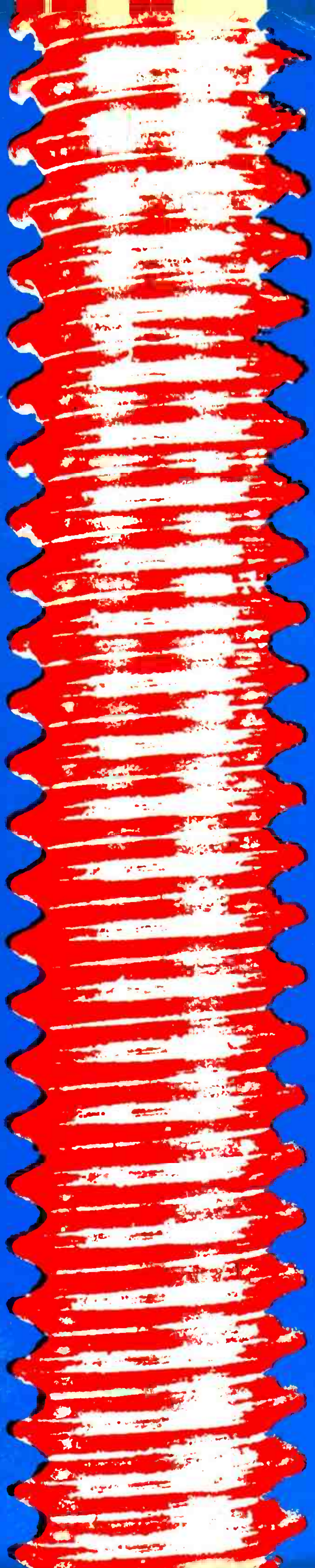

RCA Engineer

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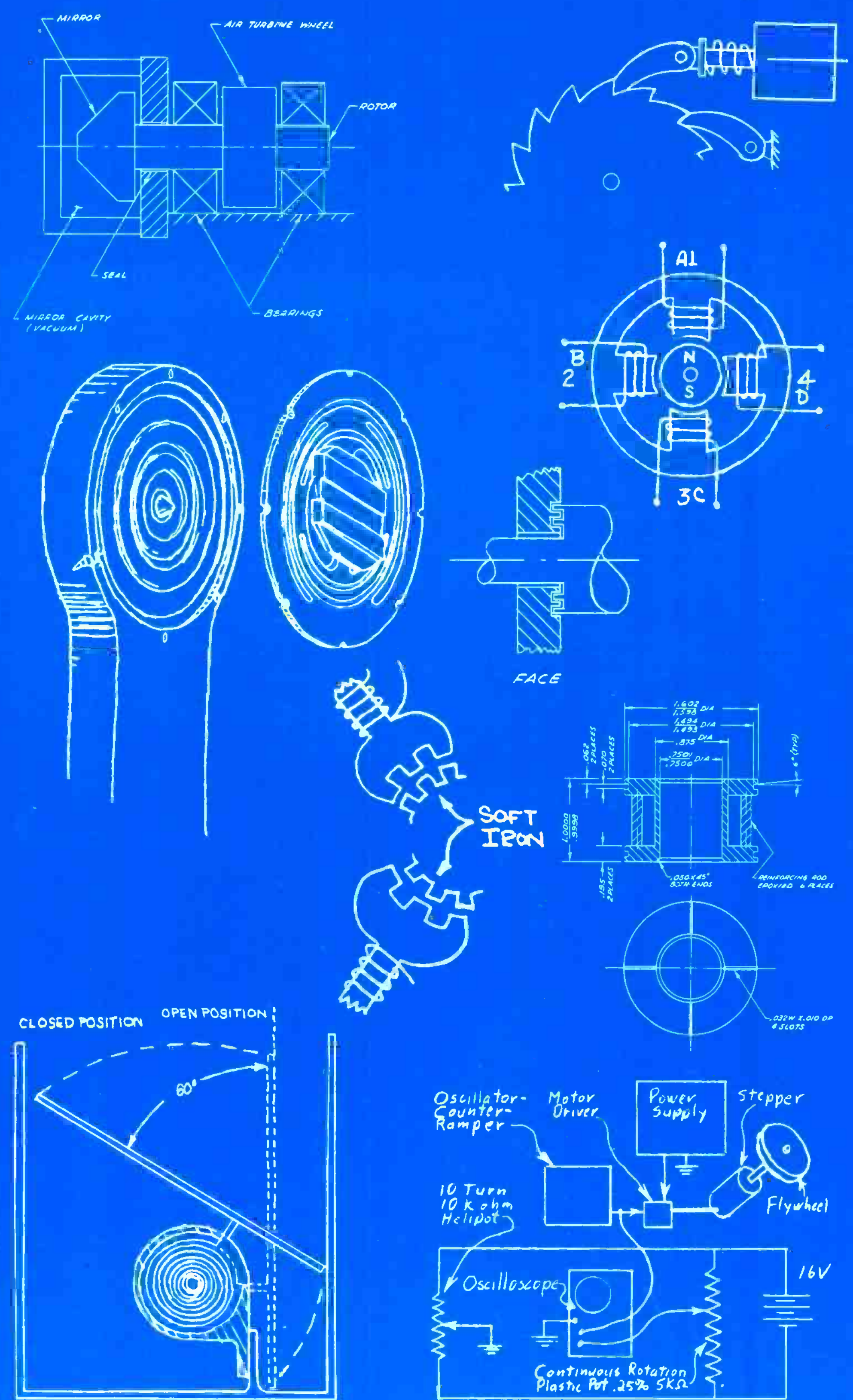

Mechanical engineering

Kinetics, statics, force, styling, kinematics, packaging, plating, weight, volume, · · · , strength, materials, · · · , design factors that go beyond the schematic, · · · I could have filled the page with such terms and not cover all the mechanical engineering skills that enhance our products everyday.

Although frequently considered as supporting the electrical engineer, today's mechanical engineer is taking over the key role in many of the newest electronic products. Computer peripherals, holographic devices, video recording, and space equipment are only a few of the areas that demonstrate the new ingenuity and involvement of the mechanical engineer. In assuming the leadership role, the mechanical engineer has added many new tools to the industrial scene: computer-aided design, automated drafting, numerically controlled machines, and automatic wire-wrap machines to name just a few.

If you are an electrical engineer ready to release the masks for a large-scale integrated circuit and have some reluctance to say "package the first 1000," think of the mechanical engineer who just released the drawings for the molded enclosure that will house that precious circuit. He is very familiar with the feeling.

In this issue you will find examples of some of the exciting mechanical engineering activities going on throughout RCA.

R. H. Aires
Chief Engineer
Electromagnetic and Aviation Systems Division
Van Nuys, California

Our cover

· · · displays, in several rough sketches, some of the mechanical engineering concepts described in this issue. The screw threads are symbolic of the thousands of everyday products that are being examined in light of a possible switch to the metric system (see p. 8).

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RCA Engineer

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

Contents

David Sarnoff—adventurer in science

David Sarnoff February 27, 1891 — December 12, 1971.

A hundred centuries after emerging from the cave, man is still driven, Orestes-like, by the fury of wonder—wonder about himself, his origins, his environment, his destiny.

So intense have been the ideas and emotions stimulated by wonder through the ages that, under its influence, men have risked their fortunes and their lives to follow its lead. . . .

But science is more than mere wonder. It is research—the anatomy of wonder. Through diligent study, it seeks to find the causes, to explain the mystery, to grasp the meaning of life.

To this task it brings method, courage, a capacity for insight and a quality of patience.

Today, scientific research is the world's greatest adventure—and its greatest act of faith. Adventure, because it takes us into areas that have never been explored, areas where man has never penetrated. Faith, because from these explorations, we firmly believe, will come a better way of life and a deeper commitment to those principles of individual liberty and social progress for which so much of the world hungers in these critical times.

—David Sarnoff
***Working in Research at RCA* (1962)**

John Phillips, Associate Editor

At 17, Sarnoff became operator at a lonely wireless station maintained by the Marconi Company at Siasconset, on Nantucket Island, Mass. The station's excellent technical library was an added attraction to the $60-a-month pay. Then too, at that station he had an opportunity to communicate with some of the top-notch operators on the trans-atlantic liners.

For David Sarnoff, the adventure ended on December 12, 1971. But for us, his personal commitment to science and engineering is a constant reminder—a reminder that we can dream as well as do—a reminder that there is a joy in accomplishment, a joy that increases in proportion to challenge—and a reminder also that technology remains a significant force for the improvement of human well-being.

Most of the eulogies have characterized General Sarnoff as a pioneer whose vision, relentless drive, and ambition helped create a company and an industry. No doubt, Sarnoff's leadership was a primary force in the rapid growth of RCA and the electronic communications industry.

But more than that, he was totally involved with the "gadgetry" of the electronic communications industry. As biographer Eugene Lyons observed: "What sets Sarnoff aside from the clan of self-made industrialists is that he has helped create the things and the needs he worked with, and that he has been more fascinated by the creative than the money-making aspects of his dual role."

It was probably this genuine interest in the creative role of engineering and science that engendered the warm personal relationship General Sarnoff enjoyed with many members of RCA's technical staff.

He often visited the operating units of RCA, talked at length with the engineers and scientists, and assembled and sorted ideas—returning challenges for new products built on a combination of those ideas and his own perceived market needs. It was this combination of vision, fact, and challenge that was the driving force behind several historically innovative developments, including black-and-white television and, later, all-electronic compatible color television.

Although he had little formal education beyond eighth grade, Sarnoff had a firm grasp of the technology, the needs, and the benefits of the electronics industry. His interest in radio, in fact, pre-dated most of the engineers and scientists

One of the best "fists" in the business, Sarnoff's love for telegraphy stayed with him throughout his career. For many years, he had a private telegraph hookup between his office in Radio City and the RCA Global Communications office on Broad Street. **1908** — early experience with the Marconi Company (top); **1930** — assuming the Presidency of RCA at the age of 39, his key beside the desk (lower left); **1951** — tapping out three dots of the Morse code letter s to commemorate the fifty-fifth anniversary of the successful transmission of the same letter by Marconi on December 12, 1901 (lower right)

←In 1921, David Sarnoff demonstrated RCA's transoceanic station at New Brunswick, New Jersey, to many distinguished scientists. In the photo (front row, left to right) are David Sarnoff, Dr. E. J. Beng, Professor Albert Einstein, Dr. C. P. Steinmetz, Dr. Irving Langmuir, Dr. Saul Dushman, Dr. G. A. Campbell; (second row, left to right) Thomas J. Hayden, S. Benedict, John Carson, Dr. Alfred N. Goldsmith, A. Melsin, Dr. Albert W. Hull, E. B. Pillsbury, and R. H. Ranger.

Throughout his career, David Sarnoff received more → than two dozen honorary degrees. One of the first was the honorary Doctor of Science from Marietta College, Marietta, Ohio in 1935 (left). One of the last, and perhaps one of the more pleasant for Sarnoff, was the honorary diploma bestowed on him in 1958 by Stuyvesant High School in New York (right).

he was later to stimulate to advanced work in the field.

Attracted early to the new "wireless" means of communications, 16-year-old Sarnoff applied for an operator's job with the Marconi Wireless Telegraph Company of America. There was no operator's job available, but he accepted a job as an office boy for $5.50 a week to "get his foot in the door."

At 17, he jumped at the opportunity to communicate with some of the best operators in the world as an operator at the Siasconset wireless station. He then spent 1910 and 1911 at sea broadening his wireless experience.

Seeking to learn more about the new communication medium, Sarnoff asked for a transfer to the Marconi station at Sea Gate, N.Y., not far from Pratt Institute, in Brooklyn, where he could study electrical engineering. While attending Pratt, Sarnoff became wireless operator at the Marconi station atop Wanamaker's Store in New York. On the night of April 14, 1912, Sarnoff was on duty when the *S.S. Titanic* sank with a loss of 1,517 lives. Sarnoff picked up the message reporting the *Titanic's* distress signal and sinking. He promptly made the news available to an anxious world. From the rescue ship *Carpathia*, Sarnoff received the list of survivors and other important messages related to the disaster. He stayed on duty continuously for 72 hours, during which time President Taft ordered every other wireless station along the East Coast silenced to prevent interference.

I have in mind a plan · · · which would make radio a household utility · · ·

The *Titanic* disaster focused world wide attention on the importance of wireless. Radio blossomed and so did Sarnoff. He became successively Chief Radio Inspector, Assistant Chief Engineer, and in 1915, Assistant Traffic Manager. In 1916, at the age of 26, he wrote the now-famous "radio music box" memorandum to Edward J. Nally, then General Manager of the Marconi Company:

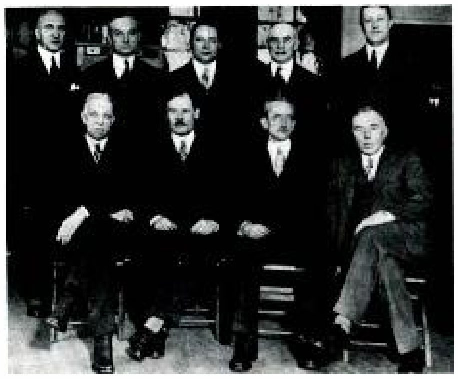
I have in mind a plan of development which would make radio a household utility in the same sense as a piano or phonograph. The idea is to bring music into the home by wireless · · · Should this plan materialize, it would seem reasonable to expect sales of one million 'radio music boxes' within a period of three years. Roughly estimating the selling price at $75 per set, $75 million can be expected.

RCA's actual sales of home radio instruments during the first three years, from 1922 through 1924, amounted to $83 million.

Within a year, Sarnoff was promoted to Commercial Manager of the Marconi Company. In 1919, when the Radio Corporation of America was formed at the request of the United States Government, it acquired the American Marconi Company and Sarnoff was appointed Commercial Manager of the new company He became General Manager of RCA in 1921 and was elected Vice President and General Manager the following year.

All branches of engineering have contributed materially to the success of · · · radio.

David Sarnoff, in his new role as Vice President and General Manager, was well aware of the Commercial significance of radio, but he was aware also of the interdisciplinary role of engineer-



First demonstration of television broadcasting, by RCA and the General Electric Company, at Schenectady, N.Y., Left to right, standing: J. L. Ray, Gen. Sales Manager, RCA; E. P. Edwards, Mgr. Radio Division, General Electric Co.; David Sarnoff, VP and GM, RCA; E. W. Rice, Jr., Vice Pres., Westinghouse Co.; E. F. W. Alexanderson, chief consulting engineer to RCA, whose apparatus is being tested; D. McFarlan Moore, G. E. engineer and inventor of neon lamp used for television; S. M. Kinter, Manager, Research Div., Westinghouse Company (February, 1928). →

←Television history was made April 20, 1939, when David Sarnoff, then President of the Radio Corporation of America, stood before the television cameras and dedicated RCA's pavilion at the 1939 New York World's Fair. The dedication marked the first time a news event was ever covered by television. At the right is an unretouched photo of the television image as it appeared on receivers inside the pavilion. General Sarnoff's speech, entitled "Birth of an Industry," predicted that television one day would become an important entertainment and information medium: **". . . Now we add sight to sound. It is with a feeling of humbleness that I come to this moment of announcing the birth in this country of a new art so important in its implications that it is bound to affect all society.**
It is an art which shines like a torch of hope in the troubled world. It is a creative force which we must learn to utilize for the benefit of all mankind. This miracle of engineering skill which one day will bring the world to the home also brings a new American industry to serve man's material welfare. When it does, it will become an important factor in American economic life."

ing in its creation. In addressing a meeting of the Engineering Societies of Buffalo on January 9, 1923, he said:

This development [radio] was not accomplished solely by any given group of specialists; indeed, practically all branches of engineering have contributed materially to the success of present day radio. For example, to mechanical engineering we owe the Diesel Engine drive which is used at some high power radio stations for driving high frequency alternators. Civil engineering is responsible in a large measure for the hugh self-supporting towers elevating the radio antenna, some of which rise to heights as great as 800 feet. The combined efforts of chemical and electrical engineers have developed the vacuum tube to a point where today this highly specialized instrument is considered the very heart of radio transmission and reception. And it is to the electrical and radio engineers that we owe the fundamentals of development, the placing into practical operation of the radio transmitter and receiver and, finally, the coordination of effort which has made radio one of the most outstanding achievements of modern science.

As early as April 5, 1923, Sarnoff foresaw the possibility of television. In a report to the RCA Board of Directors, he wrote:

I believe that television, which is the technical name for seeing as well as hearing by radio, will come to pass in due course . . . It may be that every broadcast receiver for home use in the future will also be equipped with a television adjunct by which the instrument will make it possible for those at home to see as well as hear what is going on at the broadcast station.

The National Broadcasting Company was organized by Sarnoff in 1926 as a service of RCA "to provide the best programs available for broadcasting in the United States." There were then 5 million homes equipped with radio, and this first national network did much to expand the usefulness and public interest in broadcasting.

Sarnoff was elected President of RCA in 1930 and was confronted with serious economic and legal problems during his first two years.

The radio industry was hit by the great depression. RCA's income dropped from $182 million in 1929 to $62 million in 1933; however, Sarnoff's indomitable faith in radio was not diminished. On September 19, 1930, he spoke at the dedication of the RCA plant at Camden,

Now we add sight to sound.

N.J., as the Radio Center of the World:

We hear much discussion at present here and abroad of our immediate economic needs, and much of this discussion is carried on by two vociferous groups, who hasten along at the sides of the moving business column. They are the professional optimists, amiable and indiscreet, and the professional pessimists, dour and acrimonious. They tread the rims of our industrial tableland and are swayed by the breezes of moving forces that may push them and their philosophies over.

Pacing the broad plain between are workers—men and women of undertaking and accomplishment, who represent the substance of the country and its reliance in periods of economic readjustment and stress.

Their will and energy to attempt, their courage and determination to go ahead, are the forces which give the nation a sound industrial constitution, which neither the misgivings of the professional 'bear' nor the misleadings of the professional 'bull' can shake.

At left, David Sarnoff uses a shovel at the RCA Laboratories ground-breaking ceremonies; Dr. Otto S. Schairer, then Vice-President of the Laboratories, adds encouragement. Sarnoff and Schairer meet again during the Laboratories' 25th Anniversary ceremonies in 1967. Throughout those 25 years, Princeton was his second home; he often spent several days at the Labs visiting with the research staff. In 1951, the Laboratories was renamed the David Sarnoff Research Center to commemorate General Sarnoff's 45 years of service to radio.

On May 4, 1956, General Sarnoff dedicated the Missile and Surface Radar Division plant at Moorestown, N.J., to "the Service of the Nation". Gen. Sarnoff on that occasion said that the Moorestown plant was an important part of RCA's recently organized Defense Electronics Product unit.

↑

Dr. Lee DeForest and General David Sarnoff were brought together many times by their common interest in electronics. DeForest often complimented Sarnoff on his leadership role in electronic communications. On the occasion of Sarnoff's 50th Anniversary in radio, Dr. DeForest said: "I join with your host of admiring friends in deep appreciation of the grand things you have achieved for radio communications and in the electronics industry during these 50 years. And further, as a profound civic philosopher, the entire nation is deeply indebted to your extraordinary thinking and keen foresight · · ·" In the photo, General Sarnoff congratulates Dr. Lee DeForest at the unveiling of a plaque in 1956 commemorating the invention of his "audion" on October 6, 1906.

The industrial enterprise which has now made Camden the radio manufacturing center of the country will move, I believe, on a firmer and steadier roadway. It is founded on a public need and it bestows a public service. It seeks to perform its work honestly and conscientiously. It possesses adequate facilities. But beyond bricks and mortar, iron and steel, beyond the materials that comprise plant and machinery–is its personnel, the workers upon whom the success of this enterprise and the ultimate fulfillment of its mission depend. Camden–a city long identified with the entertainment arts–has supplied in large measure the men and women upon whose shoulders that destiny reposes.

In 1930, the Department of Justice brought suit in the Federal Court seeking termination of agreements made at the time of RCA's formation. Under these agreements, General Electric Company and Westinghouse Electric and Manufacturing Company manufactured radio products and RCA sold them. Together, these companies owned the majority of RCA stock.

The suit was settled in 1932 by a consent decree which provided certain modifications in the agreements between RCA, G.E., and Westinghouse and the distribution to their stockholders of the RCA stock they held. As a result, RCA became entirely independent, with facilities for both manufacturing and marketing radio products.

David Sarnoff played a leading role in guiding RCA through both its economic and legal difficulties. His skill and success in both ventures gained him added recognition as a leader of the still-young industry.

Industry today is following the vanguard of science into new and infinite realms of knowledge.

Through the 1930's, radio advanced, television was launched, and RCA continued to grow at a rapid pace. David Sarnoff, now firmly in command, would continue to emphasize that science was, in a sense, the real leader. In an address to the American Physical Society on April 30, 1937, he said:

Industry today is following the vanguard of science into new and infinite realms of knowledge . . . The industry which has not learned how to employ scientists to make it new, and keep it new, is doomed. Few industries are so stagnant as not to be aware of this; but there are some so conservative that the scientist is called upon to turn salesman and show them how modern science can rejuvenate them to meet present day realities and survive.

In all respects, I hope we can bring about a closer understanding and cooperation between you, who seek new truths in the universities, and leaders of industry, who seek to make the truth you discover serve society. Not only research staffs but industrial managers should at all times be kept informed of your new discoveries. With such knowledge, promptly obtained, I am certain we can shorten the time-gap which now separates technological unemployment and useful re-employment.

Any measure of unemployment relief obtained by placing a check-rein upon technology, or by arbitrarily hampering men's efficiency, is unsound, uneconomic, and cannot endure.

Sarnoff's faith in science and engineering was to be tested several times throughout his career. Two of the most prominent examples are the developments in television.

RCA spent more than $50 million on research and development of black-and-white television before realizing any financial return.

One of three birthday presents to commemorate General Sarnoff's 50th Anniversary in radio was a magnetic tape recorder for both black and white and color television. Sarnoff is standing in front of the demonstration unit on which television pictures both color and black and white were recorded for the first time. The demonstration was held at the David Sarnoff Research Center.

General Sarnoff (foreground) and some of the members of the RCA Board of Directors at RCA's plant in Van Nuys, California, in 1964. (From upper left, front row) John T. Cahill, Robert W. Sarnoff, Frank M. Folsom, Elmer W. Engstrom, Lewis L. Strauss, Mrs. Everett N. Case, and Arthur L. Malcarney; (second row) Harry C. Ingles, Harry C. Hagerty, and W. Walter Watts; (rear row) Carroll V. Newsom, Paul M. Mazur, and Charles M. Odorizzi.

Again in the development of color television, RCA spent more than $130 million prior to 1960 in pioneering, developing, and promoting compatible, all-electronic color television, and providing facilities and color programming.

Sarnoff championed the all-electronic, fully compatible color system. Part of the industry supported a mechanical system for color television which was incompatible with black-and-white TV. In 1950, the Federal Communications Commission approved the incompatible system. But Sarnoff was convinced that an all-electronic, compatible color system would be superior to the mechanical. He spurred development of the RCA tricolor tube, the key to the compatible color system. On December 17, 1953, the FCC reversed its decision, approving standards for commercial color television broadcasting based on compatible signal specifications presented by RCA and NBC and others.

. . . I have often had more faith in these men than they have had in themselves.

There are many ways Sarnoff challenged the technical staff to perform "impossible" tasks. One of the best examples is illustrated by the story of his 45th Anniversary of his Service in Radio in 1951. To commemorate the occasion, the RCA Laboratories was renamed the David Sarnoff Research Center. During the ceremonies, he asked RCA's scientists to present him with three presents on his 50th Anniversary, five years later: an electronic amplifier of light, a magnetic tape recorder for both black-and-white and color television, and an electronic air conditioner.

When he received them exactly five years later on Sept. 30, 1956, he said:

A few of the scientists and research men who heard me make these specific challenges to their ingenuity wondered if I quite grasped the toughness of the problems solved. If I did, they said, I might not have had the gall to set a 5-year time limit for their solution.

But I have often had more faith in these men than they have had in themselves. I had no doubts that they could solve these problems, and I even thanked them in advance for the presents I confidently expected to receive tonight.

The adventure of David Sarnoff's life can be captured only partially on paper. The many books and articles cover only part of his career as an industrial leader, a visionary, a statesman, a patriot. As with any great man, a large part of the real story died with him. However, his enthusiasm for the electronics business and his faith in the people that made it happen represent perhaps his greatest legacy to engineers and scientists at RCA. The adventure of his life certainly added some to ours.

Among the many memorial tributes, one is a most fitting conclusion to this article. It was written by Elmer W. Engstrom a leader of RCA's research and engineering activities for more than four decades; it appeared in the December 1971 issue of the *RCA Review:*

"For more than 35 years I had the honor of serving under David Sarnoff, first in his role as President and later when he became Chairman of the Board and Chief Executive Officer of RCA. During those years, it was my privilege to bear witness to an era of unparalleled progress sparked by the vision of a truly remarkable personality. More than any other man in his time, David Sarnoff was the driving spirit who must be credited with transforming electronic technology from its research beginnings into a vital force that now permeates all phases of our lives

"With unbounded faith in scientists and engineers—at times more faith in them than they were willing to express themselves—David Sarnoff committed himself without qualification to the principles of industrial research. He has, therefore, left us with a legacy of inspiration to guide the further progress of electronics for generations to come.

"For those of us who served with him, for those who follow in his footsteps, the story of David Sarnoff's dedicated life encompasses all of the opportunities America holds forth for the achievement of greatness. He was not content merely to dream impossible dreams. He fulfilled them. And by doing so, he has made it possible for all who continue to labor in this field to fulfill their own lives—if they have the will.

"Thus, there is only one way to properly conclude a tribute to the life of David Sarnoff. Neither nostalgia nor memories will suffice—only challenges."

Metrication in the U.S.

C. P. Kocher

Lloyd George once quashed an early attempt to metricate Great Britain with the remark "Do you expect the British workingman to go into a public house and ask for 0.56825 litre of beer?" The present move to metricate the United States cannot be so lightly dismissed. The question is becoming more academic; it is no longer "Will the United States adopt the metric system?" but rather "How will the United States go about adopting the metric system?" The Report of the U.S. Metric Study,[1] a report to Congress based on a three-year study carried out under the auspices of the Department of Commerce, has pointed out that the U.S. has been an "officially metric nation" since 1893 when the Secretary of the Treasury declared metric standards furnished by the International Bureau of Weights and Measures to be the Nation's fundamental standards. And, taking an unexpectedly positive stand, Maurice Stans, Secretary of Commerce, has urged Congress to implement a deliberate coordinated national program for the U.S. to adopt the International Metric System over a period of ten years.

Editor's note: While this paper was being written, the 14th General Conference of Weights and Measures was convened (October 1971). At that time, the Conference adopted unanimously the names pascal (*Pa*) for the SI unit of pressure and siemens (S) for the SI unit of electrical conductance (See Table I). It also adopted a definition for the mole (*mol*) as the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12. [The elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles].

THE TERM *metric system* is today most often used to refer to the *Système International d'Unités*, abbreviated SI. (The system of weights and measures that currently predominates in the United States can be called the *customary system*.)

The SI has evolved from a number of meetings of the *Conference Generale des Poids et Mesures*,[2] and rests on four independently determined, precisely defined *base units* for length, temperature, time, and mass:

Length: The *meter* (m) was initially defined to be one ten-millionth of the quadrant of the meridian of the earth that passes through Dunkirk, France. By international agreement, the meter has been more precisely defined as "equal in length to 1 650 763.73 wavelengths in a vacuum of the radiation corresponding to the unperturbed transition between the levels $2p_{10}$ and $5d_5$ of the krypton 86 atom, taken at the triple point of nitrogen."

Temperature: The *kelvin* (K) is now defined as one 273.16th of the thermodynamic temperature of the triple-point of water. A temperature difference of one kelvin is a difference of one degree Celsius. (The term "Centigrade" has been replaced by "Celsius" to avoid confusion. In some European countries, one-100th of a right angle is called a grade; a centigrade would be one-100th of a grade.)

Time: The *second* (S), originally defined as "the fraction 1/31 556 925.9747 of the tropical year 1900 January 0 at 12 hours ephemeris time," is now defined by a more reproducible standard, namely "the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels $F=4$, $M=0$ and $F=3$, $M=0$ of the ground state $^2S_{1/2}$ of the cesium-133 atom unperturbed by external fields."

Mass: The *kilogram* (kg), originally defined as the mass of one cubic decimeter of water, is now defined as the mass of a specific platinum-iridium cylinder kept in a vault in Sevres, near Paris. It is the only base unit still defined by an artifact.

For convenience, two other non-independently derived units are also taken as base units:

Electrical current: The *ampere* (A) is defined as "that constant current, which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section and placed one meter apart in a vacuum would produce between those conductors a force equal to 2×10^{-7} newton per meter of length."

Luminous intensity: The *candela* (cd) is defined as "the luminous intensity in the perpendicular direction of a surface of one 600 000th square meter of a black body at a temperature of freezing platinum under a pressure of 101 325 newtons per square meter."

Two supplementary units, the *radian* (rad) and *steradian* (sr), are used to measure plane and solid angles, respectively. It has been suggested that the *mole* (Avogadro's number of particles of a substance) also be included as a base unit; this might obviate the use of an artifact to define the unit of mass. [See editor's note.]

The SI base units are combined to form derived units, many of which have special names (Table I).

Decimal fractions and multiples of an SI unit are formed by combining a standard prefix (Table II) with the unit. Multiple prefixes, such as "micromicro-" and "millimicro-" are not permitted. The use of non-standard names for decimal multiples of metric units is also discouraged (Table III), although some of these are firmly entrenched.

A few non-SI units are used so widely that it would be impractical to abandon them; thus, the minute, hour, day, and angular degree, minute, and second, as

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well as the litre (10^{-3} m^3) are acceptable for use with SI units.

The outstanding feature of SI is its *coherence:* the product or quotient of any two metric units yields another metric unit. Thus, accelerating a mass of 1 kg at the rate of 1 m/s^2 over a distance of 1 m requires 1 kg·m^2/s^2 = 1 J of energy. In a non-coherent system such as the customary system, the simple product of two units does not, in general, yield another recognized unit. Thus, in the customary system, 1 BTU ≠ 1 slug ft^2/s^2; an arbitrarily fixed conversion factor is needed to relate units of energy as described in two separate but equally useful contexts. To maintain coherence, units such as the calorie (4.18 J) which were once considered metric have been purged from the SI. (Indeed, some purists bristle because the base unit for mass, the kilogram, is ostensibly "derived from" the gram. They have suggested renaming the kilogram the Giorgi, after Giovanni Giorgi, the Italian engineer who first recognized the advantages of a coherent system of units.)

Why metricate?

Why should the U.S. trade its well-entrenched and apparently adequate customary system for the metric system? One of the reasons cited most often by proponents of the metric system is, of course, convenience. In most disciplines, and especially in the sciences, it is much easier to do calculations with the coherent metric units (Fig. 1). Some American industries have recognized this fact; thus, the pharmaceutical industry started marketing most of its products in metric quantities about fifteen years ago;[3] manufacturers feel that reduction in errors and other benefits have more than offset the costs of conversion. Similarly, most scientists who do research in chemistry and physics on a small scale (i.e. laboratory scale as opposed to pilot plant) use metric units predominantly.

On the other hand, some U.S. industries cling to the customary system and suffer measurable losses as a consequence. Henning[4] has estimated that each engineer in the aerospace industry spends approximately 23 hours a year on extraneous conversion calculations (*i.e.* calculations that would be obviated by the use of the metric system). He estimated the total annual cost to the industry to be $65 million (65 megadollars) in 1966.

Moreover, industries would not be the only ones to benefit from the simplicity of a coherent set of units: consumers would find it easier to compare the relative prices of metrically labeled packaged goods, school children would have to spend less time rote-memorizing conversion factors and learning to manipulate mixed fractions, and housewives would be less likely to make mistakes when scaling recipes up or down.

Benefits of a common denominator

Even proponents of the metric system would probably admit that converting the U.S. to the metric system would not be a pressing matter if convenience were its only recommendation. The

Table I—Some derived units having special names.

Physical quantity	*Name*	*Symbol*	*Definition*
force	newton	N	$kg \cdot m \cdot s^{-2}$
pressure	pascal*	Pa	$kg \cdot m^{-1} \cdot s^{-2}$
energy	joule	J	$kg \cdot m^2 \cdot s^{-2}$
power	watt	W	$kg \cdot m^2 \cdot s^{-3}$
electrical charge	coulomb	C	$A \cdot s$
electrical potential difference	volt	B	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-1}$
electrical resistance	ohm	Ω	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-2}$
electrical conductance	siemens*	S	$kg^{-1} \cdot m^{-2} \cdot s^3 \cdot A^2$
electrical capacitance	farad	F	$A^2 \cdot s^4 \cdot kg^{-1} \cdot m^{-2}$
magnetic flux	weber	Wb	$kg \cdot m^2 \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	$kg \cdot m^2 \cdot s^{-2} \cdot A^{-2}$
magnetic flux density	tesla	T	$kg \cdot s^{-2} \cdot A^{-1}$
luminous flux	lumen	lm	$cd \cdot sr$
illumination	lux	lx	$cd \cdot sr \cdot m^{-2}$
frequency	Hertz	Hz	s^{-1}

*See editor's note.

Table II—Prefixes for decimal fractions and multiples of SI units.

fraction	*prefix*	*symbol*
10^{12}	tera	T
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^2	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

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received the BA in Chemistry from the University of Pennsylvania in 1971. He served as Managing Editor, and Editor-in-Chief of the *Pennsylvania Triangle* in which he published ten technical or semi-technical articles; he also conducted interviews, and published editorials, and a nationally awarded series of essays. His industrial experience includes work at the Borden Chemical Company research laboratory as Senior Laboratory Technician. At Borden, Mr. Kocher designed and carried out tests of the physical properties of polymers intended for adhesive use; in this work, he programmed and used a time-sharing computer. Since joining RCA in July 1971, Mr Kocher has worked as Assistant Editor, *RCA Engineer.*

*Since this article was written, Mr Kocher has left RCA

Table III—Decimal fractions and multiples of SI units having non-standard names.

Physical quantity	*Name*	*Symbol*	*Definition*
length	angstrom	Å	10^{-10} m
length	micron	μ	10^{-6} m = μm
area	barn	b	10^{-28} m^2
force	dyne	dyn	10^{-5} N
energy	erg	erg	10^{-7} J
kinematic viscosity	stokes	St	$10^{-4} m^2 \cdot s^{-1}$
viscosity	poise	P	$10^{-1} kg \cdot m^{-1} \cdot s^{-1}$
magnetic flux	maxwell	Mx	10^{-8} Wb
magnetic flux density	gauss	G	10^{-4} T
absorbed dose (ionizing radiation)	rad	rd	$10^{-2} J \cdot kg^{-1}$

a) Calculate the pressure of a 130 dB sound wave at an altitude of 4000 ft. using the relationship $P^2 = 2\rho CI$ where C is the velocity of sound, ρ is the gas density, and I is the intensity.

From a handbook, C=704 mph; ρ=0.0024 slugs/ft³. 130 dB=10 log I/I_o; $I_o = 10^{-16}$ watt/cm² $I = 10^{-3}$ W/cm²

$$P^2 = 2 \times 0.0024 \left(\frac{slug}{ft^3}\right) \times [illegible] \left(\frac{lb_m}{slug}\right) \times 704 \left(\frac{mi}{hr}\right) \times [illegible] \left(\frac{ft}{mi}\right) \times [illegible] \left(\frac{hr}{s}\right) \times 10^{-3} \left(\frac{W}{cm^2}\right) \times [illegible] \left(\frac{hp}{watt}\right) \times [illegible] \left(\frac{ft\text{-}lb_f}{s\text{-}hp}\right)$$

$$\times [illegible] \left(\frac{lb_f\text{-}s^2}{lb_m\text{-}ft}\right) \times [illegible] \left(\frac{cm^2}{in^2}\right) \times [illegible] \left(\frac{in^2}{ft^2}\right) = 3.396 \left(\frac{lb_f^{\,2}}{ft^2}\right)$$

$$P = 1.84 \frac{lb_f}{ft^2}$$

b) Calculate the pressure at an altitude of 1200 m. From a handbook, C=314 m/s; ρ=1.24 kg/m³.

As above, $I = 10^{-3}$ (W/cm²) = 10 (W/m²) $\quad$ 1 watt $= 1 \left(\frac{N\text{-}m}{sec}\right)$ $\quad$ therefore $I = 10 \left(\frac{W}{m^2}\right) = 10 \left(\frac{N}{s\text{-}m}\right)$

$$P^2 = 2 \times 1.24 \left(\frac{kg}{m^3}\right) \times 314 \left(\frac{m}{s}\right) \times 10 \left(\frac{N}{s\text{-}m}\right) = 7780 \left(\frac{kg\text{-}m\ N}{s^2\ m^4}\right)$$

$$1\ N = \left(\frac{1\ kg\,m}{s^2}\right) \text{ therefore } P^2 = 7780 \left(\frac{N^2}{m^4}\right);\ P = 88 \left(\frac{N}{m^2}\right)$$

Fig. 1—A sample calculation using a) customary units and b) SI units. Figures shown in gray are conversion factors that are unity in the metric system

only cogent reason for conversion to metric is: the United States is rapidly becoming the only non-metric nation in the world. Aside from the U.S., the only nations that are not either metric or in the process of adopting the metric system are Barbados, Burma, Gambia, Ghana, Jamaica, Liberia, Muscat and Oman, Nauru, Sierra Leone, Southern Yemen, Tonga, and Trinidad.

Obviously, an engineer designing a machine in a predominantly metric nation will specify dimensions in easily remembered multiples or fractions of centimeters, screws and bolts with metric thread sizes, and steel rolled to metrically specified thicknesses, just as an American designing a similar machine would specify multiples and fractions of inches, English thread sizes, and steel rolled to thicknesses that were multiples of a mil.

If *either* machine is innovative, important, and produced quickly in sufficiently large quantities, its particular dimensions may be accepted as a standard by the rest of the world. Thus, 12-inch phonograph records are sold the world over, just as is 35-mm photographic film. In many situations, where neither manufacturer has a particular technological or marketing advantage, equivalent goods may be produced to both specifications. Thus, foreign cars have metric parts, American cars generally have non-metric parts, and some cars combine metric and non-metric parts. Since metric and non-metric parts are, in general, non-interchangeable, mechanics who work on both must maintain a double inventory of tools and spare parts.

In metric countries, non-metric goods are at a disadvantage in the marketplace. Given a choice between a non-metric product and an equivalent product manufactured to metric specifications with metric parts, a foreign consumer may justifiably prefer the metric item because replacement parts are more readily available. By retaining her parochial customary system of measurements, metric advocates say, the U.S. is in effect imposing a tariff on many of her export goods.

In the past, her technical precocity has allowed the U.S. to impose her technical standards on the rest of the world over a wide range of technologies. But in light of the almost universal use of metric, it is unrealistic to assume that the U.S. will maintain enough of a technological edge to impose non-metric standards on the rest of the world. Indeed, trade associations such as the Common Market have occasionally established common (metric based) quality assurance standards that make it difficult for non-metric manufacturers to compete.

Why not?

In rebuttal, those opposed to metrication claim that trade losses due to non-metrication are inconsequential; the United States is the largest exporter in the free world, and its trillion-dollar Gross National Product is[5] "two-thirds greater than the combined output of both the Common Market and the European Free Trade Association." Moreover, foreign trade constitutes

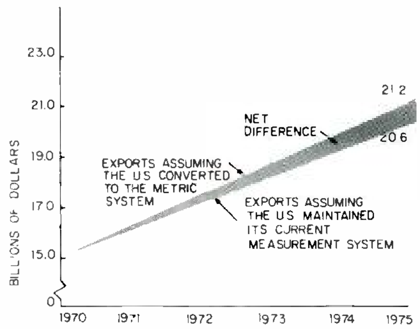


Fig. 2—Predicted loss of exports through not going metric.

only one-tenth of the American GNP; while metrication is essential to a country like Great Britain, which must trade to survive, it is definitely non-essential to the U.S.

Some claim that going metric might even harm the U.S. balance of payment: foreign goods would be imported more readily. During the actual period of conversion, when American industry is not yet producing metric materials efficiently, its necessary reliance on foreign suppliers could have a disastrous effect on the economy.

Hardships of conversion

Some claim that even without foreign competition a change to the metric system might have a disastrous effect on the economy. Workers not yet acquainted with the new system would experience a temporary loss of productivity until they developed a "feel" for the new system; industries and unions would have to finance broad retraining programs; industries and workers would have to invest in new tools. Antitrust laws as they are presently written might prevent companies within an industry from coordinating their conversion programs. The cost and confusion of conversion would outweigh any possible advantage.

Metric Study Report

The report of the U.S. Metric Study indicates that there are truths and fallacies in both the pro-metric and anti-metric arguments as outlined above. Although the U.S. balance of trade will suffer somewhat as long as the U.S. remains non-metric[6] (Fig. 2), the opponents of metrication are probably justified when they claim that an incompatible measurement system does not significantly deter U.S. foreign trade[7] (Fig. 3). The U.S. is, in fact, still the leading exporter in the free world, although its share of the market is decreasing because associations such as the Common Market are lowering trade barriers between many nations.

The Metric Study nonetheless recommends an immediate, planned, coordinated transition to the metric system. This recommendation is based on two premises: first, conversion to metric would bring certain definite economic advantages, and second, metrication is ultimately inevitable.

Economic advantages

In addition to its favorable effect on foreign trade, adopting the metric system would:

—Allow U.S. armed forces to benefit from a freer interchange of materials and weaponry with its allies, thereby reducing inventory, repair, and maintenance costs.

—Permit many industries to reduce inventory and improve designs while redesigning parts to metric specifications. The American National Standards Institute (ANSI) is even now working with the Industrial Fasteners Institute to design a metric fastener system that would drastically reduce the variety of grades, types and thread size (without sacrificing quality) and ultimately save North American fastener users over $500 million a year. In the words of R. B. Belford, technical director of the Institute[8] "Over a long period of years we have been quick to add new items to our standards; we have found it nearly impossible to subtract. We now have an over-proliferated system which is unfairly expensive to fastener users; it is strangling fastener producers. We need drastic simplification and reduction of the number of different parts being produced and used . . ."

—Eliminate superfluous conversion calculations as noted above.

—Ultimately reduce cost in training personnel and reduce errors in calculations.

The Metric Study Group feels that the ultimate benefits of these and other advantages would more than compensate for the costs of conversion.

The Metric Study Group did not feel that it was feasible to put dollar value on the new benefits of conversion.[9] It did, however, attempt to assess the costs to various sectors of the economy:

Manufacturing industries: A total cost of $6.2 to 14.3 billion. This figure includes the $0.5 billion annual cost of maintaining a dual inventory and assumes a planned ten-year conversion period.

Federal civilian agencies: $60 million annually over ten years.

Department of Defense: $18 billion over 30 years, 75 percent of which would be spent

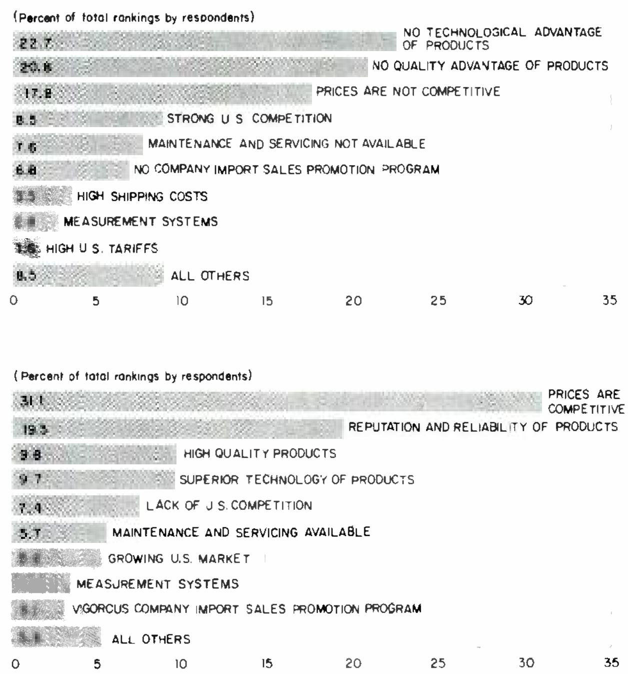


Fig. 3—Factors affecting U.S. imports and exports of machinery, instruments, and other measurement-sensitive products, from a U.S. Metric study survey of exporters. Figures shown indicate percent of total rankings by respondents.

in the first ten years.

Non-manufacturing businesses: $340 million

Education. A maximum of $1 billion over three to five years for new texts and equipment. This figure assumes that metrication is the only reason for all replacements. But texts are normally replaced after a few years use, even without metrication; therefore much of this cost would be absorbed by school budgets and would not be directly attributable to metrication.

Inevitability

The second premise of the Study is that even without a coordinated program, the U.S. will eventually adopt the metric system; day by day the metric system is encroaching further on our daily life. The American pharmaceutical industry has gone metric, and NASA has started to convert; the NCAA is recommending that schools and colleges build swimming pools in metric lengths so American swimmers can train for international events; the Department of Defense specifies ammunition in metric sizes; and some domestic automobiles are being manufactured with metrically specified engines and transmissions.

The Study Group conducted extensive surveys and found that 70% of the 4000 manufacturing firms they contacted felt that "increasing use of metric would be in the best interests of the U.S.;" 61% of the non-manufacturing businesses agreed. Although the survey showed that laymen are generally unfamiliar with the metric system, (only 40% of the members of a group of 1400 families could name a single metric unit; the survey did not indicate how many could name a non-metric unit) the same survey showed that the more people knew about the metric system the more they liked it.

The inevitability of metrication, the Study indicates, makes a strong economic argument for an immediate coordinated conversion program. The Study feels that such a program could transform the U.S. into a predominantly metric nation in ten years, while an uncoordinated unplanned "drift" toward metrication might take 50 years. A plan would minimize certain costs of conversion (Such a conversion might cost the manufacturing sector of the economy $6 to 14 billion) and bring the economic benefits much sooner (Fig. 4). For example, many industries indicate that maintaining a double inventory of metric and customary parts during the conversion period would be a major expense; minimizing the period of conversion would minimize double inventory costs.

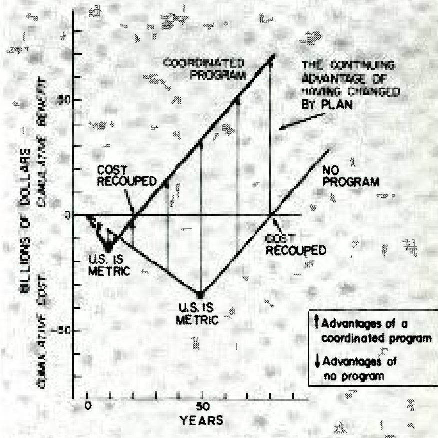
Moreover, a coordinated program would minimize expensive confusion by assuring that the various sectors of the economy metricate in some logical sequence: suppliers must furnish basic materials (*e.g.* sheet steel, lumber) in metric sizes before manufacturers can easily build metric parts and subassemblies; metric subassemblies must be ready when manufacturers are ready to produce all-metric finished goods.

When asked, what course of action should follow "if increased metric usage is in the best interest of the United States," 93% of the manufacturing industries and 86% of the non-manufacturing businesses indicated a preference for a coordinated national program; these respondents were about equally divided on the question of a mandatory *versus* a voluntary program. Most (82%) of the manufacturing firms surveyed thought that the conversion could be effected in ten years or less.

Recommendations

The Metric Study has therefore recommended that Congress implement a coordinated national program to make the United States a "predominantly" metric nation over a span of ten years. On August 6, 1971, Senator Pell introduced into the Senate the "Metric Conversion Act of 1971" (S. 2483), a bill "to provide a national program in order to make the international metric system the official and standard system of measurement in the United States and to provide for converting to the general use of such system within ten years after the date of enactment of [the] act." Congressman Fulton of Pennsylvania submitted a concurrent resolution to the House.

At this writing, the bills are still in committee; since the final wording of the legislation has not yet been decided, few industries have felt it appropriate to take an official position pro or con. Thus, RCA does not yet have an official position although key personnel have been asked to "consider the impact" of metrication to aid in preparing a position "at the appropriate time."[10] If the positive tone of the U.S. Metric Study and its report on favorable attitudes of U.S. manufacturers are accurate indicators, however, the U.S. may soon be swept up in a metrication program.



	PROGRAM	NO PROGRAM
"BASE" COST	1.0	0.2
DUAL CAPABILITY COST	0.5	0.5
COMBINED COST	1.5	0.7

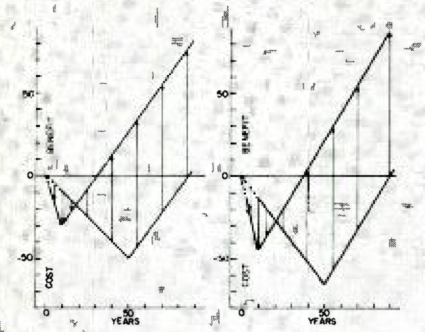
ASSUMED AVERAGE ANNUAL COSTS (Billions of Dollars)

What now?

