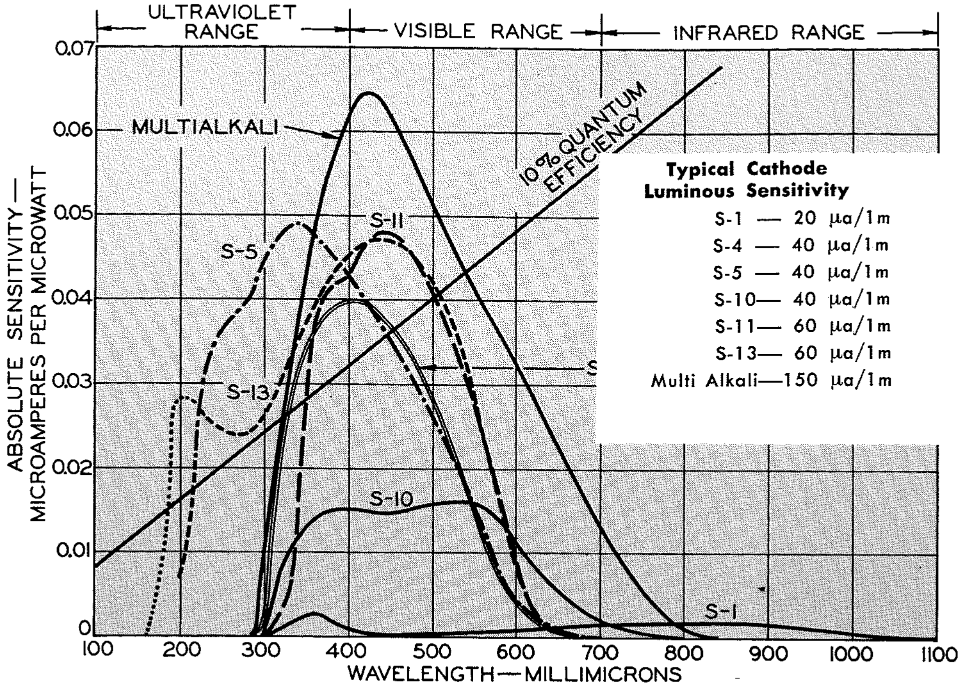

Fig. 4—Spectral Response Characteristics of Typical Photocathodes Plotted on an Absolute Sensitivity Scale for Comparison Purposes.

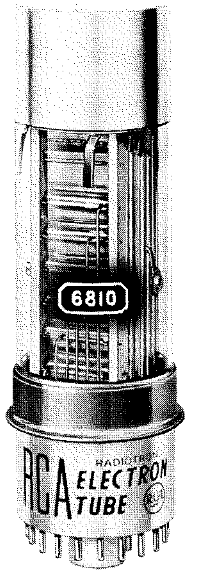

Fig. 5—Picture of the 6810, recently developed multiplier phototube having very high gain and short time response. This was the type of tube used as a scintillation counter to detect the anti-proton particle.

the output current originates from random thermionic emission from the photocathode. In general, thermionic emission is greater when photocathodes are made more red sensitive. Thus, for a silver-oxygen-cesium surface used in a phototube having a red-infrared spectral response (S-1), thermionic emission from the cathode is of the order of 10^{-11} ampere per cm^2; for an antimony-cesium surface in a phototube having a blue-green spectral response (S-4), the thermionic emission is only of the order of 10^{-15} ampere per cm^2. These values are for room temperature; a great reduction in dark emission can be achieved by cooling.

Because of the random character of thermally emitted electrons, these small currents set the low limit for detection of light. For a 1-cm^2 antimony-cesium surface at room temperature, a photocurrent of 100 photoelectrons per second can just be detected by means of an amplifier having a bandwidth of 1 cps. This current corresponds to a light level of approximately 5 x 10^{-13} lumen.

If the photocathode is cooled to liquid-air temperature, the thermal emission decreases a thousandfold and the detection level for a 1-cps bandwidth is reduced to about 3 photoelectrons per second. Detection of light at this level becomes a matter of counting individual photoelectrons and thermal electrons.

NOISE-IN-SIGNAL AND RADAR JAMMING

Because photoelectrons are emitted randomly in time, noise results even when the light source is constant. This noise in the photocurrent obscures detection of a small signal light in the presence of a larger light background. The detection of stars in the daytime or of codes or markings on paper poses many problems because of this photocurrent noise.

During World War II, multiplier phototubes were used for radar jamming. It may seem strange that multiplier phototubes, which are low-noise devices, should be useful as noise sources. It might be expected that only multiplier phototubes having poor signal-to-noise ratio could be used for this purpose; the contrary is the case. Pertinent qualifications of a multiplier phototube as a noise generator are its high gain and wide band pass—greater than 100 megacycles.

A typical airborne noise jammer of World War II utilized a 931-A multiplier phototube illuminated with a steady light source. The tube output was amplified to produce noise power to modulate a radar carrier in the band it was desired to jam. The multiplier phototube was operated at high gain, 10^6 to 10^7, and at high output current, 1 to 2 milliamperes. Jamming was very effective and not readily recognizable because of the random and "white" character of the noise generated.

FLYING-SPOT APPLICATION OF MULTIPLIER PHOTOTUBES

Multiplier phototubes are ideal sensing devices for pickup of light-pulse signals. Quite recently, L. Shapiro and H. E. Haynes of the RCA Commercial Electronic Products, Camden, New Jersey, developed a flying-spot scanner using 5819 multiplier phototubes for scanning color transparencies with a flying-spot cathode-ray tube.

The flying spot is also used for developing television signals from slides and motion picture films. Multiplier phototubes had adequate speed of response but due to the small amount

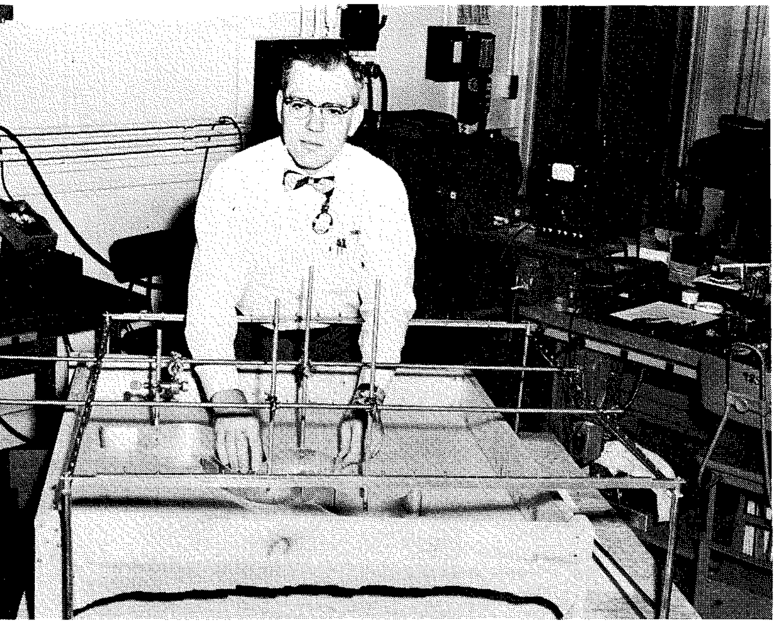

Fig. 6—Mr. Richard G. Stoudenheimer demonstrating adjustment of rubber-dam model of dynode arrangement for a multiplier phototube.

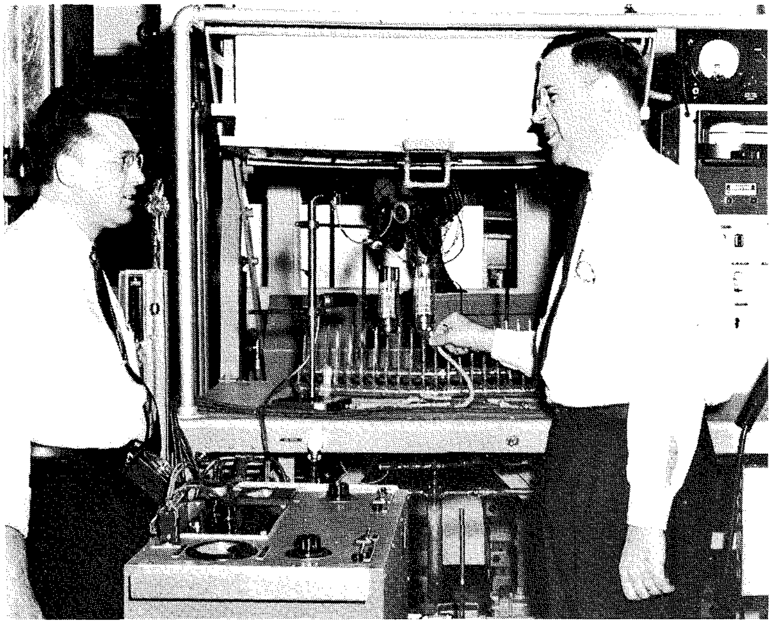

Fig. 7—Messrs. J. J. Polkosky and A. M. Splinter observing exhaust of 6810 tubes.

of light available did not always provide the noise-free picture desired. For this reason the 5819 multiplier phototube having a large semitransparent photocathode on the end of the bulb was developed. The semitransparent photocathode has nearly double the sensitivity of a typical solid-backed cathode; in addition the 2-inch bulb diameter permits much improved optical efficiency. The 5819 permitted an improved flying-spot system particularly in the blue and green regions, but its spectral response (S-9 at that time) was not suitable in the red region. The 6217, a tube similar to the 5819 but having a silver-bismuth-oxygen-cesium photocathode was developed to provide greatly improved red response. The spectral response of the 6217 was identified as S-10.