What is likely to happen during the metrication program? The first few months are likely to be devoted to little more than extensive, intense planning. In Great Britain, which is about half-way through her metrication program, the United Kingdom Metrication Board is a coordinating and advisory body rather than an executive one. The various sectors of the economy plan and implement their own conversion timetables; the Board merely coordinates and endorses them.

Early considerations

Such a system would probably work in the U.S. as well, although legal difficulties might arise. The ANSI Metric Advisory Committee points out[11] that present antitrust laws might have to be amended or exemptions offered to allow manufacturers to safely conduct the industry-wide planning necessary to ensure smooth progress. At the same time, if trade groups and associations select their own target dates for metrication, dissenting manufacturers who feel that the chosen date penalizes them unfairly should be able to take action against the majority group.



PROGRAM	NO PROGRAM
2.5	0.5
0.5	0.5
3.0	1.0

PROGRAM	NO PROGRAM
4.0	0.8
0.5	0.5
4.5	1.3

Fig. 4—The diagram compares the cumulative costs of a nationally coordinated and planned conversion to metric, lasting ten years, to an unplanned and uncoordinated drift toward metric which might take fifty years. The annual cost of the coordinated program is greater than the annual cost of no program, but the coordinated program recoups its initial cost much sooner.

Another activity that should start early and continue throughout the conversion campaign is education. In Britain both the school system and a program of posters, advertising campaigns, and broadcasts is educating the public in basic metric concepts. In the U.S., periodicals are also beginning to run informative metric articles, and certain societies such as the IEEE request that all papers submitted to them report data and dimensions in SI units. One magazine, *Measurement and Data News*, publishes in each issue a "Think Metric" lesson featuring a "Playmate of the Month" whose vital statistics are given in centimeters and kilograms.

Later considerations

What about the conversion itself? It is important to remember that the customary system is *not* being outlawed, and foolish changes will not be made for the sake of foolish consistency. It would be folly to change the distance between railroad rails to some integral number of centimeters, although the specified weight of the rails could eventually change from 135 lb/ft to some integral number of kg/m. The diameter of phonograph records will stay 12 inches (although engineering specs may say 30.48 cm), and Miles Standish will not be renamed Kilometers.

Some industries might elect to remain temporarily non-metric for special reasons. In Britain, milk and beer are still sold in pints. The imperial pint is slightly more than 500 ml; merchants fear the reduction in business that would result if consumers continued to specify "three bottles of milk" even though the new bottles held slightly less. (In the United States, this would not be a problem. The American quart is slightly smaller than a litre; conversion to metric might *increase* business. American dairymen might well be eager to go metric.)

Who pays

The U.S. Metric Study has suggested that, as in Britain, the costs of metrication should "lie where they fall." The preliminary version of the Metric Conversion Act of 1971 suggests that the government might provide financial assistance in the form of loans to small businesses and accelerated depreciation allowances.

In fact, many of the costs of metrication could be written off as normal depreciation costs. Although some machinery would doubtless have to be replaced or altered as a direct result of metrication, much could be used until worn out, at which point it would be supplanted by a metric replacement.

The cost of some equipment changes would be minimal. Many nonmetric calibrated devices such as scales, pressure gauges, and meters could be used with conversion tables until they wore out—or they could be simply and economically converted by recalibrating a dial or an indicator face. A relatively inexpensive mechanical device that attaches to the feed screws can convert precision machine tools such as lathes and milling machines for metric use.

RCA would probably not be one of the industries most financially burdened by a program of metrication. Electrical units are the same in the metric and customary systems, and firmly established standards such as tube socket sizes and record diameters would certainly not change. Documentation on product lines is updated frequently; drawings and service notes could be redimensioned at that time. The major expense facing the company would probably be the expense of temporarily maintaining double inventories of replacement parts.

It is a paradox that electrical units are the same in metric and customary systems, yet European and American electrical and electronic consumer goods are not now interchangeable nor would they be if the U.S. went metric. Electricity in the U.S. is supplied at 110 V, 60 Hz, while in Europe it is generally 220 V, 50 Hz. Generating and distributing equipment is too expensive and widely interconnected for either continent to consider changing.

Conclusion

The U.S. will convert; if not soon, then eventually. Perhaps the best advice on a conversion program comes from Gorden Bowen,[12] Director of the U.K. Metrication Board:

> "The first characteristic is that it must be based on a practical and realistic appraisal of what is involved. There is a strong tendency to have a resort to wide and vague generalizations, to deal with other people's problems, to find obstacles in the alleged inactivity of others or in the difficulties which it is surmised are likely to be encountered. The first lesson is to concentrate energies in the area where you are both knowledgeable and able to take action. Leave other men to sort out their own problems offering advice when asked for and only on those topics which are related to your experience. It is too easy to say that this or that material will not be available, or that training will be an immense task or that consumers will never accept the change. In truth, the metric change is like other major innovations. It calls for detailed exploration and examination of the possibilities. It requires decisions on what changes to make and even more important, when and how to make them. Going metric imposes the same burden of judgment and decision on the management as any other innovatory phase.

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EASD drum memories

J. M. Chambers | G. Bircsak | J. K. Mathews

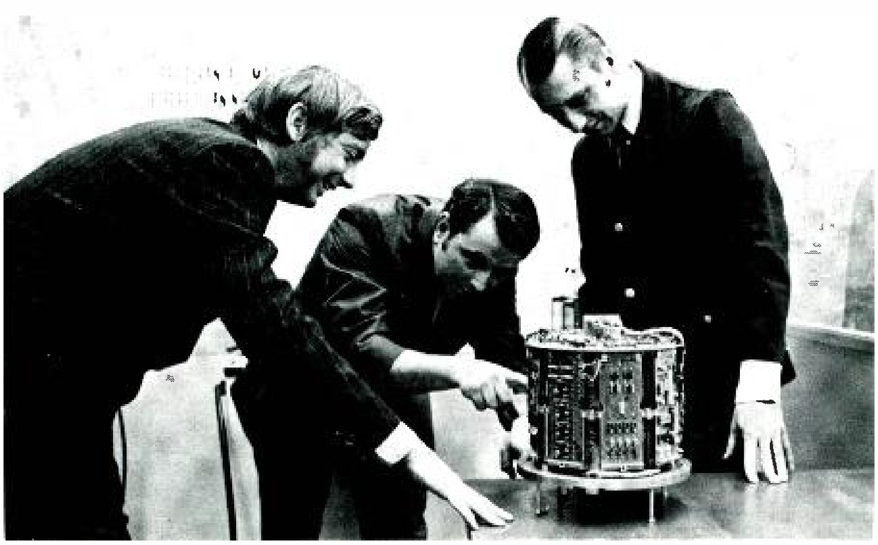
Although nonmechanical devices, such as semiconductor memories, show promise for future mass storage applications, drum memory systems presently occupy a unique position in the realm of high-capacity random access storage devices because of their lightweight rugged construction and small physical size. EASD has been in the forefront of advanced drum memory development, concentrating mainly on the needs of drum systems for tactical and airborne applications. However, EASD drum technology design techniques also have found use in non-military computer products.

J. M. Chambers, Mgr., Mass Memories, Electromagnetic and Aviation Systems Division, Van Nuys, California, received the BSEE from Rensselaer Polytechnic Institute in 1958 and the MSEE from the University of Pennsylvania in 1965. Mr. Chambers joined RCA in 1958 and has had several years' experience in circuit, logic, and system design, primarily in the field of digital computer main frames and their peripheral and real time I/O equipment. He has to his credit the logical design of a militarized mass memory system and was involved in the design of high-speed computer memories and transistorized high-speed logic circuits. More recently, he has had responsibility for several drum memory system developments for programs such as the Saturn Checkout Computer, the TACFIRE fire control system, the MPDS shipboard drum system, and the S-3A antisubmarine warfare aircraft. Each of these has been a state-of-the-art development program involving ruggedized drum and electronics equipment. He is a member of Tau Beta Pi, Sigma Pi Sigma, and the IEEE.

G. S. Bircsak, Electromagnetic and Aviation Systems Division, Van Nuys, California, received the BS in physics from San Fernando Valley State College in 1966. Mr. Bircsak joined RCA in 1967 and has been engaged in applied research and development. He has developed mathematical models of one-, two-, and four-track drum recording heads; designed and tested heads to prove concepts from these mathematical models concerning reading and recording crosstalk problems; designed several new head structures; and developed methods to test the flying and electrical characteristics of these new head structures. He has developed test methods for investigating the electrical properties of recording surfaces the wear problems with recording surface protective over-coatings, and the drag friction variation between heads and the recording surface protective overcoatings. Also, he has designed two speed-controlled DC inverter drum motor drive systems and two speed-controlled AC drum motor drive systems. He has contributed to the Tacfire CSD, NELC, S-3A, and Minuteman drum programs. Mr. Bircsak is a member of the National Physics Honor Society: Sigma Pi Sigma

J. K. Mathews, Electromagnetic and Aviation Systems Division, Van Nuys, California, received the BSEE from New Mexico State University in 1964 and has completed all course work for the MSEE at the University of Miami. Mr. Mathews is currently the lead electrical engineer on the Minuteman bulk storage memory program. He joined RCA in 1966. His past experience includes leading the group responsible for the logic design and the development of the hybrid microelectronics circuits utilized in the S-3A drum memory. He also served as program director as well as lead electrical engineer on the TACFIRE drum memory system. Mr. Mathews is a member of Eta Kappa Nu and the IEEE

Authors Mathews, Chambers, and Bircsak (left to right).



Rotating drums have been used as auxiliary computer storage devices for many years. In their conventional form, information is recorded by stationary record/read heads on circumferential tracks on the surface of a rotating cylinder that is coated or plated with a magnetic material. Most drum memories are head-per-track devices, i.e., the heads do not move axially with respect to the drum; instead, each head is used for both recording and reading on a single track.

In spite of their conceptual simplicity, drums have historically been plagued by problems arising from fundamental shortcomings in their design such as:

1) Sensitivity to shock and vibration.
2) Sensitivity to temperature and humidity effects.
3) Limited bearing life.
4) Susceptibility of the recording surface and heads to damage.
5) Bulky and heavy mechanisms.

Most of these problems are aggravated by exposure to a military-type environment. Even with these difficulties, drum mechanisms are better suited to withstand the rigors of shock and vibration than other forms of electromechanical, random access mass storage devices such as discs or tape loops. Nonmechanical devices, such as plated wire or semiconductor memories, show promise for mass storage capability in the future. However, they are currently far too expensive to be competitive with drums for most applications. Thus, despite their problems, drums continue to be designed into new systems since they are the only devices with the access time, capacity, and mechanical characteristics that will meet the requirements of many applications.

EASD drum memory development

In 1966, after first-hand experience with many of these characteristic drum problems, the Electromagnetic and Aviation Systems Division (EASD) of G & CS, Van Nuys, Calif., recognized the need for a high-capacity, lightweight drum for use in tactical and airborne applications. This need, coupled with internal system requirements for drum memories, resulted in the decision to proceed with an initial feasibility design of a drum mechanism and its associated electronics. The initial project goals

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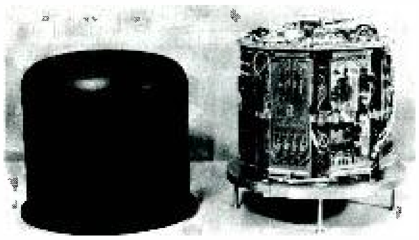

Fig. 1—EASD drum memory.

were to create a design which was rugged, small, lightweight, and which had a storage capacity in the 5- to 30-million-bit range. Later that year, the first models were built and subjected to mechanical vibrations, extreme temperatures, and thermal shock. In addition, accelerated life tests were performed by prolonged operation in a thermally cycled environment. The results of these tests demonstrated that the design was sound and had, in fact, exceeded the initial goals.

These first models used flying read/write heads designed and manufactured by an outside supplier. In 1967, EASD undertook the additional task of designing an improved head, since available head designs were not optimized for the EASD drum assembly and its environment. Extensive testing was performed on the EASD head which demonstrated read/write performance at high bit-packing-densities. In parallel with the head development in 1967, a more extensive environmental test program was completed. The drum, outfitted with heads and a simple read/write electronics system, was evaluated under thermal and mechanical shock, vibration, and temperature extremes, as well as under humidity, temperature, and altitude conditions, using MIL-STD-810 procedures. In the latter portion of 1967, a concentrated circuit design effort was undertaken to create a state-of-the-art read/write electronics package.

Early in 1968, EASD received its first contract for a drum system. This contract required development of a random access memory for the Army's Tacfire Program. At approximately the same time, an agreement was reached with RCA Computer Systems to supply drums for the RCA Spectra 70 product line. In early 1969, EASD won another military drum contract for a mass memory in the A-NEW Anti-Submarine Aircraft test bed system.

Subsequent drum contracts have included a shipboard unit supplied to the Navy for the Message Processing and Distribution System (MPDS); an airborne system for use in the S-3A ASW aircraft; and an ultra-high reliability ground-based system for Minuteman.

Drum mechanisms

The drums developed at EASD are deceptively simple in appearance. But they have been designed to achieve a rigid but lightweight structure which will withstand the rigors of the very severe environments that a military system experiences. The Tacfire drum (see Fig. 1) is a typical example of an EASD design. Fig. 2 shows the key components: cover, shroud, bearings, motor, rotor, and magnetic heads. All EASD drums share the same concept for the basic mechanism. They differ, however, in size, capacity, bearing configuration, and packaging arrangements for the electronics.

For military applications, the entire drum assembly (including the drum structure, magnetic heads, motor, and read/write and track selection electronics) is sealed within a hermetic cover which totally isolates the drum from the external environment. The unit is pressurized with an atmosphere of dry nitrogen which not only prevents the exchange of air between the external environment and the drum enclosure, but also contributes to long bearing life since no oxygen is present to adversely affect the bearing lubricant.

The 70/567 drum system supplied as a peripheral device with the RCA Spectra 70 computers is packaged differently. Since in this commercial application, the drum is not normally exposed to strenuous environments, it is supplied only with a dust cover for protection.

The shroud provides the main structural support for the recording heads and the rotating drum. The shroud is machined from an aluminum tube to form a lightweight rigid frame. Head mounting holes are cut in a helical pattern around the tube to maximize the strength of the remaining material while giving complete coverage of the recording surface by the magnetic heads.

Bearings

Because bearings can be the cause of many problems encountered in drum designs, they have been given considerable attention. EASD drums use conventional ball bearings readily available from many sources. The quantitative analyses involved in bearing engineering are highly empirical and the designer must depend heavily on his own experience and on the advice of the bearing manufacturer's applications engineering department. Bearing failure occurs when the balls or the raceways suffer fatigue, the lubrication fails, electrical discharges occur through the bearings, or the bearings are improperly aligned.

Since all metals are subject to fatigue

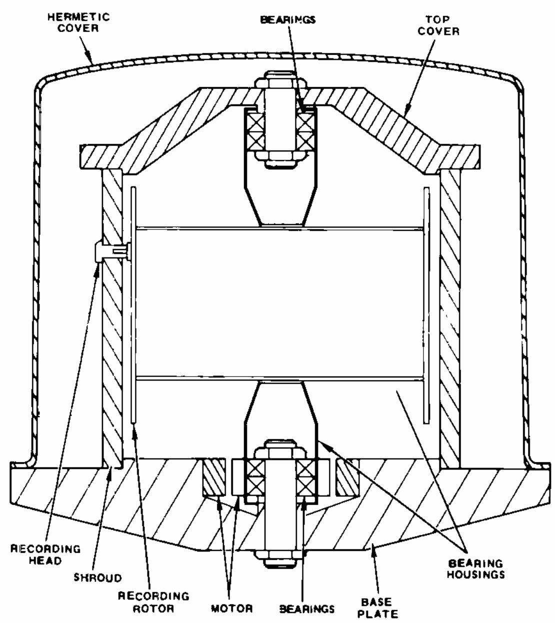

Fig. 2—Components of drum mechanism.

failure when exposed to a sufficient number of high-stress cycles, the EASD drum incorporates a sensitive accelerometer mounted on the base plate to sense acoustical noise or vibrations produced by the bearings. The noise level is a direct measure of bearing condition and by monitoring it periodically, bearing failures can be reliably predicted. By this method, the need for maintenance and the approach of end-of-life for the bearings can be anticipated, thus eliminating catastrophic bearing failures.

Brushes are mounted on the drum between the rotor and the top cover to prevent bearing pitting due to currents through the balls and race. Controlled-deflection, stress-relieving diaphragms on the ends of the rotor provide known preloads and minimize problems of misalignment.

Lubricant failures are not so simply solved. Many lubricants work at high temperature or low temperature, but not at both extremes. Some lubricants cold flow and others evaporate onto the surface of the rotor, degrading the flying characteristics of the record heads. By subjecting many bearings and lubricants to extreme temperatures and temperature cyclings, several lubricants have been found which work well under various environments.

Motor

An induction motor is used to drive the rotor. The stator is imbedded in the baseplate for effective heat dissipation. A steel shield around the motor protects the recording surface of the rotor from the motor's magnetic field.

Rotor

The surface of the lightweight rotor structure used in the EASD drum serves as the recording medium. In the military drums, the rotor weighs approximately 2 pounds exclusive of bearing housing and motor. The 70/567 drums are of a higher capacity and have a somewhat larger rotor structure. Conventional rotor structures are typically 10 to 20 times heavier for equivalent storage capacities.

The rotor is a fabricated assembly consisting of an outer shell cut from an aluminum tube with tapered diaphragms brazed into each end. Several important advantages result directly from the lightweight construction of the rotor: 1) the low mass greatly reduces bearing loads, particularly in severe shock or vibration environments; 2) the thermal inertia of the rotor is low with respect to that of the shroud; this allows the rotor to track shroud temperature variations, which reduces recording track misregistration due to the effects of differential thermal growth; 3) the motor power required to bring the rotating assembly rapidly up to speed is greatly reduced, permitting the use of motors with highly optimized running efficiency; and 4) because the flying heads do not contact the surface during normal operation but glide along in contact with the surface during starting and stopping, the low inertia of the lightweight rotor significantly lowers the head dragging time (approximately 2 seconds on start, 15 seconds on stop), thus reducing head wear.

In addition, the recording surface of the aluminum rotor is plated with a relatively thick layer of pure copper. This produces a soft and easily machined surface which is superfinished to a highly controlled surface. The cobalt alloy which constitutes the magnetic storage medium is plated on this surface to a thickness of about 30 microinches. The cobalt is in turn plated with an overcoating to produce a durable protective surface.

Heads

The recording heads are mounted in slots arranged in a single continuous helix around the shroud. These slots are precisely located so that head replacement is simple and straightforward. Should a head replacement be required, only a single circumferential adjustment need be made.

The recording heads are of a unique design but use a proven concept. This "flying" type head has evolved over a period of years for drum and disc applications. The advantages of the flying head are obvious and well known. During normal operation, they do not contact the moving surface; therefore, they are not subject to wear. Since they fly above the moving surface at heights of approximately 100 microinches and are sprung lightly on compliant suspensions, the heads are able to track many times the radial run-out of the rotating recording medium.

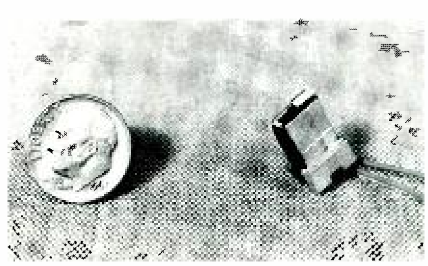

Fig. 3—Recording head used in drum assembly.

The head used in the EASD drum assembly is shown in Fig. 3. The magnetic circuit consists of a two-piece ferrite core which is assembled with a thin spacer between the pole faces to form the recording gap. A number of turns of fine, bifilar magnet wire are wound on the core. The core, pad, springs, support bar, and housing are precisely aligned in a fixture and all joints are cemented with an epoxy resin. The thermal expansion coefficients of the core and pad are compatible to minimize the possibility of the delicate core being cracked by thermal stresses. Thin beryllium copper strips serve both as the pad suspension springs and as electrical conductors for the head signals. The pad and support bar are ceramic. Slots in the ceramic are the anchor points for the springs. Thus the ceramic parts act as both insulators and structural members.

The spring structure is designed to be compliant in one dimension (radially with respect to the rotor) and to be torsionally rigid in all axes. The springs form a parallelogram structure which provides excellent tracking over the drum surface. The flying characteristics in terms of altitude and stability are determined by the size and shape of the pad, the compliance of the springs, and the surface speed. The pads are lapped to a fine finish with the gap line flush with the surface.

Electronics

The drum electronics are enclosed within the drum's external cover. They include the track selection circuitry, the read amplifiers for both clock and data, and the write amplifiers. Because of this arrangment, all of the interconnections involving low-level read signals are confined to a small area, resulting in an electronic system which is very insensitive to externally generated noise. Also, since the entire drum is sealed in an inert atmosphere, the effects of humid-

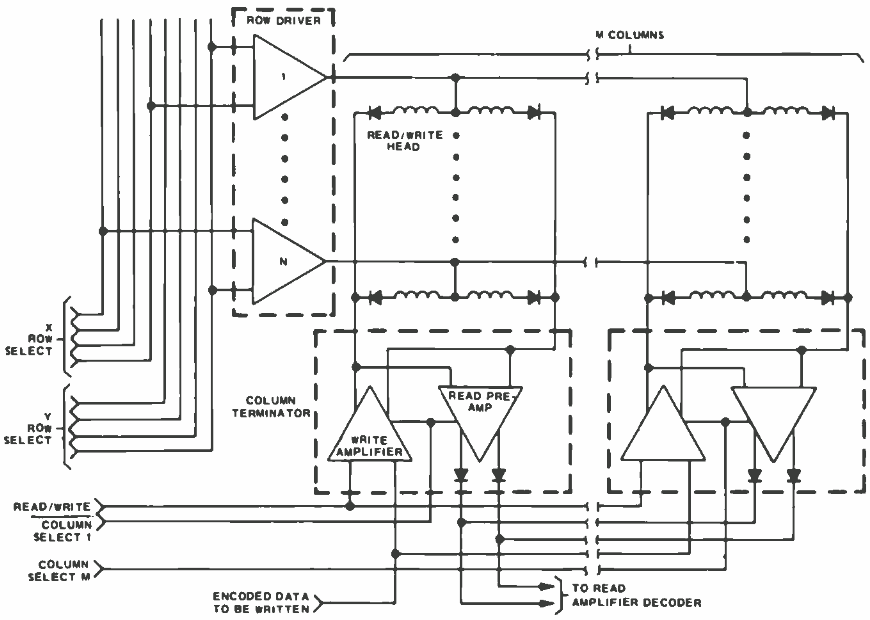

Fig. 4—Drum electronics.

ity, corrosion, sand, and dirt on the circuitry are avoided. Another feature is the completely digital interface to the drum unit. All signals to and from the drums are compatible with TTL and DTL integrated circuit logic for the military drums and with emitter-coupled logic for the 70/567 drum.

The drum electronics are packaged on plug-in printed circuit cards for easy maintenance. Most of the interconnections between the circuits are provided by a printed circuit platter. This technique provides trouble-free interconnections as opposed to the bulky and cumbersome method of relying on conventional handwired drum mechanisms. If and when maintenance is required, all components (including the read/write heads) are easily replaceable by plug-in means.

Fig. 4 shows a simplified diagram of the drum electronics. The read/write heads are arranged in a matrix. The dimensions of the matrix may vary to provide up to 800 heads. To select a particular track, the appropriate row driver and column terminator must be activated. A row is activated by energizing one of a group of X-lines and one of a group of Y-lines in a row-select submatrix. The appropriate row driver applies zero volts to the center tap of each head in its row. The other row drivers, none of which is activated, all apply a negative voltage to the center taps of the remaining heads. When the read/write line commands a write operation, the selected column terminator acts as the write amplifier. One of M-select signals activates a column terminator (or write amplifier) which provides encoded current pulses from the write data lines. This encoded information specifies whether the write current pulse is to be routed through the right or left half of the specified head. The current pulses are routed to only the read/write head of the selected column which has its center tap at zero volts. When the read/write line commands a read operation, no current pulses are generated.

The column driver also includes a read preamplifier circuit. The preamplifier monitors the output of that head in its column which has its row selected. The outputs of all the read preamplifiers are bussed together through a secondary diode matrix to the post amplifier. Reading from a specified head is achieved by activating the appropriate column select line. This causes forward biasing of the secondary matrix diodes associated with that column terminator, while those of the remaining column drivers are reverse biased. Read data from the desired head is then routed to the post amplifier.

EASD drum systems

As indicated earlier, EASD has developed several drum systems since the original Tacfire contract in early 1968. Table I summarizes the pertinent characteristics of these systems.

The Tacfire, A-NEW, and MPDS systems are supplied as full computer peripherals including interface electronics and power supplies. The S-3A, Minuteman, and 70/567 units include less electronics; however, read/write, and track selection circuitry are supplied in all cases.

Future enhancements

Several aspects of the drum technology are being investigated for potential product line enhancement. The most significant of these is increasing the bit-packing-density by using a magnetic coating with somewhat different characteristics than the one used in the present drums. Initial investigations have indicated that a twofold improvement in the bit-packing-density is well within reason and greater improvements may be feasible.

Table I—EASD drum systems.

	System					
	Tacfire	A/NEW	MPDS	S-3A	Minuteman	70/567
Parameter						
Rotational speed (r/min)	3050	3400	2630	4800	2650	3450
No. of tracks	.92	256	256	378	256	800
Rotor diameter (in.)	6	6	6	6	6	8.4
Rotor length (in)	6	6	6	6	6	13.8
Density (bits/in)	1920	2000	2159	2158	2160	1720
Capacity	6.5×10^6	8×10^6	9×10^6	15×10^6	9×10^6	35×10^6
Data rate	2 MHz	2.3 MHz	2 MHz	3.2 MHz	1.9 MHz	2.6 MHz
No. of parallel channels to drum	1	2	1	28	1	1
Interface	Parallel byte (8 bits)	Parallel word (36 bits)	Parallel word (32 bits)	Serial (28 channels)	Serial (1 channel)	Serial (1 channel)
Application	Fire control	ASW	Communi-cations	ASW	Command and control	Commercial
User	Army	Navy	Navy	Navy	Air Force	RCA Spectra customers

Signal detection in digital magnetic recording stores

Dr. Allan A. Guida

The design of a circuit for detecting signals at the output of a digital magnetic recording system can be regarded as a problem in communication theory. The required circuit is a receiver whose parameters are determined by the parameters of the magnetic recording system and the modulation or encoding scheme used to write the data on the magnetic medium. The goodness of a particular set of design parameters is measured in terms of the associated bit error rate achieved by the system. In a realistic case, the receiver will be a simple one with only a small number of components. For purposes of comparison, a more complicated receiver, known as the ideal receiver, will also be considered. The performance of this receiver, in terms of bit error rate, cannot be exceeded.

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received the BEE from the City College of New York in 1957 and the MEE and PhD from the Polytechnic Institute of Brooklyn in 1961 and 1968, respectively. He was employed by ITT Laboratories from 1957 to 1965 where he worked on various problems related to circuit design, underwater testing, satellite communications, FM systems design, digital data transmission and antenna design. He came to RCA Astro-Electronics Division in 1967 and worked on the design of satellite communications systems. In 1968, he transferred to RCA Laboratories where he has worked on the design of avalanche diode oscillators, temperature stabilized cavities, and digital magnetic recording systems. As a result of his efforts in the latter area, he received an Outstanding Achievement Award in 1971. He has published articles on such topics as directional couplers, delay modulation, spectrum analyzers and maximum likelihood estimation.

PLACING digital information (binary data) on a magnetic medium begins with a conversion of the data to an appropriate current waveform by means of an encoder. Fig. 1 shows the outputs of three possible encoders,[1] given a sequence of binary data. The encoder output is then used to drive a *write* coil which is placed near the moving magnetic medium. The magnetic field of the write coil induces a magnetization pattern on the magnetic surface and the data is *stored*.

When the moving magnetic medium passes under a *read* coil, the magnetic field of the medium induces a voltage in the coil; this is the output signal which must be operated on to obtain the stored data. Note that the read coil can only detect changes in the magnetic field, not the field itself because the induced voltage is proportional to the time derivative of the magnetic field (a Hall effect device would be required to detect the actual field strength). Hence, the output of the read coil consists of a series of pulses corresponding to the transitions in the waveforms of Fig. 1.

Magnetic storage system model

From the above description of the basic operations of a magnetic storage system, one can draw the simplified model shown in Fig. 2. Actually, this is only a linearized model since the true system is nonlinear due to hysteresis and saturation effects in the magnetic medium. However, it has been found that this model gives results that are reasonably close to those obtained from an actual magnetic storage system.

The transfer function $H(\omega)$ with im-

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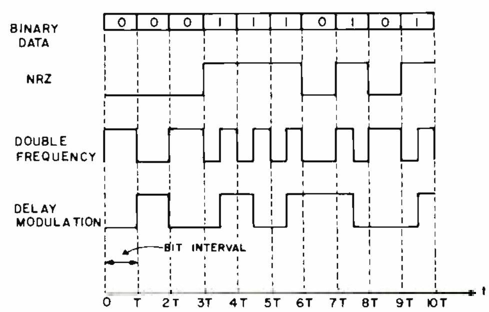

Fig. 1—Waveforms for various methods of encoding binary data.

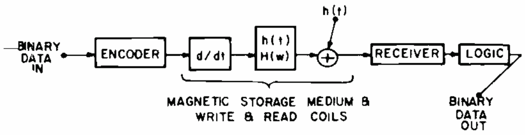

Fig. 2—Simplified model of a magnetic storage system.

pulse response $h(t)$ is given by[2]

$$H(\omega)=(\pi a/2)\exp(-a|\omega|/2) \qquad (1)$$

and

$$h(t)=[1+(2t/a)^2]^{-1} \qquad (2)$$

where a is the width of the pulse $h(t)$ when its amplitude is ½ of its peak value.

Although noise was not mentioned in the introductory description of the system, the noise present in the amplifiers at the output of the read coil is essentially white and Gaussian distributed. Often, it is the strongest of the noise sources. In addition, there is magnetic surface noise which is picked up by the read coil. The exact nature of this noise is not completely understood. A third type of "noise" is the remaining signal due to incomplete erasure of the previous signals stored in the magnetic medium. Since this noise is usually small and amplitude limited, it is not as serious as the two other noise sources. A fourth type of noise is environmental noise produced by nearby electrical equipment. It consists of infrequent short-duration spikes which are often large enough to cause an error. This noise and its associated errors will not be considered here. The first three noise sources noted are lumped together in $n(t)$ which is then assumed to be white and Gaussian.

The purpose of the receiver shown in Fig. 2 is to provide a good estimate of the original encoder signal using the output of the magnetic storage medium. This receiver will be considered in detail later.

Finally, from an estimate of the encoder signal, one can use logic circuitry to determine the original binary data. The details can be worked out from the relationship between the encoder waveforms and the input binary data.

Signal-to-noise ratio

To relate the operation of an actual system to the model, a convenient definition of signal-to-noise ratio (SNR) must be selected which will be applicable to both situations. Consequently, the following arbitrary definition was chosen:

$$SNR=\frac{\left(\begin{array}{c}\textit{Peak voltage of}\\ \textit{an individual isolated}\\ \textit{output pulse}\end{array}\right)^2}{\left(\begin{array}{c}\textit{Mean-square noise voltage at}\\ \textit{the output of an ideal low-pass}\\ \textit{filter with bandwidth equal}\\ \textit{to the bit rate } (1/T)\end{array}\right)}$$

Ideal receiver

If there were no limitations on the complexity of the receiver in Fig. 2, then one would want to use the optimum or ideal receiver[3, 4] to obtain the absolute minimum probability of bit error for the magnetic storage system. This receiver decodes received analog waveforms by comparing the received waveform with a stored table of all possible waveforms. The waveform in the table which is closest to the received waveform (based on a squared error criterion) is selected as the transmitted waveform.

Unfortunately, the number of possible waveforms is infinite and, therefore, the receiver would be infinite in size and impossible to construct. Nonetheless, the ideal receiver concept is useful in that it provides a basis for comparison with simple receivers. Using the concepts above, a lower bound can be derived for the probability of bit error of an ideal receiver depending on the type of encoder used. For delay modulation encoding, it can be shown that the probability of bit error is given by

$$PBE_{DM} > Q\left\{\sqrt{\frac{\pi a\, SNR}{4T[1+(2a/T)^2]}}\right\}$$

For double frequency, the corresponding equation is

$$QBE_{DF} > Q\left\{\sqrt{\frac{3\pi a\, SNR}{4T[1+(2a/T)^2][1+(a/T)^2]}}\right\}$$

where

$$Q(z)=\frac{1}{\sqrt{2\pi}}\int_z^{\infty}\exp(-z^2/2)dz$$

These bounds are plotted in Figs. 3 and 4.

Simple receiver

A simple receiver for the magnetic recording system of Fig. 2 would consist

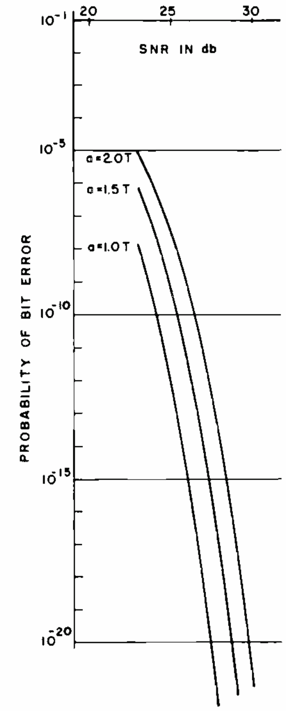

Fig. 3—Probability of bit error in an ideal receiver with delay modulation encoding; a=pulse width.

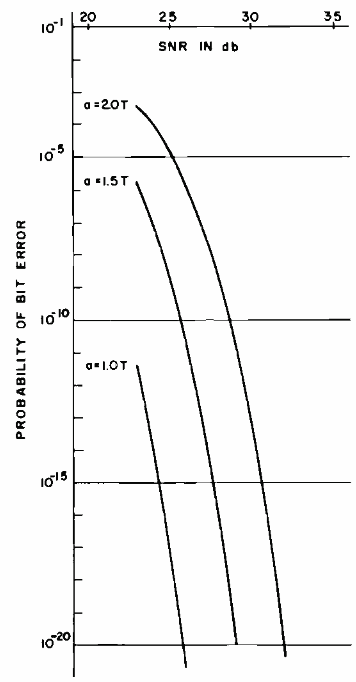

Fig. 4—Probability of bit error in an ideal receiver with double frequency encoding; a=pulse width.

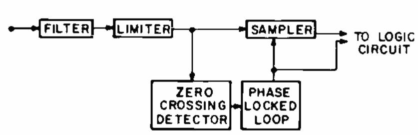

Fig. 5—Simple receiver.

of a filter, a limiter, a sampler, a zero-crossing detector and a phase-locked loop. Fig. 5 shows a typical simple receiver for a magnetic storage system.

The filter is designed to restore the signal to the original shape as well as possible, subject to the condition that the noise shall not be excessive. It can be shown that if the noise condition is ignored, the signal can be restored quite well but the noise power is unacceptably high. This is particularly true at wide pulse widths (large a). Consequently, a good design approach for the filter is to vary the filter parameters to maximize the minimum signal voltage at the filter output while holding the associated noise power at a fixed value. This guarantees that if the instantaneous noise voltage at the sampling time is less than the minimum signal voltage, no error will occur.

For the simple receiver described here, the optimum form of the filter has been determined[5, 6]. It consists of a matched filter (matched to $h(t)$) followed by an infinite tapped delay line (*TDL*) with taps spaced by $T/2$. The output of each tap is modified by a potentiometer and summed in a summing amplifier. In a realistic case, only a finite number of taps are needed since the tap gains usually fall off rapidly for taps far from the center tap of the *TDL*.

The matched filter is not always the "best" filter to use in a simple receiver if the word best means economical or practical.[7] The matched filter, although very effective in reducing the noise, doubles the pulse width at its output, so that a longer *TDL* is needed to equalize the signal. Consequently, for wide pulses, a rectangular low-pass filter (*RLPF*) (or a reasonable approximation to it) of bandwidth $1/T$ is more practical. While some signal information is completely removed by this filter, the amount lost is very small since a wide pulse corresponds to a narrow-bandwidth signal. Furthermore, the pulse shape and pulse width are nominally unchanged by the rectangular *LPF*.

Once the signal has passed through the limiter, the zero crossings are sharply defined and can be used to phase lock a voltage-controlled oscillator. This occurs in the phase locked loop which is given a narrow bandwidth so that the locations of many successive zero crossings are "averaged" to determine the phase of the oscillator. This lowers the sensitivity of the loop to zero-crossing variations caused by various data sequences as well as the noise.

Note that if *NRZ* encoding were used, long sequences of zero's and one's would produce no transitions or pulses in the output signal. Hence, timing could not be derived from the signal. Consequently, *NRZ* is not acceptable as an encoding scheme; *DM* and *DF*, on the other hand have frequent zero crossings regardless of the binary data sequence.

The timing information of the phase-locked loop is used to control the sampler, which samples the limiter output at $T/4$ and $3T/4$ in each bit period. From the waveforms in Fig. 1, it should be clear that (for *DM* and *DF* encoding) if the $T/4$ and $3T/4$ samples are the same (different), the binary bit is a 0(1). From this information, one can easily design the required logic network.

Probability of bit error for a simple receiver

For the case of a simple receiver in which the filter consists of rectangular low-pass filter and a tapped delay line, the equations for the bit error rate cannot be obtained in closed form. However, a computer simulation of this receiver can be used to obtain the desired data. Figs. 6 and 7 give the results of these computer simulations.

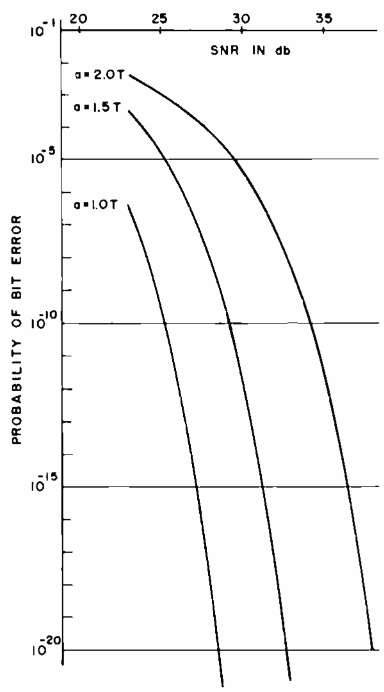

Fig. 6—Probability of bit error in a simple receiver (1 tapped delay line with 10 taps and a rectangular low-pass filter) with delay modulation encoding; a =pulse width.

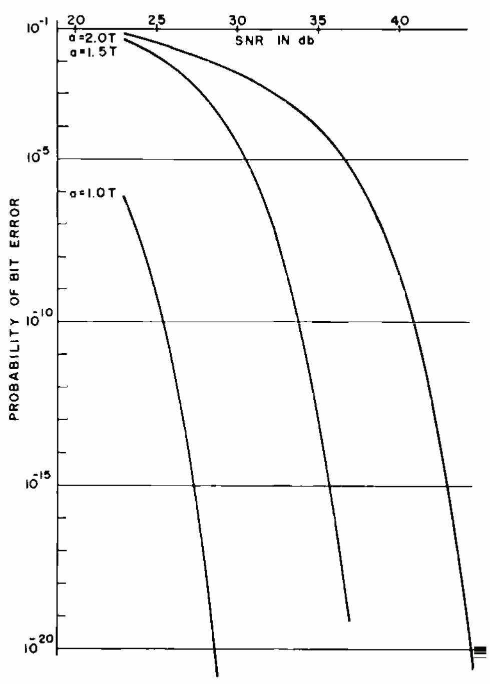

Fig. 7—Probability of bit error in a simple receiver (1 tapped delay line with 9 taps and a rectangular low-pass filter) with double frequency encoding; a =pulse width.

Conclusions

A method of signal detection used in magnetic recording stores has been described. The results of a computer simulation show how this signal detection scheme compares to an ideal receiver in terms of bit-error rate *vs* signal-to-noise ratio.

Acknowledgment

The author is indebted to Dr. Rabah Shahbender for giving him the opportunity to do the research work that led to this paper.

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Digital disk memories

Dr. R. Shahbender | Dr. J. G. Woodward

The performance of a computer system is determined, in part, by the characteristics of the on-line storage devices. The disk memory provides high capacity, inexpensive storage but is subject to certain physical characteristics that limit its speed. The enhancement of these characteristics is the subject of this paper.

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Authors Woodward (left) and Shahbender.

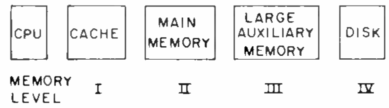

Fig. 1—On-line memory hierarchy.

For maximum efficiency in a high performance electronic computer, the on-line memory system must have high speed and large capacity. Physical hardware limitations have, to date, resulted in memories that are either high-speed and low-capacity, or large-capacity and low-speed. To obtain the desired store characteristics, systems architects employ a hierarchy of memories as shown in Fig. 1. By proper management of this hierarchy, through hardware and software design, the efficiency of the computer system is maximized at minimum cost.

Table I lists typical characteristics for the members of the hierarchy as presently available. Level IV is the replaceable disk system, the subject of this paper. Table II lists the evolutionary trend in characteristics of this type of memory, starting with the RCA 564 system. The RCA 594 was next—to be followed by the RCA 8580 which was being developed at Princeton and Marlboro.*

Disk unit

The disk unit consists of a motor-driven spindle carrying a replaceable disk pack as shown in Fig. 2. The disk surfaces in the pack are coated with a magnetic layer as described in the companion paper by E. F. Hockings.[1] A recording head in a slider pad is suspended (flown) over each disk surface. The separation between the recording gap and the disk surface is maintained constant aerodynamically as discussed in the companion paper by G. Briggs and P. Herkart.[2] The recording heads are attached to an actuator that positions them in a radial direction to randomly select a track on command from the computer.

Binary data are stored by recording concentric tracks on the surface of each disk. Normally, one recording head is accessed by the electronic circuitry for reading or writing. The write circuitry accepts digital information in serial form and converts it into a current waveform that is used to energize the recording head. This current waveform establishes a magnetization pattern in the magnetic surface (saturation

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*This paper was written before RCA announced withdrawal from the general-purpose computer field; therefore, the programs described represent the research and development goals at that time. The material is being published here because of its relevance to other RCA work.

magnetization recording is exclusively utilized in digital disk systems).

For readout, the signal generated in one of the heads is selected, amplified, and processed to recover the recorded data as discussed in the companion paper by A. Guida.[3]

In a replaceable disk memory, timing tracks are not provided. It is essential that the binary data be coded in a scheme that allows self-timing extraction. Two such schemes are in use, *viz.* DF or double-frequency and DM or delay-modulation (for description, see Reference 3). In the case of DF coding, the minimum separation between magnetization transitions is equal to half a bit period; whereas for DM coding, the minimum separation is equal to one bit period.

In reproducing a recorded waveform, each magnetization transition produces a pulse whose time width at the 50% amplitude points, PW_{50}, is:[4]

$$PW_{50}=2/V\sqrt{[d+(t/2)+a]^2+[g/2]^2}$$

where V is the linear velocity between head and recording medium;
- d is the separation between head and surface of recording medium;
- t is the thickness of recording medium;
- g is the gap length of recording head;
- $a = B_r t/2\pi H_c$, which is the demagnetization parameter;
- B_r is the remanent flux density in recording medium; and
- H_c is the coercivity of recording medium.

As the bit period is reduced (corresponding to higher linear density), the pulses from adjacent transitions (necessarily of opposite polarity) interact with one another to produce pulse crowding with resultant errors in retrieving the stored information. The PW_{50} may be decreased by reducing the parameters in the above expression. The separation between the head and the surface of the recording medium may be reduced to approximately 10 microinches—corresponding to contact recording, while the thickness of the recording medium may be reduced to approximately the same value by utilizing metallic films. Under these conditions, the dominating factors are the demagnetization parameter a and the gap length g. By raising the coercivitv of the recording medium, the demagnetization parameter may be reduced. A higher writing field is now required from the recording head. This can only be accomplished by maintaining the gap length at a relatively large value to avoid saturating the magnetic material of the recording head. Thus, a compromise is usually sought in terms of coercivity of the recording medium and gap length.

Track density is limited by the fringing field of the recording head (the actual track written on the recording medium is slightly wider than the recording head because of the fringing field) and by signal-to-noise ratio. For a given head configuration, the signal is halved every time the recording head width is reduced by a factor of 2, whereas the magnetic surface noise is reduced by a factor of $\sqrt{2}$ for the same reduction in core width. Thus, the signal-to-noise ratio deteriorates as the track width is made narrower. Additionally, in a replaceable disk system, mechanical tolerances determine the actual track that is recorded on a given surface. To compensate for these mechanical tolerances

Table I—Typical characteristics for memory devices in an on-line hierarchy.

Hierarchy member	Capacity *(bytes)*	Performance (cycle time or *latency time)*	Relative *bit cost*
I Cache	10^4	0.05 to 0.1 μs	10
II Main memory	10^5 to 10^6	0.5 to 1.0 μs	1
III Large auxiliary memory			
Large core store	10^6 to 10^7	4 to 8 μs	10^{-1}
Head/track drum	10^6 to 10^7	8 ms	10^{-2}
IV Digital Disk	10^7 to 10^9	30 to 90 ms	10^{-3} to 10^{-4}

Table II—Evolutionary characteristics of RCA disk files.

Equipment model designation	564	594	8580*	Next generation file**
Bits/inch (along track)	1100	2200	4400	8800
Tracks/inch	100	100	200	400
r/min	2400	2400	3600	4800
Average seek time (ms)	75	60	30	10
Number of recording surfaces in a pack	10	20	20	20
Megabits/square inch of recording surface	0.11	0.22	0.88	3.52
Bit capacity/spindle	6.25×10^7	2.5×10^8	10^9	4×10^9
Data rate megabits/s	1.25	2.5	7.5	20

*Tentative equipment operating characteristics
**R & D goals

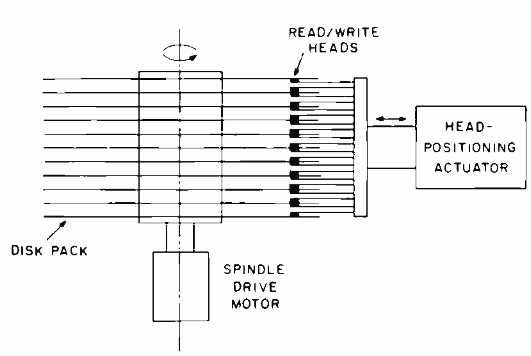

Fig. 2—Diagramatic representation of a disk memory unit.

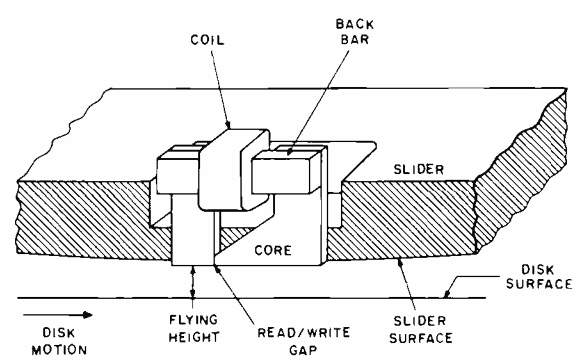

Fig. 3—Cutaway view of slider showing head configuration (flying height not shown to scale).

and allow the use of replaceable disk packs, a closed-loop servo system, as described later, was developed for the 8580 Disk File. Still more sophisticated servo systems will be needed for files having track densities beyond that of the 8580.

Heads and sliders

In the 8580 file, the same head is used for writing and reading. The electrical, magnetic, and mechanical properties of the head all play a role in determining the data pulses in readout. The magnetic portion of the head is a small U-shaped ferrite core 0.004-inch thick with a nonmagnetic gap 100 microinches long at the bottom of the U, as shown in Fig. 3. The head (gap) flies 60 to 70 microinches above the surface of the disk. The magnetic path around the core is closed by a ferrite back bar (placed across the legs of the U) while carrying a coil for writing and reading. For efficient head performance, the ferrite must have a high magnetic permeability and low losses in the frequency range of operation, which is to 7.5 MHz in the 8580 system. Typically, the initial permeability is 1500 up to 1 MHz, dropping to 450 at 7.5 MHz. The saturation flux density (B_s) of 3200 gauss is high enough to avoid saturation of the core in the vicinity of the gap for normal values of write current. The ferrite must be extremely dense, i.e., be free of pores, and must have mechanical properties to permit fabrication of cores by grinding and lapping without chipping or pull-out of grains. These characteristics are particularly critical for producing the required precise and well-defined nonmagnetic gap.

The electrical impedance at the head terminals must be a compromise between several requirements. The coil inductance must be low enough to allow fast-risetime current pulses during writing without exceeding the voltage capability of transistors. This restricts the number of turns that can be wound on the coil. On the other hand, more turns on the coil obtain signals well above the noise level of the readout amplifier. Additionally, it is necessary to insure that the coil inductance in series with the capacitance of the connecting cable and the amplifier input stage resonates at a frequency well above the highest signal frequency. These constraints can be made more or less stringent, depending on the signal coding and detection schemes used.

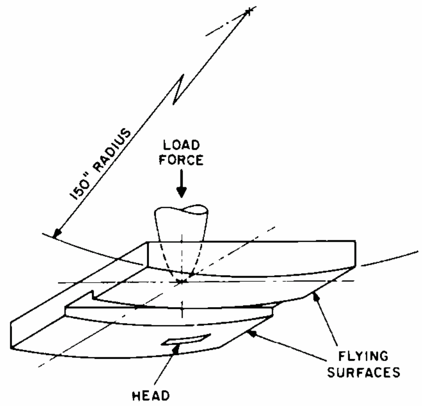

Fig. 4—Catamaran flying slider for 8580 disk file.

The importance of maintaining a close and constant spacing between the head and the disk has already been pointed out. The 50 to 60 microinch flying height for the 8580 file is a compromise between the ideal of narrow pulses with a high signal-to-noise ratio and the practical limitations of flatness and surface finish of disks. The flying height is determined by the size and shape of the slider that carries the head, by the load force pushing the slider toward the disk, and by the linear speed of the disk moving past the slider. Because of this last factor, the flying height becomes less as the head is moved from outer to inner tracks on the disk. This decrease in flying height partially compensates for the increased packing density of bits on the inner tracks. Load forces in the vicinity of 400 grams have been found to be convenient in terms of the stability and reproducibility of the mechanical members that support the slider and through which the force is applied.

A slider (Fig. 4) meeting the necessary conditions for the 8580 file consists of a rectangular ceramic block having principal surface dimensions of 0.350×0.420 inch. This surface is divided into two pads 0.125×0.350 inch separated by a 0.100-inch recess to form a catamaran structure. The two pads provide the aerodynamic lift. Their surfaces are lapped into a cylindrical profile having a radius of approximately 150 inches about an axis parallel to the disk surface and perpendicular to the linear track motion under the slider. The head core is mounted in a slot near the inner edge of one of the pads, somewhat behind the center of the slider so the gap will be at the point closest to the disk when the slider flies in its normal attitude.

With the slider loaded and flying, it must have freedom of motion in a vertical direction to follow runout of the disk, and freedom about both pitch and roll axes to accommodate itself to residual waviness of the disk surface. These conditions are met by applying the load force to a single pivot point and mounting the slider in a spring gimbal. These supporting elements are structured so that their stiffness, in conjunction with the moving mass or rotational inertia of the slider, will place their natural resonances at frequencies well above any frequencies that will be excited by the irregularities encountered on normal disks.

Mechanical considerations

With track widths of 0.005 inch, bit lengths along a track of 250 microinches, and a flying height of 50 to 60 microinches (8580 file), the need for extremely high precision in the mechanical elements can be appreciated. The vertical run-out and the waviness of the disk are the forcing functions that disturb the slider from its equilibrium flying height. The dimensions and the dynamic response of the slider require that tolerance limits be set on the disk surface, for vertical displacement of the surface from its mean position, and for the curvature of surface waviness. The curvature is frequently stated in terms of the acceleration of the disk surface passing beneath a fixed point. Typical upper limits for displacement and acceleration for the 8580 file are 0.0015 inch total indicated runout and 2000 in./s², respectively, for single disks. The limits are relaxed to 0.0025 inch and 2500 in./s² to allow for additional flexure that may occur when the disk is clamped in a disk pack. To meet and hold these flatness tolerances, the substrate of the recording disks is made of a carefully selected and processed aluminum alloy, and the substrate thickness has been increased from the 0.050 inch used in earlier disk files to 0.075 inch. The increased substrate thickness also increases the frequencies of the vibrational resonances of the disks, keeping them above the range in which they may be excited by the disk rotational frequency or its harmonics. When vibrations due to disk resonances or pack unbalance occur, they produce serious fluctuations in the data signals and, in some instances, lead to catastrophic crashing of the heads on the disk surfaces. Vibrations of the disk pack must be avoided. This is accomplished by precisely balancing the pack about two axes.

Space does not permit more than a partial listing of the mechanical elements for which imprecise dimensioning will lead to an improper alignment of a head over a recorded track. It must be remembered that the disk packs are transferable, so that data recorded by one machine may be read out on another. Hence, the case must be considered wherein the mechanical tolerances lead to dimensional errors in opposite extremes in different machines. Following are the most obvious and serious causes of head/track misalignment.

1) *Eccentric tracks.* Eccentricity of recorded tracks is caused by runout of the disk-drive spindle and by variability in the seating of the disk pack on the spindle. Seating of the pack is a much greater contributor to eccentricity than is spindle runout. Track eccentricities may be as great as ±0.0015 inch in the absence of compensation. Eccentricity compensation (track following) will be discussed below.
2) *Tolerances in the initial positioning adjustment of a head in its support.* Variability in the initial adjustment of the head can produce alignment errors of about ±0.0002 inch.
3) *Tolerances and variability in head positioning.* The head is moved from track to track as necessary and is held on the desired data track by an "actuator." Lack of reproducibility in the actuator's setting on successive positioning to the same track can produce alignment errors of about ±0.0003 inch.
4) *Differential thermal expansion.* The position of a head in relation to a disk involves a complex series of connecting mechanical elements including the head suspension, the actuator, the disk-file motor board, the spindle, the disk-pack hub, and the disk itself. These elements are made of stainless steel, steel, and various aluminum alloys so that changes in ambient temperature or in relative temperatures of different parts of the mechanical system will result in alignment errors of the head over a track. It is estimated that even in a controlled environment alignment errors of ±0.00005 inch will occur due to differential expansion.

The alignment errors just listed can cause a head to be misaligned by as much as a full track width in a worst case where data are recorded on one machine and read on another, without eccentricity compensation. Even in much less extreme cases, serious reductions in signal voltages and increases in crosstalk from adjacent tracks will occur. Clearly, this is an unacceptable situation. Since it is not feasible to provide significantly more stringent requirements on the precision of the individual mechanical elements, a track-following servo system is being incorporated in the 8580 disk file. The track-following servo greatly reduces the effects of eccentricity and also removes the effects of differential thermal expansion and of actuator variability. With track following, the correct head/track alignment can be maintained within ±0.0005 inch. To accomplish this, one of the twenty recording surfaces in each disk pack is dedicated to holding special, permanently-recorded signals on each track. These are read by a servo head, and the servo signals so generated control the actuator to keep the head accurately positioned over each desired track even if that track is eccentric. The same actuator determines the positions of all of the other nineteen heads so that if they were properly aligned initially they will follow their data tracks closely, under the control of the servo head.

Track following and counting

The servo head and the nineteen data heads are rigidly and precisely mounted on a carriage that forms part of the actuator. A circular, solenoid-type coil is also attached to the carriage. A large permanent magnet provides a magnetic field across the gap of an annular polepiece structure through which the coil can move. Current flowing through the coil interacts with this magnetic field to force the coil and carriage forward or backward, depending on the polarity of the current, thus transporting the heads across the disks to any desired track location. The actuator can be thought of as a reversible, linear motor. Once a desired track location has been reached, the current in the actuator coil is adjusted continuously under the control of signals from the track-servo head so as to follow any eccentricities in the track.

The time required to move the heads from one track to another depends on the distance between the tracks, the total mass being moved, the strength and the extent of the magnetic field cutting through the coil, and the magnitude of the current in the coil which, in turn, is limited by the capability of the current source and the permissible heating of the coil. Typical access times in the 8580 Disk File are 10 ms for a single-track move, 55 ms for a full 2-inch stroke, and 30 ms average for many strokes of varying lengths during normal operation. Added to this is the *latency:* the time required for the accessed track to rotate to the location of the desired data. On the average, this will be 8.4 ms for the 3600 r/min rotational rate.

It is not possible to give a detailed description of the track-following servo operation here, and an overly-simplified and qualitative discussion must suffice. Alternate tracks on the servo-disk surface carry different series of pulses distributed in time and polarity so as to permit their identification and detection in readout. As a result, when the servo head is reading an odd-numbered servo track, the output of the detector circuits is a negative voltage; when reading an even-numbered track, the output is positive. If the head is exactly midway between two tracks, equal signals are received from both tracks and the detector output voltage is zero. Displacements away from this neutral position produce voltages linearly related to the displacements and having polarities indicating the directions of the displacements. The voltages resulting from such displacements are amplified and converted to currents that are fed to the actuator to return the head to the neutral, zero-voltage position. The bandwidth and time constants of this servo loop must be adequate to allow the following of eccentric tracks, and the loop gain must be high enough to assure a tight lock-in of the system on the desired pair of servo tracks.

The data tracks on the other disk surfaces in the pack are centered on the neutral line between servo tracks. The 404 data tracks on each surface are numbered serially from the largest to the smallest diameter, and the track location of the servo head at all times is stored in a current address register (CAR). When the computer program calls for writing or reading data on another track, the number of the required track is stored in a demand address register (DAR). When the binary numbers in the DAR and the CAR are different, the actuator system is switched from track following to the accessing mode. Drive current is fed to the actuator in the polarity to accelerate the servo head toward the required track, and as the head crosses the servo tracks enroute, the signal polarity reversals are noted and used to continuously update the CAR. When the servo head is nearly half-way to its destination, the actuator current is re-

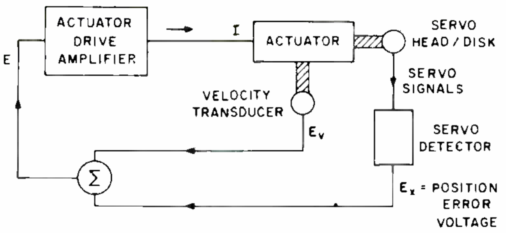

Fig. 5—Block diagram of track following servo system.

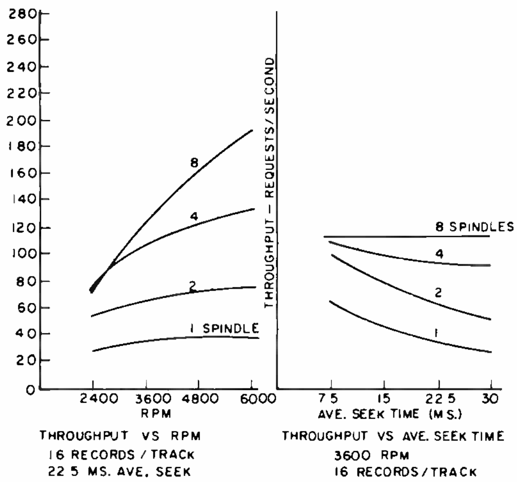

Fig. 6—Results of simulation study for disk file without rotational position sensing.

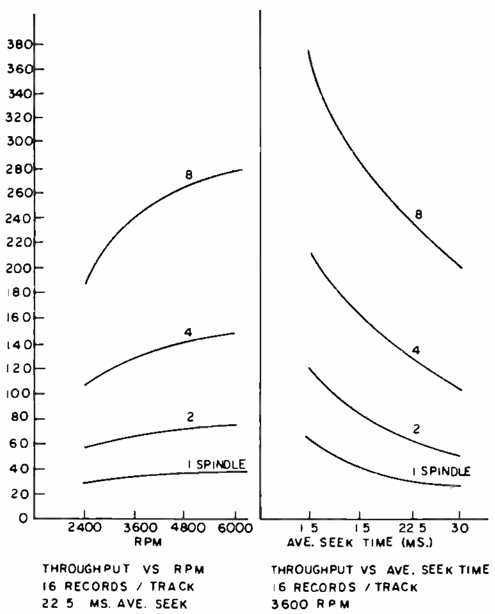

Fig. 7—Results of simulation study for disk file with rotational position sensing.

versed to decelerate the head for the remainder of the movement. When the head is within a few tracks of its destination, the current is adjusted as a function of time to permit a smooth approach to the requested track without overshoot or oscillation, and the track-following function is again activated.

Fig. 5 is a block diagram representing the servo loops involved in track following. The error signal contains both head position and velocity components that are summed.The position component is derived from the recorded servo tracks. The velocity component is derived from a separate transducer on the actuator. The velocity component plays a role during accessing, but is relatively unimportant during track-following, and the gain of the velocity loop may be reduced while the track-following function is in control. The same voltage polarity reversals that provide the position-error signals for track following are used for track counting during accessing. However, the time constants of the detector circuits must be shorter for counting than for following, and this change is made when switching from one mode to the other.

The track servo signals also are used for two other functions unrelated to head positioning. One is sector counting (also referred to as rotational position sensing). Each circular track is divided into 128 equal sectors. The track servo signal is recorded initially with an integral number of pulses per sector, with an index marker at the start of the track. During normal operation, the start-of-track index is sensed and used to reset a counter. Then the servo pulses, in conjunction with a phase-locked oscillator, are counted and used to identify the start of each sector. Each data record is identified with the sector in which it starts, and the sector address is used to permit more efficient seek operations when two or more spindles and packs are used in a disk-file system. The other non-mechanical function of the servo signals is as a clock while writing data, at which time the servo pulses control the rate at which data bits flow from a core memory or shift register into the disk file. By this means, the data flow is synchronized with the disk rotation, and problems associated with changes in the rotational speed are avoided.

Systems considerations—future developments

The performance of a computer system depends on many factors, including the characteristics of the storage devices, the degree of multiprogramming, and the efficiency of the operating system. The discussion thus far has concentrated on hardware developments to improve the performance characteristics of disk files. It is probably of greater importance to determine the improvements in the performance of a computer system that can be obtained as the performance characteristics of disk files are improved. A preliminary simulation study was undertaken to analyze the performance of a peripheral storage device as a function of the operating characteristics of that device. Specifically, the simulation analysis considered a disk file assumed to be in saturation. Maximum performance—measured in terms of throughput or requests per second serviced by the disk file were computed as a function of rpm, seek time, record length, presence or absence of rotation position sensing, and the number of spindles on line. Some of the data obtained from this simulation analysis are shown in Figs. 6 and 7.

Obviously, this type of analysis is limited in its utility since the model assumes saturation and records of constant length, and in general is extremely oversimplified. A more detailed study to determine the interaction between the peripheral storage device characteristics and system throughput for various architectural designs is essential to guide future enhancements of disk files. Tentative R & D goals for the next generation of equipment were established; these are given in the last column of Table II.

Acknowledgments

The authors would like to acknowledge the help they received from their colleagues at both the Princeton and Marlboro Laboratories. The results shown in Figs. 6 and 7 are abstracted from the work of H. Kurlansik.

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Advanced digital magnetic recording

G. V. Jacoby

The two most essential ingredients of a magnetic recording system are a magnetic medium, in which the information is stored, and a transducer (head). Both elements are in relative motion with respect to each other. Attention will be focused on the physical and spatial properties of these two main elements of the system. The subject of digital magnetic recording can also be approached from the standpoint of signal processing. This approach places emphasis on the handling of the digital information, which consists of the encoding, equalization, timing, and decoding functions. The signal processing aspects of digital magnetic recording are not a subject of this article.

Analog recording, as used in audio, video, or instrumentation purposes, is concerned with the faithful reproduction of continuous signals; the information may be in the form of amplitude, frequency, or pulse duration modulation. In digital recording, the information is not continuous; rather it consists of discrete information states called binary bits. Each single bit carries a piece of information by itself which is independent of the others. The loss of a single bit produces an error. For this reason, highly accurate performance is required of the digital recording system, since the reliable reproduction of each bit is equally important. This high reliability, or very low error rate, is the most important feature of modern digital magnetic recording systems. An additional feature is the long useful life of the storage medium. These two features explain the fact that the linear bit density in digital recording systems is considerably lower than the number of wavelengths per inch in contemporary video recording equipment.

Another basic difference between analog and digital recording is in the recording process. Analog recording uses high-frequency bias to produce a linear transfer from the information signal to the magnetization of the recording medium. In digital recording, the inherent binary nature of the magnetization process can be exploited. This is the saturation phenomenon, resulting in two well-defined states of magnetization of opposite polarity. Any pattern of magnetization changes can be composed of these discrete states. Digital recording, as it is applied in commercial equipment today, almost exclusively uses saturation recording. Thus, digital recording is definitely a nonlinear process in writing which makes the analytical treatment very difficult. The calculated results are only approximations and should always be submitted to experimental verification.

In storing digital information, three major objectives are to be realized: large data storage capacity, fast access, and long life. Large capacity usually requires close contact between the magnetic recording head and medium, while fast access and long life require fast relative motion between the head and the medium and no contact. It is seen that these requirements are definitely incompatible; therefore, a compromise based on good engineering judgement is needed.

Random-access devices

Large amounts of information at a relatively low cost can be stored on tape transports. Writing and reading of the bits of a character are done in parallel across the tape. This is very convenient from the standpoint of digital information handling; however, the information is accessed sequentially. One has to search through a whole reel for a particular piece of information, which may take minutes. Tape transports are obviously not suitable for fast accessing.

Development in data processing during the past decade has placed more emphasis on reducing the access time and on the ability to address specific locations of the storage area. This is called random accessing. Coupled with this requirement is the increased storage capacity. Thus, a whole family of random-access mass storage devices have developed which include drums, disc files (with various numbers and sizes of discs), and magnetic card equipment. Attention in the last few years has been focused sharply on disc files, which have gained wide acceptance throughout the industry. For this reason, the techniques particularly suitable for magnetic disc recording, will be discussed in somewhat more detail.

There are two types of disc files: fixed disc devices and interchangeable pack devices. Of the two, the more versatile and widely used device is the interchangeable pack disc file. Extreme versatility is assured by being able to write a disc pack on one machine and

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received the Dipl. Ing. degree in Electrical Engineering (MSEE) from the Technical University of Budapest, Hungary, in 1941. His experience in Europe included the development of photoelectric exposure control of cameras and other electro-optical devices. In the United States he worked with the Brown Instruments Division of Minneapolis Honeywell on the development of industrial instruments and process controllers. In 1958, he joined RCA and has worked in various phases of magnetic recording since then. In 1968, he conducted a course in advanced magnetic recording techniques. At present he is in charge of advanced development of large capacity, high density, fast accessing disc files for computers. He holds 13 U.S. and a number of foreign patents and is the author of several papers. He is a Senior Member of IEEE and past Chairman of various technical groups in the Philadelphia Chapter. He is a Registered Professional Engineer of Pennsylvania.

*Since this paper was written, Mr. Jacoby has left RCA.

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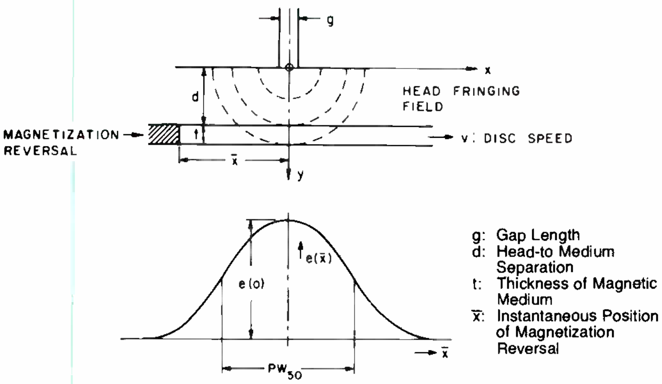

Fig. 1—Step response of an idealized head.

	DISC FILES		CARD EQUIPMENT	
	RCA 70/564 IBM-2311	RCA 70/594 IBM-2314	RCA 70/568 RACE	IBM 2321 DATA CELL
RECORDING DENSITY:	760 TO 1100 BITS/IN	1520 TO 2200 BITS/IN	1400 BITS/IN	1750 BITS/IN
SPEED:	2400 RPM	2400 RPM	400 INCH/SEC.	250 INCH/SEC.
DATA TRANSFER RATE (SERIAL)	1.25×10^6 BITS/SEC. 156 KB/SEC	2.5×10^6 BITS/SEC 312 KB/SEC.	560,000 BITS/SEC.	437,500 BITS/SEC.
STORAGE CAPACITY:	58×10^6 BITS 7.25×10^6 BYTES	232×10^6 BITS 29×10^6 BYTES	4.5×10^9 BITS 562×10^6 BYTES	3.5×10^9 BITS 437×10^6 BYTES
ACCESS TIME:	75 MSEC AVERAGE	60 MSEC AVERAGE	600 MSEC MAXIMUM	600 MSEC MAXIMUM

Table I—Random access devices.

to read it on another. The user can store a large number of disc packs and thereby obtain practically an unlimited storage capacity.

A representative high-density disc file is the Spectra 70/594, which has 11 discs in an interchangeable pack with 20 recording surfaces and 20 heads in one file cabinet. Each surface has 203 tracks on a 14-inch diameter disc. The tracks, which are vertically aligned above each other are called cylinders. Any track can be accessed by selecting the proper cylinder and head. Each head is mounted on an arm; the 20 arms form a comb-like array which is attached to a carriage, moved by a hydraulic actuator. The carriage is positioned in any one of the 203 positions by a detent mechanism. The average random-access time is 60 ms, and to reach a record on a track, an average latency time of 12.5 ms (one-half revolution of the disc) must be added.

A real breakthrough in magnetic recording occurred with the use of the air-floated head. Inserted in an aerodynamically designed slider surface, the head flies on a cushion of air, carried along by the moving disc surface. The head follows disc fluctuations of several thousandths of an inch, maintaining a very small (in the order of 100 microinches) and constant separation from the surface. In this way, the flying head assumes a reasonably close distance to the magnetic surface which is one of the requirements for obtaining high bit densities. The head does not touch the surface thereby satisfying the requirement for fast access times and long life. Thus, the air-floated head accomplishes the desired compromise, mentioned previously.

Another important feature is head tracking or track registration. The heads are positioned laterally to line up with the tracks. Accurate head tracking assures disc pack interchangeability between different machines. As larger storage capacity is required in advanced interchangeable pack disc files, the radial track density on the pack must be increased. The head positioning accuracy tolerance therefore becomes tighter.

Some comparative data on high density, large-storage-capacity, random-access devices, disc files, and magnetic card equipment is listed in Table I. This gives a general idea of the most important features of these machines. Disc files have the advantage of great versatility by using replaceable packs and combining large data capacity with relatively fast access times. In addition, their utilization can be further improved by grouping several units around one controller, thereby multiplying the "on line" capacity. Also, this way the effective access time can be greatly reduced by simultaneously reading or writing on one unit, while another one is accessing and looking for the new address.

Advanced disc-file requirements

After having reviewed some of the high-density digital magnetic-disc storage equipment available today, one might logically ask the question, "What will be the next immediate goal for disc files?" Looking back at the trends of the rapid development in the data processing industry, it is not difficult to forecast the general goals for improvements in magnetic recording: larger storage capacity, shorter access time, higher data transfer rate, and improved reliability which is evidenced by lower error rate and longer useful life of the hardware. All of this must be provided at a lower cost per bit.

Specifically, one can list these major requirements quantitatively, as follows:

Data storage capacity: 100 million bytes per pack (using 8-bit bytes.)
Average access time: 30 milliseconds.
Data transfer rate: 0.94 million bytes/sec.
Error rate: One error in 10^{10} bits.
Useful life of hardware: 5 years, minimum.

In terms of major magnetic recording parameters, the above data storage and transfer figures can be realized using the following quantities:

Linear bit density: 4400 bits/inch.
Radial track density: 200 tracks/inch.
Disc rotational speed: 3600 r/min
Bit transfer rate: 7.5 million bits/sec.
Number of usable discs in a pack: 10.

The above figures represent approximately a 3.5 times increase in capacity and 3 times increase in data rate, compared to the maximum performance of equipment available today. One computer manufacturer has recently announced a high density disc file which comes close to the above requirements. This unit is expected to appear soon on the market. It is easy to imagine that the next generation beyond the announced high density disc file will again require a similar increase. Beside the necessity of higher capacity, there is a definite need for limited capacity devices that operate with a much faster access time (preferrably reduced by a factor of ten), than available today. To put these requirements in the proper engineering perspective, the physical parameters of magnetic recording are discussed next.

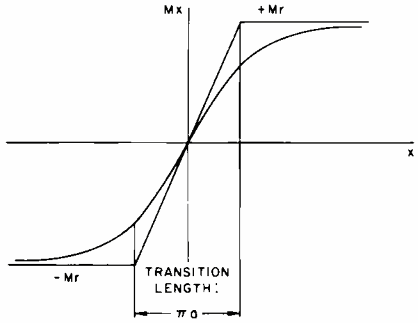

Fig. 2—Magnetization transition region.

Theory of digital magnetic recording

The usual procedure in analyzing digital magnetic recording, is to start first with the read process because it is more directly amenable to analysis. The write process, which is highly nonlinear, will modify the results obtained in the analysis of the read process and is discussed later in this article in a qualitative way. The basic analytical tool is the step function response of the head. Fig. 1 shows the geometrical relationship between a head gap, shown in an idealized form, and the magnetic medium moving at a speed (v) relative to the head. The magnetic medium is applied to the surface of a disc substrate, which is non-magnetic. The object is to determine the single pulse read by the head, as a change in magnetization occurs in the medium.

Ideal case

Several simplifying assumptions are made, as follows:

The magnetization reversal is assumed to be a step function; that is, the state of the magnetic surface changes from saturation in one direction to saturation in the opposite direction instantaneously. Furthermore, the length of the gap (g) and the thickness of the magnetic medium (t) are both assumed to be much smaller than the distance (d) between the head and the medium. Under these conditions, the following expression is obtained for the pulse shape[1] (Fig. 1):

$$e(\bar{x}) = KvwNM_r \frac{(t/d)}{1+(\bar{x}/d)^2}$$

where K is a constant; v is disc speed; w is the width of the gap (perpendicular to the plane of Fig. 1); N represents number of turns in read head; M_r is the remanence of magnetic medium; and $e(\bar{x})$ is the head output voltage as a function of relative position. Other symbols are explained on Fig. 1.

It is quite natural that the pulse amplitude is proportional to the relative speed, the width of the head, the number of turns in the head, and the remanent magnetization of the recording medium. Interesting is the functional relationship, describing the pulse shape, which clearly shows the influence of the geometrical parameters. Thus:

$$\frac{e(\bar{x})}{e(o)} = \frac{1}{1+(\bar{x}/d)^2}$$

where $e(o)$ is the peak amplitude of the pulse.

Thus, the pulse width between the 50% amplitude points (PW_{50}) is $2d$.

The width (PW_{50}) of a single pulse, as the response to a step input, is the most important parameter which ultimately determines the resolution capabilities of digital magnetic recording. The linear bit density of a system is inversely proportional to PW_{50}. As seen in this simple idealized case, the only parameter that determines the pulse width is the distance between the head and magnetic surface.

Practical case

In practice, the gap length and the medium thickness are not negligible, compared to the head-surface separation. Indeed, in many cases, these three geometrical parameters are of comparable magnitude. In addition, the magnetization reversal in the medium is not a step function but is gradual, due to self-demagnetization, which is a field inside the magnetic medium caused by its own magnetization and acting in the opposite direction. Therefore, it reduces the remanent magnetization (B_r) of the medium and spreads out the transition zone.

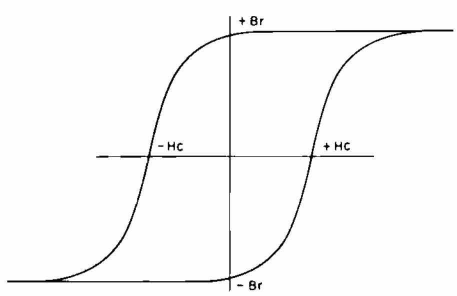

Fig. 3—Hysteresis **(B-H)** loop of magnetic medium.

Several investigators[2—6] have attacked the problem of deriving the pulse shape in the practical case with due regard to the above considerations. A convenient mathematical form for the magnetization transition is the following[5] (see Fig. 2):

$$M_X = (2/\pi)M_r \text{ arc tan } (\bar{x}/a)$$

where a is the demagnetization parameter (a characteristic of the transition length); its physical significance is illustrated in Fig. 2).

The above mentioned references[2—6] express the pulse width in terms of the following physical parameters: g, d, t, and a. The first three terms describe the geometrical relationships (Fig. 1). The demagnetization parameter, a, is related to the magnetic properties of the medium by:

$$a = 2M_r t/H_c$$
$$= B_r t/2\pi H_c$$

where H_c is the coercivity (Oersted) and B_r the remanence (Gauss) of the medium, as determined by the hysteresis loop (Fig. 3).

The best agreement with experimental results is obtained by using the following pulse-width formula:

$$PW_{50} = 2\sqrt{[d+(t/2)+a]^2+(g/2)^2}$$

The pulse shape follows an expression very similar to the one derived for the ideal case:

$$\frac{e(\bar{x})}{e(o)} = \frac{1}{1+(\bar{x}/p)^2}$$

where $p = PW_{50}/2$.

The validity of approximating the pulse shape with the above simple functional relationship has been proven by several investigators.

The pulse-width formula demonstrates that in the practical case all geometrical and magnetic parameters are equally important. Neither one can be left out when their magnitudes are comparable, which is the usual case in very high density recording. The formula gives a good first-order estimate and serves very well for engineering purposes. Its accuracy has been found to be within 20% in most experimental measurements. It always gives a narrower pulse value than the actually measured results, which shows that in real life there are still some unaccounted for phenomena.

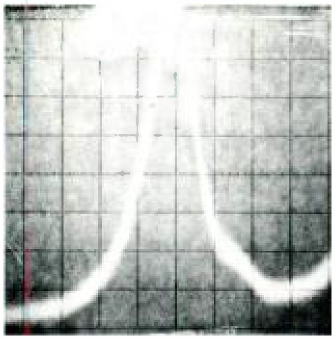

Fig. 4—Single pulse recorded on gamma-iron oxide; horizontal scale is 100 ns/cm; I_w = saturation.

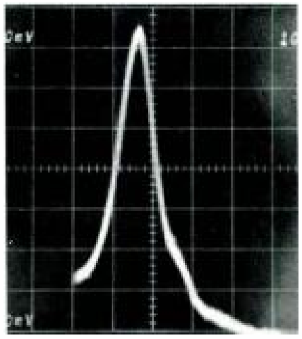

Fig. 5—Single pulse recorded on thin-plated cobalt: horizontal scale is 100ns/cm; I_w = saturation.

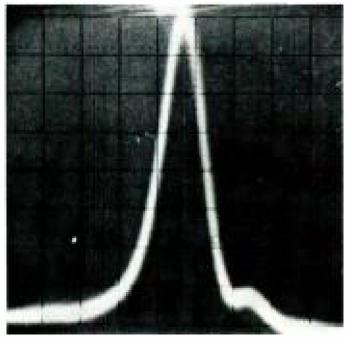

Fig. 6—Single pulse recorded on special oxide surface (ferrite): horizontal scale is 100 ns/cm; I_w = saturation.

The major part of this discrepancy is due to the write process being highly nonlinear. Closer investigation shows that the demagnetization parameter, a, alone does not describe the magnetization transition adequately. Specifically, the transition region is considerably longer than shown in Fig. 2.

It is a well known fact in magnetic recording that writing takes place in the neighborhood of the trailing edge of the gap. Several investigators[7] have done detailed computer studies and simulation of the write process. The results show that the length of the magnetization transition is a function of the slope of the hysteresis loop of the medium, of the slope of the head fringing field at the point where writing takes place, and of the write-current risetime. The steeper these slopes are, the shorter the transition. Recent investigation[8] on the effect of the write-head field gradient shows that it limits digital recording to a greater extent than any other factor. It is also a function of write current, spreading the transition length more with increasing current. At high bit densities, this effect becomes so severe that only transition zones are recorded on the media, leading to a sinusoidal magnetization distribution. Quantitative evaluation of the write-head field gradient on the transition length is very complex and can not be incorporated in the simple pulse-width formula.

A comment is due on another discrepancy between theory and practice. The read pulse is never perfectly symmetrical, as it should be according to the theoretically derived equation. The usual form of asymmetry is such that the leading edge of the pulse has a shorter rise time than the trailing edge. One simple reason for this asymmetry is the inductive time constant of the head. To avoid this difficulty, the self-resonance of the head should be kept at least 50% higher than the bit rate. Another and less obvious reason for pulse asymmetry is again the nonlinear head field contour distribution in the write process[3,8]. The pulse asymmetry is also a function of write current amplitude. The DC erase can also contribute to pulse asymmetry. Furthermore, with DC erase the nature of the asymmetry may depend on the polarity of the erase, relative to the write-field polarity. Pulse asymmetry caused by all these various factors, results in peak shift or phase distortion in a coded pattern thereby degrading the information. The detrimental effect of these various factors has been studied in the literature[9-11].

Recording parameters at 4400 bits/inch

Let us look at the basic physical parameters that are needed to realize 4400 bits/inch, which is the requirement for the immediate next goal in disc files. The 4400 bits/inch goal is equivalent to a bit length of 227 micro-inches or a bit period of 133 ns at 3600 r/min on a 14-inch diameter. Assuming double-frequency code is used for recording, it is known from past experience that the PW_{50} should be about 70% of the bit period. If delay modulation code is used, a PW_{50} equal to 120% of the bit period is adequate. (In double frequency code, two flux reversals represent a bit, while in delay modulation every flux reversal corresponds to a bit.) Therefore, the following PW_{50} values are needed for 4400 bits/inch density:

Double frequency: PW_{50} = 170 microinches or 100 nsec.
Delay modulation: PW_{50} = 272 microinches or 160 nsec.

The PW_{50} value for delay modulation can be realized with a combination of the following physical parameters, using ordinary gamma-iron oxide (γ-Fe_2O_3) medium:

Head-to-medium separation: d=50 microinches (on inside track)
Oxide thickness: t=60 microinches (on inside track)
Gap length: g=50 microinches (optical)
Demagnetization parameters: a=12 microinches
Magnetic properties of oxide: H_c=300 Oersted, B_r=350–375 Gauss
Actually measured value: PW_{50}=150–165 nsec

Fig. 4 is a single pulse recorded on ordinary gamma-iron oxide.

Much narrower PW_{50} values, those that are needed for double frequency code, can be obtained on thin plated cobalt surfaces with the following physical parameters:

Head-to-medium separation: d=42 microinches (on inside track)
Thickness of Co-layer: t=7 microinches (on inside track)
Gap length: g=50 microinches (optical)
Demagnetization parameter: a=30 microinches
Magnetic properties of cobalt: H_c=450 Oersted, B_r=12000 Gauss
Actually measured value: PW_{50}=95–105 nsec

It is seen from the above data that the demagnetization parameter is much more critical for cobalt than for oxide. Fig. 5 shows a single pulse recorded on thin plated cobalt surface.

Very good results were obtained also on special oxide surfaces, such as CrO_2 or ferrite (Fig. 6). These were almost as good as the cobalt surface.

It must be mentioned that the longest pulse width is obtained on the innermost track of any disc since the linear velocity is the smallest at the shortest radius. Considerable compensation between outside- and inside-track pulse-width values can be obtained by tapering the oxide thickness, (making it thinner toward the inside) and by flying the head at a reduced distance, going toward the inside of the disc. While a uniform pulse width is very desirable from the standpoint of equalization, its advantages must be weighed against the manufacturing difficulties of a tapered magnetic surface. Therefore, again in this area, a judicious compromise is necessary.

Magnetic storage media

The different magnetic media, discussed thus far, represent two basic technologies. The oxides, essentially powder-type materials, are in the first group: thin metallic films are in the second group. The oxide particles dispersed in an organic binder are applied to the spinning disc as a thin flowing slurry. During repeated heating cycles, the solvent is evaporated and the binder with the oxide particles forms a hard layer on the surface of the disç. In this technology, the uniformity of the thickness presents the key problem, especially for very thin layers. In the plating process the magnetic material, usually *Co-P* or *Co-Ni* is chemically deposited from a bath, as a continuous thin metallic film, on a hard, highly polished surface. This hard surface is produced by first deposting nickel on the aluminum disc. Because this nickel layer is much thicker than the cobalt on top of it, it would produce an undesirable pulse spreading effect, if it contributed to the flux. For this reason, the nickel must be non-magnetic. The plating process requires a very tight control over the chemical and thermal parameters of the bath, to keep the coercivity uniform and to avoid the presence of pin holes, specially in very thin layers (less than five microinches). In addition, an overlay, metallic or organic, must be applied on top of the cobalt film to make it resistant to occasional contacts with the head. The thickness of this overlay contributes to the separation between head and medium.

Comparing the magnetic properties of the two groups, the biggest advantage of the plated disc is its high remanent magnetization (B_r), 10 to 15 times higher than oxide. This allows a drastic reduction of the medium thickness, resulting in better resolution, while the same, or even higher, signal amplitude can be maintained, compared to ordinary iron oxide. Disadvantage of the high B_r value is the increased demagnetization (a). Special oxides (CrO_2 and Fe_3O_4) have higher remanent magnetization, than ordinary γ- Fe_2O_3, but much lower than Co. Thin metallic films have steeper hysteresis curves and higher coercivity, than oxides. Both help to achieve narrower pulse width values. On the other hand, the coercivity should not be too high since it requires very large write current to saturate the surface. This could lead to pole tip saturation in a ferrite head, which should definitely be avoided.

There are two main sources which produce noise on the disc: the previously recorded signal left on the disc after overwriting and the noise inherent in the medium itself. In general, very high coercivity materials tend to give a poor overwrite ratio. The inherent noise is somewhat lower in metallic plated discs, if the manufacturing process is kept under proper control. It has been established from test data that 28 to 30-dB signal-to-noise ratio can be obtained in overwrite with either material. The signal-to-noise ratio for inherent noise, measured for oxides is 36 to 40 dB, while for cobalt it is 38 to 44 dB.

As seen from the above brief comparison, metallic plated films ultimately promise better magnetic performance and higher bit density. At the present state of the art, they have certain technological difficulties that will definitely be overcome in the near future. Due to the complex manufacturing process, at present their cost is higher than comparable oxide discs by a factor of two. The ultimate capabilities of plated discs can best be utilized for very high bit densities, over 4400 bits/inch, in contact recording. Here the superior magnetic characteristics can be advantageously combined with excellent wear resistance of a certain type of overlay, as it has been proven in video disc recording.

Head/disc interface

From the discussion on magnetic recording theory, it has become obvious that one of the most important parameters that determines the performance of a recording system is the distance between the head gap and the surface of the disc. For high density recording, this distance must be kept to an absolute minimum and preferably constant; yet a definite separation must be maintained between head and disc in order to move the head from one track to another as fast as possible. The best known method to accomplish this is aerodynamic flying. The head is imbedded in a carefully designed slider, the surface of which is cylindrical (crowned) in the direction of disc motion. The slider assumes a very small angle of attack in the direction of flight, similar to the wing of an airplane. Under these conditions, a positive pressure develops between the slider and the disc. A constant spring force, opposing the aerodynamic load, is applied to the slider and maintains it floating at a fixed distance. The head gap must be located on the slider at the closest point to the surface. The distance of this point is the flying height.

The pertinent parameters, *i.e.* pressure distribution, center of pressure, load, and flying height, can be calculated for a particular slider design by solving the Reynolds equation for a thin film of gas. A Fortran program for the solution of this equation has been worked out by RCA Laboratories, Princeton, New Jersey[12]. Loading force *vs.* flying height is shown in Fig. 7 for a slider configuration at a specific disc speed. As the load is increased the head flies closer. The theoretical limit for the validity of the Reynolds equation is 20 microinches. Practically, the minimum stable flying height is about 30 to 35 microinches. The experimentally measured points agree very well with the theoretical curve. Flying height measurements are done by inserting an insulated probe in the slider and measuring the capacitance between the end of the probe and the rotating disc. Actual implementation of this technique requires very careful mechanical and electrical alignment and calibration. The measuring technique has been perfected now to the point that reliable and reasonably accurate results can be obtained.

Thus far, this discussion has described only the properties of the air film between the disc and the slider. Equally important for stable flying are the mechanical properties of the disc and the suspension of the head (usually some form of spring). Head and disc are tied closely together in a very complex mechanical system, exhibiting many orders of freedom. Analysis of this system would be extremely complicated; the whole problem is being investigated experimentally. The following is a qualitative description according to our present understanding.

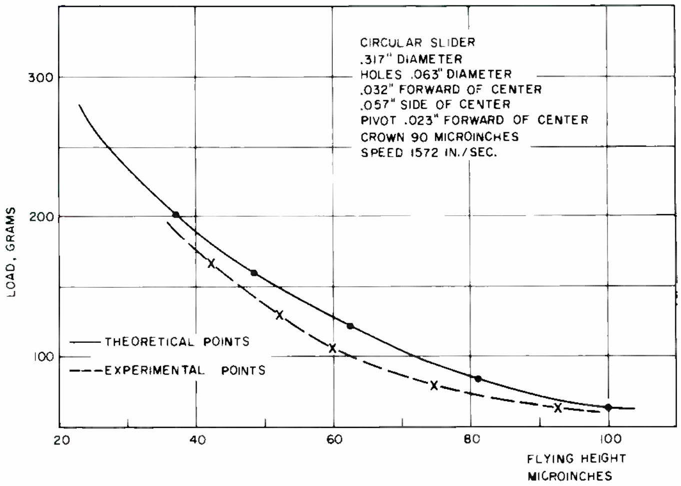

Fig. 7—Loading force *vs.* flying height.

The disc vibrates, setting up waves which cause vertical displacement on the surface, both circumferentially and radially. The disc vibrations are a function of rotational speed, thickness, vertical runout, and waviness of the substrate. The head and its suspension have their own resonant frequency which is rather low, a few hundred cycles per second at the most. The head must follow the vertical displacement of the disc to maintain constant flying height. Therefore, a high head-suspension resonant frequency and proper damping would be desirable. Disc vertical vibrations above the resonance of the head-suspension system should have low amplitudes to keep signal envelope variations small. For this reason, the surface finish of the disc, which represents irregularities over a short distance, must be below 5 microinches. The whole picture is further complicated by the presence of the air film and the ability of the slider to exhibit rotational motion (pitch and roll). The effects of all these interacting mechanical phenomena are even more important when loading and unloading since the head is the most susceptible to crashes at these times.

Track density

The 200 tracks/inch radial track density puts severe requirements on the system both from the standpoint of magnetic recording and mechanical design. The distance between track centers is only 5 mils, leaving an active track width of about 3 to 3.5 mils. This results in a rather small signal amplitude (less than one millivolt) and unfavorable signal to noise ratio, if ordinary iron oxide is used as the storage medium. This factor strongly suggests the use of special oxide materials (CrO_2 or Fe_3O_4) and also the delay modulation code, which has a 2:1 advantage in signal amplitude over the double frequency code, due to its lower range of signal bandwidth. In the noise considerations, it is not only the background noise of the medium that must be dealt with but equally important is the electrical or magnetic pickup noise (EMI) which can be a very troublesome source of read errors.

Another stringent requirement due to the high track density is the head positioning accuracy. A study of tolerances indicated that a $\pm$ 0.5 mil accuracy is needed in the relative position of head and track in order to assure pack interchangeability between disc files. This necessitates track servoing, where the final positioning reference must be taken from the disc pack. One disc surface which is reserved for this purpose has an accurately prewritten servo signal on each track. This is read by a special servo head, deriving a positional error signal that forces the vertically aligned heads through the head positioning mechanism to follow the accurately located servo track. Use of the track servo in both writing and reading establishes a common reference within each disc pack. Assuming the heads are accurately aligned, interchangeability of disc packs can be assured.

Conclusion

This brief review of the physical aspects of digital magnetic recording is intended to point out techniques that are capable of satisfying the ever increasing requirements in the field of random access storage devices. This field of engineering is rather complex; the technologies are involved and comprise areas from a great variety of scientific disciplines. It combines knowledge gained in magnetics, electronics, mechanics, aerodynamics, hydraulics, chemistry, and metallurgy. In the field of electronics and instrumentation, it relies heavily on techniques used in signal processing, servo mechanisms, vibration analysis, analog and digital, and logic design. It is necessary to use sound engineering judgement in the proper combination of these different techniques to achieve the desired goal.

It was also the intent of this article to point out that in this complex field of engineering the theories have somewhat limited value; therefore, optimum design, from an ideal standpoint, is hardly ever possible. The many practical problems, not directly amenable to analysis, and the problems of economics make it unavoidable to compromise between conflicting requirements in arriving at design decisions. This results in a number of different approaches leading to the same goal. Selection of the best, fastest, most practical, and most economical way of solving the problem represents a real challenge and makes this field of engineering extremely fascinating.

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Paper-feed system for a high-speed printer

Don Janz

The computer peripheral high-speed line printer conveys information from the computer memory to the printed page. Each second the printer can produce 20 printed lines containing 132 characters; this corresponds to an average paper feed velocity of 1,000 ft/hour with a line index increment equal to 1/6 inch. The high-speed printer imposes demanding requirements upon its paper-feed system. The system described employs a moving-coil DC motor and a unique position transducer to fulfill the demands imposed on the system.

PAPER, which may be a pre-printed form, must accurately be indexed in 1/6- or 1/8-inch increments on a line printer. Uniform printed lines and accurate spacing are desirable, not only for appearance and legibility but also because the quality of the printed documents may affect the performance requirements of automatic reading equipment that may later process these documents. The time required to index the paper a single line is usually less than 16 ms. A high-speed slew with approximately a 6-ft/s peak velocity is normally available when skipping more than 7 lines. Each line is printed while the paper is at rest during a typical 35-ms period.

The paper has punched holes accurately spaced at 1/2-inch increments on the right and left sides. Sprocket and tractor pins engage the punched holes to index the paper accurately within the prescribed time limit. The paper size and weight may vary from a lightweight single-part narrow sheet to a heavier 22-inch long, 6-part (1 original and 5 copies), 19-inch wide sheet or other special papers, such as checks and punch-card stock.

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received an engineering scholarship from the Westclox Division of General Time Corporation in LaSalle, Illinois and attended Purdue University where he obtained the BSEE in 1956. He received the MSE from the University of Pennsylvania in 1964. After completing the RCA training program in 1956, Mr. Janz was assigned to the Missile and Surface Radar Division in Moorestown, N.J. where his primary work was in automatic control mechanism development. He has been associated with printer equipment design since 1967 when he transferred into the Electronic Data Processing Division in Camden, N.J. Mr. Janz has one US Patent.

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Coarse and vernier horizontal and vertical adjustments allow positioning of margins and top of form location. A punched-tape loop can be used as a memory that contains line sequencing information to provide the format for a document page. The punched tape loop is typically 2 inches wide and the length of the loop equals the length of the document page. As many as 12 data channels are available for interrogation at each line interval. Paper feed commands, originating in the computer controller, may be used with a punched-tape reader located within the printer.

The punched-tape reader must be synchronized with the document page. This is usually done mechanically by a clutching arrangement or by logically-coupled memory devices. End-of-paper and paper-jamming signals are also provided.

Design goals

Achieving a high mean time between failure (MTBF) and a low mean time for repair and preventive maintenance is a primary design objective. A reduction in down-time for repair and maintenance service may more than justify higher equipment cost.

Other design considerations must include the safety and protection of

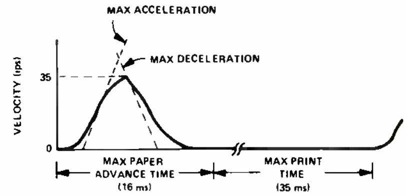

Fig. 1—Approximate single line advance profile 8244 printer paper transport.

operating and service personnel from hazardous electrical and mechanical features. Minimizing power consumption and controlling of audio, magnetic, electrostatic, and physical emissions are also desirable or necessary objectives.

A variety of factors affecting the enhancement or detraction of desired features have to be considered to achieve an optimum design that meets the fundamental requirements. For example, a restriction on excessive acceleration is a plus feature since it is accompanied by a restriction on accelerating forces that wear parts and tear the punched paper holes. Thus reliability, document handling, and registration are enhanced. If acceleration limits are imposed, then the mechanical system should not demonstrate any resonant peaking conditions that results in excessive acceleration.

Design factors

To evaluate some methods and components that could be used for the paper-feed system, an approximate velocity-versus-time profile for a single-line advance is illustrated in Fig. 1. Note that maximum acceleration and deceleration slopes are also indicated.