A new red-sensitive multialkali photocathode discovered by Dr. A. H. Sommer[6] of the RCA Princeton Laboratory is presently being developed for flying-spot application.

SCINTILLATION COUNTING

Announcement of the 5819 in 1949 coincided with the vigorous development of scintillation counting.[7] Today many measurements in nuclear science depend upon multiplier phototubes to sense scintillations in crystals bombarded by nuclear particles.[8]

Scintillation counting is not new. In 1903 Crookes introduced the spinthariscope, an optical device which permitted a dark-adapted observer to count light flashes caused by radioactive particles impinging on a phosphor. For many years this visual method was used in the study of radioactivity. Although now obsolete, the spinthariscope is still used in schools to demonstrate the principles of radioactivity.

Shortly after World War II the multiplier phototube was used to count scintillations from naphthalene and thus introduced a powerful new tool to nuclear science. Experimentation spread rapidly in this country and elsewhere. Better scintillators were found, most of which emitted a blue light that is well matched by multiplier phototubes having S-4 response. Sodium iodide is the most useful of these scintillators because of its efficiency and fast response.

The problem of efficient collection of light from the scintillating crystal by the photocathode of the multiplier phototube has brought about the development of a series of tubes in which the cathode is on the inside face of a flat-faced bulb. The 6199, which has a 1½-inch cathode, was used in portable scintillation counters during the uranium rush. The 6655 and 6342 were provided for applications requiring a 2-inch cathode diameter, and now larger types are being developed.

Because of the small amount of light involved, high photocathode sensitivity has been a most important consideration in the design of multiplier phototubes for scintillation counting. The average photocathode sensitivity of RCA tubes has been im-

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[6] "New Photoemissive Cathode of High Sensitivity," Rev. of Sci. Inst., Vol. 26, No. 7, p. 725, July 1955.

[7] A scintillation counter consists of a phosphor scintillator, multiplier phototube, and presentation circuitry. Operation: nuclear particles or rays excite the phosphor, which releases light to which the phototube is sensitive, and thereby causes a release of photoelectrons. After secondary-emission amplification, these electrons appear as current pulses at the anode. Presentation circuitry records and displays results.

[8] G. A. Morton, "Recent Developments in the Scintillation Counter Field," IRE Transactions on Nuclear Science, Vol. NS-3 #4, pp. 122-135, 1956.

proved to 60 microamperes per minute. The spectral response has been shifted (to S-11) by means of special processing to provide a better match to blue-emitting scintillators.

SCINTILLATION SPECTROMETRY

Accurate measurement of the magnitude of scintillation pulses (equivalent to only a few hundred photoelectrons) is important because the amount of light is proportional to the energy of the exciting nuclear particle. Therefore, the scintillation counter is used both as a detector of nuclear radiations and as a spectrometer to measure the energy of nuclear particles. It is in this way that nuclear products and interactions are identified.

PRECISION TIMING

Another important aspect of nuclear science is the measurement of events and their timing down to millimicrosecond intervals. From the very start, RCA multiplier phototubes have been superior in this respect because they employ electrostatic fields which minimize transit-time spreads. To utilize this high speed and avoid problems of wideband amplifiers, however, it was necessary to have a high-gain multiplier phototube which would operate directly into the deflecting electrodes of a cathode-ray tube. The 6810 14-stage multiplier phototube was developed to meet this special need.[9] It provides a gain of up to 10^9 with a time-spread of less than 5 millimicroseconds. A developmental version of the 6810 was used at the University of California[10] in experiments which led to the discovery of the anti-proton–an experimental confirmation of Dirac's prediction of "anti-matter."

HEADLIGHT DIMMING

It may seem that automatic headlight dimming does not demand the particular capabilities of multiplier phototubes. To the dark-adapted eye opposing headlights seem bright. However, the actual light flux entering a 2-inch lens mounted above the dashboard of an automobile is only 30 microlumens when dimming is indicated. A vacuum phototube would convert this flux to about 10^{-9} ampere. Amplification of this small current is difficult to achieve in a device which must be as rugged and as free from attention as that required for automotive service.

The multiplier phototube satisfactorily solves the amplification problem and today is widely used in headlight dimmers which require the same sensitivity night after night and season after season. Solution to the stability problem in the 6328 multiplier phototube for headlight dimming took weeks and months of patient and intense effort, and major credit belongs to J. J. Polkosky and A. M. Splinter of the Lancaster RCA phototube factory. Close control of cesiation schedules during processing and a special stabilization baking produced a secondary emission surface having greatly improved stability. The know-how gained is enabling RCA to process other multiplier phototubes for improved stability during life.

CONCLUSION

RCA has played a major rôle in the invention, development, and manufacture of multiplier phototubes. Fields of application for these tubes now include spectrometry; photometry, radioactive tracer technology in medicine, biology, and engineering; carbon-14 dating for archeologists; oil-well logging by radioactivity; and registration control in printing.

We may expect to see the development of larger multiplier phototubes for special scintillation counting purposes and smaller tubes for medical applications. High-quantum-yield photocathodes now used in tubes such as the new 6903 having a fused-silica window for visible and near-ultraviolet radiation will be further developed for the ultraviolet "solar-blind" region of the spectrum. A multiplier phototube is also being developed for the near-infrared region of the spectrum (Developmental Type Dev. No. C-7160). The need for low-dark-current tubes for carbon-14 dating will promote tubes with small cathodes having low thermionic emission. Certainly the future will bring new problems, the solutions to which will benefit science, industry, and RCA.

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[9] Widmaier, Wm., Engstrom, R. W., and Stoudenheimer, R. G., "A New High-Gain Multiplier Phototube for Scintillation Counting," I.R.E. Transaction on Nuclear Science, Vol. NS-3, #4, pp. 137-140, November 1956.

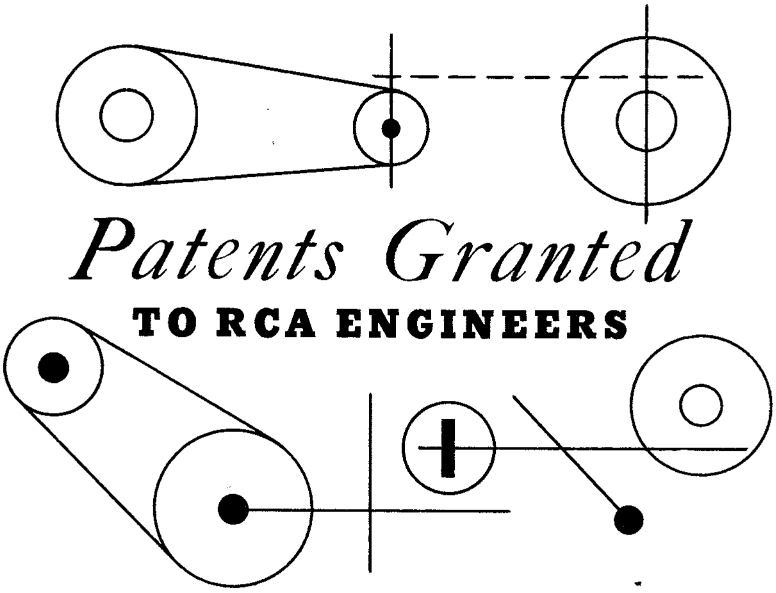
[10] Chamberlain, O.; Segre, E.; Wiegand, C.; and Ypsilantis, T., "Observation of Anti-Proton's," Phys. Rev. *100*, No. 3, pp. 947-950, Nov. 1, 1955.

DR. R. W. ENGSTROM is Manager of the Photo and Image Tube Development, RCA, Lancaster, Pennsylvania.

He received the B.A. degree from St. Olaf College, Northfield, Minnesota, in 1935, the M.S. degree from Northwestern University in 1937, and the Ph.D. degree from Northwestern University in 1939.

From 1939 to 1941 he taught physics at the St. Cloud State Teachers College, St. Cloud, Minnesota. For a short time in 1941 he worked on a project under the National Defense Research Committee at the University of Michigan. He joined RCA that same year. Since 1941 Dr. Engstrom has been associated with phototubes and related devices, their design and application. At first he was a design engineer, then a leader, and in 1956 he was appointed Manager of Photo and Image Tube Development.

Dr. Engstrom is a Fellow in the American Physical Society and a Senior Member of the IRE.



Patents Granted

TO RCA ENGINEERS

BASED ON SUMMARIES RECEIVED OVER A PERIOD OF ABOUT TWO MONTHS

DEFENSE ELECTRONIC PRODUCTS

Moorestown, N. J.