The area under the curve representing the distance traveled is typically 1/6 in. The maximum acceleration and deceleration rates of 10,000 in/s² are estimated from Fig. 1 to be roughly equivalent to 25 g's. Since a 6-part document may typically weigh 1/10-pound, a 2 1/2-pound force would be required to accelerate a single document. Paper is normally unfolded from a stack and lifted up to the tractors; thus, a 10-pound force may accelerate four documents from a stack. This force is uniformly applied to the document by engagement of the punched holes with several pairs of equally spaced sprocket

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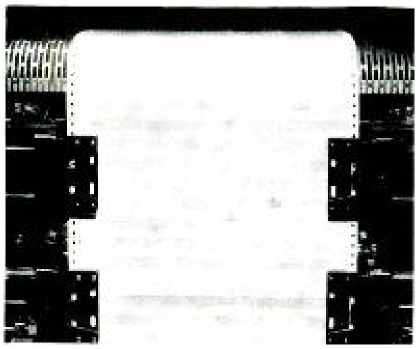

Fig. 2—Front view of paper feed system.

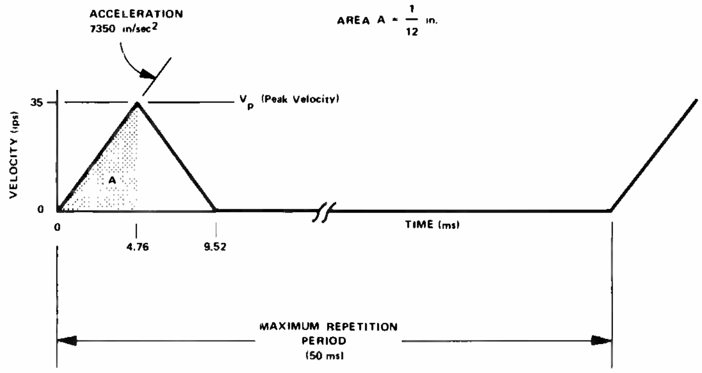

Fig. 3—Idealized single-line advance.

pins fastened to a tractor belt (Fig. 2). This method prevents excessive deformation or tearing of the punched holes and enhances good document registration. A pair of tractor assemblies is used both above and below the print line to accurately feed and hold the document in the print position.

A convenient relationship between rotary motion and linear paper movement is usually established to provide a direct correspondence between one turn of the tractor shaft and an integer number of lines uniformly spaced at either 6 or 8 lines to the inch. This relationship requires each revolution of the tractor sprocket to correspond to a multiple of a 1/2-inch linear increment. Present-day units have a 3-to-4-inch/turn relationship. One revolution of a 3 1/2-inch/turn unit would advance 21 lines at 6 to the inch or 28 lines at 8 to the inch.

The inertial load that must be accelerated by the prime mover consists of the paper, the four tractor assemblies, a pair of coupled sprocket shafts, and auxiliary hardware. The magnitude of the reflected rotational inertia is approximately 0.03 ounce-inch second^2. Assuming a 3 1/2-inch per-turn tractor unit, the necessary rotational acceleration is approximately 18,000 radians/s^2 [(10,000 in/s^2)(1 rev./3.5 in.)(2π radians/rev.)]. The peak load accelerating torque requirement is approximately 540 ounce-inches [(0.03 oz-in-s^2)(18,000 radians/s^2).

The frictional load torque can be considered to be a small percentage of the peak accelerating torque. The rotational velocity profile of the prime mover would be proportional to that shown in Fig. 1.

Secondary characteristics of selected components as well as the primary assets must be considered to evaluate the full effect upon paper-feed features. These secondary side effects may pertain to system accuracy, wear, efficiency, safety, pollution, cost, and maintenance. These secondary effects are important yardsticks when selecting, for example, a hydraulic motor, clutch brake, or DC servomotor as the system prime mover, a toothed belt, gearing, or a direct drive as the means of coupling the prime mover to the load.

A punched-tape loop memory is normally used to store a repetitive line skipping program that corresponds to the format of the documents to be printed. Twelve data channels are usually available. Data may be punched at increments corresponding to each line spacing. The tape loop can be read by photo-electric or conventional brush-type detectors. The punched-tape reader may be mechanically coupled to the tractor sprocket shaft to synchronize the punched-tape loop to the document. The punched-tape loop then usually operates at the same linear acceleration and velocity as the document; this causes wearing of the punched-tape loop memory and limits its useful lifetime. Moreover, the mechanically coupled punched-tape reader adds additional complexity and load to the paper-feed system. A clutching-type arrangement is provided to disengage the reader from the document transport to allow alignment of the top-of-form location on the punched-tape loop with the top of the document.

The paper-feed system may be simplified by replacing the mechanically coupled punched-tape loop memory by an electronic memory. A simple electronic line counter can couple the document transport to the electronic memory. Synchronization with the top of the form may be implemented by a simple reset signal.

A transducer is required to determine the paper-feed rest position as well as the number of lines advanced. Ideally, this transducer must provide consistently accurate data with a high information rate and minimum maintenance service. Several standard devices that can be considered for this purpose are digital encoders, permanent magnet pickup-coil pulse generators, analog optical sensors, potentiometers, the rotary Inductosyn, and the Microsyn.

Servomotor is prime mover

A DC permanent-magnet moving-coil servomotor was chosen as the prime mover for the paper-feed system. Many of the desired system benefits are inherent features of this motor. The inertial load presented by the tractor shafts is essentially fixed, and the friction torques are relatively insignificant. Therefore, the application of a constant torque to the load provides an essentially constant acceleration. The motor's linear torque versus current proportionality allows positive peak-torque control by limitation of the motor current levels. The low mechanical and inductive time constants provide high acceleration capability and bandwidth, with little electrostatic and electromagnetic emissions and commutator arcing. The motor is also familiar to electronic computer service personnel and can provide a long MTBF. It is anticipated that nearly 2,600 miles of paper (a billion lines) can be advanced before motor brush replacement will be required.

Electronic memory simplifies mechanism

An auxiliary electronic memory, provided for paper advance programs, negates the need for any clutch assemblies that would decrease the performance and reliability of the paper-feed system. In addition, a constant-velocity punched tape reader provides data transfer into the memory.

The conversion between linear and rotary motion in the tractor assembly is made with a 3 1/2-inch/turn relationship. Fig. 3 shows, for a 1/6-inch line advance, the document-velocity-versus-time profile that most ideally satisfies the requirements for the paper-feed system in the RCA 8244 high speed line printer. The

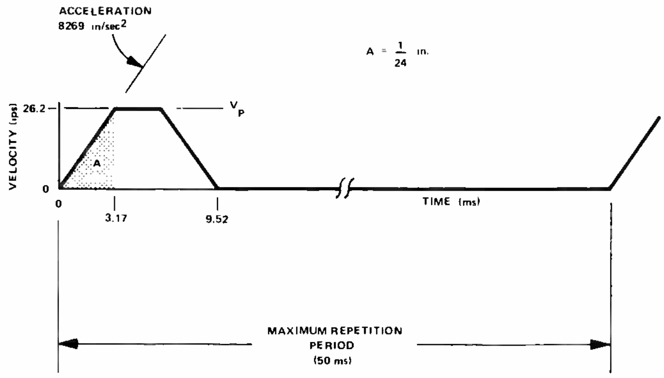

Fig. 4—Single-line advance profile optimized for minimum motor dissipation.

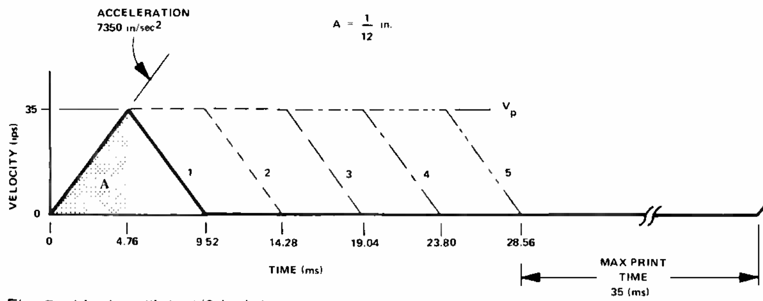

Fig. 5—Ideal multiple 1/6-inch line advances—one through five lines.

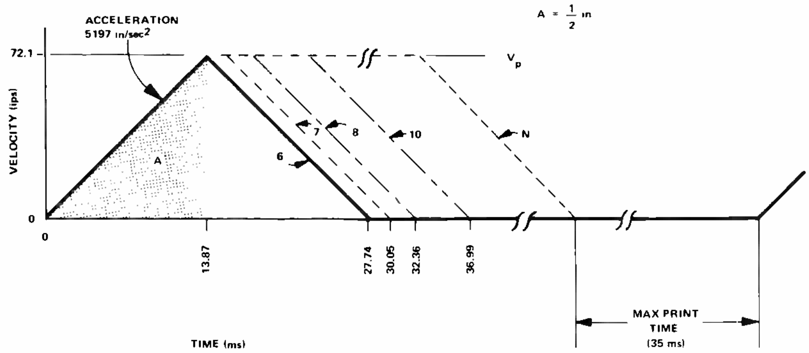

Fig. 6—Ideal multiple 1/6-inch line advance—six lines or more.

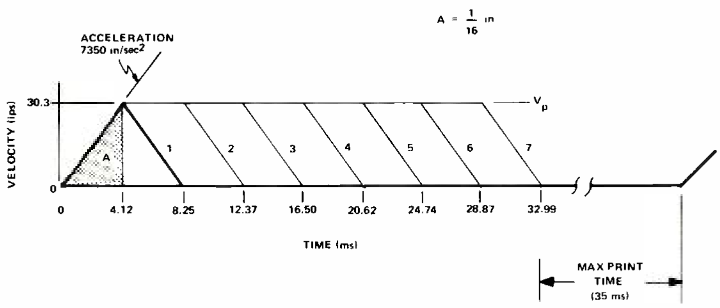

Fig. 7—Ideal multiple 1/8-inch line advances—one through seven lines.

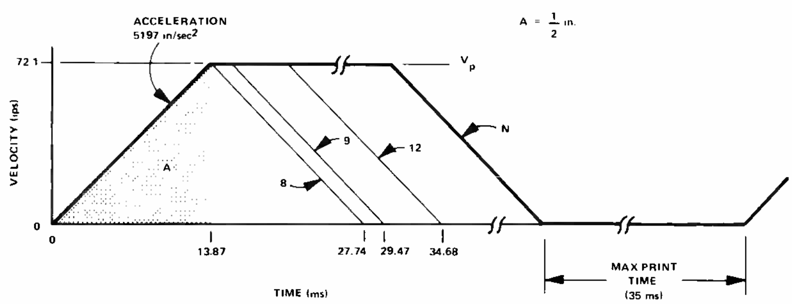

Fig. 8—Ideal multiple 1/8-inch line advance—eight lines or more.

document is accelerated to peak velocity for a 1/2-line interval and decelerated to zero velocity during the second 1/2-line interval. Therefore, the maximum allowed acceleration and deceleration forces are used during the total motion time so as to move the greatest distance and achieve the highest peak velocity in the minimum time interval. Note the acceleration is below that estimated from Fig. 1.

This velocity-versus-time profile does not minimize the heat dissipation in the DC servomotor as would the velocity-time profile in Fig. 4. Although the servomotor dissipation is reduced to nearly 84%, the acceleration forces and corresponding peak servomotor currents are increased by 12½%. The velocity-time profile for the 8244 paper-feed system is modeled from that shown in Fig. 3, since motor dissipation does not significantly limit performance.

The paper-feed system must also provide for multiple-line indexing. The concept of the velocity-time profile (Fig. 3) can also be extended for multiple-line advancement. However, as the duty cycle of the motor gradually increases with the number of lines advanced, motor dissipation eventually becomes excessive. Therefore, it is advantageous to modify the peak motor dissipation in accordance with the imposed duty cycle. The 8244 paper feed system incorporates two acceleration rates to utilize efficiently the motor dissipation capability under both high and low duty-cycle conditions.

Fig. 5 shows the ideal velocity-time profiles for 1 through 5 line advances spaced at 6 lines to the inch. Fig. 6 illustrates the ideal velocity-time profiles for 6 through 10 or more line advances spaced at 6 lines to the inch. Note that the duty cycle of the servomotor for the 6-line advance is almost twice that for the single-line advance when using a maximum print period. The acceleration level is therefore reduced by the square root of two since the motor dissipation is nearly proportional to the square of the acceleration. The 6-line advance seen in Fig. 6 covers one inch of travel. This same distance is moved for an 8-line advance with 1/8-inch line spacing; therefore, the same velocity-time profile is used for both conditions. The model velocity-time profiles used at 1/8-inch line spacing are seen in Figs. 7 and 8.

Locating print line

As can be seen in Figs. 4 through 8, the line interval to be spanned is equal to the area under velocity-time curve. Therefore, it is possible to control the distance moved from a reference position by accurate control of the motion time and deceleration rate. A practical method to determine the rest or print position is based on this principle. A reference point approximately 1/2-line prior to the rest position can be readily detected by a magnetic or other type of pickup device. At this position, deceleration begins at the established rate for a given period of time. Then a holding device or detent fixes the rest position as long as necessary.

The deceleration rate can be affected by several factors such as the variation of friction and inertial loading. However, if the deceleration rate and time duration are known to within a few percent, the distance traveled from the reference position can also be determined within several percent. For example, 10% of a 1/2-line interval equal to 1/12-inch represents less than 0.009 inch. Some of the deceleration rate and time duration parameters, such as paper inertia, would not vary significantly on a line-to-line basis. Therefore, the line-to-line variation in distance traveled could be much less than 10% for the above example. In addition, any detent could more accurately locate the final rest position.

The RCA 8244 paper feed system utilizes controlled acceleration and deceleration rates, and also incorporates a closed-position servo loop. The servomotor, therefore, operates as prime mover and also essentially provides a magnetic detent to accurately locate and hold the final rest position.

The DC servomotor is directly fastened

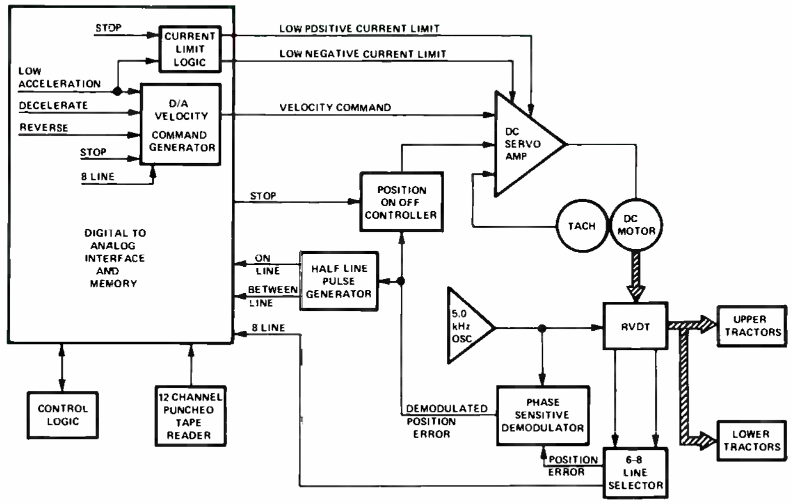

Fig. 10—System block diagram.

to the upper tractor shaft through a position transducer. This provides a stiff coupling between the motor, transducer, and upper tractor shaft. A toothed belt couples the lower tractor shaft to the position transducer. The resultant unity torque ratio between motor and load is significantly near the theoretical torque ratio that optimizes efficiency. No brushes or slip rings are necessary for the analog position transducer that provides the precision line location data. The transducer is a rotary variable differential transformer (RVDT) that is excited by a 5-kHz carrier frequency. Rotation of the low-inertia rotor varies the magnetic reluctance to produce a modulated carrier output, a 21-line stator provides the 6-line per inch signal and a 28-line stator provides an 8-line per inch signal. A signal-output-versus-rotor-angle plot is shown in Fig. 9 for the 21-line RVDT.

Further processing of the RVDT signal produces digital on-line and between-line pulses that are used in the interface between the digital controller and analog servo.

System description

Fig. 10 is a block diagram for the 8244 paper-feed system. A DC tachometer is integrally coupled to the moving-coil DC servomotor. It provides a negative feedback motor velocity data signal of low noise and high bandwidth. This signal is coupled into a DC servo amplifier to close a velocity-servo loop. The closed velocity feedback loop is the basis for stiff, fast responding servo control with a good signal-to-noise ratio. This can be illustrated using Laplace notation by comparing the transfer function of a DC motor to that of a DC motor with degenerative velocity feedback. The simplified transfer function of a typical DC motor, neglecting higher frequency electrical time constants, is of the form:

$$G(S)=M/S[(S/W_l)+1]$$

where S is the Laplace operator; M is the DC gain constant of the motor plus any associated amplifier; and W_l is the break frequency in radians per second associated with the inertial time constant of the motor. The simplified transfer function for a tachometer is of the form:

$$H(S)=-SV$$

where V is the gain constant associated with the tachometer and any coupled amplifier. The closed negative feedback loop is shown in Fig. 11.

The transfer function of the closed tachometer loop is:

$$\frac{\Theta(S)}{C(S)}=\frac{M/(1+VM)}{S\{[S/W_l(1+VM)]+1\}}$$

Comparing the transfer functions $G(S)$ and $\Theta(S)/C(S)$, it is seen that the break frequency W_l in the $\Theta(S)/C(S)$ transfer function is multiplied by $(1+VM)$ and the DC gain term in this same

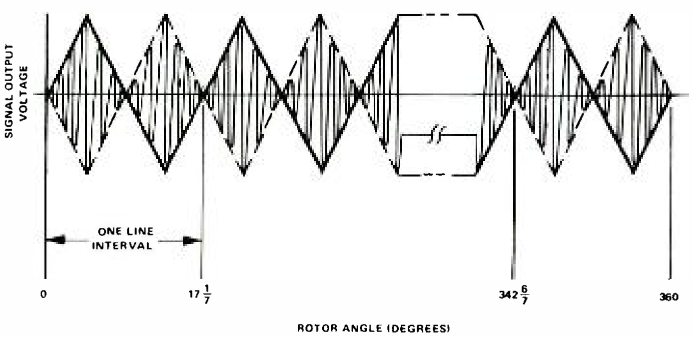

Fig. 9—RVDT signal output.

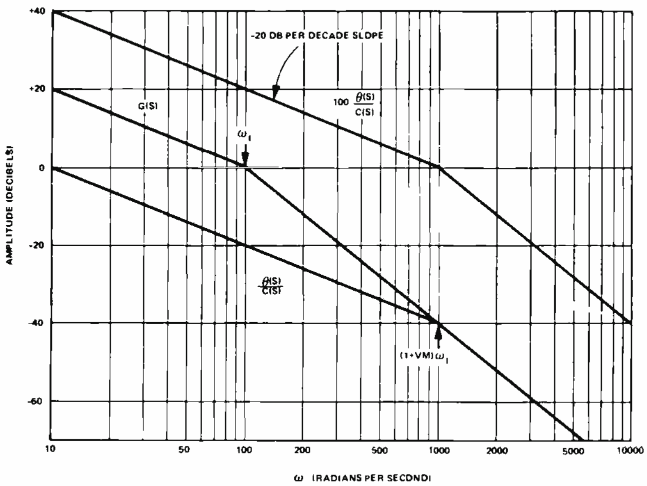

Fig. 12—System Bode plots comparing several transfer functions.

transfer function is divided by $(1+VM)$. A Bode plot of these transfer functions is shown (Fig. 12). As an example, if $M=100$ and $VM=9$, then $W_I=100$ radians/second.

The ideal motor or integrator has a transfer function of the form:

$$I(S)=K/S$$

and the Bode plot has a -20 dB/decade slope.

Any noise introduced at the input to the closed velocity loop in the frequency range below the inertial break frequency W_I produces ten times (20 dB) less noise output for the same noise input to the DC-motor transfer function.

Higher response for the closed velocity system corresponds to an extension of the ideal 20-dB/decade slope beyond the inertial break frequency (W_I radians/second) to ten times the inertia break frequency [$(1+VM)W_I$ radians/second.]

A simple DC amplifier may precede the closed velocity loop to raise the overall gain. A sample Bode plot for an amplifier with a DC gain of 100 preceding the closed velocity loop is shown in Fig. 12. The corresponding transfer function is

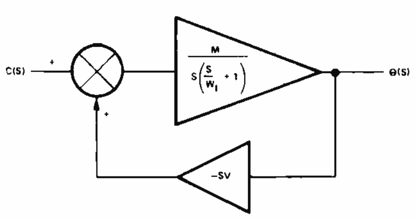

Fig. 11—Block diagram of the motor tachometer transfer function.

$$100\frac{\Theta(S)}{C(S)}=\frac{100M/(1+VM)}{S\{[S/W(1+VM)]+1\}}$$

This transfer function represents a stiffer system than the $G(S)$ transfer function since it has at least ten times the gain (20 dB) at all frequencies.

The closed velocity loop also enhances the response of a closed position loop since the phase lag associated with the inertial time constant (W_I radians/second) is shifted to a higher frequency [$W_I(1+VM)$ radians/second].

The position loop is closed through a RVDT which modulates a 5.0-kHz sinusoidal waveform carrier. The carrier is detected by a transformerless phase-sensitive demodulator and fed back to the DC servo amplifier via a solid-state switching position controller.

Typical operation

The mode of operation can be illustrated by assuming that a 2-line advance at a spacing of 6 lines/inch is demanded by the control logic (Fig. 10). The line selector is set for that spacing. The current limits are high; the lack of a stop command assures an analog 35-inch/second signal to be fed to the DC servo amplifier and the position controller opens the position servo loop. The servo amplifier output is positive-current limited to hold the paper acceleration to the 7,350 in/s² level for approximately 4.8 ms. The tachometer analog signal then reduces the amplifier output sufficiently to maintain the commanded velocity for approximately 4.8 ms (see Fig. 5).

After 1-1/2 lines have been advanced, the second counted between-line pulse —sent by the half-line pulse generator —sets a deceleration command to establish a 17.2-in/s analog velocity signal. The servo amplifier is than negative current limited to hold paper deceleration to the 7,350 in/s² level. A stop command is set 1.4 ms after the last desired between-line pulse is counted to demand a zero analog velocity signal to the DC servo amplifier and causes the position controller to close the position loop at a time when the paper is about 1/4-line from the final rest position. This point coincides with the peak servo signal available from the RVDT (Fig. 9).

Fig. 13 illustrates actual tachometer (velocity) and demodulated RVDT (position) error-signal-versus-time relationships for a 6-line advance at a 6-line/inch spacing. A calibration of the demodulated RVDT signal can be estimated since 1/4-line (0.042 inch at 6-line/inch spacing) approximately corresponds to the peak value of the demodulated RVDT signal.

Conclusion

A servo-controlled paper feed system incorporating a DC servomotor, integral DC tachometer, and an RVDT position transducer offers high performance and reliability. Additional benefits include the ease of indexing paper in either the forward or reverse direction and the precision vernier control obtained by simple rotation of the RVDT stator. Excellent repetitive line-position accuracy basically depends on the accuracy of the RVDT and is not affected practically by such variables as friction and load inertia. In addition, the system is quiet. The servo system incorporated in the 8244 high-speed printer paper-feed system meets the established goals and provides effective features that contribute to the successful operation of a computer complex.

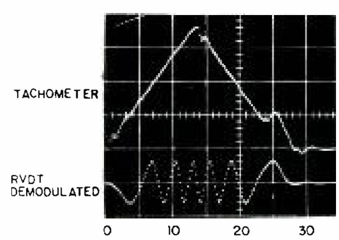

Fig. 13—Actual six-line paper advance (1/6-inch line spacing).

Aerodynamics of digital disk sliders

Dr. G. R. Briggs | J. Guarracini | P. G. Herkart

The air-bearing sliders carrying the magnetic read-write heads are the limiting mechanical components of present-day digital disk file systems. This paper discusses the physics and mathematics applicable to the flying sliders, experimental techniques for determining slider flying characteristics, the results obtained, and the correlation of experiment with calculations. The work culminated in a rectangular slider design that flies reliably less than 50 microinches above the disk surface, making possible storage densities exceeding 4000 bpi.

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Joseph Guarracini, Digital System Research Laboratory, RCA Laboratories, Princeton, N.J., received the BSME from the University of Oklahoma in 1948 and the MS in Physics from Georgetown University in 1954. He joined the National Bureau of Standards in 1949 where he was engaged in the design of input/output devices for the SEAC computer. Later, he was involved in mechanical ordnance at the Harry Diamond Laboratories. In 1956, he joined RCA as a member of a design team working on airborne fire-control equipment. In 1962, Mr. Guarracini joined the RCA Laboratories where he worked on card memories, printers, and most recently disk drives. He is a member of the American Physical Society and the American Society of Mechanical Engineers.

Paul G. Herkart, Digital Systems Research Laboratory, RCA Laboratories, Princeton, N.J., received the BSEE and MSEE in 1935 from the Massachusetts Institute of Technology. From 1935 until 1943, he was engaged in power tube manufacturing at the RCA Victor Division in Harrison, New Jersey. Since 1943, he has been with the RCA Laboratories. Mr. Herkart's early work was on television pick-up tubes, storage tubes, and color television. He led a group working in the technology and production of semiconductor materials, thermo-electrics materials, and other materials with diverse uses. Mr. Herkart headed a Materials Technology Group at the Laboratory, working on III-V compounds thin-film production of cadmium sulfide, epitaxial growth of gallium arsenide, phosphors, and laser materials. Later, he worked on the development of cadmium sulphide transducers for piezoelectric uses. He also investigated mathematically the propagation of ultrasonic pulses in thin quartz slides At present, he is working with the computer solution of the Reynolds equation for gas flow in thin films. Mr. Herkart is a member of IEEE and of Sigma Xi

Authors Briggs, Guarracini, Herkart (left to right).

In most digital disk memories, the read/write heads are carried in cylindrically crowned air-bearing sliders which ride on a thin laminar layer of air approximately 100 microinches thick, dragged between the slider and the disk by the moving disk. As part of the RCA 8580 (4000 bpi) file program, a slider that would fly closer to the disk than the slider for the RCA 594 file (2200 bpi) was developed.

Figs 1 and 2 illustrate the relation of the slider to the disk and define terms used in this paper. The passage of air between the slider and the disk is well described by the Navier-Stokes equations of gaseous flow. These equations relate two types of force to the motion of a gas: that force arising through the gas inertia, and that arising through the gas viscosity. Trial calculations considering the inertial forces alone show that the pressure under the slider deviates from the ambient pressure of one atmosphere by at most 1/6 atmosphere, at ordinary disk speeds. Calculations considering only the viscous forces show pressure distributions rising to as much as 10 atmospheres in

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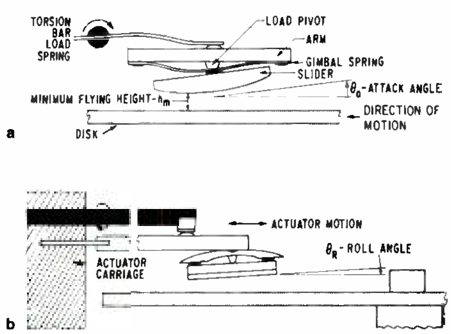

Fig. 1—Typical disk-file air-bearing slider: a) viewed radially to disk; b) viewed tangentially to disk.

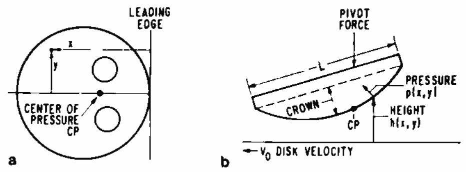

Fig. 2—Important quantities used in slider analysis: a) definition of coordinates x and y, and computed center of pressure (cp); b) definition of length, crown, pressure, height, and disk velocity.

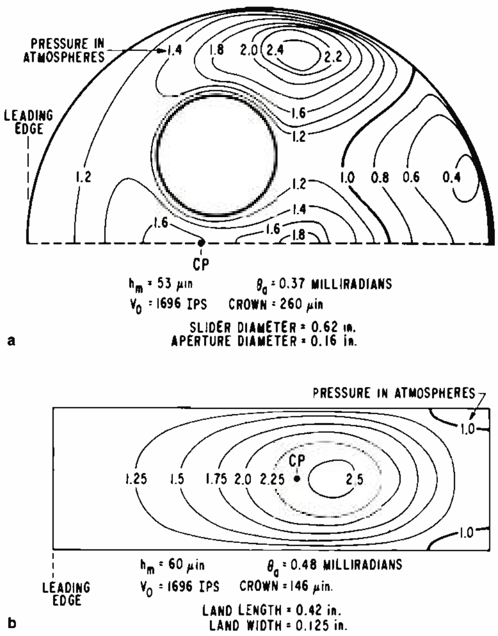

Fig. 3—Constant-pressure contour maps of typical sliders: a) circular slider (half shown) with pressure-relief apertures; b) rectangular slider (one land of dual-land catamaran design).

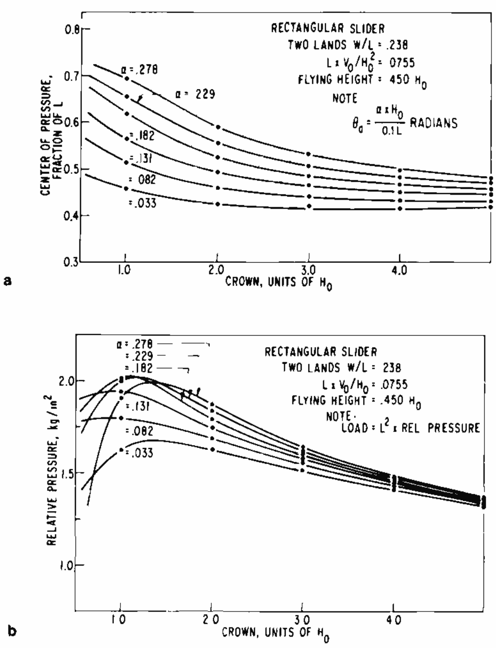

Fig. 4—Slider characteristics in normalized form: a) normalized center of pressure *vs* normalized slider crown with normalized attack angle α as parameter; b) normalized load (relative pressure) *vs.* normalized crown.

Table I. Reynolds equation.

$$\frac{\partial}{\partial x}\left[p^m h^3\left(1+\frac{6\lambda}{p^m h}\right)\frac{\partial p}{\partial x}\right]+\frac{\partial}{\partial y}\left[p^m h^3\left(1+\frac{6\lambda}{p^m h}\right)\frac{\partial p}{\partial y}\right]-\frac{6\mu V_o L}{P_o H_o^2}\left[\frac{\partial(p^m h)}{\partial x}+2\frac{\partial(p^m h)}{\partial t}\right]=0$$

x, y	are the coordinates over the slider surface (see Fig. 2a);
p	is a function of the coordinates x and y representing the pressure measured in units of ambient pressure, p_o;
$1/m$	is the polytropic gas constant;
h	is the head-to-disk separation (also a function of x and y);
λ	is the gas mean free path at pressure p_o;
μ	is the viscosity of the gas;
V_o	is the disk velocity;
L	is the slider length;
H_o	is a unit distance for slider-disk separation (typically 100 microinches); and
t	is time (measured in units of L/V_o).

front of the slider where the gas is compressed, falling to as little as 1/10 atmosphere in the decompression region at the rear of the slider. The viscous forces are thus the major contributors to the pressure.

The physical picture is that the air is viscously dragged by the disk under the front of the slider where it is compressed by the narrowing separation between the slider and the disk (Fig. 1); then the air is dragged along by the disk, causing decompression to below an atmosphere at the rear of the slider.

The viscosity model allows the complicated Navier-Stokes equations (three nonlinear partial differential equations in three-space variables) to be reduced to the Reynolds equation[1]—a single but still nonlinear partial differential equation in two-space variables.

The Reynolds equation, after appropriate normalization, is as shown in Table 1.

The assumptions that make possible the derivation of the Reynolds equation from the Navier-Stokes equations are:

1) The gas flow is laminar;
2) The vertical component of flow is negligible;
3) The vertical variation of pressure is negligible;
4) The gas obeys approximately a polytropic law; and
5) The velocity of the gas at each surface (disk and slider) is proportional to the average of the velocity of the surface and the velocity of the gas one mean free path away from the surface.

Assumption 5) is known as the slip correction. If this correction is omitted, the factor $(1+6\lambda/p^m h)$ in the Reynolds equation reduces to 1.

A computer program has been written for finding solutions to the Reynolds equation using a semi-implicit iterative technique.[2] For all the solutions, the slip correction is included and isothermal gas conditions ($m=1$) are assumed. In this form, the solutions best match the experimental results.

Two computer-generated distributions of steady-state slider pressure are shown in Fig. 3. The distribution of Fig. 3a is for a slider similar to that used in the RCA 594 file, having pressure relief apertures. Note the relatively large area at the rear of the slider for which the pressure is less than ambient, contributing negative lift. The negative-lift region is very much smaller in the apertureless rectangular slider design shown in Fig. 3b.

Figs 4a and 10 give the total lift force and center of pressure as functions of crown height. These are obtained by integrating the pressure distributions.

The curves of Fig. 4 are presented in normalized form. This is useful since it permits the use of a single set of curves to find the steady state solutions for a wide range of slider sizes, crown heights, and disk velocities. In the Reynolds equation, as long as the quantity

$$K=6\mu V_o L/P_o H_o^2$$

is maintained constant, and the relative dimensions of the slider are unchanged, the Reynolds equation has the same solution. For instance:

1) If the disk speed, V_o, is doubled, and the slider length, L, is halved, H_o is unchanged and thus the new slider flies at an unchanged height. Since the relative pressure distribution is unchanged, the new total load is 1/4 the original load. The

attack angle is doubled since the angle varies as H_o/L.

2) If the speed is doubled but the length and width are unchanged, H_o^2 is doubled, and the new slider flies $\sqrt{2}$ times as high for the same load. The crown height is also multiplied by $\sqrt{2}$ since it varies as H_o.

Figs 4a and 4b show curves of the variation in normalized center of pressure and normalized load (relative pressure) as functions of the slider normalized crown; parameter α is proportional to the attack angle. The curves are for a slider having two rectangular lands, each of width-to-length ratio 0.238, separated by a slot (catamaran design). To use such curves, the normalized crown and center of pressure fraction (slider pivot-point location) are first determined. For example, for a slider of length 0.420 inch, crown 200 microinches and pivoted at the center, one enters the curves at crown 2.0 and pressure fraction 0.5. The resulting intersection point determined from Fig. 4a yields α=0.140, from which the attack angle θ_a=0.34 milliradian is calculated. The relative pressure determined from Fig. 4b is 1.75 kg/in². Multiplying this by L^2 gives a final load of 311 grams.

The flying height for the curves shown is 0.45 H_o or 45 microinches. By using families of curves, each set for a different flying height, load and attack-angle plots may be obtained as a function of flying height (Fig. 11).

Steady-state solutions of the Reynolds equation can also be used to predict the oscillation of the slider about equilibrium if external force is applied at a low frequency (a few hundred Hertz). A typical forcing function is a wavy disk, which produces deviations from equilibrium in flying height and attack angle. The variation in aerodynamic lift force for deviations in flying height, attack angle, and disk curvature can be obtained from a set of steady-state curves; these variations can be introduced into the mechanical equations of slider motion to predict the deviations caused by a given forcing function. The net of these forces is restoring in nature and tends to make the slider fly at constant separation and angle over a wavy disk.

These analytical expressions are valid at a few hundred Hertz because the time-dependent term in the Reynolds equation, $2\,\partial(p^m h)/\partial t$, is

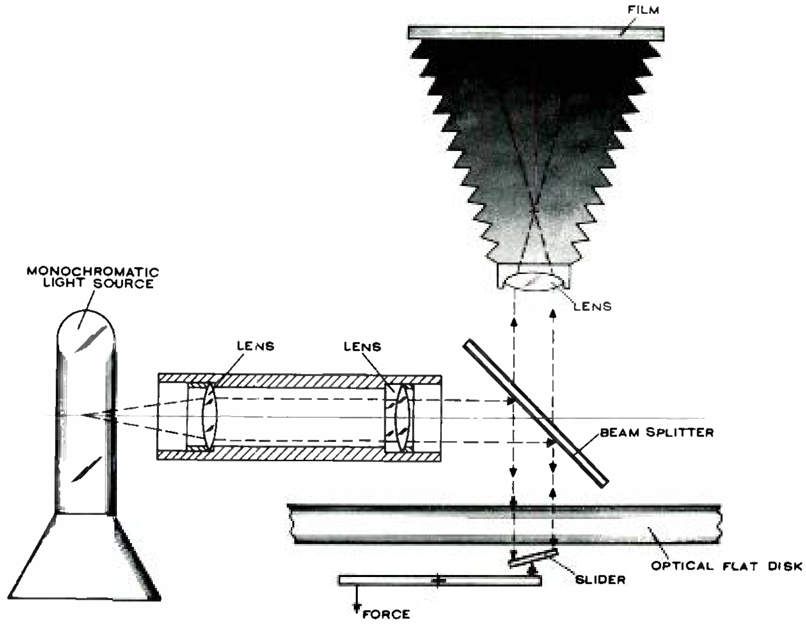

Fig. 5—Test setup for optical-interference-fringe method of determining slider flying height and altitude angle.

1) The analog of a velocity-dependent force in a mechanical system, thus damping the slider motion slightly, and

2) Small for practical designs.

As the frequency increases to the resonance of the mechanical system (a few thousand Hertz), the magnitude of the time-dependent term increases and the pressure no longer remains in phase with the separation. Under these conditions, computers are necessary to calculate the varying pressure and ultimately the slider motion.

Experimental methods

Two basic approaches for measuring the flying properties of a slider have proven of greatest utility. One approach makes use of small capacitor probes mounted in the slider. The other approach involves monitoring the interference patterns formed between the slider flying surface and a glass disk. The probe technique is of major use in relating flying dynamics to actual disk waviness characteristics, whereas the fringe technique is most useful for evaluating operating sliders.

Optical method of measuring flying height

The optical fringe technique is shown in Fig. 5. Illumination from a monochromatic light source is collimated and reflected onto the slider flying surface through an optically flat glass disk by a half-silvered mirror beam splitter.[3] The beam is partially reflected at the glass-to-air interfaces and the slider surface; the reflected beams interfere to produce fringe patterns (Fig. 6). Only the interference between light reflected at the slider surface and light reflected at the adjacent disk surface is visible, because fringes resulting from longer-range interferences are washed out due to the limited coherence length of the monochromatic light used (non-laser source).

Starting with the disk stationary and the slider in contact, a dark band is observed corresponding to the contact region. Rotating the disk causes the dark band (slider low point) to alternate in light intensity and shift in position as the flying height increases. Each complete intensity cycle corresponds to a height increase of $\lambda/2$, where λ is the illumination wavelength ($\lambda/2$=10.75 microinches for the illumination used). By counting the intensity cycles to the final flying height, the absolute height is obtained.

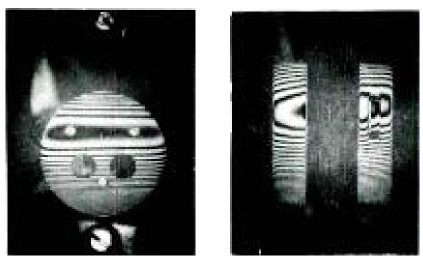

Fig. 6—Typical fringe patterns: (left) apertured circular slider (with R/W head); and (right) rectangular slider (with capacitor probes).

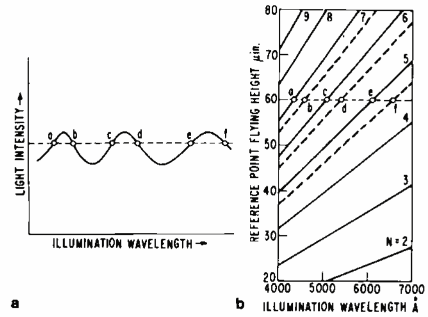

Fig. 7—Swept-wavelength optical fringe technique: a) intensity *vs.* wavelength for a fixed reference point on the slider surface; b) determination of flying height by matching constant-intensity wavelengths, λ_a, λ_b, . . . , against the curve family of allowed wavelengths *vs.* height.

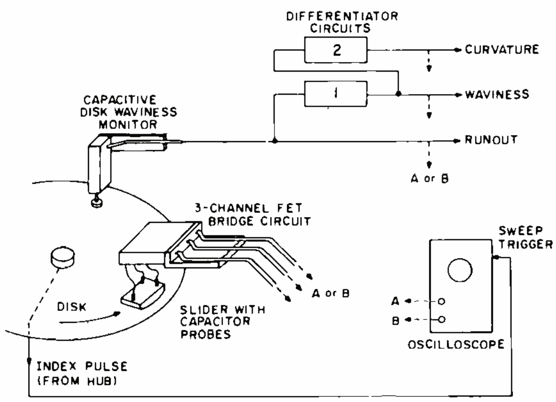

Fig. 8—Capacitor-probe setup for correlating slider dynamic flying characteristics with disk surface properties.

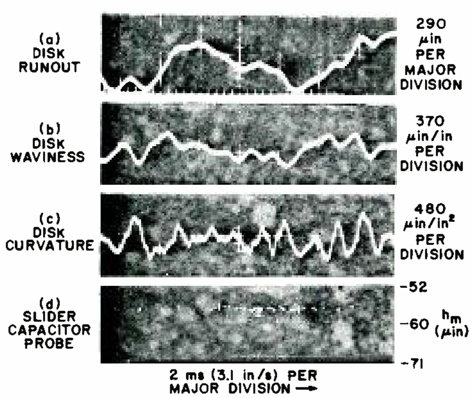

Fig. 9—Typical waveforms obtained witn the capacitor probe apparatus: a) disk surface runout; b) disk surface waviness; c) disk surface curvature; d) slider low point flying height.

Slider attitude angle is obtained from photographs of the fringe patterns, by counting the fringes between fiduciary marks.

The technique described above requires that the disk start rotating with the slider in contact. This is feasible with hard, dense alumina sliders but can be damaging to the disk and slider with softer slider materials. To avoid contacting, a swept-wavelength optical technique has been developed. In this approach (Fig. 7), the disk is brought to operating speed, the slider is loaded onto the disk, and the light source is swept continuously through a wavelength range, causing the fringes to shift position also through a range. If the light is swept from violet to red, the fringes appear to expand outward from the central fringe. By fixing a slider reference point and recording the wavelengths λ_a, λ_b, etc., for which equal fringe intensities are obtained, the height of the reference point can be found from a best-fit computer solution of the form $N_a\lambda_a/2 = N_b\lambda_b/2 = N_c\lambda_c/2 = \cdots$ illustrated graphically in Fig. 7b. The technique is accurate to approximately one quarter of the average wavelength, or ±5 microinches in flying height.

Capacitor probe method

In this approach,[4] small (typically 0.025 inch diameter) nichrome capacitor probes are epoxied into holes in the crowned slider and lapped flush (within ±2 microinches) with the slider flying surface. Generally, three probes are used per slider to permit attitude angle in addition to flying height data to be obtained (Fig. 6a shows a typical probe triad). The probe-to-disk capacitances, which usually range between 1.5 and 4 pF (200 to 35 microinches probe-to-disk separation), are recorded via a 3-channel FET-bridge circuit mounted rigidly close to the slider on an arm attached to the actuator carriage. The bridge is driven at 10 MHz, permitting dynamic capacitance fluctuation data to be obtained at frequencies approaching 1 MHz. The test setup is diagrammed in Fig. 8. The oscilloscope is triggered via a fast-rising index pulse generated at the disk hub to enable repeated runs over the same disk location. A disk-waviness-monitor probe is included for correlating dynamic slider fluctuations with disk surface runout, waviness (first spatial derivative of runout) and curvature (second spatial derivative) parameters.

Typical waveforms obtained with the capacitor probe setup are shown in Fig. 9. The slider height fluctuation (waveform **d**) is shown matched in time with disk runout (waveform **a**) waviness (waveform **b**) and curvature (waveform **c**) fluctuations. The slider fluctuation most closely matches that of the disk curvature. This relationship has been confirmed theoretically from the approximate solutions of the slider equations of motion described earlier.

Results

To obtain lower-flying sliders, initially the relief holes of the conventional circular sliders were enlarged; this produced sliders that were crash prone at high loads. A possible cause for this result was deduced from solutions of the Reynolds equation. As seen in Fig. 3a, the apertures produce relatively large areas of negative lift. For positive angles of attack, the areas are sufficiently small that the overall lift is positive. If the angle of attack is momentarily negative (e.g., by too rapid a change in disk waviness) the negative lift areas grow rapidly in size with consequent serious decrease in net lift. This action is illustrated by the computed load *vs.* crown curves, with attack angle as parameter, shown in Fig. 10a. For a typical crown of 200 microinches, the lift is dangerously reduced at a −0.42 milliradian attack angle.

The crash difficulties with apertured sliders prompted studies of new geometries. A design for which the load characteristics can be quickly computed consists of two rectangular lands separated by a slot (catamaran design —Figs. 6b and 12). As shown in Fig. 10b, this slider exhibits a lesser loss of lift with decrease in attack angle. This

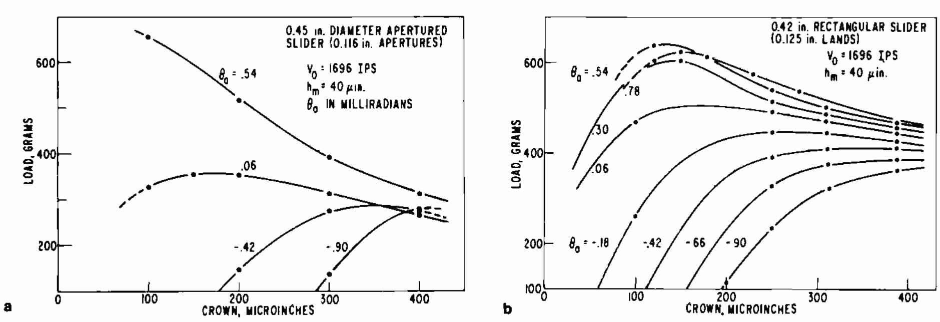

Fig. 10—Comparison of apertured *vs.* rectangular sliders: a) steady-state load *vs.* crown, computed for a 0.45 in-diameter apertured slider; b) similar curves for a 0.42-in.-length rectangular slider (load for two lands).

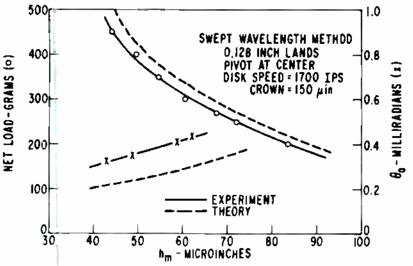

Fig. 11—Comparison of experimental results with Reynolds-equation steady-state load and attack angle *vs.* flying-height computations.

advantage was verified in tests which showed the slider to be markedly more crash resistant. This rectangular design was tentatively adopted for the RCA 8580 file.

Typical load and attack angle *vs.* minimum (low point) flying height curves for a 0.42-inch-long rectangular slider, obtained experimentally and by calculation, are shown in Fig. 11. The experimental curves were obtained using the swept wavelength optical method. The calculated curves assumed isothermal gas conditions ($m+1$) and included slip correction. In general, with these assumptions the calculated load values are in satisfactory agreement with those determined by the optical and capacitor probe methods, with the possible exception that the calculated load is slightly too high. Assumptions of reduced slip and/or adiabatic gas conditions result in even larger load values compared with experiment and are clearly untenable.

Agreement between calculations and experiment for attack angle is not as good as that for load. As shown in Fig. 11, the measured angles tend to be larger than the calculations, typically by 0.1 to 0.2 milliradian. An increase in attack angle has little effect on the expected load (see curves of Fig. 10b for θ_a larger than 0.3 milliradian) but is important in determining the optimum position of the core gap. Analysis indicates that 4.3 gram-inches of residual torque on the slider produces an 0.1 milliradian angle change at 50 microinches flying height. A conventional gimbal spring (Fig. 1—0.004-inch-thick stainless steel) has a spring rate in the pitch (attack) mode of 2.8 gram-inches per degree of twist. Normally, the slider is set at an initial attack angle of +1 degree to obtain loading and unloading characteristics free from flutter. This leads to a gimbal torque of 2.8 gram-inches on the loaded slider in a direction to increase the attack angle, accounting for most of the angular discrepancy. The remainder may result from lift produced on the top surface of the slider by disk windage; a partial vacuum caused by turbulence can be expected near the top leading edge, and this would increase the attack angle.

An improved gimbal design has been developed to minimize the influence of the spring on slider attitude angle (see Fig. 12). This gimbal has three twist axes instead of two. Fabricated in 0.010-inch-thick beryllium-copper, the spring rates are less than those of conventional springs, yet satisfactory longitudinal-position stiffness is obtained. The design shown in Fig. 12 also includes an air-pressure-activated bellows for slider loading and unloading. This has performed well but does require additional tubing, air compression, and air-filtering components.

Dynamic height fluctuations of rectangular and circular sliders during steady-state operation were obtained using capacitor probes. Results for flying over a disk of acceptable waviness (250 μin/in) are listed in Table II). The rectangular slider when crowned to 140 microinches (or greater) flies with less percentage height fluctuation (±2.3% average) than a standard RCA 594 file slider (±4.6%) or a 0.51 inch diameter apertured slider (±3.0%).

Conclusions

The solutions of the Reynolds equation show the superiority of the dual-land rectangular slider, without apertures, over the older circular slider with apertures. The superiority has been verified in numerous tests by the occurrence of fewer slider crashes, better dynamic stability, and less slider bounce during loading and unloading operations.

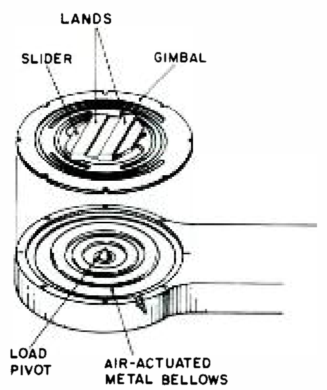

Fig. 12—Rectangular slider with 3-axis, low-torque gimbal spring and bellows-loading actuator arm.

SLIDER	CROWN (μ IN.)	PIVOT POSITION (IN.)	FLYING NOMINAL (μ IN.)	HEIGHT FLUCTUATION (%)
0 634" DIA STD	250	+0 078	66	±4 6
0 508" DIA	170	+0 064	62	±3 0
0.420" RECT	95	-0.022	59	±4 1
0.420" RECT	140	-0 022	58	±2 7
0 420" RECT.	195	-0 022	57	±2 0
0 420" RECT	200	+0 040	57	±1 8

Table II—Slider fluctuation results. Disc waviness is 250 μ in./in.; velocity is 1540 in./s.

The capacitor and optical techniques developed for measuring slider flying height and angular orientation have well complemented each other. The optical technique can be used with unmodified sliders and is therefore most suited for production testing of completed slider-core assemblies. The capacitor technique yields fast dynamic stability information not presently obtainable optically and is therefore most useful in developing improved sliders and disk surfaces.

The correlation between the solution of the Reynolds equation and experimental data, although presently imperfect, is nevertheless sufficiently good that the isothermal-gas, slip-corrected form of the equation can be accepted with confidence. Evaluation of the data shows that the Reynolds equation load values may be slightly high.

Acknowledgments

Many people have contributed to the effort described. In particular, at the RCA Laboratories, G. Kasyk and J. Walentine aided in the development of the capacitor probe technique. J. Walentine also aided in applying the single-wavelength optical method. At the Computer Systems Marlboro Product Laboratory, R. Lalchandani utilized the capacitor probes. Also, at the same location, F. Grimaldi and R. Rubenstein developed and utilized the versatile swept frequency optical technique.

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Hybrid microelectronic video amplifier

L. J. Thorpe

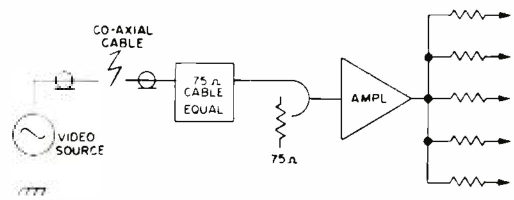

Fig. 1—Video distribution scheme using the TA-43 distribution amplifier.

RCA has developed and produced a state-of-the-art line of basic video amplifiers with performance and features meeting both domestic and international broadcasting industry demands for improved video distribution equipment. The TA-43 distribution and equalizing amplifier and the TA-45 clamping amplifier provide features useful to both the simplest and most complex TV installations. The actual video handling circuits have been designed around a rigorous "hands off" operating philosophy which is commensurate with modern TV system planning. Hybrid circuitry has been applied throughout these designs to achieve greater reliability and stable performance.

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graduated in 1961 from College of Technology Dublin, Ireland, as Grad IEE. From 1961 to 1966 he worked with BBC in London in their Television Designs Department where he worked in the Signal Processing Labs on a TV standard converter and automatic correction equipment for color-TV signals. In 1966, he became MIEE and a Chartered Engineer (C.Eng.). Mr Thorpe joined RCA in 1966 and worked on TK-44A color camera head video design. In 1969, he joined TV Terminal group and worked on distribution equalizing amplifier, clamping amplifier, and special effects equipment for video switchers

THE IMPROVED QUALITY of broadcast-picture-generating sources, such as color cameras and video tape recorders (VTR's), coupled with consumer and commercial demands for high quality color broadcasts have resulted in a close examination of all the video-handling equipment between the picture source and the domestic receiver. As a result, the onus of performance excellence has been placed on studio and TV distribution systems. This comes about because of the relative leniency of tolerances on cameras, VTR's, and (at the other end of the chain) TV transmitters. The presence, in between, of microwave links or long cable distribution systems further loosens the system tolerances.

With the advent of the larger production facilities, and consequently more extensive routing of video signals, the number of active electronic elements in a given video path can easily total twenty or more before exiting for transmission.

By far the least expensive, most convenient, accepted method of video distribution is the unbalanced, double-shielded, video cable. The cable has, of course, finite attenutation which varies with frequency and unit length. The current extensive use of long cable lengths has accentuated the need for convenient and accurate means of equalizing these cable runs. In response to this need, the TA-43 distribution and equalizing amplifier was developed. This unit can be used as a straight distribution amplifier and as an equalizing amplifier to restore an impaired video signal to its proper level.

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An additional problem is presented by the use of long coaxial cable throughout a building or between building complexes. This has left the video signal quite susceptible to low frequency disturbances from several diverse sources, including different ground potentials at either end of the run, electromagnetic induction from power lines, interferences arising from telemetry sources, or "spikes" from switching heavy power systems.

These problems have created a need for a video device which can easily be placed at a suitable point in a system to remove the offending disturbance which "rides," as it were, on the wanted video signal. The TA-45 clamping amplifier has been designed to remove such disturbances on the video signal where sync pulse stabilization is not required.

The underlying concepts of the TA-43 and TA-45 amplifiers will be discussed in the paragraphs that follow.

TA-43 distribution and equalizing amplifier

Changing the frequency response of an amplifier alters its delay and upsets the timing of a video path. Also, few amplifiers can have their gain altered without changing the amplifier delay: the gain change is normally accomplished by varying one resistive element in a negative feedback path which affects the group delay of the closed-loop amplifiers. In systems demanding delay specifications of ±1 ns for the color subcarrier, such adjustments wreak havoc on an overall system timing. Accurate prediction and maintenance of video performance figures are virtually impossible to achieve and tandem connections give rise to many frustrations. The problem was approached with the following premises:

a) Modern picture sources (cameras, VTR's) go to considerable lengths to produce a 1-V p-p composite video output signal which is quite stable.
b) A TV system exists solely to distribute this video signal to various production facilities (mixers, etc.) and finally to the studio output for transmission. Therefore, the distributing media should have no operational controls available.
c) When a video signal is impaired in level or response due to traversal through coaxial cable or a lumped delay line, it shall be immediately equalized and restored to a 1-V p-p level, and distributed further if required.
d) All adjustments of video level shall occur at the source or at the destination.

Having established the basic ground rule of no video control inside a distribution system, attention was now concentrated on the production of a video distribution amplifier which possessed the following features:

1) Highly stable and fixed gain;
2) Minimum distortion to a coded-color signal;
3) Minimum insertion delay with tight tolerance on that signal;
4) Five 75-ohm outputs for one input;
5) Self contained power supply to facilitate insertion at any point in a system; and
6) Low cost.

The design effort produced a single amplifier which could be employed as a straight distribution amplifier of O-dB gain. The amplifier can also be used with a fixed-cable equalizing network to restore the video level to 1-V p-p. The basic distribution scheme is shown in Fig. 1.

To minimize the cost per installation and to optimize the equalizing network for a particular cable installation, a fixed 75-ohm constant impedance network was designed for a series of discrete lengths of cable. A unique equalizing network is available for every 50 feet of double-shielded co-axial cable, from 50-feet to 600 feet. Each equalizer in a series with its associated cable length produces a combined loss of 6 dB; this loss is made up by a 6-dB amplifier. Thus, a single amplifier type can be used for all equalizing installations up to 600 feet. To cover the range from 700 to 1500 feet another series of equalizers are available in 100-foot increments, each producing a fixed 15-dB loss when associated with its own length of cable. A fixed amplifier gain

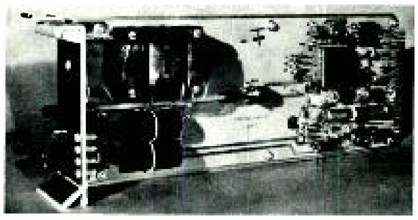

Fig. 2—Plug-in TA-43 amplifier.

of 15 dB is used to restore the video level to 1V p-p.

The three basic amplifiers offered in the TA-43 line are therefore 0 dB, 6 dB, and 15 dB. The performance specifications of each amplifier (Table I) are identical. The amplifiers are of the plug-in type, as shown in Fig. 2. The particular equalizer employed is constructed on a plug-in card which mounts adjacent to the amplifier (see Fig. 3).

Both sockets are an integral part of a connector assembly which also houses the two co-axial input BNC sockets and the five co-axial-output BNC sockets.

Video amplifier as a hybrid microcircuit

The amplifier is sufficiently flexible to meet many video needs other than those required in the TA-43. Because of the extensive Broadcast product line manufactured by RCA, there arises diverse demands for amplifier circuits capable of meeting modern stringent specifications in handling coded color signals. The desirability of having a single amplifier design capable of answering the majority of these needs is apparent, and this desirability is enhanced if the particular circuit is available in a package which would interface with a variety of circuit boards and packing densities. These factors lent stimulus to a design

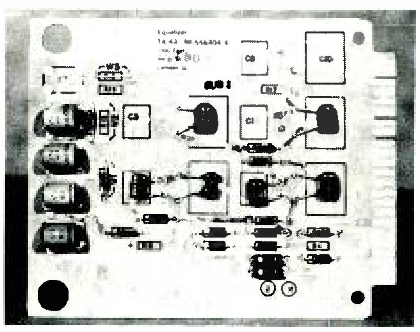

Fig. 3—Equalizer plug-in card.

Table I—Electrical specifications for the TA-43 distribution amplifier.

Type of input	High impedance, bridging
Input return loss (amp. power switched *on* or *off*)	46 dB up to 6 MHz
Permissable input voltages	1.5 V. pp. positive-going composite video. 2.0 V. pp. color subcarrier 3.58 MHz of 4.43 MHz.
Signal outputs	5 outputs of nominal 1 V. pp. positive going video from 75-ohm source impedances (resistive fan out)
Signal outputs	5 outputs of nominal 1 V. pp. positive going video from 75-ohm source impedances (resistive fan out)
Output return loss	45 dB up to 8 MHz
Isolation between outputs	60 dB up to 1 MHz. 46 dB up to 4.43 MHz, 40 dB at 8 MHz
Input/output isolation	80 dB up to 1 MHz. 60 dB up to 8 MHz
Quiescent output dc voltage	Factory set to $0V_{DC} \pm 10mV$ at 25°C into 75 ohms termination maintained within ±50 mV over any temperature change of 20°C from 0°C to 55°C
Polarity of output video signal	Same as input positive going
Overload margin	3 dB for any input APL with 40% overshoot or 3.2V. pp., sinewave from 10 kHz to 2 MHz with all inputs loaded
Amplitude frequency response (reference to 100 khz)	Freq. range 10 Hz to 6 MHz ±0.05 dB. Freq range 1 Hz to 10 MHz ±0.2 dB, Freq. range 10 MHz to 15 MHz ±0.5 dB. No rise >1dB above 15 MHz.
Group delay frequency response	1 MHz to 14 MHz, 1 ns
Propagation delay	22.5° at 3.58 MHz or 16 ns.
Squarewave transmission	Response to T-step <0.25% line-time distortion <0.25% short-time distortion Response to 50-Hz squarewave <0.25% tilt or sag
Pulse transmission	K rating K_{2t}<0.25%. K rating KT <0.25%
Chrominance luminance delay inequality (measured with standard 20T pulse)	1 ns
Chrominance luminance gain inequality	0.05 dB
Non-linear distortion at 3.58 MHz:	
Differential gain for output voltages (1V, pp. composite video with all outputs loaded)	0.1% for all APL's
Differential phase for output voltages 1v, pp. with all outputs loaded	0.1° for all APL's
S/N ratio	76dB, pp, signal-to-RMS noise, unweighted, referenced to 0.7V pp picture signal, and measured over a bandwidth of 10 kHz to 5.5 MHz.
Low frequency bounce	Single time constant performance with 63% decay time of 10 seconds
50/60 Hz, pp, hum	60 dB below 0.7V pp

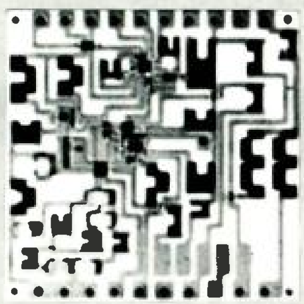

Fig. 4—Hybrid microcircuit amplifier.

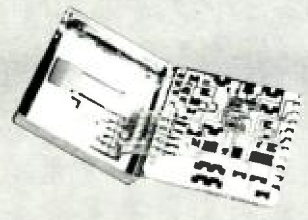

Fig. 5—Eutectic bonding to case maximizes heat transfer.

program which resulted in the production of the above amplifier in hybrid microcircuit form.

The actual hybrid substrates (Fig. 4) contain various semiconductors in chip form, fired thick-film resistors, and chip capacitors. Because of the appreciable power capabilities required to drive five 75-ohm lines from a class-A output stage, the total package must dissipate some 3.5 watts. To alleviate the package thermal design, the power-output totem pole is mounted on a beryllium substrate of its own which is eutectically bonded to the cover of the case, thus maximizing heat transfer to the outside world (see Fig. 5). The rest of the amplifier circuit is mounted on a second beryllium substrate which is bonded to the lower portion of the hybrid package. Connections between the two substrates is via wire bonds.

As used in the TA-43 amplifier, the hybrid package dissipates 3.5 W and operates at a case temperature of 75°C. Because of the very low thermal resistance of the components, the semiconductor chips operate at a temperature only a few degrees above that of the outside case, and are hence comfortably within their ratings. The concentration of so much circuitry in so small a package, while leaving the overall power requirements unchanged, does offer an educational problem to customers who will purchase a hybrid video amplifier for the first time. A note has been stamped on all hybrid packages to alert the user to the fact that the high case temperature is perfectly normal.

Many applications other than the particular one of the TA-43 will require less power capability, and for this reason, the hybrid video amplifier has been designed with the capability of altering simply the standing current in the output driving stage to meet a variety of load requirements. The hybrid itself has the capability of driving a single 75-ohm line, with the overload margins quoted in the specifications given earlier. To raise the power capability to drive two or more 75-ohm loads, (with a maximum permitted of 5), two shunt resistors are externally connected across terminals provided on the hybrid microcircuit.

TA-45 clamping amplifier

The TA-45 has been designed to cope with almost all environments met by unbalanced co-axial systems. For each type of disturbance met, the appropriate cancelling circuit may be set up via simple switches on the module front panel. In most installations, the particular form of the disturbance is not precisely known. However, the TA-45 has been made directly interchangeable with a TA-43 amplifier, so if a problem is encountered in an installation the TA-45 can be plugged in, and a few adjustments on its front panel will quickly locate the appropriate cancelling mechanism.

A block diagram of the TA-45 is shown in Fig. 6. The differential amplifier is followed by a feedback clamp of the shunt variety. This circuit samples the output of the hybrid video amplifier during the video back-porch interval and feeds back a low frequency correcting signal.

The clamp is operated from clamp pulses derived from the sync on the incoming composite video, and it clamps the back porch of the signal to 0V DC. The sync separator is of special design which permits the system to operate undeterred in the presence of considerable random noise and over a range of incoming signal levels.

To obtain the best compromise between clamp performance and clamp streaking when handling a variety of incoming noisy signals, a control has been provided on the module front panel which permits selection of one of two time constants for the clamp circuit. This control is operated on a subjective basis.

Conclusion

A new high performance video distribution system has been described which employs stable fixed insertion loss elements. The various amplifiers employed are built around a basic hybrid microcircuit video amplifier. The cable equalizing circuits are 75-ohm passive networks which terminate the particular cable. This scheme should contribute to accurate paper design of TV systems and prediction of parameters such as picture impairments, timing, etc. The new TA-45 clamping amplifier should prove useful in the many instances where disturbances appear on the video signal, but where sync pulse stabilization is not required.

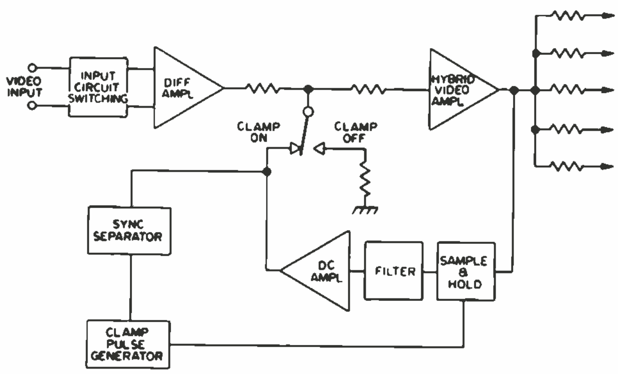

Fig. 6—The TA-45 clamping amplifier satisfies a need in TV transmission systems where susceptibility to interference from extraneous low frequency potentials is commonplace.

Magnetic materials for disks

Dr. E. F. Hockings

The magnetic recording surface used on RCA disk packs 506 and 511 is a dispersion of very fine particles of gamma ferric oxide in an epoxy resin binder system. The thickness of the magnetic coating on the 506-type disks is about 240 microinch and on the 511-type disks is about 160 microinch. This reduction in coating thickness is one of the ways by which the bit packing density on the 511-type disk was increased to 2200 bits per inch compared to the 1100 bits per inch on the 506-type disk. Further increases in bit packing density firstly to 4000 and then up to 10 000 bits per inch are likely to be utilized. This paper discusses the possible ways these improvements might be achieved through the optimization of the magnetic medium.

DIGITAL DATA are commonly stored by magnetic recording on either a continuous surface or a discrete array of magnetic material. The continuous surface has to be moved relatively to its read/write transducer to access recorded data and to obtain surface for further recording. This required mechanical motion leads to long access times and a serial form of readout. A discrete array of magnetic material does not involve motion and hence can be manipulated at electronic switching speeds in a random sequence. However, these highly desirable features are obtained at such relatively great expense that discrete arrays are not feasible for large quantities of data.

The cheaper approach to high capacity storage—continuous surface and concomitant motion—requires magnetic recording surfaces with areas of at least several square feet, and the arrangement of this area governs the behavior and manner in which the store is used. Magnetic tape with its long narrow format provides strictly serial access and has a long average access time. This can be reduced by use of a more square surface that is scanned mechanically in two perpendicular directions. A single surface of this form is the curved surface of a drum, but this has a low ratio of area to volume when magnetic surfaces of many square feet have to be provided. A more compact arrangement is to divide the magnetic recording surface into separate disks and then stack these coaxially.

Rotation of a disk readily provides motion in one direction and radial positioning of the transducing magnetic head provides the perpendicular motion needed to exploit the available magnetic surfaces. The radial head motion can be synthesized by sequentially switching an array of stationary heads or by mechanically moving one head across the surface of the disk. The latter procedure needs only one head for each side of each disk in a stack, but this simplicity is obtained at the expense of increased access time. However, a multi-disk stack with radial mechanical positioning of heads can store large quantities of data with a very useful combination of speed, cost, and volumetric efficiency.

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Storage density concepts

The bit packing density achievable on a magnetic recording surface can by increased in three ways[1]:

1) *Decrease the thickness of the recording medium.* Thickness affects the self-demagnetization behavior of a recorded transition, and theoretically the minimum stable magnetic transition width is about one-half the recording medium thickness.[2] Another effect of thickness is to introduce a multiplicity of superimposed output signals whose components derive from layers at different depths in the recording medium. The further a layer is from the magnetic head, the smaller its corresponding output signal amplitude and the broader its pulse width. For saturation recording, the highest pulse resolution should occur for the thinnest coating. The selected thickness has to be consistent with acceptable output signal, good surface finish, uniformity of coating thickness, and good wear characteristics. The last is important because, although the recording heads usually glide over the disks, transient contacts do occur.

2) *Increase the coercivity (half width of the hysteresis loop) of the coating.* High coercivity coatings are able to maintain closely spaced magnetic transitions with-

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received in 1950 the BSc in Chemistry from the University of London, England. He served in the Army and then joined the research laboratories of the Electric and Musical Industries, Hayes, England. After working on photoemitting and photoconducting materials for two years he entered Imperial College London, and received the PhD in Chemistry in 1957, and since that time has been with RCA Laboratories. Dr. Hockings has carried out research on the preparation and properties of thermoelectric semiconductors and on magnetic materials for recording media. Currently he is head of Recording Materials and Glass Research. He has co-authored a dozen technical papers and has three patents. He is an Associate of the Royal Institute of Chemistry and a Fellow of the Chemical Society.

Table I—Properties of magnetic powders.

Material	Particle size: Length (μ)	Particle size: Width (μ)	Coercivity H_C (Oe)	Magnetization B_S (gauss)
γFe_2O_3	0.44	0.10	260	4400
γFe_2O_3	0.27	0.06	300	4300
$Co\text{-}\gamma Fe_2O_3$	0.05	0.05	650	3650
Fe_3O_4	0.27	0.06	320	5400
$CoZn\text{-}Fe_3O_4$	0.27	0.06	485	5150
CrO_2	0.31	0.03	430	5050

out undergoing self-demagnetization. Not only is the resolution improved but also the output amplitude should increase with increasing coercivity.[3] The selected value has to be consistent with the magnetic field generating capability of the recording head.

3) *Achieve high squareness of the hysteresis loop.* Dispersions of long narrow particles can be magnetically oriented during coating, and this leads to an increased signal output and also to a reduction in background noise level.[4] On a disk, the direction or orientation change must continuously coincide with circular recording tracks, since unidirectional orientation would cause modulation of output to occur during disk revolution. Although circular orientation has been described,[5] it has not been used hitherto in disk packs. For continuous magnetic films, the squareness can be controlled by variations during the deposition.

Some other ways to increase storage capacity also involve the magnetic material. Increases in track density achieved by decreasing track width require magnetic materials capable of retaining sufficient magnetic flux to produce an acceptable output signal from a narrow track. Increased resolution obtained by decreases in head-to-disk separation lead to transient head-to-disk contacts, and these accentuate the need for disk surfaces that can adequately protect the magnetic material.

Magnetic fine powders

The magnetic material used in current disks is gamma ferric oxide, γFe_2O_3; its properties are listed in Table I. The values of coercivity and 'saturation' magnetization depend somewhat upon the conditions of the measurement. The values shown have all been determined under the same conditions and can be compared to each other, but do not necessarily agree exactly with other published data. The two examples of γFe_2O_3 have different particle sizes, and the smaller particle gives the higher coercivity; 300 oersteds is, in fact, near the maximum that can be achieved with γFe_2O_3. Higher coercivities can be obtained by the incorporation of cobalt into γFe_2O_3 during its preparation. Two types of $Co\text{-}\gamma Fe_2O_3$ material can be prepared. One has a small cube-shaped particle with typical properties shown in Table I. The other type has a long narrow particle with a length of about 0.3 μ; this material has only recently been developed and hence its magnetic properties are not included in Table I. The concentration of cobalt controls the coercivity, and thus a range of coercivities can be obtained that extend from 300 to 800 oersteds, depending upon the cobalt content which ranges up to 5%. The higher values of coercivity are associated with lower magnetization values.

A magnetic material with a 50% higher magnetization is magnetite, Fe_3O_4, but this has not been used in commercial disk coatings because there is a tendency for small particles of this material to oxidize at room temperature.

The incorporation of cobalt and other elements, such as zinc, into Fe_3O_4 increases the stability and allows the coercivity to be controlled in the range of 350 to 1000 oersteds, and the material has a high magnetization value. Chromium dioxide, CrO_2, is another important recording material, and its magnetic properties are also shown in Table I. The high value of its length/width ratio leads to a desirable high squareness of the hysteresis loop. The coercivity can be controlled by varying parameters in its hydrothermal preparation, and values in the range 100-600 oersteds are readily achievable. However, at the higher end of this range, the magnetization is somewhat lower.

The oxide powder material most likely to increase bit packing density over the present γFe_2O_3 is a coating about 80 microinch thick of $CoZn\text{-}Fe_3O_4$ with a coercivity of 500 oersteds dispersed in an epoxy-resin binder system. Experimental disks made with these materials have been shown to store more than 4000 bits per inch. Further advances can be made by reducing the thickness of the recording medium; but because of the requirement to have sufficient output signal, higher magnetization materials have to be used.

High magnetizations are provided by metals, and these can be used either as discrete fine particles or as continuous films. Very fine particles of iron, cobalt, or their alloys can be prepared to have coercivities in the range of 500 to 1100 oersteds. The use of materials in the upper end of this range leads to a need for recording heads capable of generating magnetic fields that are higher than those currently achievable. The lower coercivities have the potential of providing disk coatings that would be superior to present oxide coatings. However, they would probably be limited by the thickness of the coating for two reasons:

1) Fine metal powders are very susceptible to oxidation; hence, each particle has to be protected by an inert layer that is usually non-magnetic. Even though it may be only a few atomic layers thick, the large specific surface area of sub-micron powders leads to a dilution of the magnetic material by as much as 25 wt. %. Thus, the recording medium has to be thicker to compensate.
2) The dilution arising from the organic binder causes the recording layer to be thicker than the amount of magnetic material would indicate.

Nevertheless, metal powders could be used in disk coatings of a thickness and coercivity such that they would provide higher resolution than the present oxide powder coatings. The improved disks could be prepared using the same spin-coating method as is used for present disks.

Continuous films

Further improvements in bit packing density can be anticipated if the magnetic metal on a disk is in the form of a continuous thin film; however, this requires different methods of preparation and is a considerable departure

Table II—Properties of metal films.

Material	Thickness (μ)	Coercivity H_C (Oe)	Magnetization B_S (gauss)
Ni	0.4	250	6000
Co	0.1	600	15000
85 Co 15 Ni	0.1	700	15000

from present technology. Nevertheless, research is underway to develop such metal films on disks. The properties of some of these thin metal films are shown in Table II.

These films are generally prepared by electrolytic or electroless plating. Thin films can give recording outputs that are comparable in magnitude to those from particulate oxide coatings even when only one-tenth their thickness. This is possible because the films consist entirely of active materials (not diluted by an organic binder) that have high magnetizations. The metal films are not pure but contain small percentages of other elements such as phosphorus; and it is the concentration of these impurities that is used to control the coercivity. In the case of nickel, the highest coercivity is below 300 oersteds — too low for high bit-packing density applications. Cobalt, containing phosphorus, can be prepared with coercivities in the range 300 to 700 oersteds, and this, together with the high magnetization, makes it a very useful material. An additional advantage is that the hysteresis loop has a high squareness. Thus, the three methods for increasing bit packing density—decrease thickness, increase coercivity, increase squareness—can be simultaneously satisfied when cobalt-phosphorus is used as the magnetic recording medium for disks. Alloys of cobalt and nickel can also be used, as these have similar physical properties. An advantage is that alloys of high coercivity can be readily deposited by electrolytic plating, which is not the case for cobalt alone.

The optimum thickness for magnetic metal films is about 0.1 μ and such layers need to be protected from damage by the recording head during the transient contacts that accidentally occur. The protective layer has to be thin, so as not to lead to excessive losses arising from head-to-disk separation, and it must be abrasion resistant, and also have a low coefficient of friction. These properties are not readily available in one material, and frequently a thin, tough coating is lubricated by another material. Thin, tough coatings can be obtained by the controlled oxidation of cobalt.[6] Only mild heat-treatment cycles can be used so as not to cause distortion of the disk or undesired magnetic effects. The thinness of the magnetic film means that most of its impact resistance depends on the underlayer upon which it is deposited. The underlayer has to be hard, non-magnetic, platable onto the aluminum substrate material, and able to receive cobalt. Potential underlayers are hard copper and nickel. The advantage of copper is that it is inherently non-magnetic. Disadvantages are that it is often not sufficiently adherent to aluminum, and it is slow to build up thick deposits by electroless plating. The advantages of nickel are that it can be deposited after a zincating process so as to give excellent adherence upon aluminum, and thick deposits can be readily obtained. The disadvantages are that the deposition of non-magnetic nickel requires very close control of the plating solution, and non-magnetic nickel can only be subjected to mild heat treatment cycles, to avoid conversion to its magnetic state. Despite these problems, nickel has been found to be a good underlayer material.

Experimental disks have been made with a range of properties so that they can be optimized through the direct evaluation of recording performance. The method of disk preparation is by electroless plating. Flat, smooth aluminum disks 14 inches in diameter are cleaned and then placed in an alkaline zinc solution which deposits a very thin, adherent zinc layer upon the aluminum. The zincated disk is then placed in a nickel electroless plating solution that is controlled by composition and temperature so as to deposit non-magnetic nickel. The surface roughness increases during the plating, and the next step is to polish the nickel to give a surface finish of less than 0.1 μ roughness. The polished surface is then cleaned and plated with cobalt. The composition and temperature of the solution determines the coercivity, magnetization, hysteresis loop squareness, and plating rate. For a thickness of about 0.1 μ, the coercivity can be in the range of 300 to 700 oersteds; saturation magnetization, 10 000 to 16 000 gauss; and squareness, 0.8 to 0.9.

Protective coatings have been prepared by partial oxidation of the cobalt layer under very mild conditions, but the resulting oxide surfaces do not have low coefficients of friction. These can be modified by a controlled lubrication. Coatings of 0.3 μ epoxy were used to provide temporary protection for heads that fly at more than 2 μ above the disk surface. Results from testing under these conditions have shown that the highest resolution is obtained from the thinnest magnetic coatings. Two cobalt-plated disks with similar coercivities and with thicknesses of 0.15 and 0.07 μ gave pulse widths of 160 and 120 ns. respectively, under comparable conditions. The flying height was very much greater than the coating thickness, and this suggests that the decrease in pulse width observed for the thinner film does not arise entirely from geometrical effects. Probably the thinner film has the shorter magnetization transition region. Transition regions have been observed[7] to have domain walls arranged in a sawtooth pattern, and the size of the sawteeth can vary with magnetic properties. The thinner film possibly has a different type of domain wall from that in the thicker film, and this reduces the height of the sawtooth pattern and hence reduces the width of the transition region. Further studies are needed to correlate the width of the transition region with the plating conditions.

Conclusions

The packing density achievable in disk coatings of the present type that contain dispersed magnetic particles can be improved through the use of superior powders of either oxides or metals. Further requirements for bit packing densities up to 10 000 bits per inch can be obtained from metal films. It must be realized, however, that the selection of a magnetic material for a particular application depends upon many factors. The advantages of a recording material with a high packing density have to be considered along with its cost and reliability.

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Stepper-motor film drive

F. R. Goldammer

This paper illustrates a new method of analyzing and designing stepping-motor drives. The basic principles of the method are derived from the characteristics of stepping motors. The effects of the various parameters on stepper motor operation are analyzed.

DESIGN INFORMATION provided by manufacturers allows the selection of a stepping motor for a particular load inertia or friction torque, but a more comprehensive design method is needed for critical applications where combinations of inertia and friction torque are encountered, where oscillations in speed during running must be minimized, or where oscillations must be minimized when stopping.

Motor performance can be analyzed more completely by using the manufacturers information on motor characteristics to construct an instantaneous-motor-torque curve. From this curve, instantaneous drive acceleration, velocity, and position can be calculated. This approach is valuable for analyzing motor performance, designing a new system, or gaining insight into the system drive characteristics.

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Drive requirements

Assume that a drive is required to advance film in steps of one printer's *point* (approximately 1/72 inch) at a speed of 625 steps/second. Possible film widths range from 35 mm to 310 mm, and film thicknesses include the extremes of thin 0.0035-inch film and heavy 0.008-inch phototypesetting plates. The drive should be able to take from five to 250 steps in any one advance, and should be able to make a second advance within ten milliseconds of completing the previous advance. Stopping accuracy of 0.002 inch is required.

Since the final position of the film is determined by the maximum overshoot of the drive system, the static accuracy of the drive system must be controlled and the overshoot must be minimized or made constant. Gear accuracy, sprocket accuracy, and bearing clearance must also be controlled to minimize error.

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Earlier developments

An earlier version of this film-advance system incorporated a slip-clutch drive with a ratchet wheel and solenoid-operated pawl to limit shaft rotary motion. Wheel position was sensed by a photocell and light bulb. This system required considerable maintenance and was difficult to align.

Several alternative drives were considered, including

1) Servo drive with digital feedback;
2) Servo drive with digital feedback and a ratchet and pawl for improved accuracy;
3) Stepper motor with ratchet and pawl detent; and
4) Straight stepping motor.

The straight stepping motor was chosen because of its low cost, inherent reliability, and expected accuracy.

Stepping motors

The three basic types of stepping motors are: the permanent magnet (Fig. 1), variable reluctance (Fig. 2), and the small-angle stepper (Fig. 3). The solenoid type shown in Fig. 4 has a completely different principle than the above three steppers and is not considered in the following analysis.

Permanent-magnet stepping motor

The permanent-magnet stepping motor incorporates one or more permanent magnets in the rotor. The rotor in Fig. 1 is held in the position shown with coils **A** and **C** energized to produce a north pole at coil **C**. The rotor is rotated clockwise if coils **A** and **C** are de-energized and if coils **B** and **D** are energized to produce a north pole at **B**. An additional 90° rotation is produced when coils **A** and **C** are energized to produce a north pole at coil **A**. This produces an incremental rotation of the rotor for as many steps as required. Permanent-magnet stepping motors are generally large-angle devices with steps of 45° through 180°.

Variable-reluctance stepping motor

Variable-reluctance stepping motors employ soft-iron rotors. Fig. 2 shows a variable-reluctance stepper with an 8-tooth, soft-iron rotor and three windings. Winding **C** is energized and lined up with rotor tooth a. If winding **C** is turned *off* and winding **A** is turned *on*, the rotor rotates counter-clockwise so that tooth **d** lines up with winding **A**. If winding **A** is turned *off* and simultaneously winding **B** is turned *on*, tooth **c** of the rotor lines up with winding **B**. If winding **C** is turned *on* again at the same time winding **B** is turned *off*, tooth **h** of the rotor lines up with **C**. This sequence can be repeated indefinitely. Fig. 2 shows a 15° stepper.

Small-angle stepping motor

Fig. 3 shows a variation of the variable-reluctance stepper called a small-angle stepper. This type of stepping motor utilizes subsalient poles so that when a particular winding is de-energized and the adjacent winding energized, the rotor moves a fraction of a pole.

Operational characteristics

The above three types of stepping motors have basically the same torque curve as shown in Fig. 5, which shows static torque of a stepping motor as a function of its rotary displacement. The motor remains at the origin if no external torque is applied and if the windings remain energized. A positive torque is required to rotate the motor to the right, and a negative torque is required to rotate the motor to the left. If the rotor is displaced from its static position, the torque is given approximately by

$$Torque = (T_{max})\ sin\ [90\ M - (90\ \theta/\Delta)] \qquad (1)$$

where M is number of steps taken; θ is instantaneous rotor position (degrees); and Δ is motor step angle (degrees).

The actual torque curve deviates from the ideal sine curve, but this difference will be ignored. A more accurate torque curve could be generated with a Fourier series.

In addition, the inductance of the windings limits the rate of buildup of current through the coil and, therefore, the buildup of torque in the rotor, thereby reducing the T_{max} of the curve in Fig. 5 at a particular instant and shrinking the entire curve towards the x-axis. This reduces motor-output torque at high stepping rates and limits the speed at which a stepper motor can step and maintain synchronization.

If the permanent-magnet stepping motor of Fig. 2 is stopped at the stable position (the origin in Fig. 5) and the windings are instantly switched to the next position, the old torque curve disappears and the motor possesses the torque of *curve 1* in Fig. 6; the maximum torque portion of the curve coincides with the initial rotor position, and the rotor produces its maximum acceleration. As the rotor accelerates towards the right the torque decreases until rotor reaches position **A**, where the net torque is zero. But the momentum of the rotor carries it beyond **A** on the negative part of the torque curve; this decelerates the rotor, stops it, and reverses its motion. The rotor oscillates about the point **A** until energy is dissipated, and the rotor finally comes to a stop at point **A**. If the windings are switched when the rotor first reaches position **A**, the rotor continues to accelerate towards position **B** without stopping and develops torque of *curve 2*. An even higher rate of acceleration and higher average torque can be generated if the windings are switched at posi-

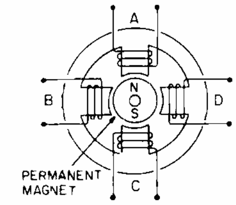

Fig. 1—Permanent-magnet stepping motor; rotor changes position 90°, as adjacent coils are energized.

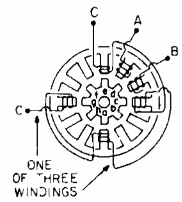

Fig. 2—Variable-reductance stepping motor (15° stepper).

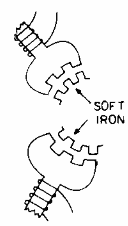

Fig. 3—Small-angle stepper motor.

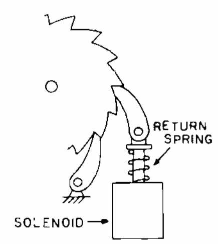

Fig. 4—Solenoid-type stepper.

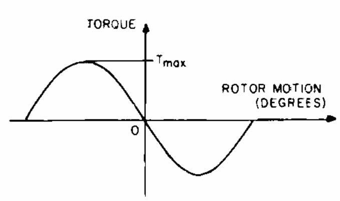

Fig. 5—Basic torque curve for stepping motors.

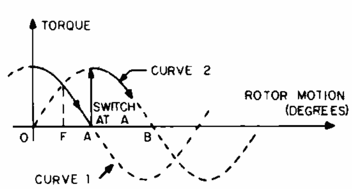

Fig. 6—Torque generated by switching windings in a stepper motor.

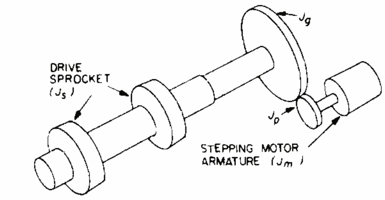

Fig. 7—Arrangement for determining total system inertia.

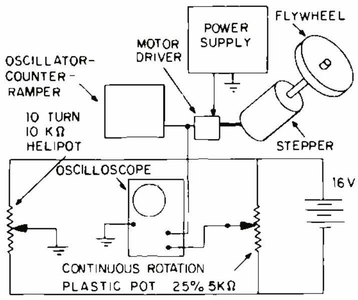

Fig. 8—Setup for measuring instantaneous motor displacement.

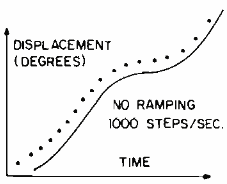

Fig. 9—Motor displacement.

tion F instead of at position A. The area under the curve is proportional to energy output by the motor.

Comparitive analysis and selection

The stepping motor is required to drive an output sprocket shaft in increments of one-point intervals (0.013852 inch) at a minimum rate of 625 steps/second. With a standard 16-tooth sprocket engaging the perforations, the sprocket must advance in increments of 1/216 of a revolution. No standard motor is available with this ratio; we must therefore consider standard motors with appropriate gearing.

Various motors can be compared on the basis of angular acceleration of the sprocket shaft. The total equivalent system inertia, J_{os}, of the motor, gears, and sprocket shaft of Fig. 7 is calculated by

$$J_{os}=J_s+J_g+N^2(J_p+J_m)\approx J_s+N^2J_m \quad (2)$$

where J_s is the inertia of the sprockets and shaft; J_g is the inertia of the sprocket shaft gear; J_p is the inertia of the motor pinion; J_m is the inertia of the motor armature; and N is the gear ratio (motor speed/sprocket speed). This equation converts all inertias to the equivalent inertias at sprocket speed.

The maximum motor torque at shaft speed, T_{ms}, is found by

$$T_{ms}=T_m\times N \quad (3)$$

where T_m is the maximum torque of the stepping motor.

The ratio of the two equations, α_s, is the maximum theoretical angular acceleration of the sprockets in radians per second

$$\alpha_s=T_{ms}/J_{os}=T_mN/[J_s+J_g+N^2(J_p+J_m)] \quad (4)$$

The published maximum stepping rate is also considered, as well as the published motor angular accuracies. Motors with 800 or more positions per revolution are not considered in this example because of the error added by a small gear on the sprocket shaft.

Development and testing

Bench testing

Using the criteria above, several motors can be selected for testing. A precision disc with equally spaced dots around its periphery is attached to each motor shaft, and the motor is advanced one step at a time. The motor-stepping accuracy is measured by observing the location of the test spots at each step with a measuring microscope.

Dynamic tests are run by installing on the motor shaft an inertia wheel equivalent to the reflected inertia of the sprocket shaft, sprocket gear, and pinion. Moment of inertia of the flywheel is given by

$$J_f=[(J_s+J_g/N^2]+J_p$$

Dynamic motion is measured with a precision, continuous-rotation potentiometer connected to the motor shaft with output displacement displayed on an oscilloscope.

A better analysis of the motion can be made if the electrical pulses to the motor driver are introduced into a second channel of the oscilloscope and the two traces combined to show the instantaneous motor displacement with the motor pulses superimposed. The circuit is shown in Fig. 8. A typical output trace is shown in Fig. 9.

System testing

A special drive package such as the Measurematic DCM-4-4-7 can be used to provide start ramping, stop ramping, and preset counting. Start ramping is produced by eliminating preselected pulses such as the second, fourth and sixth; stop ramping is produced by generating a new pulse for each pulse eliminated during the start ramp, but at a pre-selected lower frequency. Based on the bench tests, a 15 degree, variable-reluctance stepping motor with a 9:1 gear box was selected for further testing, and installed on the film drive system.

A three-step ramp caused the motor to accelerate to a higher speed than the normal running speed, and then to nearly stop when the high-speed pulses started. This produced about the same effect as no ramping at all. Under these conditions, the system sometimes lost synchronization and oscillated around a single position. Starting was improved by reducing the ramping to two starting pulses.

A graphical analysis of the start-failure with a three-step ramp is shown in Fig. 10. This graph is taken from an oscil-

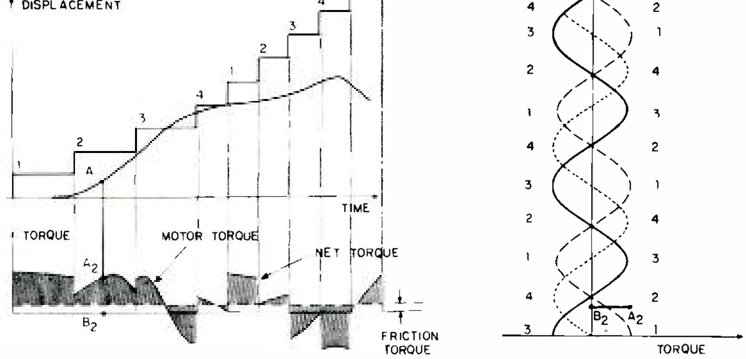

Fig. 10—Analysis of start-failure with a three-step ramp.

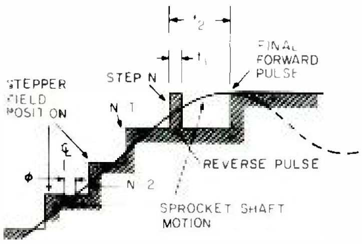

Fig. 11—Method for stopping motion; reverse pulse followed by forward pulse.

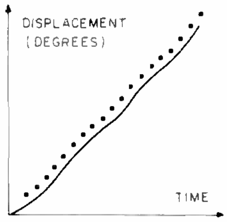

Fig. 12—Acceleration and early-run of a stepper motor system using a single-step ramp and running at 650 steps.

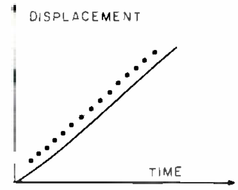

Fig. 13—Start achieved with a starting ramp having two indepently adjustable pulse durations.

loscope record. The displacement of the rotor is plotted versus time. A calibration is made when taking the pictures to determine the displacement of a step. A series of "stairsteps" are constructed on the same figure corresponding to the pulse advances of the stepping-motor field. The stairsteps represent the position an ideal stepping motor would achieve with no inertia and perfect damping; *i.e.* the origin in Fig. 5. The torque and displacement at each position can be estimated by laying out the torque rotation curve of Fig. 5 along the vertical axis for each step of the motor. The torque of the stepping motor is determined from the corresponding curve as the stepping-motor windings are advanced from one position to the next. The vertical displacement of a point on the motor displacement curve, such as point **A**, produced a torque equivalent to the horizontal displacement **B_2-A_2** on torque *curve 2*. This displacement is plotted along the lower graph as a vertical displacement proportional to the instantaneous torque at time **A**. This torque is the ideal motor output at that instant. It should be reduced to include the effect of the time constant of the inductance and resistance of the winding (L/R) as shown by the dashed line in the lower graph. Friction reduces the torque further by a more or less constant amount. This is shown by raising the base line of the lower figure to the line labeled friction torque. Other effects can also be considered, such as the counter-EMF produced by generator action and motor damping. The resulting net accelerating torque of the stepping motor is equivalent to the shaded area of the lower figure. This parameter can be numerically intergrated to find instantaneous velocity and displacement. This construction can also be simulated on a digital computer to calculate actual stepper motor drive performance.

Stop ramping

To provide accurate film advance, it is necessary to stop the motion of the sprocket shaft with a constant amount of overshoot.

The best method of stopping can be determined through experimentation. In one case, it was found to be a reverse pulse followed by a forward pulse as shown in Fig. 11. The motor has been running at a constant speed long enough so that there is no rotor oscillation as in Fig. 9. This is important for accurate stopping. The motor displacement curve intersects the field position "stairstep" at a constant time θ after the zero average torque intersection. This corresponds to a phase angle.

When the final step is reached, (step **N** in Fig. 11) the stepper field position is returned to the N−1 position after a short time interval t_1. This time interval is adjusted so that the sprocket shaft comes to a stop at the same angular position as the final step **N** for the field. When the sprocket shaft reaches this position, it would continue to decelerate and follow the path shown by the dotted line if the stepper field position were kept in the N−1 state. However, after the time internal t_2, the motor field is returned to the **N** position to prevent further motion. This method works quite well in practice although it is sensitive to instaneous shaft velocity and phase angle.

Start ramping

Fig. 12 shows an acceleration and early part of the run of a stepper motor in a system using a single-step ramp and running at 650 steps/second. Although this system accelerates and runs reliably, the motor speed oscillates for many steps. This type of motion makes accurate stopping very difficult.

In an actual case, a system was set up to produce good stop ramping for large advances where the oscillations die out. It was programmed to write a horizontal line on the film at the end of each advance. To test the effect of the oscillation shown in Fig. 12, a special program was written to alternately advance the film in 6-point increments followed by 9-point increments. These are, respectively, a higher than average speed and a lower than average speed. As expected, the 6-point advances were longer than they should have been and the 9-point advances were shorter. No combination of skipped pulses and stepping speed could be found that would produce an oscillation-free start. A better method of start ramping was required.

To achieve an oscillation-free start, the motor must not only get up to synchronous speed, but must also achieve this speed when the constant speed pulses start and when the steady-state phase angle is ϕ. Since both displacement and velocity are variable, at least two parameters must be varied to adjust the starting ramp. Using the instrumentation described earlier, a starting ramp with two independently adjustable pulse durations produced a low-oscillation start. Fig. 13 shows an example of the start achieved with this type of start ramping. Ramping was adjusted by observing system motion during operation and adjusting the pulse times for optimum results.

The variation in friction due to the use of various widths and types of film and paper causes only a slight change in the start curve. The system operates accurately with all media. If variation in friction becomes a problem, a mechanical friction brake can be added with an adjustment for each material to provide a constant system friction.

Conclusions

Stepping motor drives can be analyzed and designed to produce predictable and repeatable dynamic motion. Specifically, for film-drive applications, the amount of overshoot can be controlled by carefully selecting start and stop ramping methods. In addition, the graphical analysis developed here can be used to analyze any stepping motor drive for optimum performance of any parameter.

Air bearings for high-speed mirrors rotating in a vacuum

B. W. Siryj

The feasibility of rotating a 2-in.-OD pyramidal mirror in a vacuum at 120,000 r/min. has been demonstrated experimentally. The mirror was fastened to an air turbine-driven rotor which in turn was supported on porous-wall, carbon-graphite air bearings The air bearings were supported by rubber O-rings to increase the operational stability range of the rotor. The mirror was located in a cavity whose pressure was maintained at 3.0 torr. A noncontacting dynamic face seal was used to isolate the air bearing area from the mirror cavity. Good correlation was obtained between the predicted and measured optimum load carrying capability of the journal.