Third Order Pressure Gradient Responsive Microphone
Pat. No. 2,793,255—granted May 21, 1957 to V. A. Schlenker.

Gain-Modulated Amplifier
Pat. No. 2,794,077—granted May 28, 1957 to C. L. Olson.

Radar Moving Target Indication Method and System
Pat. No. 2,797,410—granted June 25, 1957 to N. I. Korman and W. P. Bollinger, formerly employed by RCA.

Timing Signal Generator
Pat. No. 2,798,976—granted July 9, 1957 to J. M. McCulley, Moorestown, and C. C. Eckel, IEP, Camden, N. J.

Automatic Frequency Control System Which Stops Hunting When in Tune
Pat. No. 2,798,946—granted July 9, 1957 to R. W. Howery, A. M. Sheeder and S. C. Stribling, Jr.

Metal Detecting Device
Pat. No. 2,803,341—granted August 20, 1957 to H. F. Schneider, Moorestown, and W. M. Adelman, IEP, Camden, N. J.

Voltage Regulating Circuits
Pat. No. 2,807,774—granted September 24, 1957 to C. Dudziak, Moorestown, and J. F. McCoy, DEP, Camden, N. J.

Microwave Phase Compensation System
Pat. No. 2,810,908—granted October 22, 1957 to C. F. Crawford and J. R. Ford.

Camden, N. J.

Transistor Indicator Circuits
Pat. No. 2,776,420—granted Jan. 1, 1957 to H. J. Woll.

Voltage Correction Circuits
Pat. No. 2,794,122—granted May 28, 1957 to Arthur C. Stocker, Camden, Louis Pensak, RCA Labs, Princeton, N. J. and F. D. Covely, III, Industrial Electronic Products, Camden, N. J.

Frequency Synthesis System
Pat. No. 2,797,326—granted June 25, 1957 to F. L. Putzrath.

Code Converter System
Pat. No. 2,798,667—granted July 9, 1957 to I. H. Sublette, and A. M. Spielberg, formerly employed by RCA.

Wide-Band High Frequency Amplifier
Pat. No. 2,802,066—granted August 6, 1957 to H. J. Woll.

Regulated Power Supplies
Pat. No. 2,806,963—granted September 17, 1957 to H. J. Woll.

Voltage Regulating Circuits
Pat. No. 2,807,774—granted September 24, 1957 to J. F. McCoy, Camden, and C. Dudziak, Defense Electronic Products, Moorestown, N. J.

Color-Correction Systems.
Pat. No. 2,807,660—granted September 24, 1957 to H. E. Rose.

Los Angeles, Calif.

Magnetic Switching Circuit
Pat. No. 2,742,632—granted April 17, 1956 to Richard L. Whitely.

Magnetic Sound Recording
Pat. No. 2,791,640—granted May 7, 1957 to W. V. Wolfe.

RCA VICTOR TELEVISION DIVISION

Cherry Hill, N. J.

Radio Receiving System
Pat. No. 2,790,896—granted April 30, 1957 to E. L. Clark and F. T. Ksiazek.

Noise Cancellation Circuits with I-F Amplifier Screen Grid Noise Detection
Pat. No. 2,791,627—granted May 7, 1957 to L. P. Thomas and C. W. Hoyt.

Cathode Ray Deflection System
Pat. No. 2,793,322—granted May 21, 1957 to S. I. Tourshou and B. E. Nicholson.

Keyed Automatic Gain Control Circuit Compensated for Keying Pulse Amplitude Variation
Pat. No. 2,794,067—granted May 28, 1957 to L. P. Thomas.

Multiple Resonant Slot Antenna
Pat. No. 2,794,184—granted May 28, 1957 to R. F. Kolar, Cherry Hill, and E. O. Johnson, RCA Labs, Princeton, N. J.

Television Circuits
Pat. No. 2,794,065—granted May 28, 1957 to Leonard Dietch.

Signal Generating Systems
Pat. No. 2,795,733—granted June 11, 1957 to B. S. Vilkomerson.

Cathode Ray Beam Centering Apparatus
Pat. No. 2,795,717—granted June 11, 1957 to M. B. Finkelstein and B. R. Clay.

Crosstalk Reduction System for Color Receivers
Pat. No. 2, 795, 643—granted June 11, 1957 to R. K. Lockhart.

Cathode Ray Beam Deflection Circuit Arrangements
Pat. No. 2,795,734—granted June 11, 1957 to L. Dietch.

Automatic Gain Control Circuits with Hum Compensation
Pat. No. 2,796,462—granted June 18, 1957 to L. P. Thomas.

Deflection Coil Isolation Circuitry
Pat. No. 2,796,552—granted June 18, 1957 to L. Dietch.

Television Color Synchronization
Pat. No. 2,751,430—granted June 19, 1956 to G. E. Kelly.

Television Receiver Noise Suppression
Pat. No. 2,797,259—granted June 25, 1957 to L. P. Thomas.

Sync Separator
Pat. No. 2,797,258—granted June 25, 1957 to B. E. Denton.

Semi-Conductor Sawtooth Wave Generator
Pat. No. 2,797,327—granted June 25, 1957 to M. C. Kidd.

Tunable High Frequency Oscillator Circuit
Pat. No. 2,798,158—granted July 2, 1957 to L. A. Horowitz.

Signal Coupling System
Pat. No. 2,799,008—granted July 9, 1957 to D. J. Carlson.

Color Television Receiver
Pat. No. 2,799,723—granted July 16, 1957 to A. J. Torre, L. R. Kirkwood and R. D. Flood.

Oscillator Synchronizing Circuit
Pat. No. 2,801,282—granted July 30, 1957 to R. W. Sonnenfeldt.

Dynamic Electron Beam Control Systems
Pat. No. 2,801,363—granted July 30, 1957 to R. W. Sonnenfeldt.

Oscillator Control System
Pat. No. 2,802,899—granted August 13, 1957 to R. W. Sonnenfeldt.

Ultrahigh-Frequency Tunable Structure and Circuit
Pat. No. 2,803,745—granted August 20, 1957 to W. Y. Pan and D. J. Carlson.

Background Control for Color Television Receiver
Pat. No. 2,804,496—granted August 27, 1957 to L. R. Kirkwood.

Beam Convergence Apparatus for Tri-Color Kinescopes
Pat. No. 2,806,164—granted September 10, 1957 to B. R. Clay and J. H. DuBois.

Wave Generating Circuits
Pat. No. 2,808,454—granted October 1, 1957 to B. S. Vilkomerson.

Coupling Circuits for High Frequency Signals
Pat. No. 2,809,356—granted October 8, 1957 to L. A. Horowitz.

INDUSTRIAL ELECTRONIC PRODUCTS

Camden, N. J.

Power Supply
Pat. No. 2,784,321—granted March 5, 1957 to J. F. Byrd.

Web Feeding Mechanism
Pat. No. 2,788,209—granted April 9, 1957 to R. E. Montijo.

Character Printing and Encoding Apparatus
Pat. No. 2,791,310—granted May 7, 1957 to L. F. Jones.

Raster Width Control
Pat. No. 2,792,523—granted May 14, 1957 to S. L. Bendell and N. P. Kellaway.

Multi-Path Optical Systems
Pat. No. 2,792,740—granted May 21, 1957 to H. E. Haynes.

Magnetic Core Circuits
Pat. No. 2,794,130—granted May 28, 1957 to Vernon L. Newhouse, Camden, and G. R. Briggs, RCA Labs, Princeton, N. J.

Voltage Correction Circuits
Pat. No. 2,794,122—granted May 28, 1957 to F. D. Covely, III, Camden, Louis Pensak, RCA Labs, Princeton, N. J. and Arthur C. Stocker, DEP, Camden, N. J.

Switching System
Pat. No. 2,796,597—granted June 18, 1957 to G. E. Poorte and D. L. Nettleton.

Card Handling Mechanism
Pat. No. 2,797,095—granted June 25, 1957 to R. D. Grapes and E. A. Damerau.

Dichroic Reflector Optical System
Pat. No. 2,797,256—granted June 25, 1957 to F. W. Millspaugh.

Branch Line Connector
Pat. No. 2,798,204—granted July 2, 1957 to C. H. Bennett.

Cathode Ray Deflection Systems
Pat. No. 2,799,799—granted July 16, 1957 to B. V. Vonderschmitt.

Radio Beacon
Pat. No. 2,800,651—granted July 23, 1957 to J. N. Marshall.

Television Apparatus
Pat. No. 2,801,385—granted July 30, 1957 to S. L. Bendell.

Electron Microscope Alignment
Pat. No. 2,802,111—granted August 6, 1957 to J. H. Reisner.

Metal Detecting Device
Pat. No. 2,803,341—granted August 20, 1957 to W. M. Adelman, Camden, and H. F. Schneider, Defense Electronic Products, Moorestown, N. J.

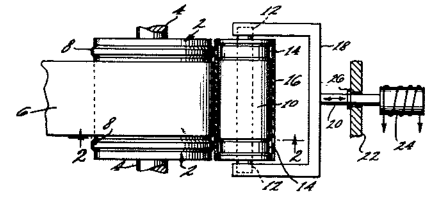
Class B Signal Amplifier Circuits
Pat. No. 2,761,917—granted September 4, 1956 to A. I. Aronson.