CURRENT LASER TECHNOLOGY employs several types of scanners. A scanner consists of a high-speed rotating mirror attached to, or part of, a shaft. Supported on bearings and driven by a turbine or an electric motor, the scanner is used to deflect a light beam onto a recording medium. Rotor speeds of 120,000 r/min are common. If a mirror is rotated in air at such speeds, turbulence will degrade the recording spot profile. The spot degradation is not apparent, however, if the mirror is rotated in a vacuum of 15 torr or less.[1] In addition, by placing the rotor or part of the rotor—preferably the part with large diameters—into a reduced atmosphere, the driving power requirements are substantially reduced. This paper describes the use of rubber O-ring supported, porous wall carbon-graphite air bearings to support a four-faceted pyramidal "mirror" rotating in a vacuum of 3 torr at 120,000 r/min.

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General physical characteristics of the scanner assembly are shown in Fig. 1. The operational requirements of the scanner are listed below:

Rotor speed	120,000 r/min with higher speeds under consideration.
Rotor drive	air turbine.
Air avail.	plant air at 80 psig.
Environment	laboratory conditions.
Mirror size	2-in. OD, four-faceted, 45-deg pyramid, separately attached to a rotor.
Bearing diameters	small enough to minimize drive power.
Seal	Mirror housing and air bearings separated by a noncontacting dynamic seal.
Vacuum	15 torr or less.
Vacuum pump	minimum capacity

Bearing selection

An air bearing support system is the best choice for this application because:

1) The dynamic radial runout of the mirror will be minimized. This requirement is critical in systems where the depth of focus of the recording spot is shallow. [The depth of focus is the height of the recording spot over which the cross sectional area varies within specified limits.]
2) No contaminating materials (for example, oil from oil bearings) will be in the vicinity of the mirror faces.[2]
3) Dynamic response to a speed-sensing servo can be substantially increased when air bearings rather than ball bearings are used for rotor support.

Air bearing instability

Whirl (a hydrodynamic phenomenon) and pneumatic hammer (a hydrostatic phenomenon) are two serious instabilities associated with lightly loaded air bearings. The inversion point must also be considered; its effect, however, can be minimized by proper dynamic balancing. [The inversion point is the speed at which the rotor begins to rotate about its mass center rather than its geometric center.]

Whirl instability

Whirl is a self-induced dynamic instability which manifests itself as an orbital motion of the rotor around the center of the bearing at a frequency equal to or less than half of the rotor speed. The speed f_w at which the cylindrical half-frequency whirl instability sets in is given by

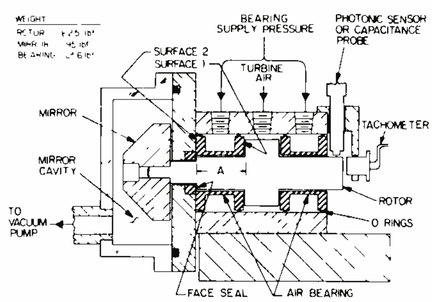
$$f_w = \frac{1}{\pi}\left(\frac{2K}{M}\right)^{1/2} \quad (1)$$

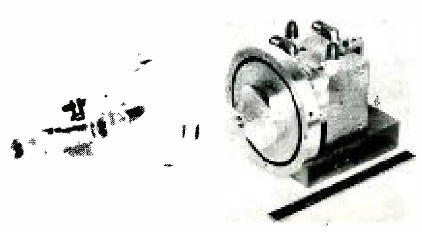
To stay below the half-frequency whirl speed, a large air-film spring constant is desirable (Eq. 1). Sneck[3] has indicated that the load-carrying capability of a porous bearing exceeds that of an orifice-type bearing at the same supply pressure, flow, and clearance. Since the load carrying capability of an air bearing is almost linear up to an eccentricity of about 50%,[4] which is also a practical usable range, it may be concluded from the previous statement that the air-film spring constant of the porous wall bearing is higher than that of an orifice-type bearing, all other parameters remaining constant. Successful operation of a rotor above the calculated half-frequency whirl threshold has been accomplished by supporting the air bearings on rubber O-rings. Presently used high-speed (300,000 r/min) dental drills are prime examples.[5]

Pneumatic hammer

Pneumatic hammer is a self-induced hydrostatic instability encountered

Fig. 1—Scanner assembly.





when the shaft is stationary. Its physical manifestation resembles the action of a mechanical vibrator.

Sahib[6] has shown that porous bearings will not absorb vibrations but rather contribute to pneumatic hammer instability; he suggested that bearings be made from thin, low-permeability materials to decrease the void volume of the material. It is believed that the compressibility of air in conjunction with a large void volume in a porous material contributes to pneumatic hammer. This correlates with previous experiments conducted when testing orifice-type bearings with pockets. Although the addition of pockets (void volume) increased the load carrying capability of a bearing, it also contributed to pneumatic hammer.

Air bearing optimization

A desirable large air-film spring constant, probable operation in the vicinity of or above the half-frequency whirl speed, and ease of manufacture and assembly suggested the use of porous-wall, O-ring-supported bearings.

It has been shown[4] that for porous-wall journal bearings, there exists an optimum load-carrying capability. Another important factor influencing the decision to use porous carbon-graphite bearings was the fact that a rigidly mounted porous-wall air bearing was previously tested in our laboratory at the half-frequency whirl point of 95,000 r/min. Physical contact was encountered between the porous-wall carbon-graphite bearing and a heat-treated nitralloy shaft. However, lock-up did not occur. Inspection of the shaft and bearing following five physical contacts showed no visible damage either to the bearing or the shaft.

The bearings used for the scanner assembly are optimized about the maximum load-carrying capability point.[4, 7]

Permeability

Constantinescu[4] has developed a simple method for determining the load-carrying capacity of a bearing when the permeability of the porous material is known. Taking a similar approach, Sneck and Yen[7] make use of the experimentally determined flow rate through the bearing to calculate the load-carrying capacity. This procedure is particularly useful for bearings whose final permeability, and thus flow rate, cannot be accurately predicted. Such unpredictable permeability can result from lattice changes introduced when materials such as porous-bronze or porous-sintered steel are machined. Eqs. 2 and 4 relate the permeability to the flow rate for the two most common geometric configurations used in air bearing design.

For a porous-wall cylinder,[9]

$$K=\frac{\mu \bar{R} T W \ln (r_o/r_i)}{\pi b(P_0{}^2-P_a{}^2)} \qquad (2)$$

Using air at standard conditions,

$$K=\frac{2.88\times 10^{-4}\ W \ln(r_o/r_i)}{b(P_0{}^2-P_a{}^2)} \qquad (3)$$

For a porous-wall disk or annulus,[10]

$$K=\frac{2\mu \bar{R} T W H}{A(P_0{}^2-P_a{}^2)} \qquad (4)$$

Again, using air at standard conditions,

$$K=\frac{18.1\times 10^{-4}\ W H}{A(P_0{}^2-P_a{}^2)} \qquad (5)$$

Journal bearings

Once the permeability of the material and bearing geometry are known, the load-carrying capability of a journal bearing may be optimized. An example of the procedure used for determining optimum load-carrying capability and thus maximum air-film spring constant of a journal bearing at a given eccentricity is shown in the Appendix. For stable operation at high speeds, both the rigid and elastic methods of bearing mounting require a large air-film spring constant.

Rigid mount

The stability of an air-bearing rotor combination may be extended only up to a point beyond which the whirling amplitude of the rotor will exceed the thickness of the air film and lock-up (rotor-to-bearing contact) will occur. In most cases reported in the literature, lock-up is destructive by causing a seizure between rotor and bearing.

Elastic mount

By proper design of the air bearing, air bearing support, and rotor, the stable operating range of the system can be extended substantially beyond the calculated (rigid mount) half-frequency whirl threshold.

Thrust bearings

In this scanner design, two lubricated thrust surfaces (marked 1 and 2 in Fig. 1) are required. Both surfaces support the load produced by the pressure difference between the vacuum in the mirror cavity and the atmosphere. Thrust surface 1 provides the lubricating air film for the rotor, while thrust surface 2 lubricates the bearing-to-seal surfaces. The latter lubrication minimizes inertia of the rotor-air-film-bearing-O-ring spring-mass system. The bearing thrust surface is essentially isolated from the faceplate, permitting bearing movement independent of the relatively massive housing. In the limit of large inertias, the behavior of rubber O-ring-supported bearings approaches that of rigidly mounted bearings. Small bearing inertias and masses are required to maintain the advantages of rubber O-rings in combating whirl.[11]

Nomenclature

symbol	definition	units
k	permeability coefficient	in.^{2}
μ	absolute viscosity	lb_f-s/in.^{2}
R	gas constant	in-lb_f/lb_m-°R
T	temperature	°R
W	flow rate	lb_m/s
r_0	outside journal radius	in.
r_i	inside journal radius	in.
b	width of bearing	in.
P_0	supply pressure	psia
P_a	atmospheric pressure	psia
H	thickness of porous material	in.
A	flow area	in.^{2}
f_w	rotor angular velocity at which whirl sets in	r/s
K	air bearing spring constant	lb_f/in.
M	mass of rotor	lb_m
R	dimensionless bearing parameter	
c	radial clearance for journal bearings	in.
f_N	natural frequency of rotor support	r/s
ξ	dimensionless load coefficient	
P	journal load	lb_f
ϵ	eccentricity	

Bearing construction

Considerable effort was expended determining the optimum porous material for the bearing. Porous bronze, porous stainless steel, porous carbon-graphite, porous ceramic, and porous Teflon were investigated. Porous carbon-graphite was finally chosen because:

1) It has a high-dimensional stability and can be ground to close tolerances without closing the pores at the contact surface. Therefore, its permeability is unaffected by machining.
2) It is available in many different permeabilities.
3) It is a naturally dry lubricant.

Graphitar 2 was readily available and was used for all bearings constructed.

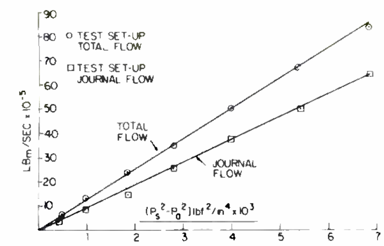


Fig. 2—Flow rate *vs.* pressure.

To insure that the permeability of the bearing material remained constant (laminar flow) throughout the usable pressure range, a flow rate *vs.* pressure test was conducted. The results are shown in Fig. 2. It is apparent from Eqs. 2 and 4 that if the graph of flow rate *vs.* $(P_0{}^2 - P_a{}^2)$ is linear for a particular geometric configuration, the permeability is constant. Fig. 2 confirms that the permeability of the designed bearing is constant throughout the tested pressure range.

Previous experiments pertaining to rubber-O-ring-supported air bearings[11] have indicated that there are no appreciable effects on the dynamic characteristics of the O-ring when it is compressed to between 2 and 12% of its cross-sectional area. The choice of rubber compound for the O-ring and its hardness did show some effect on the whirl threshold. However, the most significant observation was that above some supply pressure (24 psig for the model tested), all rubber compounds performed equally well.

The O-rings used in this application had a 1.625 in. OD with a 0.070-in.-dia cross section and were made from a standard commercially available rubber compound, Buna N, with a Shore A durometer hardness of 70 deg. The cross section of each O-ring was compressed 6%. Tighter seal and ease of assembly and alignment were enhanced by applying Dow Corning silicone grease to the O-rings and their mating surfaces.

Load *vs.* deflection

Journal load—static approach

An attempt was made to determine the static load-eccentricity relationship for the air bearings by loading the rotor and obtaining the difference between the deflection of the rotor and the bearings. This procedure was necessary since, as the rotor was loaded, both the rotor and the rubber O-ring-supported bearings deflected. This method proved impractical because it was impossible to obtain a consistent and meaningful rotor deflection in the bearing for a given load. One point, however, could be determined: bottoming load—100% eccentricity. At $P_0 = 5P_a$, the experimental bottoming load was 17.5 lb/bearing, compared to the analytically determined load of 19 lb/bearing. The calculated air-film spring constant per bearing up to an eccentricity of 50% and a supply pressure equal to $5P_a$ was determined to be 53,800 lb/in. If these bearings were rigidly mounted, half-frequency whirl would set in at about 136,000 r/min.

Another approach was used to determine the static load-eccentricity relationship.[12] A capacitance probe was faced toward the shaft and attached to the air-bearing housing. A pressure of $5P_a$ was supplied to the bearings. The rotor was struck a sharp radial blow and the output of the capacitance probe was displayed on an oscilloscope. Fig. 3 shows the damped natural frequency of the rotor and the air-film "spring"-rubber O-ring combination. Knowing the mass of the rotor and the natural frequency of the combination f_n, the combination's spring constant K may be calculated from

$$f_n = \frac{1}{2} f_w \qquad (6)$$

where f_w is given by Eq. 1.

The spring constant of the rotor O-ring combination was calculated to be 40,800 lb/in. The inversion point which occurs at f_n is then predicted to occur at 48,000 r/min.

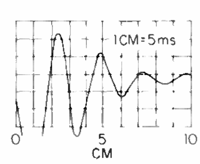


Fig. 3—Damped natural frequency of rotor/O-ring combination.

Journal load-dynamic approach

With the bearings, rotor, and capacitance probes in place, the bearing supply pressure was set at $5P_a$. The rotor speed was slowly increased and the shaft eccentricity recorded and displayed on an oscilloscope. To make the inversion point pronounced, the shaft was not dynamically balanced. The results of this test are shown in Fig. 4. The inversion point occurred at 50,000 r/min, which is in good agreement with the statically obtained value of 48,000 r/min. Fig. 4 shows no increase in orbiting amplitude at 96,000 r/min, which should coincide with the half-frequency whirl speed.

Throughout this evaluation, the dynamic movement of both the shaft and the rubber O-ring-supported bearing were displayed on an oscilloscope. The following observations are of interest:

1) The bearing orbit was in phase with the rotor orbit (runout) through 120,000 r/min.
2) The amplitude of the bearing orbit varied between 50 and 100% of that of the rotor orbit. At 120,000 r/min, the orbiting amplitudes of both the rotor and the bearing were equal to 15 μin. At this speed, the orbital center of rotation of the rotor shifted 220 μin. while the orbital center of the bearing shifted 50 μin. in the opposite direction. Repeated rotor cyclings have shown that the shift in opposite directions is a consistent and repeatable phenomenon; however, the causes of this behavior have not yet been identified.
3) As shown in Fig. 4, orbital center of rotation shifted radially as the rotor speed was increased. The rotor did, however, return to its original position after deceleration to 0 r/min. Cycling of the rotor between 0 and 120,000 r/min did not shift the extreme positions of the rotor.
4) The inversion point manifested itself as a speed at which both the rotor and bearing-orbiting amplitudes were maximum.

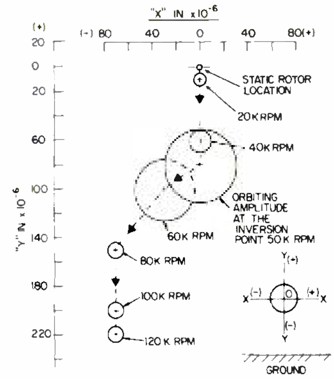


Fig. 4—Dynamic rotor shift.

Thrust load

When the two bearings were assembled initially in the bearing housing and the mirror cavity was evacuated, pneumatic hammer instability set in. To alleviate this condition, four radial slots were cut into the bearing surface opposite the turbine face. This allowed the journal air to exhaust directly to atmosphere. As expected, the face with the slots has a lower maximum load-carrying capability; however, at small loads it is free from pneumatic hammer through a larger pressure range. For instance, at $5P_a$, the thrust face without the slots hammers when an external load of 0.75 lb is applied as compared to 7 lb for the slotted face. On the other hand, the thrust face without the slots stops hammering at a load of 28 lb and bottoms at 41 lb while the slotted face stops hammering at 17 lb and bottoms at 22 lb.

These results suggest two other possible approaches for future designs. One approach would be to use a nonpermeable thrust face in conjunction with a porous journal. Another approach would be to impregnate the porous thrust surface with a resin. In both cases, the exhaust air from the journal would lubricate the thrust surfaces.

Mirror rotating at 120,000 r/min

For the final test, a 2-in.-dia, four-faced pyramidal "mirror" was attached to the shaft as shown in Fig. 1. The "mirror" was a dimensional simulator made from 7075-T6 aluminum. Most high-speed rotating mirrors are made from beryllium. The angular relationships between mirror faces are critical; tolerances of one second of arc are common. Such mirrors are expensive to manufacture from beryllium. Aluminum was selected for the mirror simulator because its density ρ is similar to that of beryllium [$P_B \approx (^2/_3)\ P_{Ae}$] and it is less expensive to machine to "close" tolerances. With a bearing supply pressure of $5P_a$ and the vacuum pump on, the "mirror" speed was varied between 0 and 120,000 r/min. The vacuum in the mirror cavity remained steady at 3 torr. Shaft runout at the inversion point was observed to be 1.2×10^{-4} in., and at 120,000 r/min it was observed to be 0.7×10^{-4} in. Maximum shaft runout was at the inversion point as expected.

The slight bearing misalignment caused by the rubber O-ring support appears to be an asset instead of a problem. Using dimensionally matched O-rings, a rotor lift ranging from 0.0003-0.00045 in. was always available. A theoretical lift of 0.0005 in. should have been obtained. It is well known that stability is a serious problem in lightly loaded rotors supported on air bearings. However, when a rotor is displaced from its original position by applying a radial load, the stability range increases.[12] It is, therefore, concluded that the slight bearing misalignment caused by the O-ring, coupled with the energy absorption capability of the rubber O-rings, is responsible for the

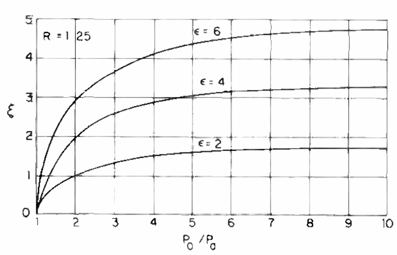


Fig. 5—ξ as a function of eccentricity and P_0/P_a.[4]

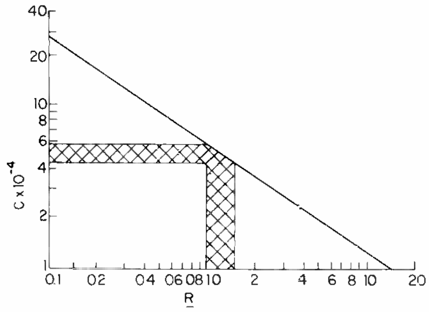


Fig. 6—R a function of journal bearing radial clearance.

stability of the scanner over a wide frequency range.

Carbon-graphite materials proved to be excellent materials for the air bearings and seal. The great variety of available permeabilities, ease of machining, maintainability of original pore sizes at machined surfaces, and excellent dry lubricating properties are the major assets of this material.

Although the rotor was elastically supported, it always shifted and returned to the same positions. This is of primary importance for rotating mirror applications since it should be possible to locate exactly a mirror rotating at the desired speed and expect it to maintain this position as the scanner is cycled between zero and maximum speed. Thus by using elastic supports for the bearings in place of hard mounting the bearings, not only is the destructive whirl omitted, but the orbiting amplitude of the mirror is decreased.

Appendix—Optimizing load-carrying capability of a journal air bearing.

The load-carrying capability of a journal bearing may be optimized with the aid of the following equation:[4]

$$R^2 = \frac{3kb^2}{c^3 r^2 \ln(r_0/r_i)} \qquad (7)$$

The optimum load-carrying capability occurs for $R=1.25$.

Eq. 8 can be rewritten in the following form

$$\ln R = -^3/_2 \ln c + B \qquad (8)$$

Thus, if $\ln(R)$ *vs.* $\ln(c)$ is plotted, the resulting curve is a straight line with a slope of $-^3/_2$ (Fig. 5) The optimized load coefficient is approximately constant for values of R ranging from 1 to 1.5. If this range is plotted as shown in Fig. 5, the result will produce the permissible air film thickness tolerance for an almost constant load-carrying capability. This range is significant since it determines the allowable machining tolerance for the rotor-bearing combination.

The following example shows a procedure for determining the actual load carried at a given eccentricity. The outside radius of the porous wall journal bearing, r_0, can be determined from Eq. 7 using the following parameter values

$R=1.25$
$b=0.750$ in.
$k=0.55\times10^{-11}$ in.^{2} (Graphitar 2)
$r_i=0.375$ in.
$c=5\times10^{-4}$ in.
$r_0=0.426$ in.

Result

A wall thickness of 0.051 in. is reasonable and in line with the minimum wall thickness requirement for the suppression of pneumatic hammer.

From Fig. 6, the dimensionless load coefficient $\xi=0.16$ for $R=1.25$, $P_0/P_a=5$ and eccentricity $\epsilon=0.2$. The load coefficient is defined by

$$\xi = \frac{P}{2r_i b P_0} \qquad (9)$$

Thus, $P=6.4$ lb.

This yields an air film spring constant of 64,200 lb/in. per bearing up to an eccentricity of about 50%.

Acknowledgments

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Design engineering all the way

An interview with J. L. Hathaway, NBC

Typically, an engineer switches job functions and employers several times throughout his career, often moving to an administrative role as he gains experience. Thus, when we learn of an engineer who devotes his entire career to one field of engineering and one company our natural curiosity is aroused.

Immediately we question whether such a career could keep pace with today's rapidly changing technology. In this interview, the *RCA Engineer* explores this question and several other topics relevant to the engineering profession with an engineer who has 42 years of design and development success with one company, in one department.

Editor's note: There are other engineer and scientist readers in RCA whose remarks about their profession would be of general interest; we hope to interview some of you in the future. Lew Hathaway was chosen for this interview on the basis of his rather unique background, long service record, and his impending retirement.

Our thanks to W. A. Howard, Technical Publications Administrator for NBC, who arranged the interview and joined the discussion.

Why did you go into engineering in the first place?

L. HATHAWAY: My dad was an engineer. That is probably where I got my interest initially. From there, I went into ham radio and I built a great deal of equipment. I got my first commercial license in 1922 or 1923. When I went to the University of Colorado, I completely dropped ham radio; but, after a year at the University, I had the opportunity to become the Engineer at one of the radio stations in Denver. I worked all summer; the money was pretty good. So I dropped out of school for a year. I then worked every summer at the same radio station and every weekend. Occasionally, I would go down from Boulder to Denver when there was technical trouble at the station. After graduation, the course was pretty obvious—NBC and NBC alone.

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Why NBC alone?

L. HATHAWAY: I guess I thought it was a pretty good company to work for and mainly I enjoyed the work and I liked the people.

As I look through your biography, I notice that you have been 42 years in one field of engineering, leading to 37 patents. In general, what was the basis for these patents?

L. HATHAWAY: Most of them have been in broadcasting equipment and systems. Two of the more important early ones dealt with automatic audio-gain control. I got the feeling that there had to be something a little different than linear automatic gain control, and I worked out a system called unsymmetric automatic gain control. The unsymmetric part was in the rapid gain reduction and very slow gain restoration.

You received an Engineering Award in 1962 from the IEEE; the David Sarnoff Outstanding Achievement Award in Engineering in 1969; have been nominated for two Emmys and an NAB Award in Engineering. To what do you attribute your success?

L. HATHAWAY: Perhaps I have been very lucky. I think first of all, working for NBC has been a good break. It's been a good stable Company. I can remember during those depression days when letters used to come in to my boss from people that I had known back at the University of Colorado and some of these were the very tops of the class, the number one man, and the number two man scholastically. One of them had been President of the Senior class.

These fellows had started work for some company and by the time the Depression really got dug in, they were out of jobs, and they were trying to get absolutely anything they could get. Well, that's why I say this is largely a matter of luck. I could have gone with one of the companies that hired these fellows, and I certainly would have lost my job. I don't know if I could have made it somewhere else, because I wasn't that good.

That's an unusual statement coming from a man with as much development success that you have had. You must have done something right along the line.

L. HATHAWAY: Either I did something right, or I didn't do too many things wrong.

W. A. HOWARD: I believe Lew is being modest here. I have known Lew for a long time and he has a combination of abilities that a lot of engineers don't have. He has the creative ability, along with the ability of being very practical—knowing how to make equipment work, trouble shooting, and then also an ability to spot needs. I think a good example is his development recently of a new low- impedance PL (communications) amplifier which solved a long-standing problem in the broadcast field equipment. He developed the hum-bucker which eliminates ground current and hum pick-up in video circuits for remotes; it eliminated a problem that has plagued broadcasters as long as they've been trying to do television pick-ups. He didn't mention the Audlock development; this was in response to the need of locking remote sync generators together. There was a development that allowed audio to be mixed in with the video for television transmission.

Does the challenge of developing new devices for broadcasting still exist?

L. HATHAWAY: Yes I think it does. Although most of the things that now need extensive development are far more sophisticated.

Does NBC offer all of the challenge that an engineer could want?

L. HATHAWAY: Well, it has challenged me over all these years.

What do you think is ahead for the new engineer?

L. HATHAWAY: It looks to me like some of the things ahead for him are some pretty tough times. Engineering has been a rather cyclical thing. It's hard to tell what the immediate future is going to be or the far future, unless some of this cyclical action is removed.

That seems unusual coming from you. You obviously got a job just at the outset of the Depression.

L. HATHAWAY: I was very lucky.

Are times worse now than they were?

L. HATHAWAY: No I don't think times are as bad now as they were then. But for engineering, compared to other professions, they might be worse now. Back in 1930, to about 1934, things were just terrible, not only in engineering, but in all fields. And some of the other fields were probably worse off than engineering. Well, right now, some of the other fields are in much better shape than engineering.

When you went to school, they taught electrical engineering as 90% power and 10% communications. Without additional formal education and with the amount of technology change that you have seen over your 42-year career, have you ever felt the need to be re-treaded?

L. HATHAWAY: Yes, but quite a while ago I decided I was not going to become an expert along all lines. Now some of these things which would require a bit of re-treading . . . I have had absolutely nothing to do with them. For example, systems relating to computers . . . I decided that was one field to leave alone . . . I turned a deaf ear to it. I believe it's necessary to be selective unless a person is going to spend all his time as a student.

Could you turn a deaf ear to solid state electronics?

L. HATHAWAY: I didn't turn a deaf ear to solid state. I learned solid state, and I use . . . I have used solid state for many, many years, and I love it. It's so much easier than using vacuum tubes. Even making up a breadboard is so much easier.

Has the possibility of a higher management slot ever appealed to you?

L. HATHAWAY: Frankly, there have been times when I have kind of wondered about this. I am part of management, but I have always wanted to stay away from the type management which has nothing to do with systems or engineering as such. In other words, I have wanted to stay away from personnel problems, and that type of management.

Some engineers seem to run a productive technical span of 15 years, then feel they must enter some sort of administrative work. You chose to stay in with the equipment . . . breadboarding, designing, developing, and patenting. For example, your humbucker was a commercial success as of last year, your 41st year in engineering. What kept you on the track?

L. HATHAWAY: Some time ago, I read an article by someone in RCA which supports exactly what you said. The usual span is perhaps 15 years for this kind of activity. Well, I don't believe everything I read. Maybe that's the case for them, but for me, I can't see any reason for it being 15 years, 30 years or perhaps even 45 years.

What are you doing after retirement?

L. HATHAWAY: Well, I am going into some more electronic development. I have picked out certain areas that I can do that are not too complicated. I have a list built up over many years of things that look like they would be worthwhile, simple developments, and I hope to get into them.

You also have been involved in Patent litigation.

L. HATHAWAY: Yes. I've spent three years, most of the time on patent litigation.

Can you offer some advice to an engineer as to how to avoid Patent problems?

L. HATHAWAY: After I had been in this for a very short time, I realized that many patents are granted, but declared invalid when they come to Court; they really are not much value until they have been validated. I was somewhat amazed to learn how many patents can be declared invalid. For example, I had to study various articles . . . not patents . . . just articles . . . in obscure magazines which had appeared in Japan or Germany or elsewhere in the world. If your opponent can show that an idea had been covered in some publication before you filed your application, your patent could be invalidated.

Aren't there certain items that you can use as proof that you did have prior knowledge?

L. HATHAWAY: Yes, any kind of written material that you have will help you to determine your date. But, on the other hand, you can still develop plenty of problems if you don't know what the prior art has been. And the prior art can consist of some old magazine that you never dreamed existed.

What do you see as the role of Professional Societies in relationship to the Engineer?

L. HATHAWAY: Well, it would be nice if the engineer could view his society as sort of a guiding light. In many cases, he's not able to do that. The Societies in some cases have catered more to certain aspects of engineering and not to others. For example, in the broadcast field, the IEEE quite a few years ago didn't seem to be catering to the broadcaster at all. And, as a result, many broadcast engineers left the Society and are more interested in others—for example, the SMPTE and NAB.

In general, what do Professional Societies do for you?

L. HATHAWAY: I really can't say what they do. I can say what I think they should do. I think that a Society's publication should have articles that do you some good. In some societies, the published articles are good only for the student; but, for the man who is working in the field and who is not studying mathematics, they certainly don't do much good. This was one of the many reasons why I felt IEEE had lost most of its broadcast interest. Everything published in the *Transactions* seemed to require a great deal of mathematics and only mathematics. There wasn't a good explanation of what was being done; just a good amount of mathematics. When you need help in the practical field, you need articles that offer practical advice.

There are some political areas where a Society can be of tremendous help. When new regulations are proposed, the Societies should be willing to get in and help in the direction that seems reasonable.

Didn't you receive an award in 1962 from the IEEE?

L. HATHAWAY: That was a *Scott-Helt Award* for the best paper appearing in *Broadcast Transactions*.

If you were just entering the University of Colorado, would you do it over again?

L. HATHAWAY: That's an interesting question. If I were just equipped with 20/20 foresight, I am sure there are alot of things I'd do much better.

The first thing, of course, would be to make a million dollars which would be very easy with all that foresight, but without it I don't see how I would have done things appreciably different. I think that in the year I graduated I was doggone lucky to land with someone like NBC.

Frictionless bimetal-actuated louver system

R. J. Williams

A unique, frictionless, bimetal-actuated louver system has been used for spacecraft thermal control.* The frictionless characteristic is obtained by using a spiral-wound bimetal element to support and actuate an ultra-lightweight louver. The ultra-lightweight louver is an open-cell-foam sandwich structure. The louver system exhibits an unusually high open-blade louver transmissibility ratio (LTR) of approximately 0.96. LTR is defined as the ratio of net radiation heat transfer through the louver control area to the net radiation heat transfer for an identical system without louvers. The closed-louver LTR is approximately 0.19. The results of vibration and thermal testing are presented and discussed.

Richard J. Williams
Thermal Design
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received the BSME from Ohio University in 1959 and the MSME from the University of Pennsylvania in 1961. From 1959 to 1963, Mr. Williams was with Microwave Mechanical Group at M&SR. Since joining the Thermal Design Group at AED in 1963 he has been Lead Thermal Design Engineer on several space projects and is presently engaged in the design and development of advanced passive and active bimetal actuated thermal control louver systems. He designed and developed a passive radiation cooler for space application, the cooler is part of a very high resolution radiometer and cools the IR detector to a controlled temperature of 105°K. Mr. Williams has been awarded patents on the cooler and an anti-icing device. Mr. Williams is a member of AIAA and was recognized as an AED Engineer of the Month. He is also a member of the Phi Kappa Phi and Tau Beta Pi honorary societies.

In the past, most bimetal-actuated louver systems for spacecraft thermal control were designed with bearing supports, resulting in systems susceptible to sticking or freezing at the bearings. The bearings also reduce the available louver control area, thus limiting the amount of radiant thermal energy that can be transmitted through the louver system when the louvers are in the open position.

The bimetal-actuated louver systems presented in this paper were designed to eliminate the bearings and thus the possibility of failure due to bearings. This was accomplished by using the bimetal element to provide the necessary support for the louver blade. The resulting system is virtually frictionless and has a very high open-blade louver transmissibility ratio (LTR) of approximately 0.96 and a low weight-to-control-area ratio of approximately 0.4 pound per square foot. LTR is defined as the ratio of net radiation-heat transfer through the louver control area to the net radiation-heat transfer for an identical system without louvers. The LTR was chosen to describe performance since it is not dependent upon the spectral properties of the radiator surface. The term "effective emissivity," which is often used to describe louver performance, is affected by the radiator spectral properties. Therefore, it is not the best characteristic to use when trying to compare one louver system with another, since various radiator surface finishes can be used.

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*The application of this system to an actual spacecraft was described in the paper by K. Schilling "A Simplified Bimetallic Actuator for Use in Spacecraft Thermal Control," appearing in Vol 16, No 3, Oct/Nov 1970, of the *RCA Engineer*, page 81

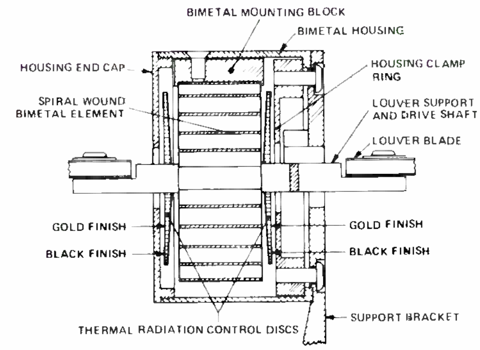

Fig. 1—Bimetal supported louver—center mount.

Mechanical configurations

Fig. 1 is a cross-sectional view of a center-mounted louver assembly. (The

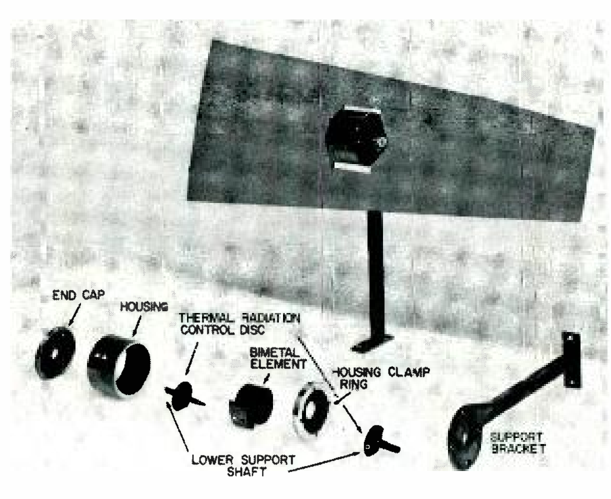

Fig. 2—Center-mounted louver assembly showing also the primary parts.

louver is supported by the center of the spiral-wound bimetal element.) The primary components of the assembly are:

1) Support bracket,
2) Bimetal housing,
3) Housing end cap,
4) Louver support and drive shaft,
5) Spiral wound bimetal element,
6) Bimetal mounting block,
7) Housing clamp ring,
8) Thermal radiation control discs, and
9) Louver blade.

Fig. 2 is a photograph of a louver assembly showing the primary components laid out as in an exploded view.

All components except the bimetal element, louver blade, and hardware are aluminum. The external surfaces of all aluminum components are polished and finished with vapor-deposited gold to reduce heat loss. All inner surfaces which have a radiation view factor to the bimetal element are black to increase the thermal coupling between the bimetal element and the assembly. The bimetal element is sized in thickness and free length to provide 90 degrees of rotation with a temperature change of 10 Celsius degrees. The width of the element provides sufficient mechanical support to prevent the drive shaft from touching any other component when in a 0- to 1-g field. The thermal-radiation control discs are machined as part of the drive shaft and are finished with vapor-deposited gold where they have a direct radiation view factor through the drive-shaft clearance holes. All remaining surface area is black. This helps to maintain the drive-shaft and bimetal-element temperatures near the housing temperature in two ways: 1) by reducing the heat leak from the bimetal element through the drive-shaft clearance holes and 2) by increasing the bimetal and drive-shaft thermal coupling to the housing. The discs also act as bumpers during vibration. The drive shaft has machined tabs on the end nearest the support bracket. These mate with machined stops on the support bracket. This prevents rotation of the louver beyond the desired 90 degrees from fully open to fully closed. Four screws pull the support bracket and the housing-clamp ring together to hold the bimetal housing in place (see Fig. 1).

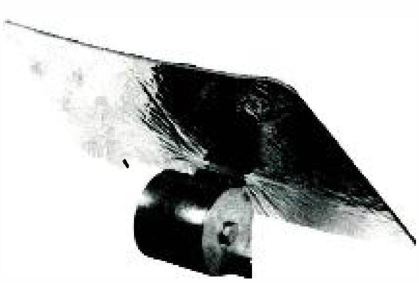

Fig. 3—Tip-mounted louver assembly.

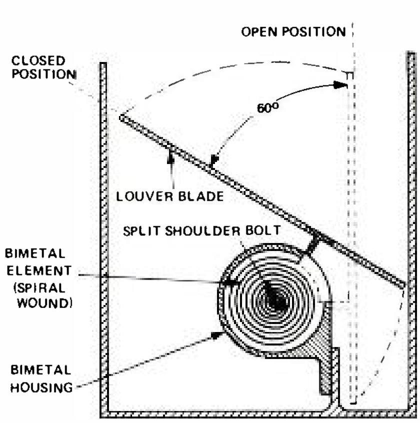

Fig. 4—Bimetal supported louver—tip mount.

The operating range of the louver assembly is easily adjusted by loosening the clamp ring and rotating the bimetal housing in the desired direction. The limits of range adjustment are constrained only by changes in the bimetal element OD and center location at any given temperature. These changes can be compensated for in the housing design if very high or low temperature operation is desired. The louver is mounted on flats at the ends of the drive shaft by screws. The drive shaft fits into the inner spiral of the bimetal element and is held in position by a tab on the bimetal and a mating slot on the shaft. The shaft is made in two pieces and assembled by insertion into the bimetal from each side and then pinning the parts The support bracket stem provides sufficient mechanical strength to withstand the launch vibration as well as a satisfactory thermal coupling between the radiator and the bimetal housing.

An alternate design approach for a bimetal supported louver system is shown in Figs. 3 and 4. In this design, the louver is supported at the tip of the bimetal element instead of at the center. The primary elements are:

1) Louver blade,
2) Bimetal element (spiral wound),
3) Bimetal housing, and
4) Split shoulder bolt.

The louver is attached to a tab on the bimetal element by a nylon tee bracket, which is bonded into the louver blade during its fabrication. The bimetal housing is shaped in the form of a cylinder, closed at one end, with an opening cut into the side. The open end of the cylinder is closed with a cap during assembly and is held in place by the split shoulder bolt. The opening in the side of the cylinder permits the bimetal tab to move through 60° of angular rotation. The split shoulder bolt fits into the inner spiral of the bimetal and mates with a tab on the inner spiral. The inside of the housing is finished with a high emissivity material to maximize the thermal radiation coupling between the bimetal and its housing. The outer surface of the bimetal element, which is exposed to the housing opening when the louver is open, is finished with vapor-deposited gold to reduce the bimetal heat leakage to the surrounding environment. The assembly is easily set to the desired operating temperature range by rotating the split shoulder bolt to the desired position when at the desired temperature. The bolt is then locked in place by a lock nut.

Both louver designs require the use of radiation barriers at each end of the louver so that the radiator has a minimal view factor to the environment. These are normally highly polished and have a low infrared absorptivity such that very little energy from the radiator is absorbed and re-radiated back or reflected back due to diffuse reflection. The external surface of the radiation barrier is usually insulated from the environment by multilayer insulation.

Louver blades

Since the louver blades are supported solely by the bimetal elements, they must be as light as possible to avoid excessive error when performing thermal evaluation tests on the ground. Heavy louver blades would deflect the bimetal element excessively and cause sticking of the drive shaft in the center-mounted design. Excessive angular deflection, due to torque created by the louver-blade weight, would occur for the tip-mounted design.

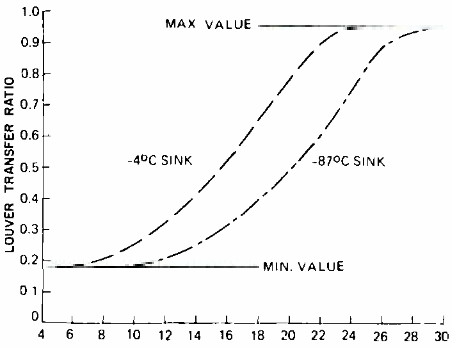

Fig. 5—Louver transfer ratio *vs.* radiator temperature (configuration one).

To avoid or minimize these problems, a louver blade was designed which consists of aluminized 0.5-mil polyimide film (Kapton or H-Film) bonded to each side of a 0.06-inch-thick sheet of 100-pore, open-cell, polyurethane foam. This creates a semi-rigid sandwich structure, which can be bent or crumpled but which returns to its original shape when all external forces are removed. This characteristic is highly desirable, since it can be accidently abused without permanently damaging the louver. Also it prevents the blade from being damaged during vibration. The material is easy to fabricate and only simple tools are needed to make any changes (e.g., for physical clearance) which may be required during integration.

The sandwich structure weighs approximately 12 grams (0.026 pound) per square foot. The louver blades made of this structure created no error or sticking problem for the center-mounted design during thermal testing. The tip-mounted design produced a 3° C error when in the open position and no error when in the closed position.

Testing and test results

Both the center-mount and tip-mount designs were vibration tested to spacecraft qualification test levels in three axes. These levels are 15-g sine from 7 to 2000 Hz at 2 octaves per minute and 35.9-g (RMS) from 20 to 200 Hz. The tested units passed all tests with no apparent damage or change in calibration. A bimetal element was life tested for 8000 cycles over an 18°C temperature excursion with no apparent damage or change in calibration; 8000 cycles represents approximately 18 months of space operation.

Both types of louver systems were given thermal-vacuum tests to determine their thermal performance. The center mounted louver testing was performed using a test fixture fitted with three louver units. The tip mounted test fixture was fitted with two louver units. Test results are presented for the center-mounted louver tests only.

Two configurations of the center-mounted louver were tested. They were identical, except that thermal-radiation control discs were added to the second configuration tested. Fig. 5 presents the test results for the first configuration with surrounding sink temperatures of −4°C and −87°C. As shown, the bimetal response was strongly tied to the sink temperature. Although the bimetal element was designed to rotate the louver from fully open to fully closed over a temperature change of 10C° (8 to 18°C), the test unit actually required a change of 16 to 19°C. This appeared to be caused by a relatively strong thermal coupling between the bimetal element and the external sink. This coupling appears to increase as the louver blade opens. The maximum and minimum LTR values were as good as, or better than, expected—0.96 and 0.18 respectively.

To reduce the bimetal element coupling to the external sink, the thermal-radiation control discs were added and the texts repeated with the active range of the louvers set at a higher level (15 to 25°C as opposed to 8 to 18°C for the first configuration). Fig. 6 shows that the addition of the thermal-radiation control discs greatly improved the louver-system performance. The active temperature range was reduced to 12 to 13C° which is only 2 to 3C° wider than the 10C° design range. The maximum and minimum LTR was the same as before. Although the second configuration performed much better than the first, some coupling still existed between the bimetal element and the external sink. This was within acceptable limits for the particular application, so no further effort was made to reduce this coupling. All tests were performed over increasing and decreasing temperature conditions with no detectable hysteresis.

The tip-mounted configuration did not exhibit the strong coupling characteristics of the bimetal element to the external sink. This was probably due to

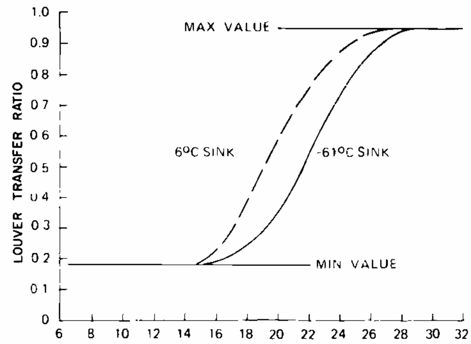

Fig. 6—Louver transfer ratio *vs.* radiator temperature (configuration two).

the use of a heavier (thicker, wider, and shorter) bimetal element and the mechanical configuration. This created a stronger conduction and radiation coupling to the housing. The test data for the tip-mounted design is not presented, but the performance was similar to the configuration 2, center-mounted design and has been verified by spacecraft flight data.

Conclusions

The louver system described has excellent thermal characteristics. The open blade LTR is very close to the ideal value of 1.0, and the closed blade LTR is comparable to values achieved by other types of louver systems reported in the literature. The use of the foam sandwich blade structure coupled with the bimetal-element-supported louver concept creates a lightweight system which is highly reliable and practically indestructible. The reliability has been verified by many months of handling, testing, and flight with no failures of any kind. Although the open-blade LTR has very little room for improvement, the closed-blade LTR can probably be improved with minor mechanical and finish changes such as mounting a low-emissivity hood on the blade (such that it covers the bimetal housing and clearance gaps) and finishing the outer surface of the louver blade with vapor-deposited gold instead of aluminum.

Acknowledgements

The author acknowledges the contributions of Mr. D. Nelson of the Aerospace Corporation for his valuable suggestion of bimetal supported louvers and Mr. K. Schilling of RCA for his work in the mechanical design and analysis of the louver systems.

Corporate laser symposium

Dr. H. Sobol, Chairman

Research and Engineering
Princeton, New Jersey

During the past decade, many man years of research and engineering efforts were devoted to the development of lasers, and to finding the proverbial problems that the laser was allegedly capable of solving. RCA has been a part of these efforts from the early beginnings and has made significant contributions and advances to laser technology.

A corporate-wide Laser Symposium was held in Princeton in the Fall of 1971 to review recent RCA advances in the laser field. The discussions of laser devices centered on current work and projections of future advances of gas, solid-state, and injection lasers. RCA work on laser applications was discussed in papers on range finders, trackers, and target designators; optical memories; illuminators, laser communication systems and modulation; and holographic displays. In addition, overviews of the commercial, industrial and the government markets were presented.

The purpose of the two-day Symposium was to encourage the interchange of information between the various groups within the Corporation working on laser devices and applications. Informal work sessions on optical waveguides and modulators; laser displays; and detectors and receivers were held following the formal presentations. More than 100 RCA scientists, engineers, and management personnel participated in the Symposium and based on the feedback from attendees, the meeting was very successful; and, the goals of the Symposium were accomplished. The authors are to be congratulated on their excellent presentations.

The Program Committee consisting of Dr. T. T. Reboul of Government Engineering, D. Herzog of Advanced Technology Laboratory, Camden, and Dr. D. H. Vilkomerson of RCA Laboratories also are to be congratulated on organizing the Symposium.

The fifteen capsule summaries presented in this article provide a brief insight to the professional efforts of many RCA engineers and scientists. For convenience, the Symposium presentations are grouped (as they were presented) in two major categories: 1) devices, and 2) applications.

Editor's Note: The information summarized in this article has been compiled from information provided by the speakers, and by Dr. H. Sobol, Staff Engineer, RCA Research and Engineering, who was chairman of the meeting.
The symposium provided a convenient medium for the interchange of professional information and for describing the progress being made in Laser engineering and research. Capsule summaries are provided in this article; however, additional information can be supplied to *RCA Engineer* readers by the RCA speaker-contributors.

For more information on laser technology, refer to the *RCA Engineer* special issue on lasers, Vol. 15, No. 5 (Feb.-Mar., 1970). For more information on holography, refer to *RCA Engineer*, Vol. 16. No. 1 (June-July, 1970).

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Session I: Devices

Dr. G. Cody, Chairman

RCA Laboratories
Princeton, N.J.

Gas lasers

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Since the operation of the first gas laser in 1961, lasing of gases and vapors has been observed for more than one third of the elements of the periodic table. These elements have yielded more than 1000 transitions ranging in wavelength from the vacuum ultraviolet, through the visible and infrared into the millimeter band.

Gas lasers in the visible and UV may be classified into three groups, each having a characteristic output power and driving current range:

1) He-excited lasers (such as *He-Ne, He-Cd, He-Zn, He-Se*). These lasers typically yield power outputs in the 1 to 100-mW range, using discharge currents of 5 to 100 mA, and tube voltages of 1 to 5 kV. They are characterized by simplicity of construction and operation. Most prominent lasers in this group are *He-Ne* at 6328 Å and *He-Cd* at 4416 Å.
2) Noble gas ion lasers (*Ar, Kr, Xe, Ne*). These lasers are recommended when output powers of the order of a watt or more are required. Typically using discharge currents of tens of amperes at a few hundred volts, these lasers are more complex than the previous group. They usually need water cooling and a solenoid.
3) Pulsed, self-terminating lasers (*Cu*, N_2). Outputs of up to 100 kW for pulse lengths of about 10 ns have been obtained. These lasers operate with large apertures at super-radiance and the output beam is not of the high quality characteristic of the lasers of group 1) and 2).

The wavelength selection table (Fig. 1) shows the most important laser wavelengths in the range 3000 to 8000 Å. The most efficient transitions are indicated by the heavier lines.