Deflection Circuit
Pat. No. 2,806,176—granted September 10, 1957 to A. C. Luther, Jr.

Omni-Directional Long Slot Antenna
Pat. No. 2,807,019—granted September 17, 1957 to W. Darling.

Information Translating System
Pat. No. 2,807,664—granted September 24, 1957 to H. Kleinberg and J. S. Baer.

Color Correction Systems
Pat. No. 2,808,453—granted October 1, 1957 to H. E. Haynes.



Pat. No. 2,788,209
R. E. Montijo

Cathode Ray Tube Protecting and Energizing Circuits
Pat. No. 2,808,536—granted October 1, 1957 to J. F. Eckert, Jr., G. A. Senior and G. F. Musolf, formerly employed by RCA

Semi-Conductor Modulation Circuits
Pat. No. 2,810,110—granted October 15, 1957 to H. J. Paz.

Turnstile Antenna and Feed System Therefor
Pat. No. 2,810,127—granted October 15, 1957 to M. S. O. Siukola.

Electromechanical Filter Assembly
Pat. No. 2,810,889—granted October 22, 1957 to D. L. Lundgren.

SEMICONDUCTOR DIVISION

Somerville, N. J.

Orthicon Electrode Structure
Pat. No. 2,792,514—granted May 14, 1957 to R. B. Janes, Somerville, and A. A. Rotow, Tube Div., Lancaster, Pa.

Semiconductor Devices and Method of Making Same
Pat. No. 2,805,968—granted September 10, 1957 to G. E. Dunn, Jr.

COMPONENTS DIVISION

Camden, N. J.

Powdered Iron Magnetic Core Materials
Pat. No. 2,783,208—granted February 26, 1957 to George Katz.

RCA VICTOR
RADIO & "VICTROLA" DIVISION

Cherry Hill, N. J.

Variable Tone Control Circuit
Pat. No. 2,802,063—granted August 6, 1957 to R. S. Fine and S. V. Perry.

ELECTRON TUBE DIVISION

Harrison, N. J.

Metal-Working
Pat. No. 2,792,627—granted May 21, 1957 to E. S. Thall.

Cataphoretic Coating Machine
Pat. No. 2,800,448—granted July 23, 1957 to M. N. Fredenburgh.

Electron Emissive Coating Material and Method of Application
Pat. No. 2,800,446—granted July 23, 1957 to M. N. Fredenburgh.

Electron Tube Base and Shield
Pat. No. 2,802,190—granted Aug. 6, 1957 to R. G. Talpey.

Traveling Wave Tube
Pat. No. 2,806,170—granted September 10, 1957 to A. J. Bianculli.

Sealing Apparatus for Electron Tubes
Pat. No. 2,807,913—granted October 1, 1957 to E. F. Nickl.

Lancaster, Pa.

Method of Processing a Photosensitive Mosaic Electrode
Pat. No. 2,776,227—granted Jan. 1, 1957 to R. E. Hoffman and W. G. Rudy.

Orthicon Electrode Structure
Pat. No. 2,792,514—granted May 14, 1957 to A. A. Rotow, Lancaster, and R. B. Janes, Semiconductor Div., Somerville, N. J.

Phototubes
Pat. No. 2,794,140—granted May 28, 1957 to J. L. Weaver and J. J. Polkosky.

Electron Photography Plate Construction
Pat. No. 2,748,288—granted May 29, 1956 to T. A. Saulnier, Jr.

Color Kinescopes
Pat. No. 2,795,719—granted June 11, 1957 to A. M. Morrell.

Color Kinescopes
Pat. No. 2,795,718—granted June 11, 1957 to F. VanHekken and M. R. Weingarten.

Methods and Means for Transferring Printed Indicia
Pat. No. 2,796,374—granted June 18, 1957 to D. J. Donahue.

Measurement of Cathode Ray Tube Screen Color Uniformity
Pat. No. 2,799,825—granted July 16, 1957 to A. E. Hardy.

Tri-Color Kinescope Screen
Pat. No. 2,802,753—granted Aug. 13, 1957 to G. E. Crosby and J. A. Markoski.

Electron Discharge Device
Pat. No. 2,806,166—granted September 10, 1957 to W. P. Bennett and H. F. Kazanowski.

Fluoride Phosphors
Pat. No. 2,806,002—granted September 10, 1957 to A. L. J. Smith.

Method of Manufacturing Pickup Tubes
Pat. No. 2,807,517—granted September 24, 1957 to F. D. Marschka, F. S. Veith and H. W. Kuzminski.

Cold-Working Process for Articles
Pat. No. 2,807,971—granted October 1, 1957 to L. P. Garner and W. N. Parker.

Preparation of Photoconductive Layers
Pat. No. 2,809,087—granted October 8, 1957 to F. S. Veith.

Ion Trap
Pat. No. 2,810,091—granted October 15, 1957 to M. D. Harsh.

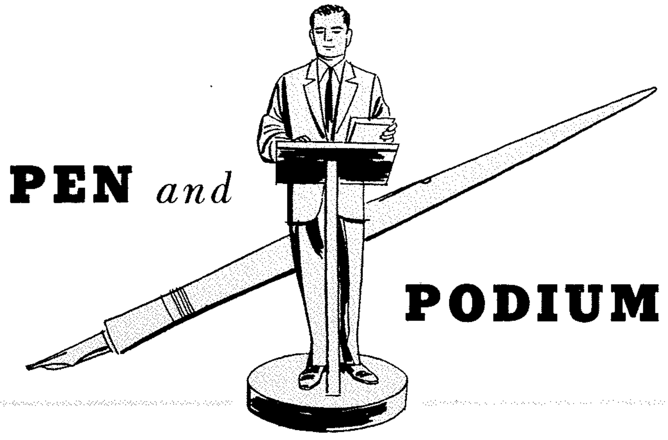
Findlay, Ohio

Cathode Ray Tube Deflection Yoke
Pat. No. 2,800,615—granted July 23, 1957 to D. E. Stubbins.

RCA STAFF

Camden, N. J.

Hum Reduction in Feedback Amplifiers
Pat. No. 2,792,458—granted May 14, 1957 to L. H. Good, Director, Engineering Utilization.



PEN *and* PODIUM

Based On Reports Received Over a Period of About Two Months

ELECTRON TUBE DIVISION

Lancaster, Pa.

Effects of Beam-Landing Errors on Signal-Output and Dark-Current Uniformity of Vidicon-Type Camera Tubes
By R. G. Neuhauser and L. D. Miller: Presented at National Electronics Conference, Chicago, Oct. 7-9, 1957. Vidicon tubes made with new techniques have a more uniform thickness of photoconductive layer and are more suitable for uses requiring maximum sensitivity.

New Image Orthicon Employing a Multi-Alkali Photocathode for Color Cameras
By P. W. Kaseman: Presented at National Electronics Conference, Chicago, Oct. 7-19, 1957. A tube, with 3 times the sensitivity of tubes using conventional cathodes—and improved life characteristics, is described. Advantages given in terms of required lighting and air-conditioning costs.

Recent Developments in TV Camera Tubes
By F. S. Veith: Presented at IRE Symposium, Broadcast Transmission Systems, Wash., D. C., Sept. 27, 1957. Advantages of micromesh and superdynodes, characteristics of new image orthicon with high photocathode sensitivity, and new vidicon having increased sensitivity are described.

Development of a High Perveance Beam Power Tube for Amateur Use
By J. W. Gaylord: Presented at National ARRL Convention, Chicago, Aug. 31, 1957. Advantages and application of a high-current, low-voltage transmitting tube for telegraphy, telephony, and single-sideband are discussed.

Use of the Potential-Shift Diagram for Analysis of the Operation of Display Storage Tubes
By R. P. Stone: Presented at National Electronics Conference, Chicago, Oct. 7-9, 1957. "Potential-shift" diagram application to display storage tubes is presented together with a method for visualizing the mode of tube operation.

Effects of Voltage-Divider Characteristics on Multiplier Phototube Response
By R. W. Engstrom and E. Fischer: Published in REVIEW OF SCIENTIFIC INSTRUMENTS, July 1957. Effects of voltage-divider circuits on operating characteristics of multiplier phototubes, and voltage dividers that protect the tube from excessive current are described.

Calculation of Anode Current from a Hollow Cathode
By T. N. Chin: Published in JOURNAL OF APPLIED PHYSICS, June 1957. Paper describes method for estimating total anode current from a planar hollow cathode of assumed conditions.

An Improved Developmental One-Inch Vidicon for TV Broadcast Use
By L. D. Miller and B. H. Vine: Presented at SMPTE Convention, Phila., Pa., October 4-9, 1957. An improved vidicon having a higher degree of uniformity of characteristics (tube to tube) and better registration in live and film color cameras is described.

Harrison, N. J.

Spectrochemical Determination of Ferric Oxide and Silicon Dioxide in Alumina
By Doris G. Conrad: Published in APPLIED SPECTROSCOPY, VOL. II, No. 2, 1957. A rapid, accurate, more convenient spectrochemical method for determination of ferric oxide and silicon dioxide in alumina is described.

DEFENSE ELECTRONIC PRODUCTS

Camden, N. J.

Natural Frequencies of Non-Uniform Beams
By R. A. DiTaranto: Presented at the American Society of Mechanical Engineers Fall Meeting, Hartford, Conn., Sept. 23-25, 1957. Method for determining natural frequencies of non-uniform beams on multiple elastic supports is presented. Critical rotor speeds are determined.

Pickup Tube Performance with Slow Scanning Rates
By Charles T. Shelton: Published in SMPTE JOURNAL, Sept. 1957. A Signal Corps sponsored study of operation of standard image orthicons and vidicons at reduced scanning rates is reported.

Airborne Closed Loop TV System
By A. F. Flacco: Presented at National Electronics Conference, Chicago, Ill. Oct. 4-9, 1957. A militarized airborne television system utilizing image orthicon cameras is described. System requirements are suited to the use of wide-spaced image orthicon (type 6849). Non-standard line and field rates are used.

Digital Simulation of Complex Traffic Problems
By L. Brotman and J. Minker: Published in *Operations Research Society Journal*, Oct., 1957. A new method of simulating on a digital computer the performance of a large complex communications system is presented.

Automatic Test Systems for Production
By H. S. Dordick: Presented at WESCON, San Francisco, Aug. 22, 1957. Progress in the introduction of automatic instrumentation in today's operations is reviewed and several equipments evaluated. Degree of mechanization is dependent upon testing required, the manufacturing technique, and economics of system.

Component Application Engineering at RCA
By R. H. Baker: Presented at Ninth National Conference on Aeronautical Electronics, Dayton, Ohio, May 13-15, 1957. A DEP organizational and procedural plan which contributes to design, development, and production of RCA equipments is described, emphasizing relationship between Component and Materials Engineers and the Design Engineers.

Single-Server, Time-Limited Queues
By Herbert M. Gurk: Presented to American Math Society, Summer Meeting, Penn State U., Aug. 29, 1957. A general technique for obtaining characteristics of the waiting line forming at a single service center. Service time per customer may have any probability distribution . . . results are given for distributions of interest.

Simplified Reliability Testing Based on the Poisson Distribution
By C. M. Ryerson: Presented at Western Regional Quality Control Conference, San Francisco, Calif., Sept. 20, 1957. A method of applying the "Poisson" to the direct design of reliability tests is described. From curves given, tests for measuring reliability can be set up.

Personalized Military Radio Sets
By R. B. Rudd: Presented at U. of Penn., Phila., Pa., May 7, 1957. A subminiature radio set designed to meet requirements of concealment, small size, low weight, ruggedness and simplicity of operation is described.

RCA Broadband Recorder
By W. H. Erikson and J. R. Hall: Presented to Instrument Society of America Conference, Cleveland, Ohio, Sept. 10, 1957. A precision magnetic recording equipment for military use. Bandwidth 250-360 KC ± 3db, less than .004% rms wow and flutter. Tape width ½", speed 100 ips.

Case Histories of Mature Equipments and Systems
By R. H. Baker: Presented at 1957 RETMA Reliability Symposium, Syracuse, N. Y. A case history of the AN ARC 21 communication system describes reliability problems encountered in quantitative terms, and action taken to solve problems.

On Question Raised by J. Schur
By I. H. Sublette: Presented on Aug. 27, 1957 at Summer Meeting of American Math Society, Penn State U. A paper by J. Schur in 1917 is applied by author to synthesis of electrical networks. A theorem is produced to yield partial answer to mathematical question raised, but not answered, by Schur. Proof of theorem in final form makes no references to network theory.

The Buyer and Reliability
By C. M. Ryerson: Presented at Nat'l. Assoc. of Purchasing Agents Conference, Atlantic City, May 28, 1957. This paper reviews the reliability theory the buyer needs to know, and presents a discussion of costs relative to production of reliable equipment.

Waltham, Mass.

Automatic Control of Aircraft

By R. C. Seamans and H. P. Whitaker; Prof. J. Bicknell and Prof. E. Larrabee, M.I.T.: Presented to Journees Internationales de Sciences Aeronautiques, Paris, France, May 27-29, 1957. Automatic flight control systems that are integral parts of completed aircraft and essential to its operation, as airframe and propulsion systems, are described.

INDUSTRIAL ELECTRONIC PRODUCTS

Camden, N. J.

Metallurgical Structure Analysis by Ultrasonics

By Herbert A. Elion: Presented at National Electronics Conference, Chicago, Ill., Oct. 9, 1957. Experimental and theoretical results are given to identify metallurgical structure by ultrasonics. Identifiable metallurgy includes nineteen major categories such as depth of hardness, alloy phase changes, etc.

A Transistorized Ferrite Plate Memory

By N. R. Kornfield, M. M. Kaufman, T. E. Gilligan, and V. L. Newhouse (formerly at RCA): Presented at National Electronics Conference, Chicago, Oct. 7-9, 1957. A prototype two-dimensional memory (one side driven by a two-dimensional d-c bias type switch) is described. Apertured ferrite plates are used for both memory and switch, and transistor diode circuits used for drivers.

The Bizmac Trancoder

By D. E. Beaulieu, D. P. Burkart and C. H. Propster, Jr.: Presented at WESCON, San Fran., Calif., Aug. 23, 1957. This paper describes the basic circuit and logic design, accuracy and reliability features of the BIZMAC Trancoder.

The Transition from Engineer to Supervisor

By Herbert M. Elliott: Presented at WESCON Convention, Aug. 20, 1957. Transition problems and methods are described to guide engineers through such periods in rapidly expanding engineering departments.

The RCA TM-21 — A Stabilized Color Monitor

By E. E. Gloystein and N. P. Kellaway: Published in SMPTE JOURNAL, Sept., 1957. A new color monitor has been designed as a high-quality picture display device, and as an instrument for judging quality of color TV signals.

Split-Channel System Analysis

By J. R. Neubauer: Published in GAS Magazine, Oct.-Nov. issues and RCA COMMUNICATIONS NEWS. Author describes method of avoiding split-channel interference.

Radio's Service to Man Today and Tomorrow

By J. R. Neubauer: Presented Oct. 15 at Akron University, Institute for Civic Education. Role of Communications for mankind in the past, present and future is reviewed briefly.

Formalized Analysis Techniques — Aids to Computer Design and Computer Use

By H. B. Ladd and W. P. Markovic: Presented at 4th Annual Symposium on Computers & Data Processing, Denver, Colo., Aug. 29, 1957. A practical approach for collecting applications data, and the subsequent analysis of data processing from generation of source documents to final reports are explained.

Logical Organization of Tape Instructions in the Bizmac II Computer

By Harry Kleinberg and E. J. Schmitt, IEP, Camden, N. J.: Presented Oct. 8, 1957 at National Electronics Conference, Chicago, Ill. Provision of a new flexibility of magnetic tape handling, while maintaining complete variable word length operation is described. The logical design used to mechanize features is given.

Medium Screen Color TV Projection

By S. L. Bendell and W. J. Neely: Presented at the SMPTE Convention, Sheraton Hotel, Phila., Pa. The engineering and economic factors influencing design and use of Closed Circuit TV Projection Equipment for color or monochrome operation are discussed.

Qualitative Performance Evaluation of Land

By J. R. Neubauer: Presented at WESCON Convention, San Francisco, Calif., Aug. 22, 1957. A "companion receiver measurement technique" helps determine performance limits of communication equipment systems. Fixed and variable parameters influence results. Data obtained enables facilities design for given set of conditions.

Interrogation in Bizmac System

By D. E. Beaulieu and C. H. Propster: Presented at WESCON Convention, San Francisco, Aug. 20, 1957. A description of BIZMAC Interrogation Unit covering its ability to interrogate any particular message in file, without disturbing scheduled data processing routines. Saves many valuable hours.

Operating the 2C39 at 2000 MC

By N. C. Colby: Published in June 1957 ELECTRONIC INDUSTRIES AND TELE-TECH. Author describes a conservative equipment design which resulted in greatly increased tube life and improved reliability.

Reduction of Image Retention in Image Orthicon Cameras

By J. H. Roe, S. L. Bendell, and K. Sadashige: Presented by Mr. Roe to IRE Professional Group on Broadcast Transmission Systems, Washington, D. C., Sept. 28, 1957. Methods are discussed which minimize "picture sticking" in color or monochrome cameras. Tube image is rotated in small circular orbit by optical or electronic means.

New Developments in Gastrointestinal Pressure Measurements

By Dr. J. T. Farrar and W. J. Bieganski: Presented at the IRE CANADIAN CONVENTION, Toronto, Canada, Oct. 17, 1957. A new pressure telemetering "radio pill" permits permanent recording of human gastrointestinal motility without disturbance of normal physiology.

RCA SERVICE CO.

Cherry Hill, N. J.

Technical Aspects of Motion Picture Sound Systems

By E. Stanko: Presented to the Audio Engineering Society, Wash., D. C., Sept. 24, 1957. A review was given of various motion picture sound systems and different types of sound tracks and recording techniques used during past 30 years.

CORPORATE STAFF STANDARDIZING

Camden, N. J.