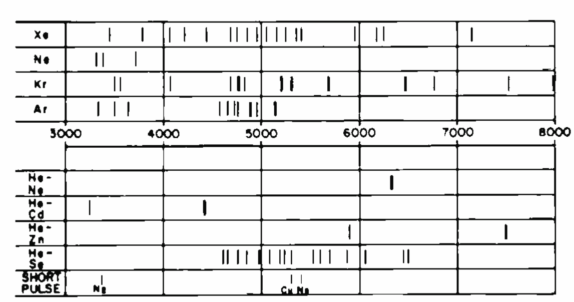

Fig. 1—Wavelength selection table.

Solid-state lasers

Dr. J. P. Wittke
RCA Laboratories
Princeton, N.J.

Solid-state lasers provide a compact, high-energy (or power) source of coherent light with moderate (a few percent) overall efficiency. Three materials are dominant: ruby, yttrium aluminum garnet: neodymium (*YAG:Nd*) and glass:*Nd*. Some typical performance characteristics of commercially engineered lasers are shown in Fig. 1. *YAG:Nd* is the only useful continuous laser, but ruby can give higher power pulses, and glass can be fabricated into large, relatively cheap units. $YAlO_3$ is a new *YAG*-like material under study. It is strongly birefringent; this should eliminate many thermal-stress-induced birefringence problems found with *YAG*; it is also considerably cheaper. *Er*- and *Ho*-doped glasses permit lasing in the 1.5 to 2.0 micron "eye-safe" region.

	YAG.Nd		GLASS:Nd	RUBY	
CONTINUOUS					
POWER	1 kW		–	–	
POWER, TEM_{00}	25 W		–	–	
EFFICIENCY	3%		–	–	
REPETITIVELY PULSED					
PEAK POWER	2 kW		140 W (Avg)	250 MW	
PULSE ENERGY	4 mJ	500 mJ	450 J	5 J	
PULSE DURATION	200 n sec	25 n sec	10 n sec	20 n sec	
REPETITION RATE	1.6 kHz	10 pps	* pps	4 ppm	
BEAM DIVERGENCE		10^{3}		$< 5 \times 10^{3}$	
TEM_{00} MODE OUTPUT	> 3 W, mode-locked			.15 J	1 J (Ampl

Fig. 1—Typical performance characteristics of commercially engineered solid-state lasers.

Cladding laser rods can increase pumping and cooling efficiencies; disc lasers may provide improved cooling, with less thermal "lensing" and distortion. Mode-locking and *Q*-switching techniques permit trains of verv intense pulses to be produced. By using non-linear crystals, frequency-doubling (and tripling and quadrupling) gives intense (~kilowatt) pulses in the visible and ultraviolet. With non-linear optics, tunable parametric oscillators can be made, providing outputs ranging from near the pump frequency (often the 5320 Å output of doubled-*YAG*) into the near infrared.

Crystal laser components can sustain optically-induced damage. Intense UV from pump lamps can generate color centers in ruby and glass laser rods, degrading their performance. At multi-megawatt/cm^2 power levels, damage to optical components, especially non-linear crystals, can be a serious problem.

Laser or flash-lamp pumped organic "dye" lasers provide cw coherent light sources tunable over the visible, while pulsed outputs in the UV have also been attained.

Injection lasers

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RCA Laboratories
Princeton, New Jersey

The performance of *GaAs* injection lasers which emit at 9000 Å at room temperature has dramatically improved since 1968 when the (AlGa)As-GaAs "close-confinement" heterojunction technology was first developed at RCA Laboratories which resulted in much lower threshold current densities at room temperature (Table I) and higher differential quantum efficiency (40 to 50%) level. Additional device innovations including the use of two heterojunctions (1969) and the new "large optical cavity" construction have further increased the basic design flexibil-

Table I—Historical evolution of laser diodes at room temperature.

Year	*Threshold Current Density (A/cm^2)*	*Diff. Q.E. (%)*	*Max. Duty Cycle at R.T.*
1962	∞	—	—
1963	100,000 to 300,000	5	10^{-5}
1963	40,000 to 60,000	15	10^{-4}
1968	8,000 to 10,000	50	10^{-3}
1969	4,000 to 8,000	50	10^{-2}
1970	1,110 to 5,000	50	$\sim 3 \times 10^{-2}$ (cw for short time)

Definitions of some laser terms used in these summaries (provided by Dr. J. P. Wittke).

He-excited lasers—Lasers primarily excited by the transfer of energy, during a collision, from a metastable excited helium atom.

Self-terminating laser—A laser that "turns itself off" by populating, by laser action, the lower level faster then relaxation processes can depopulate it.

Eye-safe region—The region of the spectrum, from 1.6 to 2.0 micrometers, where the radiation does not penetrate the eye and cause retinal damage.

Disc lasers—Lasers in which the active material is in the form of many thin disks.

Q-switching—Changing the losses in a laser cavity suddenly to produce an intense output pulse.

Close-confinement—The technique of varying the index of refraction of an injection laser near the p-n junction to confine the optical wave to the region near the junction.

Heterojunction—A p-n junction with different materials on each side.

Large optical cavity—A very thick (several micrometer) region in an injection laser to which the optical energy is confined.

Fraunhofer hologram—A hologram made with the object effectively at infinity.

Focused-image hologram—A hologram made by imaging the object onto the hologram plane.

Fourier transform hologram—A hologram resembling in its properties a Fraunhofer hologram that can be made without using lenses.

Brewster window—A laser window mounted at such an angle that one polarization wave can be transmitted without any reflection.

Thermal lensing—Thermal distortions in the laser rods causing them to act as lenses.

Mode locking—A technique whereby many oscillating (axial) modes of a laser are phase-locked to produce a train of short output pulses.

Cladding—Coating a laser rod with an optically inactive medium to enhance heat transfer and/or increase pumping light concentration.

PMT—Photomultiplier tube

YAG:Nd—Yttrium aluminum garnet, doped with (active) neodymium ions.

Glass:Nd—Glass laser material, activated by doping with neodymium ions.

ity of laser diodes to fit them for a variety of applications requiring either low-peak-power, high-duty-cycle operation or short-pulse, high-peak-power output. A great deal of progress has been made in the control of diode life, making pulsed operation with 1000-hour life feasible for most systems of current interest.

Helium-neon laser products

R. A. Jeuch
Electronic Components
Lancaster, Pa.

The RCA helium-neon line modular concept of tubes, heads, exciter, and complete lasers was devised to meet the many diverse needs of the OEM laser applications designer, allowing him to design from tube, head, or simply to incorporate a complete, operating laser into his system.

The fundamental ingredient in RCA's *He-Ne* line is the rugged, stable, long-life, cold-cathode laser tubes produced by mass production techniques. These tubes are of a true coaxial design with no side-arm appendages and have a thru-bore for maximum stability. Integral mirrors assure positive alignment and immediate lasing with the application of the required voltages. Tubes are available in powers of 2mW, 4mW, and 5mW, and in fundamental or multimode operation.

The basic *He-Ne* tube line is also incorporated into laser heads. The tubes are shock-mounted within a sturdy aluminum cylinder and sealed in a dry nitrogen atmosphere. Also available to operate with any of the *He-Ne* tubes or heads is a specially designed, compact, exciter. A ready-to-plug-in and operate laser may be obtained by ordering any combination of heads and an exciter.

The blue output of these lasers is ideal for applications in:

Chemical analysis
Raman spectroscopy
Large screen displays
Optical memories
Holographic memories
Video recording (selectavision)
Alignment and surveying

The low-noise feature of the J15414 helium-cadmium laser, plus its comparative low cost, makes it highly competitive in applications now using small noble-gas lasers.

Solid State Division laser products

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Injection lasers fabricated by the single heterojunction close-confinement process are available commercially as single laser diodes, linear series-connected arrays, and stacked diodes.

Single diodes with emitting junction widths of 3 to 55 mils give peak power outputs of 2 to 70 W respectively at drive currents ranging from 10 to 250 A. The peak power output of these diodes is limited to approximately a watt per mil of emitting facet to avoid catastrophic damage to the diode while the current density is limited to 40,000-50,000 A/cm^2 to minimize gradual degradation of the diode.

Maximum duty cycle is 0.1%. Thus at a maximum pulse width of 200 ns a repetition rate of 5 kHz is allowed. Because heat generation is the factor that limits operation, a direct trade-off can be made between pulse width and repetition rate. Thus at a pulse width of 10 ns, repetition rates of 100 kHz have been obtained with *GaAs* diodes.

At 75°C, with constant-current drive, the peak power output of laser diodes falls to 40 to 50% of their room temperature value. At −55°C the diode is more efficient and room temperature peak power outputs can be obtained with 70% of the room-temperature drive current.

There are two basic difficulties in achieving high peak power output from a single laser diode. One is the high drive currents required to drive the larger laser pellets, the other is the large source size of these diodes which require large and costly optics. One approach to the problem of achieving maximum optical power density with practical drive conditions is a stacked laser device, wherein the device consists of two or more laser pellets stacked one on top of another to form a compact emitting source. As many as eight single diodes have been series stacked to achieve peak power outputs of over 300 W from a source size of 0.035×0.035 inch with a power efficiency of 9%.

Linear-series-connected arrays in a hermetic TO-5 package with 10 to 60 diodes emit peak powers up to 300 W at a drive current of 25 A at 300°K. At 77°K, larger arrays, giving kilowatts of peak power and 30 W average power from up to 1000 laser diodes in series-parallel arrangements are now commercially available (see Fig. 1).

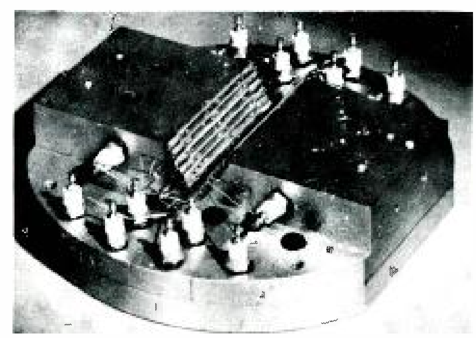
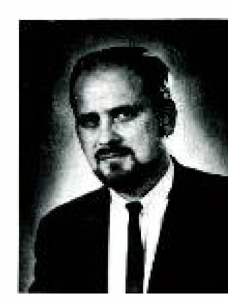


Fig. 1—Commercially available 30-W-average-power *GaAs* laser array (RCA Type TA7924).

On an experimental basis, single laser diodes using the new double heterojunction large optical cavity (LOC) laser diode developed by RCA Laboratories are now available commercially. The LOC laser diodes feature high repetition rates (1 MHz), high duty factors (1%), high temperature capability (100°C) and low drive current (5 amperes).

Gallium-aluminum-arsenide laser diodes and arrays with variable center wavelength of emission (8000 to 9000Å) are also available commercially. These wavelengths provide a better match to the newer image tubes and allow for improved systems performance.

CO_2 lasers



Dr. R. A. Crane
Research Laboratories
RCA Ltd, Montreal

The Research Laboratories of RCA Limited, Montreal has been involved, during the past two and a half years, in developing efficient, long life, sealed-off CO_2 lasers for space applications. Concentrating on the cathode problem, a cathode (designated RCA LTD-10) has been developed which allows long tube life to be obtained without the rejuvenation techniques associated with nickel cathodes. Fig. 1 shows the sealed-off operational life characteristic to 11,000 hours. This was obtained with a 20-cm-long glass laser tube shown in Fig. 2 and is currently at the 12,000 hours level. Reliability in tube life is presently at the 8,500 hour level.

Development of special Brewster window sealing techniques has allowed output powers, close to that obtained in internal mirror systems, to be obtained with 2 GaAs Brewster window configurations. For example a 40 cm tube can produce 6 watts, TEM_{00} mode of output at 11% efficiency.

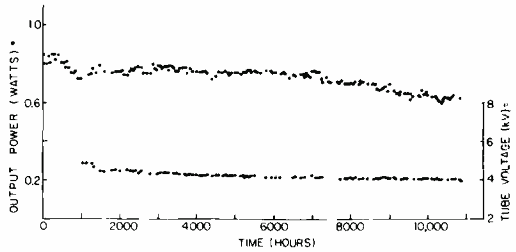


Fig. 1—Operational life characteristics of sealed-off CO_2 lasers.

CO_2 laser tubes constructed of ceramic alumina have also been developed in space qualifiable configurations. Life testing in these configurations are currently at the 2,000 hour level.

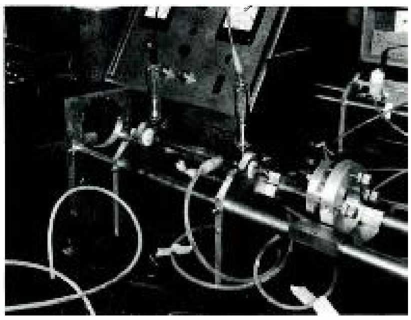


Fig. 2—Glass laser tube (20 in) designed for 12,000-hour life.

Session II: Applications

F. Sashoua, Chairman
Advanced Technology Laboratories
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Commercial and industrial overview

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The laser industry in the U.S. can be conveniently grouped into three major categories:

1) Military/Aerospace
2) Government Sponsored R&D
3) Commercial/Industrial

Various researchers estimate the 1970 total U.S. laser system sales at approximately $110M of which 42% was military/aerospace, 21% Government R&D, and 37% in the consumer industrial area. More significant are the predicted growth trends. Market researchers estimate that the U.S. laser system market by 1980 will exceed $0.5 billion: 75% in the consumer/industrial field and less than 25% in the military/aerospace and Government R&D area. EC's gas laser group has aimed its product development plans at the industrial/commercial marketplace because of this growth rate.

The military/aerospace laser market is predominantly infrared oriented. Laser illuminated range finders, night vision, in-flight data transmission, laser fusing, and high power laser weaponry are the predominant systems in this marketplace, and the component requirements are primarily solid-state injection and/or CO_2 lasers.

The Government research and development market is basically research oriented—dominated by university, government laboratory, and large corporation research organizations. It addresses itself to the needs of the military applications and consequently has low interest in gas laser products manufactured at Lancaster.

You may be aware that the EO group in Lancaster which recently assumed the responsibility for diodes, has substantial interest in this marketplace. However, my subsequent remarks will be limited to the gas laser.

The commercial/industrial market is the fastest growing segment of the laser market. Historically, it has been research instrument oriented and characterized by both low volume and a high degree of technical obsolesence. The dynamic growth predicted—e.g., a 10-fold increase will not be realized with these types of instruments as present suppliers lack the technical, financial or distribution attributes necessary to successfully market this vast array of equipments. The predicted increase will come forth with the development of new laser oriented end-use products in such diverse markets as information processing, material working, communications, construction alignment, surveying, interferometry, metrology, and industrial non-destructive testing/inspection. Thus we look forward to a new industrial OEM manufacturer base which is now beginning to evolve.

Current gas laser product emphasis in EC is on *He-Ne* lasers which satisfy the majority of these new OEM applications requiring a sturdy, low-cost reliable device for low power, cw, coherent light. In addition, the gas laser product group at Lancaster also provides a low cost *He-Cd* metal vapor laser which because of its simple construction and its blue and UV wave length, offers system designers flexibility, not made possible by either HeNe or argon lasers. Blue and UV lasers offer better photochemical sensitivity and are in the area of maximum sensitivity for most commercial detectors. This type of laser should find application in chemical analysis. Raman spectroscopy, large screen displays. optical memories, holographic memories, and video recording.

The $40M worth of system sales during 1970 attest to the fact that the laser system has arrived. There are today many established laser systems in the U.S. utilizing the type of gas lasers manufactured at Lancaster. Some examples of these would be of interest to RCA engineers and scientists. For instance:

Laser transits—There are laser transits on the market today manufactured by such companies as Varitech, K&E, Automatic Grade Light and Laser Alignment. There are 16,000 construction companies in the U.S. alone, each of which portends to need 1 to 5 such systems. Prices of such systems range from $3,000 to $10,000 each; however, the cost of sewer pipe alignment crews is cut in half—an approximate saving of $200./hour. Similar systems are already being marketed for other uses in the construction industry—for example, the installation of suspended ceilings.

Laser gauge—The unique properties of the gas laser have brought forth laser instruments which help improve the machining measurement accuracy by better than an order of magnitude, *e.g.*, from 10^{-4} to 10^{-6}. Companies such as Perkin Elmer and Hewlett Packard are marketing such systems. Indeed under controlled environment, accuracy up to 10^{-9} inch have been demonstrated.

Inspection systems—Holographic inspection systems are made possible by using the unique properties of the gas laser—highly collimated monochromatic light. GC Optronics Inc. markets a system utilizing this principle. In one application, holographic photos are compared between a partially inflated tire and a fully inflated tire and subsurface defects are identified. In another application, aircraft wings, or any laminated structure, can be flexed and observed holographically to detect flaws not visible to the eye.

Raman Spectroscopy—Again, the laser's unique attributes is creating another type of inspection analysis system. A monochromatic laser system is used to cause liquid to fluoresce (Raman scattering). The resultant emissions can be compared to known standards and control limits established. Companies such as Spex Inc. and Cary Instruments are marketing systems of this nature. Continuous flow, quality inspection systems can be envisioned and, of course, systems of this nature can greatly facilitate laboratory analyses.

Photoresist applications—The gas laser's highly collimated beam (no light spreading) offers a solution to very fine photo-engraving and mask-making requirements. Exposure time are a function of the chemicals and the light source. RCA offers a full line of gas lasers from red to UV which can be matched to various light sensitive materials.

The above applications are examples of systems now being marketed. They are all characterized by the use of small gas lasers of the type manufactured at EC and thus represent significant growth opportunities for gas lasers.

What about the future? Most of you are aware of the gas laser potential in the SelectaVision player system and/or video recording. Should this system use a gas laser and find mass market appeal, it alone could dwarf the industry laser projections I have indicated earlier. In addition, the unique attributes of the gas laser suggests possible applications in supermarket automation and the entire field of information storage and retrieval—all of which suggests a strong growth potential for the gas laser.

Acknowledgement: The author wishes to acknowledge the contributions made by Mr. John Crowe, Manager, Laser Marketing, RCA Lancaster.

Government overview

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The Government laser market is a systems market, and the laser makes possible new systems not otherwise available to the military. Examples of these new systems are: laser-aided weapons delivery; 1-Gbit satellite communication; laser weapons; and laser-aided night vision and reconnaissance. These four will provide the bulk of the Government funding for R&D and production of laser systems in the foreseeable future.

	R & E (6.0,6.2)	*A & E (6.3,6.4)*	*Prod*	*Total*
Army	$ 7.0M	$12.0M	$12.0M	$31.0M
Navy/MC	4.0	7.0	2.0	13.0
AF	9.0	18.0	20.0	47.0
ARPA	16.0	—	—	16.0
NASA	—	5.0	—	5.0
Total	$36.0	$42.0	$34.0	$112M

Fig. 1—Total market value of R&D and production laser components and systems, 1971 (from CAMP Reports, 7-3, "Lasers," Frost & Sullivan, 1971).

Fig. 1 provides an estimate for the total laser market available in fiscal year '71. Note that this market includes the three Services plus ARPA, NASA, and the Marine Corps, and furthermore contains information on both R&D and production funding. The first funding column indicates those dollars available for basic research and exploratory development (the funding categories defined as 6.1 and 6.2 in the Government budget). The second funding column refers to advanced development and engineering development (or 6.3 and 6.4 funding). The third funding column itemizes production funding for FY '71. Of the total of $112M available, approximately $20M is spent in-house by the Services and NASA—leaving $92M for contractors. Since most in-house funds are spent in the R&D area, the impact of Government in-house programs is to reduce the total market available in R&D to approximately $58M.

Since we are in a climate of constant defense budgets during a period of inflation, the actual number of industry man hours supported by laser oriented R&D funds will decrease at an annual rate approximately equal to the rate of increase in the cost of living. It is my opinion that FY '72 will look just like FY '71, within 10%.

I know some of you would like to measure these dollars against the total dollars available in the DoD budget for R&D. In FY '71, total contract awards in this area reached $5.5 billion against a total budget, including in-house programs, of approximately $7 billion. This level of funding is expected to remain relatively constant over the next five years with an increasing portion of funds devoted to supporting the in-house research staffs of various Government laboratories. Putting it more directly, there will be fewer man hours of R&D support available across the board from DoD.

I do not mean to paint a totally negative picture. There are substantial areas of Government funding available to RCA. In the area of laser-aided weapons delivery, for example, Aerospace Systems Division in Burlington has booked in excess of $10M over the last three years in its Integrated Observation System and Red Flame II programs. Burlington expects to use the experience gained on these contracts in order to become a significant factor in the Army's Laser Target Designation System program. The laser-aided weapons delivery portion of the market has matured due to the success of these devices in S.E. Asia. A consistent market of approximately 70M per year, consisting of lasers and related equipment, is potentially available to RCA.

High-data-rate satellite communications will receive approximately $5M worth of technology funding in 1972. This area will continue to expand up to the point of an operational launch of 1-Gbit data relay satellites which should occur before 1980. The RCA market here not only includes the specialized laser transmitters and receivers, but also the integrated spacecraft and its attendant high accuracy attitude control system.

The laser weapons area will be funded by ARPA for $23M in fiscal year '72. These funds will be supplemented by approximately an equal amount of Services funds in '72 for a total market of about $40M per year. This level of funding is expected to continue over the next ten-year period at which time operational laser weapons will be in the hands of the Services. RCA's role in this market is largely an outgrowth of our experience at the Missile and Surface Radar Division in the area of precision trackers and instrumentation radars. RCA Ltd. in Montreal is proceeding with some very fundamental work in high-energy CO_2 lasers which, when integrated with Moorestown's radar capability, gives RCA a credible image as a systems integrator.

Laser-aided night vision and reconnaissance covers a very broad variety of systems. Currently, RCA through its Advanced Technology Laboratories in Burlington is working very closely with the Air Force in the integration of a high powered gallium arsenide laser illuminator into the GUNSHIP program. We expect our first production of laser illuminators by the end of this calendar year, and anticipate a continuing market of about $3M in this area.

I've tried to give you a broad picture of those areas of the Government marketplace of importance to RCA. You'll notice that I've omitted holography from my discussion, although holography certainly has to be an important part of all our plans. In G&CS, we have not marketed holography as a technique, but rather as a means of providing improved system performance for existing Government requirements. Stated another way, we have sold the application—and not the technique. Since we have been quite successful with this marketing philosophy, we intend to continue it and, therefore, holography does not appear in our projection of the laser market.

Laser rangefinders and target designators

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Considerable development effort by industry and governmental agencies over the last decade has brought the laser rangefinder and target designator to mature technological levels. Low-power lasers, in conjunction with co-operative targets, are finding increasing commercial use in surveying and construction. High-power systems have proven their utility in the U.S. space program and in ground and airborne military systems. RCA has contributed significantly in these areas and is continuing advanced development for the next generation of systems.

Historically, the only lasers seriously considered for long range non-cooperative ranging and target designation have been ruby, neodymium, and erbium which can emit short nanosecond pulses with megawatt peak powers for time-of-flight range measurement.

Some important properties of each laser type are summarized in Table I. Until recently, the ruby laser was supreme for rangefinder applications due to the availability of sensitive high gain photomultiplier detectors.

Table I—Important laser properties.

Laser type	*Principal laser wavelength (microns)*	*Thermal conductivity ($W\ cm^{-1}\ {}^{\circ}K^{-1}$)*	*Threshold Energy* (Joules/cm^3)	*Efficiency (%)*
Ruby	0.6943	0.42	80	0.2
Neodymium *YAG*	1.064	0.11	1	2
Erbium glass	1.54	~0.01	50	0.1

Neodymium *YAG*, however, has almost completely supplanted ruby (except for very long-range applications) due to the development of the silicon avalanche detector which is almost as sensitive as the PMT for rangefinding. The much lower threshold and high efficiency of *Nd:YAG* allow considerably smaller, higher repetition-rate systems to be built which still possess long-range (>10km) capability. Erbium has also received much attention since it emits in the "eye safe" region around 1.5 μ. At present, however, its low efficiency and the relatively poor performance of the germanium avalanche detector preclude its use in most military systems.

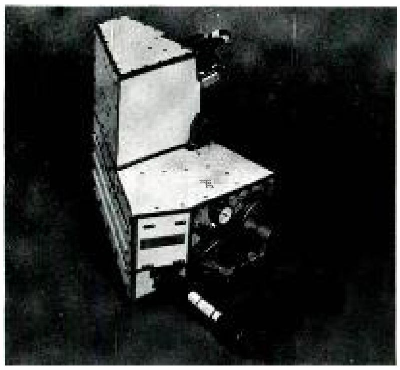

Fig 1—Lunar altimeter for Apollo.

For the very long ranges encountered in space, the ruby laser remains an important tool. It is used for the earth to moon ranging experiments and in the first laser to orbit the moon (Apollo 15). The lunar altimeter shown in Fig. 1 was built by Aerospace Systems Division, for ranging to the moon's surface from the orbiting command module. It is used in conjunction with a survey camera for precise mapping of the lunar surface. It has a range of 80 miles and an accuracy of ±1 meter.

RCA has also delivered numerous ruby rangefinders to the military. These units have seen extensive service in Vietnam where they have proven to be rugged, reliable and added significant new capabilities. The designs have subsequently been converted to use Nd:YAG operating at high repetition rates to fulfill both the rangefinder and target designation roles.

Optical memories

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Of the many possible types of optical memories, five appear likely to have some impact on future computer technology:

1) A *read-only non-holographic memory* uses either a scanned laser or light-emitting diodes for addressing an array of stored images arranged as pages of data. When illuminated, each data page is focused on single detector array by an optical system.
2) *A read-only holographic memory* utilizes the same type of addressing and sensing but stores the information as holograms of the original data.
3) *A write-once bit-by-bit optical memory* uses a laser to burn holes in a specially coated strip which revolves on a drum. Although not erasable, writing is in real time and provision is made for automatic strip changing.
4) *A read/write bit-by-bit optical memory* resembles a conventional magnetic disk memory except that a laser is used to write on a disk coating which is magnetooptic. Sensing is also optical.
5) A *read/write holographic memory* is the most advanced optical memory concept; in this memory, holograms are written in real time on an erasable storage media.

Read-only optical memories are available today in non-holographic form and could be developed in holographic form in 2 to 3 years. The write-once bit-by-bit laser memory is also here today. Read/write bit-by-bit disk memories are 3 to 6 years in the future. For the erasable holographic memory, we shall probably have to wait a decade before it becomes a commercial reality.

Table I—Performance of some optical memories.

Type of Memory	*Typical capacity (bits)*	*Typical access time (sec)*	*Cost/bit (cents)*
Read only (non-holographic)	1.5×10^5	6×10^{-6}	1.6
Read only (holographic) (note 5)	1.6×10^7	3×10^{-6} (note 1) 5×10^{-8} (note 2)	4×10^{-1}
Write once (bit-by-bit)	10^{12}	5 (note 3) 2×10^{-1} (note 4)	10^{-4}
Read/write (bit-by-bit) (note 5)	10^{10}	10^{-9}	2×10^{-3}
Read/write holographic (note 5)	10^{10}	10^{-5} 5×10^{-8} (note 2)	2×10^{-6}

Notes:
1) To a page
2) To a word within a page.
3) To a block of 3×10^9 bits.
4) To a word within a block of 3×10^9 bits.
5) Projected.

Injection-laser-illuminators

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For many years, RCA has been active in the application of injection lasers for pulsed illuminators for use with gated night-vision viewing devices.

The use of a pulsed illuminator in conjunction with a viewing device which is only gated on when the illumination pulse is being received from a target offers considerable advantages over the use of CW illumination. In the presence of fog or mist the backscattered energy from the illuminated pulse is not accepted by the viewing device resulting in virtual immunity to control degradation from this effect. Further, by controlling the width and delay of the viewing in time, selective illumination of portions of the target area may be achieved in a manner analgous to range-gating techniques used in radar systems.

To achieve highest efficiency and maximum power output from injection laser diodes, they should be operated at temperatures around that of liquid nitrogen (77°K). To reduce thermal losses to manageable proportions, early versions of illuminators used these devices inside a vacuum space and cooled by a Sterling cycle refrigeration system. Such an approach, although thermally very efficient, resulted in systems that required vacuum pumps for maintenance and were very difficult to maintain in a field environment, a very important factor in practical applications.

In 1969, RCA conducted an extensive development program designed to provide a solution to this problem and to establish design concepts applicable to all injection laser illuminator systems for field applications.

As a result of this program, illuminator design concepts were developed that incorporated high efficiency thermal insulation without the use of vacuum pumps and in which access and repair time for the injection-laser diode assembly could be accomplished in less than 15 minutes without the use of special tools.

In addition to these improvements, special protective circuitry was developed to fully protect the laser diodes in the event of any system malfunction or improper operation. These basic design concepts have been used in all illuminator systems designed.

Three units were delivered to the U.S. Army Night Vision Lab for ground-to-ground operation. These units provide up to 6W of average power and use liquid nitrogen for cooling; units are self contained and provide eight hours of continuous operation.

After two years of extensive field use, all three units are still operating at specified performance and have proved to be highly reliable, needing very little general maintenance.

Following the success achieved with these units, a contract was obtained from the U.S. Navy to supply a complete Low-Level Surveillance System consisting of a multibarrel Gallium Arsenide illuminator and a gated ISIT camera. This system has been extensively evaluated both on the ground and in an airborne environment with complete success.

The most recent illuminator units built by RCA are three 22-W units delivered under contract to the U.S. Air Force Systems Command, WPAFB for airborne application. These units which are intended for field deployment have to date achieved over 300 hours of essentially fault-free operation and have received the highest service rating for fault free operation and design integrity.

Optical tracking systems

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This paper describes two optical tracking systems developed at ATL.

The first system is a laser tracking and ranging system (Fig. 1) developed for NASA to monitor continually the position of an astronaut on the lunar surface. The system tracks and measures range to a cooperative target (retroreflector) with a range accuracy of ±1 milliradian. The system has been operated on earth out to a range of 1200 meters. A TV camera is mounted on the unit to maintain constant video contact with the astronaut.

The laser tracking and ranging system uses a *GaAs* laser diode transmitter coupled with a silicon quadrant photodiode receiver to provide a compact, rugged, lightweight system with high accuracy and low power consumption.

The second system is a receiver/seeker for laser designators. This system has the capability of detecting and generating position information to a particular laser designated target when returns from other designated targets are also being received.

The receiver/seeker uses a unique 12-element PIN photodiode array to cover a wide (10°=25°) field of view while maintaining a very high degree of sensitivity (Fig. 2).

All pulsed optical returns from the system's field of view are examined to determine if they are coming in at a particular selectable

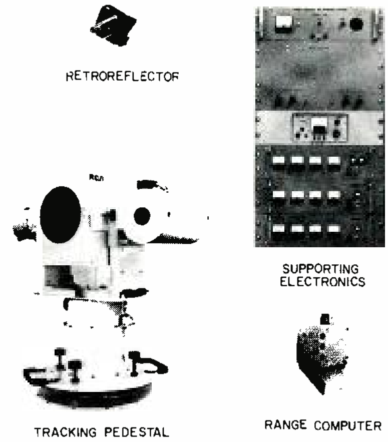


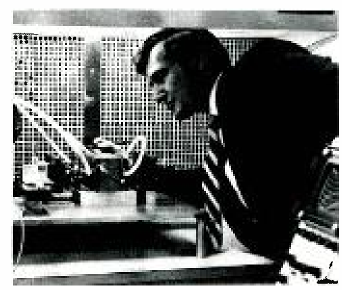
Fig. 1—Components of laser tracking and ranging system.

Fig. 2—Receiver/seeker head.

frequency. Signals at this frequency are gated into a tracking loop which determines from where in the system's field of view the correct returns are being received.

The receiver/seeker system can detect signal strengths as small as 10^{-16} joules/cm^2 and generate tracking errors with a ±0.5 milliradian accuracy over an 80-dB signal-input range.

Laser communications



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The laser has long held out hope that it will be able to solve all our communication problems with its narrow-beam and high frequency, etc., but it won't. However, it can do better than conventional techniques on some tasks, such as short range (<5 km) fixed-point to fixed-point, with bandwidths ranging from voice to approaching gigabit capability. The principal reasons for low data rates are; no ICC regulations, relative low-cost units, and security. Army transportable field equipments use lasers to replace cables which make up a significant portion of equipment weight and mobility limitations. Fig. 1 is a block diagram of a typical high-data-rate laser transmitter for communication uses. Fig. 2 illustrates several modes of operation.

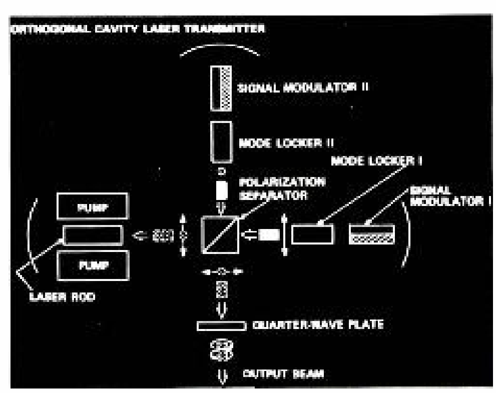


Fig. 1—Typical high-data-rate laser transmitter.

Another application area is very long range space communication where two currently funded programs for a 1 Gbit/s communications link are being worked on at Lockheed and McDonnell-Douglas. They are working on external modulators for either a single frequency cw laser or a cw mode-locked laser.

The Advanced Technology Laboratories approach employs internal modulation of a mode-locked laser operating in two orthogonally polarized modes. It can be used to transmit two "independent" orthogonal circularly polarized laser beams from a single CW-pumped laser medium. This improves the efficiency by 50%. Operation is feasible at both 1.06 μm and 0.53 μm.

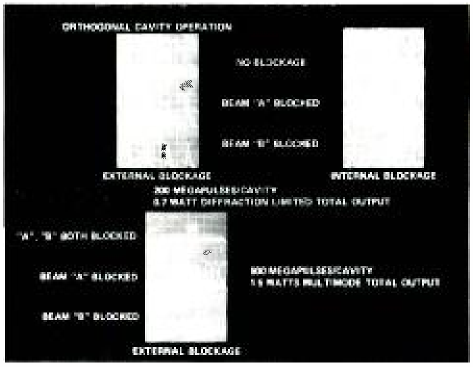
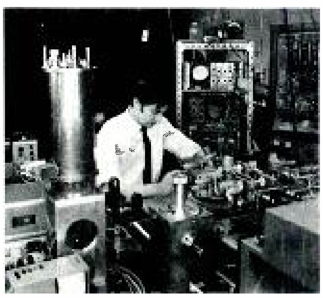


Fig. 2—Modes of operation of high-data-rate laser transmitter.

Laser communication experiments at the RCA Ltd. Laboratories



A. Waksberg
Research Laboratories
RCA Ltd
Montreal, Quebec

The RCA Ltd. Research Laboratories have been involved in laser communication studies for a number of years. One facet of the work consisted in the design, construction and operation of a phase-locked *He-Ne* PCM laser link. Fig. 1 shows the complete system in operation. The 80-Mbits pulse stream produced by the laser was used as the Master time clock. A TV receiver (top left) supplied the analog signal which was encoded by an 8-bits per word PCM encoder. A parallel-to-serial converter transformed the digital information into a serial stream at 80-Mbits rate. This was used to drive a $LiNbO_3$ modulator which modulated the *He-Ne* pulse stream. The small laser link (within the lab) was then collected and detected by a fast avalanche diode. The digital information was then converted back into an analog signal which was then presented on the monitor (top right) with no visible degradation in quality of the picture. A special automatic optical bias compensator (developed here) was used to offset the thermal effects of the modulator. Pulse position jitter measurements on a ½-mile link in downtown Montreal was also performed.

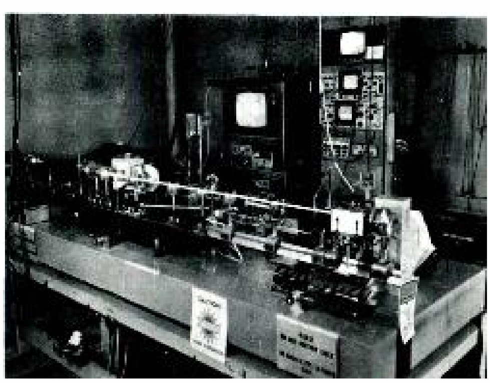


Fig. 1—Complete laser communication system in operation.

Another facet of our work involved a NASA feasibility study of an FM CO_2 laser communication system for satellite-to-ground and satellite-to-satellite optical links. The heterodyne set up that was used to permit system definition studies is shown in the author photo. This included laser AM and FM noise, signature measurements, heterodyning of transmitter and LO, *etc*. Also, a long-life sealed laser tube was developed for space use and will soon be evaluated by NASA. Lifetimes of more than 12,000 hours have already been obtained. This is discussed by Dr. R. A. Crane in this article.

Other studies involves the employment of CO_2 laser radar for active IR imaging systems and its possible use in aerial mineral exploration.

Acknowledgement: J. Wood, S. Sizgoric and D. Bennett worked with the author on these various projects.

Holographic displays

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The storage and display of documentation-type information is a problem of major concern—particularly in light of the ever increasing tendency to generate, store, and retrieve alphanumeric, graphical, and continuous-tone color and black-and-white information. Holography offers a method of storing this type of data in a compact, highly redundant, easily duplicated, inexpensive and readily retrievable manner. At Advanced Technology Laboratories in Burlington, a number of programs are being conducted to develop a variety of techniques for holographically storing both black and white and color information.

One technique employs a laser source to reconstruct holographically stored textual and digital program material required to operate automatic test equipments such as the LCSS (Land Combat Support System) and the VAST (Versatile Avionics Shop Test) equipments. This storage system employes Fourier and quasi-focused image holograms (a hologram formed close to the image plane of an imaging lens system) to store respectively a 5×10^5 bit digital machine language program and a 100-page (8½×11-inch) technical manual on a plastic card about the size of a standard credit card. The storage card, in addition to being compact, is durable and offers the possibility of transporting the card with the unit to be tested.

A quasi-focused image hologram storage technique is being utilized on programs for the Navy and NASA to allow restoration of full color images using white light sources. In the Navy program, red, blue, and green color separations derived from aerial charts are used to produce three overlayed holograms recorded in a common area. A 12½×12½-inch aerial chart is recorded as a 12mm×12mm area hologram. The holograms are reconstructed using a white light source to produce a moving map display viewed through a six-inch viewing aperture having resolutions of ten line pairs/millimeter and a color fidelity equivalent to that of existing aerial charts. A Fraunhofer hologram is recorded over the three color separations holograms to allow the storage of indexing information.

The program conducted for NASA allows the simultaneous display of archival and volatile information. The archival information is holographically stored in a manner similar to that used in the Navy Moving Map Display. The volatile information is displayed using a 512×512-element neon plasma panel. The two displays are superimposed and simultaneously viewed over an 8½×8½-inch.

Multicolor moving map display characteristics

Viewing area:	Circular, 6 in. diam., rear projection
Resolution:	10 lp/mm
Color fidelity:	Equivalent to existing aircharts
Screen brightness:	Acceptable for viewing in a cockpit environment
Storage form:	Three overlayed quasi-focused image holograms
Storage medium:	Vinyl tape; embossed from a metallic master; stripped from photoresist
Motion capability:	Continuous east to west; ±3½ in. North to South per stored map segment; 360° rotation capability
Data retrieval time:	6 seconds to retrieve any one of 500 maps; 500 ms to do a 30-frame jump
Storage capability:	Equivalent of 500 12½-in. × 12½ in. aerial charts stored as 500 12 mm × 12 mm holograms on a 250 in. tape strip in a cassette 5½ in. × 3 in. × ¾ in.
Index:	9-bit overlay address recorded as a Fraunhofer hologram.

Automatic communications equipment tester

F. Pfifferling | D. H. Williamson

A programmable RF test system is being used by the Camden Manufacturing activity of Government and Commercial systems to test deliverable radio equipment. The system, called ACET for Automatic Communications Equipment Tester, incorporates an RCA 1600 computer and a high-order test programming language to perform complete tests on receivers and transmitters as well as sub-assemblies and components in the HF, VHF and UHF frequency ranges.

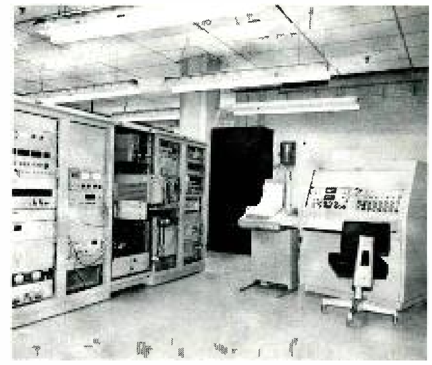

Fig. 1—Complete Automatic Communications Equipment Tester (ACET). Control console is on the right; the Unit Under Test (UUT) is the AN/ARC-142 Receiver/Transmitter.

Automatic test systems typically consist of stimulus equipment, measurement equipment, and switching. The computer controls the application of the proper stimulus to the unit under test, selects the proper measurement devices, and makes a series of *go/no-go* decisions as the test progresses. In some cases, the computer is also used for statistical analysis and process control.

The Aerospace Systems Division in Burlington, Massachusetts, has been a pioneer of this type of system for the military for more than ten years. RCA automatic testers are in use at depots and Army tactical areas all over the world. Test automation in factories, however, either did not exist or had been limited to expensive special-purpose testers dedicated to a single product or project. The recent introduction of the low-cost minicomputer and commercially available programmable instruments has changed this picture to the point where many electronic manufacturers are now using some sort of automation for testing deliverable products.

Most automatic test systems available to the commercial market are used for testing components and digital circuits. These systems are usually dedicated to a minicomputer and perform functional (truth table) testing, DC testing, or parametric (pulse characteristics) testing; these are multipurpose equipments in that they test types of product rather than a single product on a given project.

The Automatic Communications Equipment Tester (ACET) described here measures radio parameters such as sensitivity, selectivity, power output, and distortion.

Advantages of ACET

Although the AN/ARC-142 HF Receiver/Transmitter was chosen as the first equipment to be tested with ACET, the tester includes a broad range of commercially available programmable equipment which generate stimuli and perform measurements from DC to 500 MHz. The interface to the unit-under-test (UUT) has been designed to accept, with some modification, many of the products produced in the Camden Plant. Engineers have been, and are presently, designing radio products for compatibility with the automatic tester. The result is lower test costs for our bids to capture new business.

Some of the types of equipment that can be tested with ACET are:

Audio amplifiers
Video amplifiers
IF amplifiers
Mixers
Receivers
Transmitters
Power amplifiers

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Authors Fred Pfifferling (left) and Don Williamson.

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received the BEE from CCNY (1951) and the MSEE from Drexel (1957) He served as Professor of Electrical Engineering at the Drexel University Evening College from 1958 to 1966 He has been active as a specialist in development of test equipment and techniques for more than ten years His designs include Launch and Checkout equipment for the Dynasoar Program Radar Test Simulators for the F-102 Aircraft, Atlas missile checkout equipment, automatic depot test equipment for the Army and test equipment for the Lunar Orbiter Spacecraft He was a member of the Engineering Team which developed the Multi-Purpose Test Equipment and Digital Evaluation Equipment used by the Army In recent years Mr Pfifferling has been directing his attention to developing cost effective testing on the production line He is presently responsible for test automation in the G&CS divisions Mr Pfifferling is a member of Tau Beta Pi Eta Kappa Nu and IEEE

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received the BEE from the University of Delaware in 1956 and has completed several courses toward the MBA Before joining RCA in 1968 he worked for nine years at Thiokol Chemical Corporation during which time he was instrumental in the design and development of techniques and equipment for high accuracy data acquisition systems for rocket motor testing From 1968 to 1970, he was Administrator of Production Programs G&CS Manufacturing Staff His responsibilities encompassed the coordinating and implementing of automatic test concepts and projects with particular emphasis on computer controlled systems He was appointed to his present position in 1971

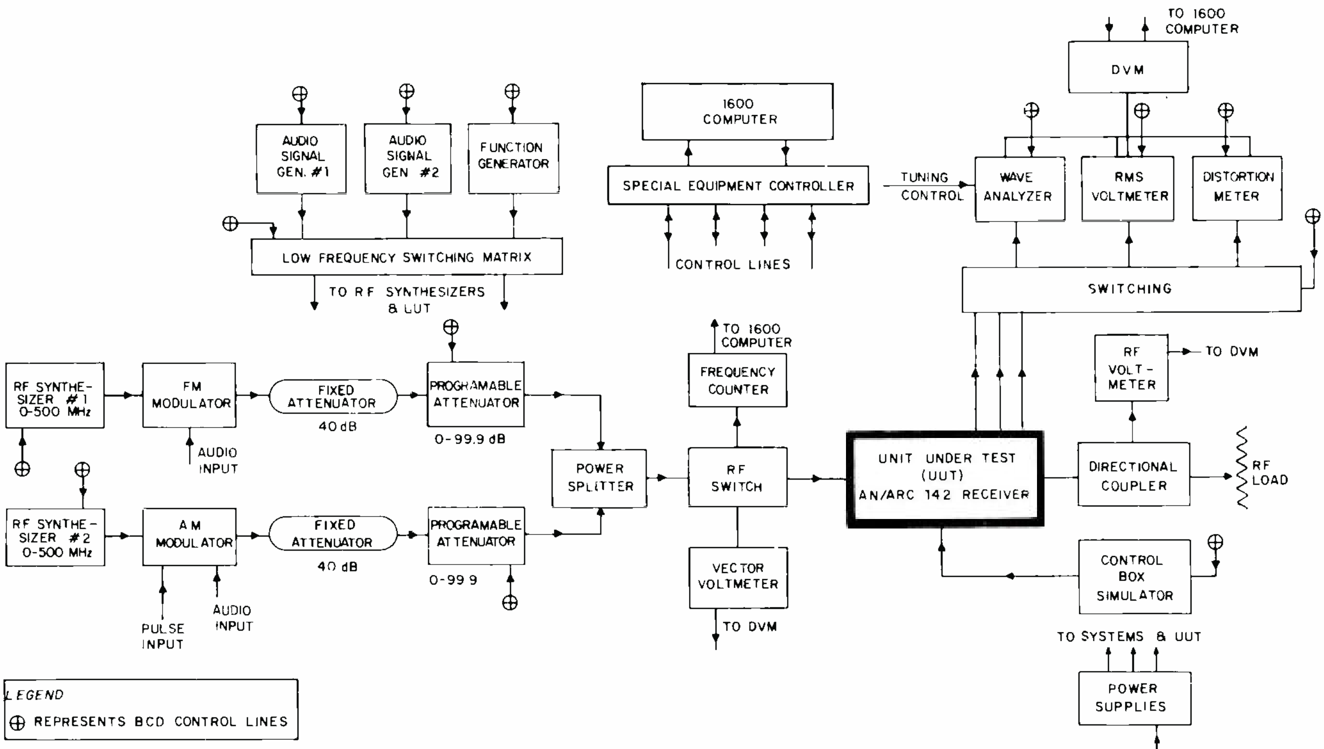


Fig. 2—ACET being used to test an AN/ARC-142 Receiver/Transmitter.

Multiplexers
Oscillators
Analog modules
Power supplies
Control electronics
Sweep electronics
Sweep circuits
Mobile radios

ACET can be used to monitor most important performance characteristics. Among these are:

Distortion
Gain
Bandwidth
Frequency response
Sensitivity
Selectivity
Signal to noise
AC to DC voltages (0 to 500 MHz)
RF phase
Spurious signals
Frequency
True RMS voltages
Power output
Time duration
AGC and audio output
Squelch and noise blanking
Hum and noise
Dynamic range

Some of the more significant advantages of ACET over manual techniques are speed of test, reliability and repeatability of data, self calibrating capability, and the direct economic advantages accruing from reduced labor costs and fewer test positions.

System description

The ACET system (Fig. 1) consists of the following basic elements:

Stimuli,
Measurements,
System switching,
Programming, and
Control.

The simplified block diagram in Fig. 2 shows how these elements are interconnected to test an AN/ARC-142 Receiver/Transmitter.

Stimuli

Audio and video

Two audio signal generators provide high purity waveforms to the unit under test (*e.g.*, for transmitter distortion measurements) or to the RF synthesizers for modulation purposes. Frequency is programmable to 100 kHz in 1-Hz increments. Amplitude is programmable to 10 V in 1-mV steps. Amplitude distortion is more than 80 dB below the fundamental.

The function generator (high-frequency waveform generator) allows continuously variable selection of frequency from 0.01 Hz to 1 Mhz. Outputs are sinewaves, squarewaves, and triangular-waves and a sine-squared pulse. Both frequency and amplitude are programmable.