Practical Numerology and Application to Part Numbering

By D. C. Bowen: Presented at Standards Engineers Society, Washington, D. C., Sept. 16, 1957. Practical problems in processing and handling part numbers through complex systems of production department are discussed. Relative merits of significant vs. sequential numbering methods are included.

Design and Standards

By M. S. Gokhale: Presented at Sixth Annual Meeting of Standards Engineers Society, N. Y. City, Sept. 24, 1957. The ultimate goal of "Standardization" is to develop design engineers who use standard items because they are complementary to the designs. Standards become part of engineers' design technique, removing the repetitive burden of evaluating components.

RCA VICTOR TELEVISION DIVISION

Cherry Hill, N. J.

Design Considerations of Transistor I-F Amplifiers for TV Receivers

By W. F. Sands and H. K. Schlegelmilch: Presented at National Electronics Conference, Chicago, Oct. 8, 1957. Authors describe design of practical I-F amplifiers, for TV receivers using RCA experimental VHF drift transistors, providing substantially equivalent "vacuum-tube performance".

COMPONENTS DIVISION

Camden, N. J.

Designing Relays for High Reliability

By D. H. Cunningham: Presented at WESCON, San Francisco, Calif., Aug. 20-23, 1957. An objective for a component reliability of 99.99% is emphasized. Engineering effort put forth and the areas in which further work can be done are described.

SEMICONDUCTOR DIVISION

Somerville, N. J.

Class A and Class B Transistor Power Amplifier Design

By Robert Minton: Published in ELECTRONIC DESIGN, July 15 and Sept. 15, 1957. Use of alloy-junction p-n-p power transistors in a-f output stages, and operating conditions for practical circuit designs are described.

Alloying of Junction Transistors

By A. S. Rose: Presented at Semiconductor Symposium of Electrochemical Society, Buffalo, N. Y., Oct. 6-10, 1957. Alloying processes must be controlled to yield junctions that are planar parallel and completely alloyed over large areas with narrow inter-electrode spacing. Correlation between physical aspects and electrical characteristics is given.

Control of Boron Diffusion in Silicon-Transistor Fabrication

By L. D. Armstrong and D. Des Jardin: Presented at IRE Semiconductor Device Conference, Boulder, Colo., July 15, 1957. Two methods of obtaining controlled deposition and diffusion of boron into silicon are described, evaluated, and surface concentrations given.

Design of a High-Speed Transistor Decimal Counter with Neon-Bulb Read-Out

By R. D. Lohman: Presented at WESCON, San Francisco, Calif., Aug. 20-23, 1957. Paper discusses design for high-speed transistor decimal counter and gives design equations for circuitry that will provide high reliability of triggering and d-c stability.

RCA VICTOR RECORD DIVISION

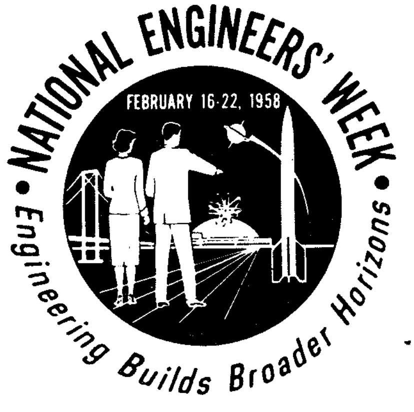
Indianapolis, Ind.

Iron Plating

By Dr. A. M. Max: Prepared for inclusion in "Metal Finishing Guidebook" by Metal Finishing Publications, Westwood, N. J. The article summarizes solution formulas and operating conditions used for iron plating and electroforming.

Engineering NEWS *and* HIGHLIGHTS

ENGINEERS' WEEK IN FEBRUARY



NATIONAL ENGINEERS' WEEK is celebrated annually during the week of George Washington's birthday; this year, 1958, it will be observed from February 16 to 22. The selection of this week is a tribute to the first U. S. president because of his contribution to engineering. Aside from his accomplishments as a soldier and statesman, he was one of the first engineer-builders who laid the foundation of modern America, being a lifelong believer in technical progress.

In proclaiming Engineers' Week, President Eisenhower, along with the governors of various states and mayors from hundreds of cities throughout our land, will honor the engineer. In fact, the Mayor of Philadelphia, Richardson Dilworth, will officially proclaim Engineers' Week for Delaware Valley on February 14 at 11:00 A.M. in City Hall. The public as well as all engineers are invited to attend the reading of this formal proclamation.

The theme for the 1958 occasion is:

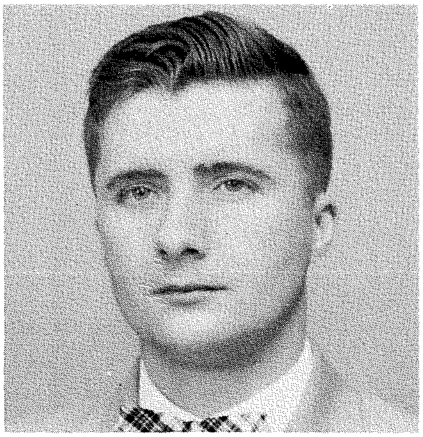
ENGINEERING BUILDS BROADER HORIZONS

This is a very appropriate theme, for it was chosen in light of the International Geophysical Year as man extends his horizons further than ever before—even by sending a satellite into outer space. Efforts and accomplishments in this direction are currently being made through engineering progress, for it is the engineer who is giving us the instruments, the rocket fuels, the electronic devices and all the other equipments which are being utilized to gather the scientific information during the IGY.

The function of National Engineers' Week is to acquaint the public with the facts about the engineering profession and the role it is playing in our society. This will be made possible through the efforts of radio and television, displays and publicity featured by many engineering firms and industry in general, and last but most important, through our schools and educational facilities. With this latter effort, we will muster the engineering talent, the trail blazers, of future America.

Thirty-nine affiliated engineering societies from the Engineers' Club of Philadelphia are taking active part in the celebration; their representatives are working diligently to make this affair a huge success, and by so doing they will aid in advancing the engineering profession to a higher plateau.

—G. B. Cranston, Chairman, Radio and TV Committee, RCA Corporate Standardizing



G. S. Gadbois

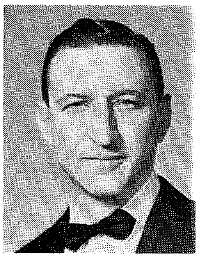
WINS ARRL PRIZE

QST Magazine reported that G. S. Gadbois, Lancaster Chemical and Physical Laboratory, was, for the second consecutive year, awarded the First Place Prize by the American Radio Relay League in the VHF Contest for having obtained the highest score in a recent national contest sponsored by the League. Points were accumulated on the basis of the number of contacts achieved by a single radio operator in the maximum number of areas and in the maximum number of frequency bands. Mr. Gadbois set up his station atop Mt. Equinox, Vermont, obtaining 310 total contacts on four bands for 16,900 points. His 12 section contacts on 220 mc set a record for that band. *—D. G. Garvin*

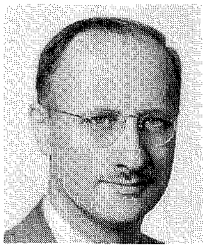
ENGINEERS IN NEW POSTS

J. J. Toyzer named manager of TV Division's Findlay plant, recently acquired from Components Division . . . **Dr. George H. Brown** becomes Chief Engineer of Industrial Electronic Products, recently formed to include CEP and RCA Communications, Inc. . . . **G. G. Hoberg** has joined BIZMAC Engineering from the Burroughs Corp. He reports to Wes Leas as Manager, Special Data-Processing Equipment Engineering . . . **Dr. E. M. Pritchard** becomes Special Systems and Development Operations Manager in an organization move by Dr. C. B. Jolliffe, Mgr. of DEP's SS&D Dept. Reporting to Dr. Pritchard are Messrs. Dimmick, Gay, Vance, Ankenbrandt and Zemke . . . **Clarence D. Tuska** moves into a newly created post as Staff Consultant, Patents, at Princeton—**O. V. Mitchell** assumes Mr. Tuska's former post as Director of Patent Operations . . . **Norval H. Green** is named Manager, General Quality Control for the Semiconductor Division at Somerville.

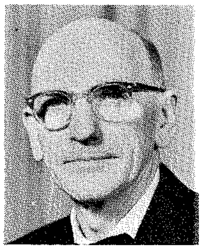
G. H. Brown



C. P. Smith



E. E. Spitzer

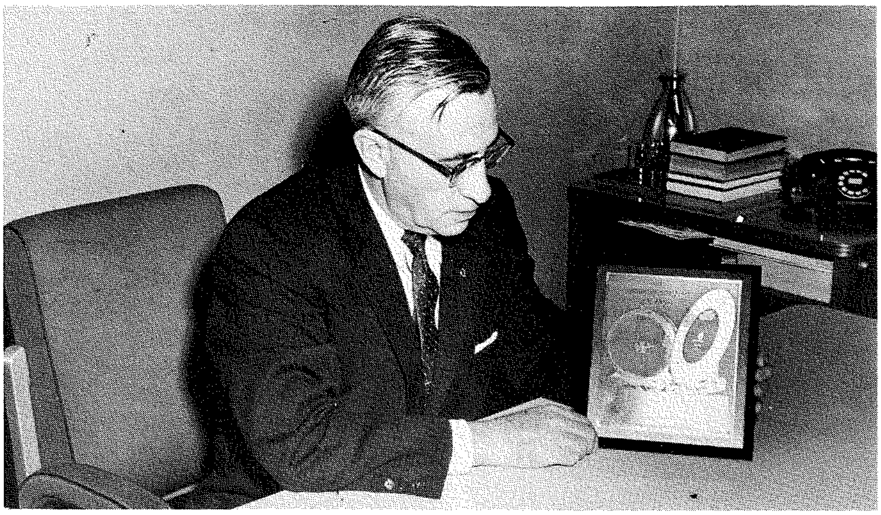


D. H. Cunningham

In the Electron Tube Division, **Harry R. Seelen's** Kinescope Operations activity has been broadened to include black-and-white kinescopes at Marion as well as color at Lancaster . . . in the same combining move, **C. Price Smith** adds **C. W. Thierfelder's** Marion B/W kinescope engineering to his color responsibilities . . . the Marion Equipment Development Engineering under **J. F. Stewart** now reports to **S. M. Hartman** at Lancaster. In the newly formed Industrial Tube Products activity, **E. E. Spitzer** is appointed Manager of Engineering . . . **R. L. Kelly** joins the Tube Division Commercial Staff as Administrator of Technical Coordination.

D. H. Cunningham becomes Manager of Electromechanical Devices Engineering for R&V Division's **J. L. Franke** . . . **A. T. Harding** will coordinate engineering projects in Ferrites as Staff Engineer for **D. D. Cole.**

ED ROYS WINS BERLINER AWARD



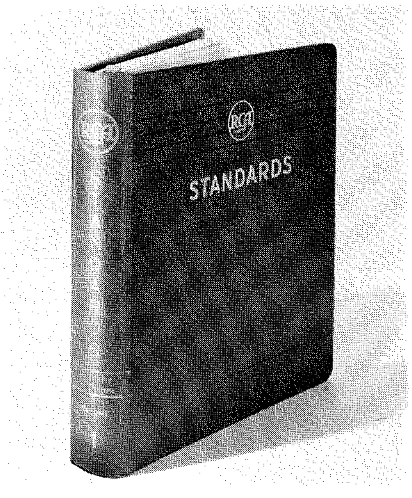
The Audio Engineering Society has conferred its Emile Berliner Award on H. E. Roys, Record Division's Engineering Manager at Indianapolis. The citation was presented for "an outstanding development in the field of Audio Engineering" in recognition of his contributions to the reduction of distortion in reproduced sound.

No stranger to RCA ENGINEER readers, we have announced Mr. Roy's appointment to his present position (Vol. 2, No. 2), his receipt of the IRE's PGA Achievement award (Vol. 2, No. 6), and published his editorial message in Vol. 3, No. 2.

—S. D. Ransburg

ABOUT THE NEW MILITARY SUPPLEMENT TO THE RCA DRAFTING MANUAL

By M. S. Gokhale, Central Engineering, DEP and A. Tomassetti, Airborne Systems, DEP



A new military supplement to RCA Drafting Manual, to facilitate the preparation of drawings in Defense Electronic Products (DEP), was recently made available to all DEP draftsmen. This supplement has been prepared primarily to eliminate the delays encountered in the acceptance of DEP drawings by the contracting Government Agencies. These delays were caused by varying interpretation of Military specifications. The contents of this supplement, on the other hand, reflect an agreement between DEP Drafting Managers and representatives of the U. S. Air Force.

One of the prime factors contributing towards the variety of interpretations of Government specifications was the discrepancy between these specifications. The Standardization and Cataloging branch of the Department of Defense (DOD) is now engaged in the project of evaluating and editing these conflicting requirements. It is anticipated that a unified Department of Defense Drafting Manual, which will aid in the preparation of drawings of military equipments, will be forthcoming in the not too distant future.

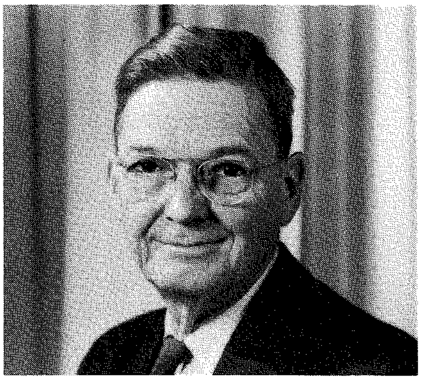
The advantage to be gained by the publication and use of this Military Supplement to the RCA Drafting Manual is that the acceptance of RCA drawings on Government contracts will not depend on the differences in interpretation due to changes in personnel. It has been our experience in the past that even when controversial points had been settled by conferences with individuals, those decisions did not remain effective throughout the life of the contract. It is hoped that as a result of the publication of the Supplement these interpretations would be more stable.

While awaiting a single unified set of Military Drafting Practices, additional supplements to facilitate the preparation of DEP drawings for other agencies are necessary. It is planned to keep a continuous record of comments and criticisms on this supplement to determine its effectiveness. This record will aid in the preparation of manuals for other Governmental agencies whose requirements may be substantially different from those of the U. S. Air Force.

W. A. TOLSON DIES

William A. Tolson, who was a member of the technical staff of RCA Laboratories for fourteen years, died recently in Florida after an illness of several months. He had been transferred last November from the David Sarnoff Research Center in Princeton, N. J. to the Missile Test Project at Cocoa, Fla.

Mr. Tolson was born November 2, 1896, in San Angelo, Tex. He received his B.S.E.E. degree from A. & M. College of Texas and joined the General Electric Co. in Schenectady, New York in 1923. In 1930, he transferred to RCA Victor Division in Camden, N. J., where he worked on television development and then to the Princeton Labs. in 1942.



Mr. Tolson was one of the pioneers in television development; he was largely responsible for the synchronizing and deflection circuits used in substantially all modern television receivers, both black and white and color. "Doc," as he was called by his associates, was perhaps the best known as the inventor of the universally used automatic synchronizing separator circuit, the picture linearity control circuit, and as the co-inventor with Roscoe Duncan of the blocking oscillator circuit which has enjoyed application in radar, as well as television. Included also in Mr. Tolson's forty-two issued U. S. patents is his contribution to the present-day standard television transmission system wherein the power line frequency is employed as the vertical or field scanning rate.

Mr. Tolson was active in the design of the equipment used in early 1930 television field tests. In 1940, he received the award of "Modern Pioneer" from the Radio Manufacturers' Association. He directed the design and installation of the first theater television projection system which was demonstrated at the New Yorker Theater in 1949. During World War II, Mr. Tolson was associated with development of radar fire-control and infrared systems.

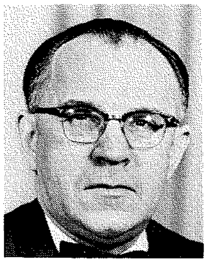
NEW LAB AT LANCASTER

A new laboratory has been set up within Chemical & Physical Laboratory at Lancaster to apply radiotracer techniques to cleaning, cathode plating and other problems. In conjunction with this effort, a Radiological Safety Committee has been formed. Members include: R. H. Zachariason, Chairman; C. H. Miller, Plant Safety Manager; Dr. D. J. Donahue, Radiological Safety Officer; and H. A. Stern.

—M. N. Slater

MEETINGS, COURSES AND SEMINARS

SPEAKERS AT COLOR TV SEMINARS



H. N. Kozanowski

B. F. Melchionni

Two seminars were conducted for Television Broadcasters by members of IEP's Broadcast and TV Equipment Dept.; one in San Francisco on Sept. 19 and 20, the other in Camden on Sept. 30 and Oct. 1. The seminars were designed to provide maximum practical details on installation, maintenance and operation of color broadcast equipment.

Engineers participating in the program were: A. F. Inglis, H. N. Kozanowski, B. F. Melchionni, N. J. Oman, and J. W. Wentworth. —*J. H. Roe*

Records

The RCA Plant at Indianapolis acted as host to members of the Indianapolis Section of IRE on September 27. Mr. A. G. Evans, Record Engineering, showed the movie, "The Sound and the Story", and gave a demonstration of stereophonic sound using prerecorded tapes. —*S. D. Ransburg*

Electron Microscopy

A three-day electron microscopy seminar using closed-circuit TV to project intricate laboratory demonstrations to a remote audience of medical and industrial scientists and student microscopists, was conducted the week of Sept. 2 by RCA's Industrial Electronic Products.

The session was devoted to lectures and laboratory demonstrations of advanced techniques in medical and industrial microscopy, specimen preparation, and electron microscope operation.

The seminar was attended by more than sixty medical and industrial research microscopists and students. Some of the nation's outstanding biologists and scientists were invited to view the potential of closed-circuit TV as a teaching medium for instructing large student groups in the intricate details of electron microscopy techniques.

DR. E. W. ENGSTROM HONORED FOR RESEARCH

Dr. Elmer W. Engstrom, RCA executive who was a teacher in the development of television in the 1930s, was named recently to receive the 1958 medal of the Industrial Research Institute.

It will be presented to Dr. Engstrom at the institute's annual meeting next May in Colorado Springs.

GIVES TALK AT INDIANAPOLIS

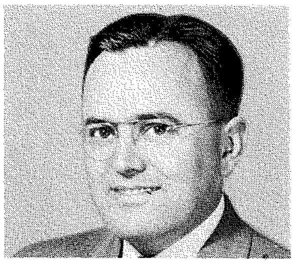
Dr. G. R. Shaw

The Indianapolis Engineering and Training Staffs have organized a lecture series for the benefit of the local Tube Plant Engineers. It is designed somewhat along the lines of a college convocation series, in which prominent personalities are brought to the campus auditorium to speak on pertinent subjects. In this series, top engineers from the RCA staff will be brought to Indianapolis to speak on various topics which will serve to keep the engineers abreast of Tube Engineering advancements, as well as keeping them informed generally.

Dr. G. R. Shaw, Chief Engineer of the Electron Tube Division, spoke at the first session, which was held in the Building 1 Auditorium on Wednesday, October 16, 1957, on the subject, "The Engineer and RCA". Dr. Shaw traced the development and history of RCA and explained the increasing importance of engineering to our company.

The series will have approximately 6—8 subsequent lectures at intervals of 3—4 weeks. —*F. H. Ricks*

CORRINGTON ELECTED FELLOW



Murlan S. Corrington, Manager of Audio, Acoustics and Antenna Engineering in the Television Division's Advanced Development Engineering at Cherry Hill, was elected Fellow in the Acoustical Society of America in May, 1957. The honor was presented "for theoretical and experimental advances in the knowledge of the transient response of loudspeakers and the complex vibrations of loudspeaker diaphragms." —*R. W. Sonnenfeldt*

Air-Ground Communications

On September 16, 1957, Mr. W. F. Meeker of Surface Communications attended a meeting of the Radio Technical Commission for Aeronautics, Special Committee No. 72, "Audio Response of the Air-Ground Communications Systems", held in Washington, D. C. Others in attendance were J. A. Parrot, AT&T, Chairman; H. F. Tanke, RTCA, Secretary; E. Lazur, Wright Air Development Center; C. A. Petrg, Aeronautical Radio Inc. and E. D. Daniel, National Bureau of Standards. The purpose of the meeting was to consider comments which have been received regarding a draft of committee reports and if possible to prepare the final report.

The essentials of the characteristics which will be recommended are:

1. Noise cancelling microphones in aircraft.
2. Microphone frequency response substantially flat at high frequencies and falling off at 6 db per octave toward the low frequencies at 500-700 cps.
3. Remaining system response to be substantially flat from 200 to 3000 cps.
4. Volume indicator to insure adequate talking level.
5. Automatic gain control.
6. 6 to 12 db of pre-modulation speech peak clipping.
7. Emphasis on proper training and use of the system.

Interested persons should contact Mr. Meeker. —*T. T. N. Bucher*

REGISTERED PROFESSIONAL ENGINEERS

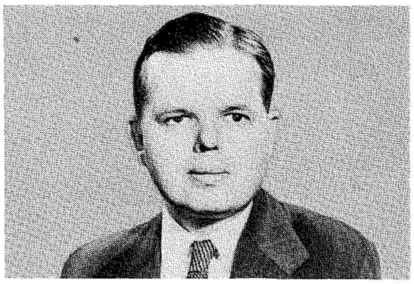
The following names have been added to the RCA ENGINEER list of registered professional engineers:

Name	*State*	*Licensed As*	*License No.*
DEP Surface Communications			
P. G. Pecorara	Arizona	Mech. Eng.	2981
D. W. Hudgings	Ill.	Prof. Eng.	62-4675
IEP BIZMAC Engineering			
Ralph Herman	N. J.	Prof. Eng.	9841
DEP Missile & Surface Radar Engineering			
Henry S. Siesel	N. J.	Prof. Eng.	9803

COMMITTEE APPOINTMENTS

DEP Surface Communications

Two RCA engineers have been elected to serve as Section Officers for the IRE Section in Tucson for the 1957-1958 period. Other RCA engineers were appointed Section Chairman and Arrangements Chairman. Section Officers and the offices held are: **C. L. Becker,** Secretary; **D. Pascoe,** Treasurer (RCA Service Company, Tucson); **D. W. Hudgings,** Program Chairman; **A. B. Clinton,** Arrangements Chairman.

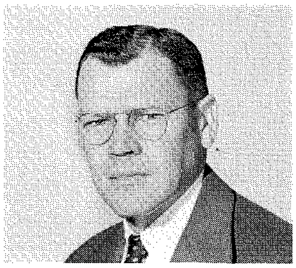


T. T. N. Bucher

T. T. N. Bucher has been appointed a member of the AIEE committee on Communication Theory. On October 8, 1957, he attended a meeting of this committee during the AIEE Convention in Chicago.

P. G. Pecorara of Surface Communications Systems, Tucson, a senior member of the American Society of Tool Engineers, is presently chairman of the Educational Committee for the Arizona state section of this society.

IEP BIZMAC Engineering



T. T. Patterson is appointed to the Administrative Committee of IRE's new Professional Group on Engineering Writing and Speech.

ENGINEERING DEGREES AWARDED

Robert S. Sinn, DEP Special Systems & Development, successfully completed the RCA sponsored Systems Engineering program at the University of Pennsylvania, and received the degree of Master of Science in Systems Engineering and Operations Research, in June, 1957.

D. E. Townsend, of DEP SS&D Department, was awarded a MS degree in Physics at Drexel Institute of Technology in June 1957. —*L. M. Seeberger*

CORRECTION

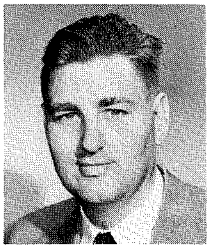
Leon Levy, of IEP BIZMAC Engineering was erroneously reported in the last issue as receiving a MSEE at Harvard. Mr. Levy received the ME degree in Applied Science at Harvard, and is continuing his studies toward a PhD degree under a David Sarnoff Fellowship.

IEP Communications Engineering

J. C. Walter, Chief Engineer, Communications Products Dept., IEP, has been elected chairman of the IRE Philadelphia chapters of the Professional Groups on Communications Systems and Vehicular Communications.

E. J. Forbes, IEP Communications Engineering, has been elected Chairman of the Philadelphia IRE Chapters of Professional Groups on Microwave Theory & Techniques, and on Antennas and Propagation. —*B. F. Wheeler*

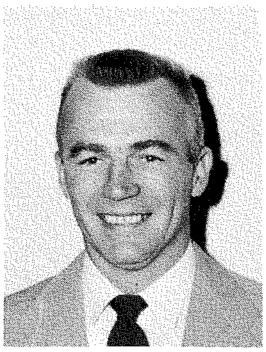
DEP Special Systems & Development



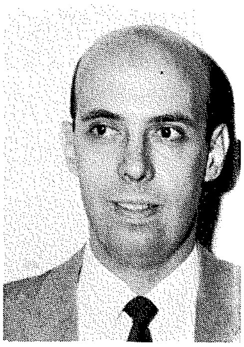
John S. Rydz has been elected Chairman of the DEP Engineering Training Committee. —*L. M. Seeberger*

Indianapolis Plant

Dr. A. M. Max, RCA Victor Record Division, Indianapolis, was recently honored at the Forty-fourth Annual Convention of the American Electroplaters Society. He was appointed to the Editorial Board for a three year term and in this capacity will serve the Journal of the American Electroplaters Society, "Plating". —*S. D. Ransburg*



N. G. Drilling



E. Van Keuren

Norbert Drilling and **Ed Van Keuren** of the Indianapolis Resident Engineering Department of the TV Division were recently elected Chairman and Vice-Chairman, respectively, of the Indianapolis Section of the Institute of Radio Engineers. Norbert G. Drilling received the BS in E.E. at Iowa State College, and joined RCA in 1949 as a specialized trainee. For the past 6 years he has been a factory engineer in the Resident Engineering Group. Edgar Van Keuren attended the Junior College of Connecticut and the University of Bridgeport. He joined RCA in 1948, and spent 3½ years with the RCA Service Co. For the past 5½ years he has been a factory engineer in the Resident Engineering Group. —*J. Osman*

ENGINEERING MEETINGS AND CONVENTIONS

December, 1957 - January, 1958

DECEMBER 4-5:
Professional Group on Vehicular Communications, Annual Meeting, Statler Hotel, Washington, D. C.

DECEMBER 9-13:
Eastern Joint Computer Conference, IRE, ACM, AIEE, Park Sheraton Hotel, Washington, D. C.

DECEMBER 18-19:
Electronic Industries Conference (formerly RETMA) on Maintainability of Electronic Equipment, Univ. of Southern California, Los Angeles.

JANUARY 6-8:
Fourth National Symposium on Reliability and Quality Control, Hotel Statler, Washington, D. C.

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EDITOR, RCA ENGINEER
Radio Corporation of America
Bldg. 2-8, Camden 2, N. J.

RCA ENGINEER

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