Radio frequency

The RF-signal sources are extremely pure output signals (100dB below carrier) ranging from 1 Hz to 500 MHz and can be rapidly and accurately adjusted in least increments of 1 Hz. Frequency is synthesized by a single 10-MHz frequency standard. When the standard frequency is obtained from the built-in master oscillator (accurate to 2×10^{-9}) the maximum error at 50 MHz is 0.1 Hz. If desired, other frequency standards can be used as a master oscillator for even greater accuracy.

The output voltages of the RF sources are adjustable by means of precision digitally controlled attenuators. Maximum output voltage of the synthesizers is 2.5 V, and automatic leveling is used to keep the level constant within 0.5 dB over the entire frequency band. Modulation capabilities, AM or FM, exist with each source.

Significant characteristics of the RF source are:

1) Frequency may be changed in less than 5 μs;
2) Frequency stability is 1 part in 10^9;
3) Phase noise level and spurious signals are more than 100dB below the desired carrier.

One of the important features incorporated into ACET is the verification of the precise RF input level into the receiver. This is accomplished by measuring the RF level prior to each test with a sensitive Vector Voltmeter and storing correction factors in the computer prior to each measurement.

RF attenuators

In series with each synthesizer is a fixed 40-dB attenuator and a programmable 100-dB attenuator. The programmable attenuation can be varied from 0.1 to 99.9dB in 0.1-dB increments, with switching times in the order of several milliseconds. When used in conjunction with the RF sources, the attenuators provide a dynamic range from 0.1 V to 1 V, programmable in 0.1-dB steps.

AM modulator

Specially designed modulation circuitry is included which generates an AM wave with less than 1% distortion at a modulation index of 100%. The modulation system also supplies repetitive RF pulses of 10-μs duration at 100,000 μV. The *on/off* ratio is better than 100 dB. All functions are digitally programmable.

RF amplifier

To obtain higher RF signal levels, a broadband amplifier may be switched into the system. The amplifier has a gain of 40 dB from 2 to 475 MHz and is capable of driving 5 V RMS into 50 ohms.

Power supplies, programmable

Programmable DC voltage is provided by two bi-polar 0-to 36-V, 5.0-A supplies, and one 0- to 100-V, 1.0-A supply. The voltage output of each supply is controlled via four BCD decades. The primary functions of the power supplies are 1) to modulate, either AM or pulse, the RF sources; 2) to provide DC-level change to control the UUT volume; and 3) to control squelch operation of the receiver. In general, the supplies may be programmed in increments of one part in 10^4 of full-scale value. The absolute accuracy is 0.02% of full scale.

Measurements

The measuring devices can be divided into two basic categories: analog and digital. The analog instruments measure a wide variety of parameters such as RF level, modulation level, distortion, and spurious signals. The digital instruments contain devices which convert time, frequency, voltage, and resistance, into a digital format for processing by the computer.

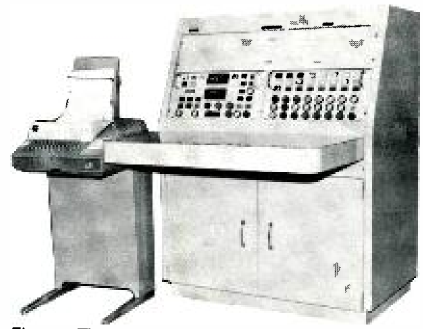


Fig. 3—The control console.

So that the RCA 1600 computer can process the data generated by ACET, all analog data is digitized.

Digital multimeter

This device is the basic analog-to-digital converter in the system. Analog signals from the other test instruments are digitized into BCD format for processing by the computer. The digital voltmeter also measures DC voltage to 1000 V, accurate within 0.01% of full scale; AC voltage within 0.2% of full scale to 100 kHz; and resistance up to 10 megohms.

Frequency counter

This instrument measures frequency to 500 MHz (200 MHz direct count) and time interval. It is used to count radio transmitter frequency as well as calibrate the RF test sources in the self-test mode.

Distortion meter

This device contains a 1-kHz switchable filter for signal-to-noise measurements. It measures total harmonic distortion as well as signal to noise.

Waveform analyzer

A remotely tunable waveform analyzer is used to measure spurious as well as intermodulation distortion components. The device contains four selectable narrowband filters, has a dynamic range of 85 dB, and a maximum center frequency of 620 kHz.

RF voltmeters

Three RF voltmeters are included in the system. Together they provide capability for true rms measurements, low-level RF-calibration capability, and a means for measuring power in the HF band.

System switching

The ACET system has an extensive programmable switching network, which permits versatile operation and facilitates expansion. Twenty-eight programmable switching matrixes, ranging from 1×2 switches to 1×32 switches, switch RF, audio, DC, and control voltages. These matrixes not only connecting one device to another, but also measure and verify each critical signal. Before a series of measurements is made, a computer program automatically compares the stimulus level against the measuring device which, in turn, is certified by a traceable standard.

The RF switches were selected for their high reliability (100 million operations) and their high inherent isolation (120 dB). The contacts are physically and electrically isolated from potential sources of interference.

Programming

The TESTRAN software concepts developed by RCA specifically for use with the 1600 computer simplifies the writing of test programs, since they permit the user to generate a program using common (English-language) test-procedure terminology.

Each test is contained in the General Test Program. The individual tests provide details of test data and analysis of results, branching to the General Test Program upon determination of the *pass/fail* condition of each test. For the AN/ARC-142 Radio Set, individual test programs have been written for each of the following acceptance tests:

- Automatic self test
- Receiver sensitivity
- Receiver selectivity
- Receiver AGC and audio output
- Receiver squelch and noise blanking
- Receiver hum and noise
- Receiver intermodulation
- Receiver dynamic range
- Transmitter power output
- Transmitter spectrum analysis

Diagnostic programs are included to help the operator establish where the unit-under-test has failed. The entire software package was written expressly for maximum simplicity and flexibility so that project and technical changes could readily be incorporated.

Control

The control console is a device through which the operator can command the computer to perform a specific task. Once contact has been established, the operator relinquishes control and the entire test is performed automatically under computer control.

The control console (Fig. 3) consists of two functional sections:

1) The main control panel allows the test operator to perform tests automatically under computer control.
2) The option control panel enables the test engineer to modify instructions related to test sequence, output devices, and manual intervention. The option control panel is also an excellent troubleshooting device for hardware and software problems. The options are available only to authorized personnel in possession of a key to the option panel.

The control console has considerable universality in that no deletions, additions, or other changes are necessary to test different units.

All characteristics unique to testing various test units are contained in the computer program. The console contains the means to access instructions prescribed by the programmer through selector switches. This technique permits up to 10,000 different instruction programs to be manually accessed.

Data output

Through use of the option panel, a wide variety of output-data devices can be selected. Three output data devices are normally available: magnetic tape, teletypewriter, and video display. Magnetic tape is employed when maximum speed is desired. Real-time data is stored on magnetic tape and later printed out off line. Stored magnetic-tape data can also be analyzed for trends in acceptance data. Instructions to the operator can be presented on a kinescope video display. The teletypewriter prints out a permanent record of test data and/or test instructions. The test data is typed in commonly understood terms, and the format can be altered easily to meet individual customer requirements.

The console was designed for simplicity by employing several visual aids. Each operating function can readily be monitored by its shape, color, or illuminated state. The normal process flow is indicated by engraved lines and light steering as each test sequence progresses.

Pushbutton controls are round and are to be actuated to command an operation, while display lights are rectangular and are used as indications only. The color of each function light immediately indicates to the operator the state of the function and the urgency of the condition. For example, functions requiring caution or warning are lighted yellow; red indicators are for a stop condition; and green is for proceed.

Calibration and self test

The automatic features of ACET provide self test and calibration capability not attainable with manual test stations. A software program has been developed which sequentially switches the output of each stimulus into the inputs of corresponding measurement devices for verification. This self-test program is performed at least once a day. In addition, the digital voltmeter and counter are calibrated periodically to establish reference points for the self test.

Troubleshooting and maintenance

Failure diagnosis of the unit under test is accomplished by monitoring selected voltage levels through a 1×32 matrix switch and the digital voltmeter. More sophisticated diagnostics, using deterministic as well as probabilistic techniques, are being planned for the future.

Troubleshooting of ACET itself is accomplished by examining the results of the self-test program which can isolate malfunctions to a replaceable box in the system.

Conclusion

The Automatic Communications Equipment Tester has been used by the Manufacturing Activity in Camden to test a broad range of communications equipment—quickly, accurately, and efficiently. In the first year of operation, more than fifteen AN/ARC 142 Receiver/Transmitter units were tested resulting in a reduction of unit test time from 40 hours to 3 hours. In addition, nine types of LHA modules (including tone receivers, sensing circuits, and detection circuits) were tested, with a reduction in testing time from 20 minutes to 55 seconds per unit. Also, five commercial-type units were processed, reducing the unit test times from 1 hour to 5 minutes; among the commercial types were sound-track amplifiers, power supplies, and audio monitoring amplifiers. One of the most significant benefits derived from this type of automatic system is the tremendous reduction in test positions and test equipment as well as their associated maintenance and calibration costs. Also important, of course, is the enhancement of our competitive position for future work.

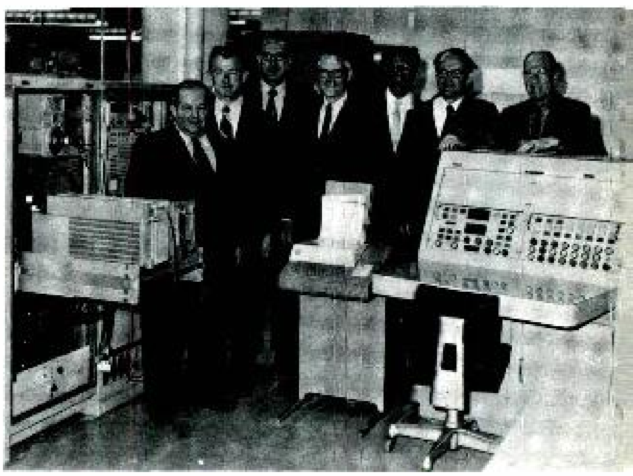
Reference

1. *RCA Engineer*, Vol. 14, No. 3 (Aug-Sept 1968) entire issue. See also, *Automated Test Systems*, RCA reprint brochure PE-403 (collection of 36 technical papers by RCA engineers and scientists).

Acknowledgements

The detailed design and programming of ACET were performed by test engineers in Government Manufacturing in Camden. H. Jordan was manager of the project with N. Ross, R. S. Newman, and J. Scott performing the programming. The hardware design team consisted of D. DeLaurentis, D. Simpson, E. Tomlinson, and H. Spicer. The Aerospace Systems Division also contributed to the planning of ACET and participated in several design reviews. Corporate Staff AT&MS provided help in software and hardware planning and review.

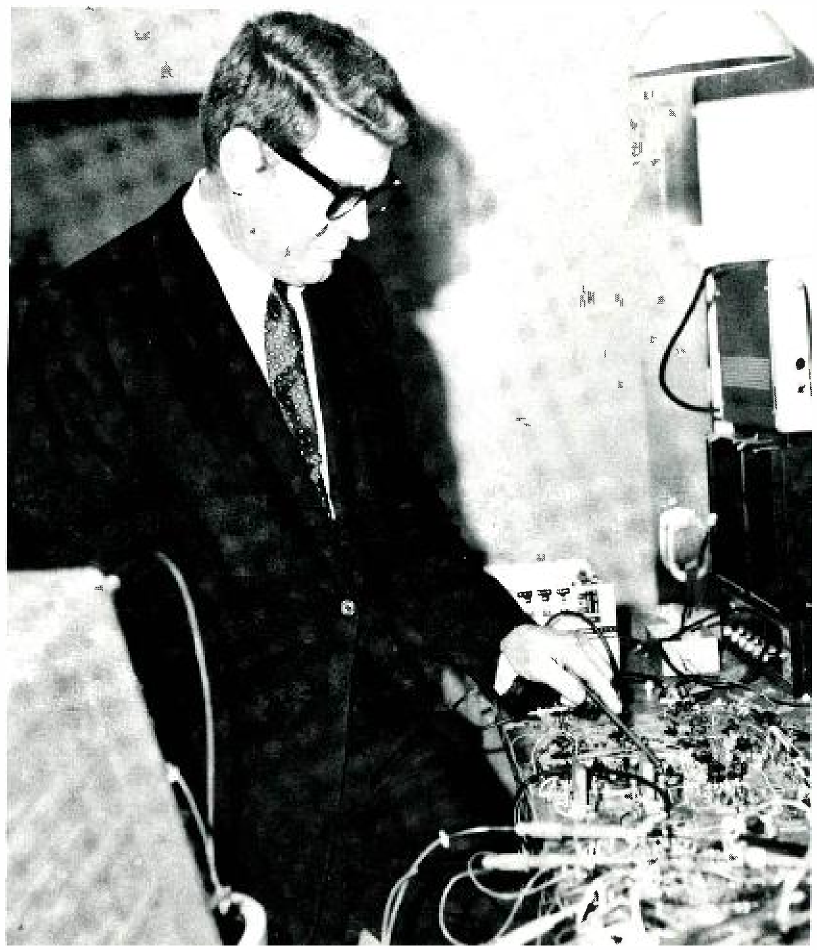
ACET design team (left to right): D. Simpson, E. Tomlinson, H. Jordan, N. Ross, D. DeLaurentis, J. Scott, and S Newman. H. Spicer was also a member of the design team, but was not available for the photograph.



New products engineering in consumer electronics

R. K. Lockhart

This article describes the role of New Products Engineering in providing assistance to the regular product design groups at Consumer Electronics. The author deals with the basic philosophy behind the search to produce potential products, gives examples of trial projects undertaken, and discusses the intra-Corporate effort required to share information in meeting design goals.



R. Kennon Lockhart, Mgr., New Products Engineering, Consumer Electronics, Indianapolis, Ind. received the BSEE from Purdue in 1947. Earlier, he had served in the USNR from 1942-1946 as an Ensign in radar and radio electronics. After graduation, Mr. Lockhart joined RCA in the Advanced Development section of Consumer Electronics. He was active in color television during the years 1949-1959. During this time he was named Manager Color Television Advanced Product Development. In 1959, he transferred to Computer Systems where he managed Project Lightning. This project was completed in 1963, and he was transferred to Advanced Technology Laboratories. In 1965, he was named Manager, New Products Engineering, and presently serves in this capacity. Mr. Lockhart was a recipient of the RCA Award of Merit in 1953. In 1969, he was recipient of the David Sarnoff Outstanding Achievement Award as an engineering team member.

The basic concept of New Products Engineering was started in 1965. This concept embraced the following ideas: 1) as new technologies (integrated circuits and ceramic circuits) were developed, new products would become feasible where they were previously forbidden by high cost; 2) in the case of a radically new product, mere description was not enough; visualization would be difficult for the product planners unless a model was available for demonstration. Furthermore, full feature recognization would be limited unless the planners could live with the product, operate it, and discuss it with peers. This necessitates the building and debugging of a working model; 3) the model must have sufficient reliability to function for the prescribed test time without excuse or failure; and 4) sufficient styling must be included in the model so that the unit could be displayed in its proposed environs.

General duties

Basically, three responsibilities were delegated to New Products Engineering:

1) Assist the regular product design groups in adding new features as "maintenance of line" (with the understanding that these should be limited to those studies beyond the time available to the design group. Every effort should be made to perform those functions within the appropriate design group where possible, because of their specialized skill).

2) Pick up projects as they become available from the RCA Laboratories, Princeton, N.J. This included performing the normal applied research and, at the same time, effecting the orderly transfer of skills and knowledge from the Laboratories to the engineering groups.

3) Generate and screen new systems ideas to establish task priorities for New Products Engineering, thereby eliminating the "shotgun" approach which would be both unwieldy and costly.

The new products cycle

The total New Products Engineering cycle was defined as follows:

1) *Idea generation*—Ideas should be accepted from all sources available, whether they be from top management or the janitor.

2) *Screening*—There is, of course, no foolproof way in which accurate prophecy can be generated concerning the needs of people; but there are some guiding generalizations that can be employed. These are both demographic and non-demographic in nature. It is important to have a consistent method of screening, but equally important not to assign excessive credence to it.

3) *Model building*—Once the idea has passed the screening step successfully, it is essential to build a working model. This is not a prototype, except in its capacity to demonstrate the function. It also must have the approximate appearance its final form will take. (The initial purpose of the model is to let the product planners examine it so they may decide if further action is appropriate.)

4) *Market research*—If the idea "grabs" the examining planner, the unit must be made available to the market research people. They will test the concept on a cross-sectional sample and, from the analysis, make their projections.

5) *Decision*—After the information has been retrieved, a purely subjective decision can be made. It must be recognized that all the information generated heretofore serves only to assist the product planner in making his decision. At this point, he has to rely on his lone judgment; he still has no guarantee of successful acceptance of the product in the marketplace.

These steps represent a gross oversimplification of the real problem. Actually, careful monitoring must be done at all times. Each step must be interpreted in a cooperative effort of Engineering, Marketing, and Industrial Design so that the best concept features and human engineering will be incorporated in the demonstration model.

Often, a cooperative work effort is conducted with other divisions as needed. In fact, many of RCA's successfully introduced new products of great impact have involved the focused effort of several divisions. For example, the development of color television involved research from the RCA Laboratories; circuit design by Consumer Electronics; color kinescope from the Industrial Tube Division; TV camera from RCA Laboratories; studio equipment from Broadcast Systems; software by NBC, etc.

Projects of New Products Engineering

It is recognized that for maximum efficiency, where possible, all product improvement projects should be conducted in the appropriate product design group having the responsibility for that particular type of product. It is also true that many aspects of the end-product design decisions can be made while the development is being carried out. Occasionally, however, ideas are advanced for which the appropriate design group cannot assemble a staff because of limited time in which the project must be completed. As a support service, New Products Engineering undertakes such projects. Several of these projects conducted by New Products Engineering are described below:

One concept—the stereo chair—was built with a standard FM/AM stereo tuner mounted in one arm of the furniture and a Stereo 8 tape player mounted in the other. A speaker was mounted in each wing of the chair for relatively private listening. The fidelity and stereo separation of the sound produced was comparable to that achieved with headphones.

Several emergency radio warning concepts were tried; one displayed a red light for storm, a yellow light for unsettled weather conditions, and a blue light for fair weather. The indicator system was actuated by an AM pulse burst on the FM carrier. Thus, the indicator system was actually controlled at the broadcasting station. A second example is an AM receiver, adjusted to turn itself on upon reception of a high-frequency tone and off with a lower frequency tone. Again, these are actuated from the transmitting station and allow tornado or civil defense information to be broadcast from a receiver which is apparently "off."

An example of an attempt to get "more mileage" from an existing design is the guitar amplifier. This design used the 300-watt (peak) power amplifier from the console stereo receiver. Additional features included built-in FM receivers so that the guitar could be operated in wireless mode (under FCC, part 15, which pertains to low-power regulations governing unlicensed operation). This idea of extending a present capability was also tried in an application where a combination FM/TV receiver was constructed which used a common IF and audio path. The goal was to add FM reception to a portable TV receiver with minimum cost.

Joint applied research activities

Another important responsibility of New Products Engineering is to give

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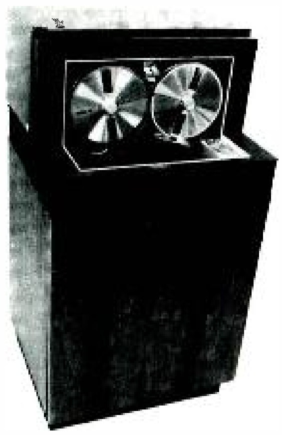


SelectaVision demonstration unit

Homefax player

design, limited manufacturing, and test support to the Laboratories. The first such project was to construct twenty Homefax receivers to be used for field test by the Laboratories personnel. The initial design was done in Princeton and the effort of New Products Engineering was to construct, test and modify (where necessary) so as to update, and make the design compatible with our construction techniques. In addition, some of the units were placed in cabinets built by the Industrial Design section in Indianapolis. The styled unit also contained a small-screen portable TV receiver for program monitoring, in conjunction with the Homefax printing feature.

Following the construction of the twenty units for hard-copy printout, a complete working unit was built which stored the information on an Alphechon storage tube produced by the Industrial Tube Division. This unit could be used (by changing plug-in cards) as Homefax "soft" copy, for freezing single frames from off-air reception, or for other storage usages.

A second example of this type of support to the Laboratories lies in the area of SelectaVision. Two units were built in Indianapolis and used in the SelectaVision demonstration given in Princeton for the press in September, 1969. Following closely the concepts developed in the Laboratories, New Products Engineering combined color circuits it developed on another project with those generated in the Laboratories to provide the instruments used in the press demonstration. Again, the final instrument was housed in a cabinet designed and built by the Indianapolis Industrial Design section. This work in continuing as part of the Corporate effort on SelectaVision.

Another area where the Laboratories support was in evidence was joint applied research carried out by the then New Electronics Systems group in the applications of new devices. A cathodochromic kinescope was built into a system which became a rather sophisticated picture-and-accompanying sound unit for use over a wide range of applications—from children's entertainment to an educational terminal. Characterized as single-frame still pictures with accompanying sound track, the complete program used a standard cassette audio tape as the storage medium. The basic playback unit was simply an audio player. Since no software source was available, it had to be generated. This required building and debugging a slow-scan camera chain and suitable signal processing circuitry needed to record into audio recorders directly. All component blocks were debugged and the system was successfully demonstrated. As byproducts of these developments, successful studies were carried out showing the feasibility of transmitting still pictures over a telephone line.

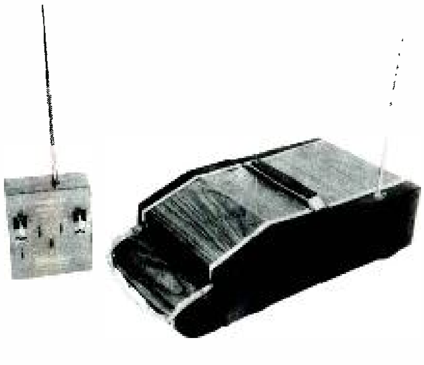
Selecting a technology

As mentioned earlier, another responsibility of New Products Engineering is that of generating and screening new ideas. The first step in this direction was to edit all the existing idea lists, remove the redundancies, and recombine the lists. In addition, ideas were solicited from other divisional areas including such as Applied Research in Camden, N.J., (now Advanced Technology Laboratories) and RCA's facility in Somerville, N.J. When the master list was completed, screening was done and priority was set for engineering work. In addition, a computer program was written for some of the business simulation ideas.

The basic idea plan at New Products Engineering was to concentrate in areas where a single technology could produce several potential products. One example was remotely controlled devices. Probably a universal dream of suburbia residents is to possess a lawn mower which could be remotely operated so the man of the house could lie in the shade while the mower did the work. Because a gasoline-powered lawnmower is somewhat impractical to demonstrate indoors, another application was chosen; that of a vacuum cleaner. This unit was built to operate remotely through the citizen's band radio link (again according to part 15, FCC, on unlicensed low-power transmissions).

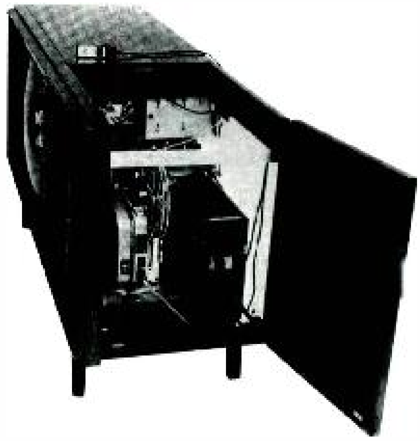
There is always a continuing search for other uses for TV equipment. One such tested was called "Picturecom" (a TV-intercom). The unit scavengered sufficient deflection and high voltage power from the main receiver to operate a vidicon. By thus minimizing the number of components added to a black-and-white monitor, and using conventional stereo shielded cable for interconnection, cost was reduced to a minimum while maintaining picture quality at least equal to that obtained on off-air reception.

Not all the projects undertaken have been successful—nor can success always be expected. However, it is presumed that the project will be either concluded successfully or the technical reason for its failure will be determined. One such example was a project in bandwidth compression. The primary application was to be a video



Remotely controlled vacuum cleaner

Programmable tape player



Home color theater for playing slides and movies

disc; however picture transmission over telephone lines was also considsidered. The basic technique used was dot interlaced sampling with expected 4-MHz equivalent resolution transmitted over a 100-kHz channel in real time. The equipment was designed and built using several types of storage devices including an Alphechon. It was determined that although acceptable results can be attained on still pictures, the distortion during movement was of a type highly visible and therefore intolerable.

Another technique used can be classified as programmable or perhaps as a form of information retrieval by random access. As the playtime of home entertainment playback machines is lengthened, it becomes more and more difficult to find any individual number. This situation calls for an automatic search feature. A good example is the 8-track stereo cartridge. This unit is excellent for generation of background music, but it lacks one important feature of the disc recording—the ability to locate a single number on the record. There are several applications readily identifiable; obviously audio, video tape, pre-recorded video, home movie search—to name a few. The first was chosen for our investigation. Not only was location search made available, but a stored program capability was demonstrated. In this particular model, three musical numbers were randomly located within a tape. The machine would seek out the numbers in the order selected regardless of the order of location. After these selections were played, the machine would return to the start of the tape and turn itself off.

Intra-company cooperation

The most far-reaching project undertaken to date has been the development of a single vidicon color camera. This project represents a good example of operation across division lines and is discussed in detail below:

The Stanford Research Institute approached New Products Engineering in 1965, reporting some preliminary work the Institute had done on color encoding. The basic principle on color encoding was first introduced by the RCA Laboratories in the 1950's.[2] The Institute had been successful in reducing the idea to optical practice and believed that the next logical step was to implement the system by electronic techniques. (Progress at the Laboratories had run into difficulty in obtaining high-quality performance with the pickup tubes then available, the vidicon not yet having been developed.) Work was begun at the Institute's facility in Menlo Park, Calif. in the first quarter of 1966 under the direction of CE, New Products Engineering direction. By the end of the first year, the basic system was essentially complete in its analysis, and pictures reproduced from color slides were of good quality.

In the second year, work was continued on the basic system, concentrating upon "pruning" to find the highest quality obtainable within the basic limitations. The main effort, however, was to study the possibility of making a balanced-white system which would improve the signal-to-noise ratio by 6 dB and correct other inherent problems such as "green overload." At the end of the year, the first part was successfully completed while the second failed to yield an acceptable solution.

During the second year two additional forces were enlisted: the Professional Electronics Systems Division of RCA Burbank and Electronic Components began work upon a vidicon which would generate the special color-encoded signals directly.[3] In support, the Laboratories made its contribution in analysis and in the technology of dichroic and sputter etching.

During this period, representatives of several other groups within the Corporate family, including Government & Commercial Systems, journeyed to Menlo Park for briefings.

In the third year of development on the single vidicon color camera system, coordination was assumed by Corporate Staff because of the widening importance of the system. As a result of the central coordination, several modifications to the basic system have been made, and several new encoding systems have been invented both here and at RCA Laboratories.

There are several potential applications of this technology including a home color camera for use with video tape units, home pickup devices for playing slides and home movies through a color TV receiver, home surveillance camera, etc. In addition, the experience gained and the techniques developed may be directly useful in the SelectaVision project.

Acknowledgement

The basic need for New Products Engineering was initially recognized jointly by R. N. Rhodes and L. R. Kirkwood in a series of discussions held in 1965.

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The new celestial navigation—inexpensive position fixes by satellite

J. E. Board

The stars sailors once used to chart their courses are being replaced by man-made moons. An electronic navigational technique utilizing satellite-based radio transmitters, a relatively inexpensive receiver, and graphical plotting techniques similar to those of celestial navigation can provide accurate position data on demand in all weather, anywhere in the world.

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received the BS in Electrical Engineering with honors in Mathematics and Electronics from London University in 1950. He subsequently completed postgraduate courses in Advanced Mathematics, Semiconductor Technology, and Nuclear Technology. Mr Board has had 18 years of experience in the fields of microwave antenna design, radar system engineering, weapon system design and evaluation, and spacecraft development. Before coming to the United States, Mr. Board was a senior systems engineer for the United Kingdom Atomic Weapons Research Establishment from 1957 to 1964. Previous to this appointment, he worked for six years at the U.K. Admiralty Signal and Radar Establishment on the design and development of microwave antennas for radar and communication systems. He was directly responsible for developing a circularly polarized antenna for carrier-borne approach radars. Mr. Board came to AED in March 1964 and is presently conducting a design study for an advanced Medium-Altitude Satellite Navigation System designed to provide high-accuracy position fixes and continuous world-wide all-weather coverage. He is a member of the IEEE and of the IEE (UK).

For hundreds of years, the principal technique used by mariners to navigate their ships when out of sight of land or in unknown waters has been celestial navigation. Celestial navigators must take sights of the sun or stars with a sextant, be able to determine time at the Greenwich Meridian precisely, and possess the almanacs and mathematical tables necessary to calculate the ship's position. Since sightings can only be taken in clear weather, celestial position fixes have to be supplemented by dead reckoning based on estimates of the ship's headings and speeds.

The development of radio brought with it many aids to navigation that permit navigators to determine position using electronic measurements of angle, range, or range difference from land-based radio stations, with relative immunity to weather conditions. To make these measurements, the navigator uses a radio receiver and charts showing the positions of the transmitters. But ground-based radio aids to navigation are limited because their range of effectiveness is seldom greater than 2,000 to 3,000 miles, and they progressively lose accuracy at extreme ranges. In addition, many parts of the world are not covered due to the considerable expense required to set up chains of transmitting stations.

In recent years, the application of artificial earth satellites as aids to navigation has received much attention. A single polar-orbiting satellite can be observed at least once every 12 hours from any point on the surface of the earth, and a suitably designed constellation of such satellites can provide continuous world-wide coverage.

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The Navy Navigation Satellite is an example of a satellite navigation system presently in operation from which a position fix can be obtained approximately every two hours. The Navy satellites transmit fixed-frequency signals modulated with regularly updated orbital information. These signals enable navigators to determine a satellite's geographic coordinates and compute their position from measurements of the Doppler frequency shift observed as the satellite passes in and out of view. Other navigation satellite systems under investigation will permit near-instantaneous three-dimensional position fixes derived from simultaneous measurements of range or range difference from three or more satellites. Satellite navigation systems are capable of position fixing to an accuracy of better than a hundred feet. However, to attain this level of precision, sophisticated and expensive receivers are required, together with digital computers to process the data. The simplest receiver currently available for use with the Navy Navigation Satellite costs about $50,000.

Position fixes utilizing satellite data can be obtained more economically with suitably adapted celestial navigation techniques. A simple receiver designed to supply satellite position and range-difference data of moderate accuracy is combined with a plotting chart on which the navigator's assumed position (AP) is marked. The geographical positions (GP) of the satellites at the times of the range difference measurements are used to derive the necessary navigational triangles from which the azimuthal angles and great-circle distances between the navigator's assumed position and the satellite geographical position are obtained. The satellite bearing lines are plotted on a chart and the assumed satellite range differences are computed. The computed differences are compared with the differences measured by the receiver and a simple graphical technique is used to construct hyperbolic lines of position (LOP) corresponding to the true range differences. Intersections of these

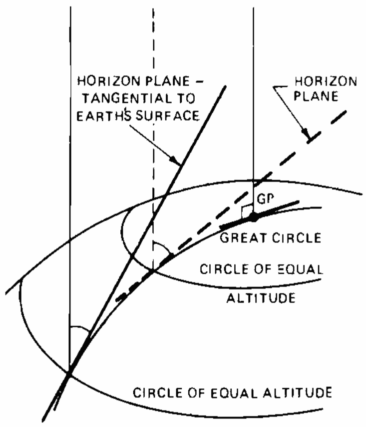

Fig. 1—Circles of equal altitude.

LOP's indicate the navigator's true position. The accuracy of the fix depends on the quality of the data supplied by the receiver and the care used in plotting, but should compare favorably with the two-to-five miles accuracy attainable with sextant observations. Suitable receivers can be produced in quantity for prices that should attract commercial and general users.

Celestial navigation

Celestial navigation can be defined as navigation with the aid of the sun and the stars. The only tools needed are a sextant, a chronometer, and a set of tables.

As a first step in the celestial position-fixing procedure, the navigator uses his sextant to measure the angle of elevation above the horizon (or altitude) of a selected star. Since the fixed stars are enormously distant from the earth, this angle of elevation equals the complement of the angle which measures the navigator's displacement from the geographical position (GP) of the star. The GP is the location at which the star would appear directly overhead. As shown in Fig. 1, a given angle of elevation defines a circle centered at GP, and the navigator must obviously be located at some point on this circle.

The basis of all celestial navigation is the spherical or navigational triangle. This triangle is defined by three points on the surface of the earth and formed by arcs of the great circles connecting those points. (A "great circle" is a line formed by the intersection of the Earth's surface and a plane passing through the center of the earth.) Fig. 2 shows a typical triangle; the vertices are: the navigator's position (M), the geographical position of the star being referenced (GP), and the earth's pole nearest to the navigator (P). The sides are labelled *co-altitude* (M, GP), *co-latitude* (M, P), and *polar distance* (GP, P) respectively, and distances along the great circles can be expressed in degrees of (the earth's) arc. For any given moment in time, a navigational triangle can be constructed which connects a navigator anywhere on earth to the nearest pole and the GP of any celestial body.

The navigator notes the time at which the star's altitude was measured and determines the geographical position of the star from a current nautical almanac. The navigator then assumes himself located at a convenient position on his chart close to what he estimates his true position to be. This assumed position (AP) completes the navigational triangle and allows him to compute the bearing of the star's GP and its co-altitude. The star's computed altitude (Hc) is the complement of the co-altitude. Hc is compared with the measured altitude (Ho), and if Hc is greater than Ho, the navigator's true position is displaced from AP and away from the GP; if Hc is less than Ho, the navigator's true position is displaced towards the GP. In either case, the difference is marked off on the *azimuth line* (the line connecting the AP and the GP). Since the plotting chart covers a small area in the vicinity of the AP, the azimuth line is indicated by a straight line pointing in the direction of the GP. Another line drawn through the point and perpendicular to this line represents an arc of the circle of equal altitude. This line of position (LOP) passes through the navigator's true position. A typical

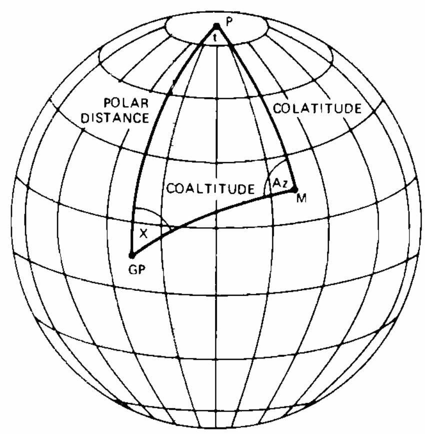

Fig. 2—Navigational triangle.

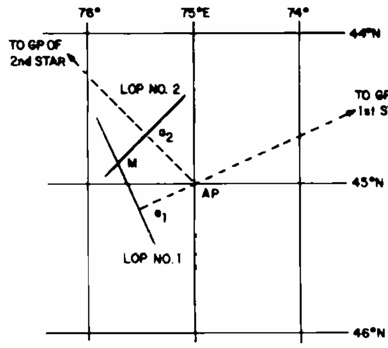

Fig. 3—Celestial position fix.

LOP plot is shown in Fig. 3. Additional LOP's can be plotted from observations of other stars. The navigator's true position is defined by the intersection of two or more LOP's. If the navigator's ship is in motion while the observations are being made, the LOP's must be displaced to the time of interest in accordance with the ships speed and heading.

Satellite navigation

Navigation by the aid of artificial earth satellites has similarities to both celestial navigation and radio navigation by ground transmitting stations. As indicated in the previous section, celestial navigation is fundamentally a range-measuring technique in which intersecting circular arcs centered on the GP's of the observed stars are used to establish a position fix. Similarly, if a satellite's GP and height above the earth's surface were known, altitude measurements of individual earth satellites could yield intersecting LOP's. Since satellites are not easily visible to the naked eye and shine only by reflected light, it is more practical to have each satellite transmit a radio signal from which a bearing, range, or range difference can be measured. The navigator is equipped with a receiver that accepts the signals and extracts the desired information.

This approach is well known and has wide application in ground-based electronic navigation aids. The navigator determines the appropriate parameter relative to two or more radio transmitters at known locations and plots the resulting LOP's. The LOP's may be radial bearing lines derived from angle data, arcs of circles derived from two-way range measurements, or hyperbolic arcs corresponding to con-

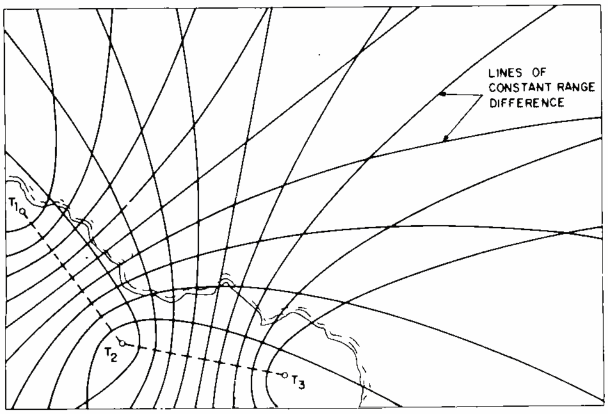

Fig. 4—Hyperbolic plotting chart (LORAN).

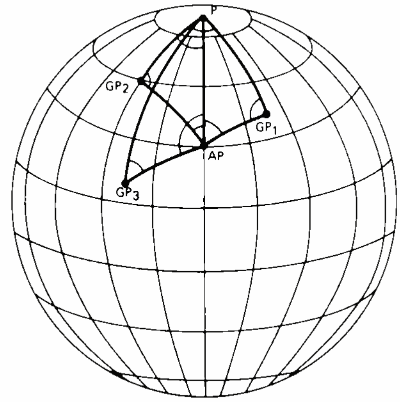

Fig. 6—Satellite navigational triangles.

tours of constant range and time difference between signals from pairs of radio transmitters. Hyperbolic radio navigation as practiced by the Decca, LORAN and OMEGA systems covers large areas and is *unsaturable,* (*i.e.* an unlimited number of users can use the system simultaneously) since the user does not require a transmitter. A typical hyperbolic plotting chart (Fig. 4) indicates the intersecting families of hyperbolas derived from three fixed transmitting stations. Each curve corresponds to a fixed propagation time difference for a pair of transmitters. Such charts simplify the navigator's task and relieve him of much computation.

Satellite navigation can be accomplished in a similar fashion, and surfaces of constant range difference can be generated from measurements at the navigator's receiver. In Fig. 5, LOP's derived from the intersection of the hyperbolic surfaces with the earth's surface intersect at the navigator's position. Sometimes the LOP's intersect in more than one point, but the intersection corresponding to the navigator's true position is usually apparent. It is evident that a suitably designed "constellation," of satellites

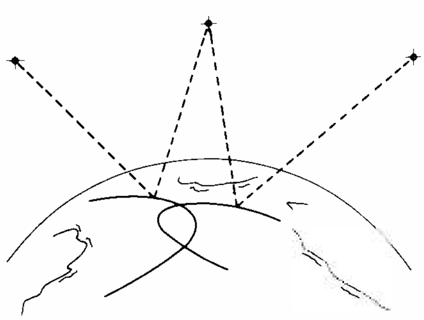

Fig. 5—Satellite hyperbolic position lines.

can offer world-wide continuous navigational coverage not subject to the propagation restrictions imposed on ground-based systems. The potential for high-accuracy position fixing has already been demonstrated by the Navy Navigational Satellite System. Although satellite orbits change unpredictably, and it is not practical to publish almanacs with tables of satellite coordinates as a function of time, a chain of tracking stations can provide the necessary data, put it in ephemeris form and store it in the satellite for periodic transmission to navigators. The ephemerides could be updated as often as necessary to maintain the accuracy of the data.

For precise position fixing, the navigator's receiver must be sophisticated and costly and would require a digital computer to process the data into a position fix. But navigators requiring a continuously available fix of accuracy equal to or better than that offered by celestial methods could be served by a combination of a receiver no more expensive than commercial LORAN equipment and a graphical plotting technique that can be easily understood and applied by any experienced navigator.

Graphical position fixing by satellite

The procedure used to plot position fixes from measurements of the altitude of celestial bodies can be easily adapted to satellite position fixes.

Instead of using a sextant to measure the altitude of selected stars, the navigator uses his receiver to measure range difference from two or more satellites relative to a third reference satellite, and simultaneously he acquires ephemeris data transmitted from each satellite. He can then derive geographical positions and altitudes. As in celestial position fixing, the navigator selects a convenient AP and defines the appropriate navigational triangles (Fig. 6). The tables used to compute coaltitude and azimuth angle (Az in Fig. 2) for celestial bodies can supply these parameters for the satellites. The computed coaltitudes are converted into slant ranges from AP (*i.e.* the straight-line distances from AP to the satellite) by solving the planar triangle shown in Fig. 7 (see Appendix) and the range differences of the other satellites (GP_2, GP_3) relative to the reference satellite (GP_1) can be determined. The computed range differences are compared with those obtained by measurement. The differentials are noted and designated positive or negative according to whether the computed range difference is greater or less than the corresponding measured range difference.

The plots are made on a small plotting sheet calibrated for the area of interest, as shown in Fig. 8. The azimuth lines indicating the directions of the satellite GP's are drawn through AP. The slant-range-difference differentials are converted to ground distances and measured off from AP toward the appropriate GP if the differential is negative, or away from the GP if the differential is positive. These points define coaltitudes (ground ranges) which are functions of the navigator's true position. The true position is found by deriving hyperbolic LOP's, which correspond to the measured range differences.

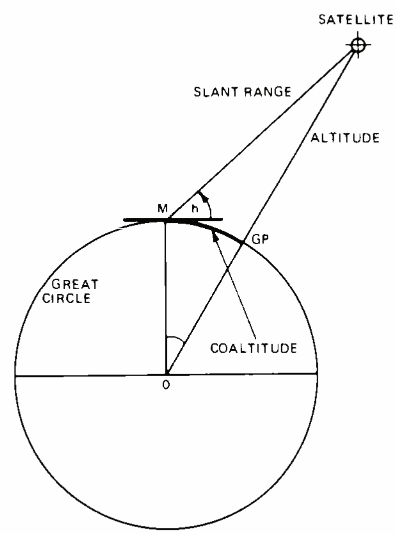

Fig. 7—Satellite/observer triangle.

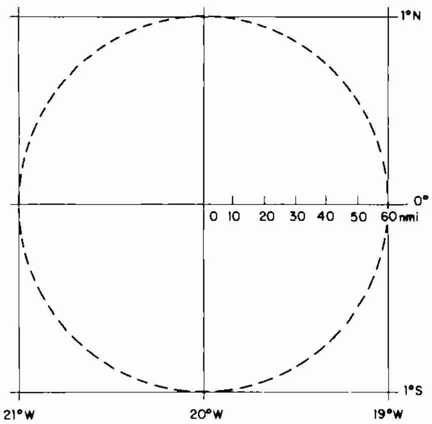

Fig. 8—Satellite plotting chart.

As shown in Fig. 9, hyperbolic position lines can be derived from families of range circles centered on the radio transmitters. In similar fashion, intersecting pairs of range circles (represented by perpendiculars to the azimuth lines) can be drawn so as to indicate the required hyperbolic LOP's. (Fig. 10) One set of perpendiculars (P1, P2, P3) is drawn through the points defined by the range-difference differentials, with the other set (P11, P22, P33) displaced from the primary points by a fixed distance. The intersections of P1, P2 and P11, P22 are points on one hyperbolic LOP, while the intersections of P2, P3 and P22, P33 are points on the other LOP. These two LOP's indicate the navigator's true position. With practice, the procedure can be completed rapidly. Measurements can be made simultaneously or consecutively, depending on the configuration of the satellite constellation and the number of receiver channels. If any significant time elapses between measurements, allowances must be made for the observer's motion during that period.

The accuracy of the fixes obtained in this manner depends on the navigator's plotting skill and the quality of the data received.

In the same way that corrections are made to the sextant reading, the range measurements can be corrected for atmospheric refraction errors and equipment calibration errors. Fix accuracy should be at least as good as that obtained by a skilled sextant operator and much less dependent on the navigator's personal equation.

Conclusions

It has been shown that celestial navigation techniques can be applied to position fixing by artificial earth satellite. A graphical position plot can be substituted for computer processing of the position data, manual calculations are limited to the evaluation of a few simple trigonometric formulas, and the tables commonly used for celestial position fixing can be directly applied to satellite navigation. Thus, the graphical approach to satellite navigation can be easily understood and applied by any navigator familiar with celestial navigation.

An inexpensive receiver designed to measure satellite slant-range difference and to decode the satellite ephemeris broadcast can furnish world-wide position data on demand in all types of weather and should attract a wide range of users particularly the less affluent.

Appendix

To determine his position, the navigator must find solutions to the navigational triangle (Fig. 2) and the triangle formed by the navigator's assumed position, the position of the satellite, and the earth's center (Fig. 7).

The parameter sought from the navigational triangle is the co-altitude or great circle distance from M to GP. This is easily obtained from the cosine formula:

cos (co-altitude) = cos (polar distance) × cos (colatitude) + sin (polar distance) × sin (colatitude) × cos (meridian angle)

The nagivator's assumed position (AP) specifies one meridian and the colatitude, while the satellite ephemeris supplies the longitude of the other meridian and the polar distance.

The satellite/observer triangle is used to determine the satellite slant range and elevation angle from the following formulas:

$$\rho = [R^2 + (R+h)^2 - 2R(R+h)\cos\psi]^{1/2}$$

$$\cos\beta = (R+h)\sin\psi/\rho$$

Where ρ = satellite slant range
R = radius of the earth
h = satellite altitude
ψ = co-altitude in angular units
β = satellite elevation angle

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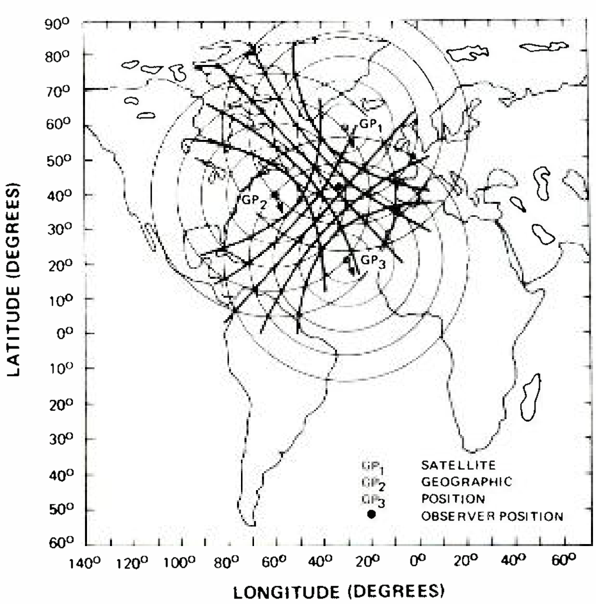

Fig. 9—Derivation of hyperbolas from intersecting circles.

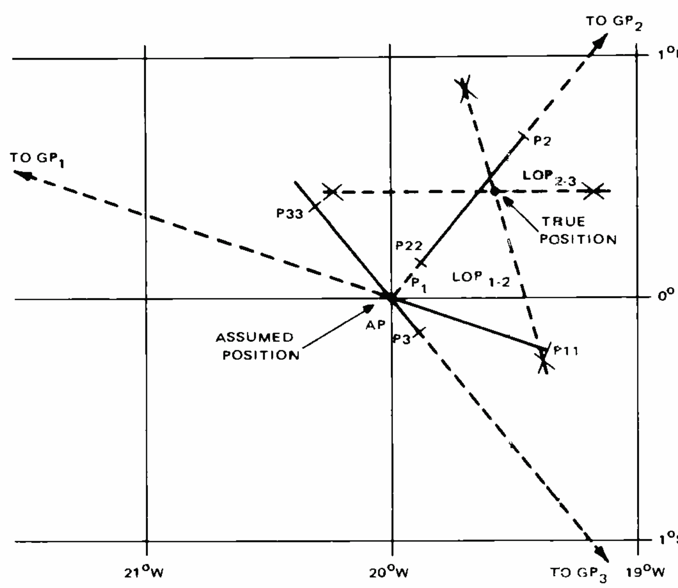

Fig. 10—Satellite position plot.

Peripheral data management system

S. A. Goodman

The computer user who adds on-line terminals to his existing system faces considerable hardware, software, and operational problems. In response to the challenge of providing a low-risk solution to these problems, EASD has developed the Peripheral Data Management System (PDMS) concept—a small satellite processor with an associated terminal and storage devices.

In January 1970, Electromagnetic and Aviation Systems Division (EASD) of G&CS, Van Nuys, Calif., initiated a program to explore, develop, and exploit its display terminal/mass memory capability to further penetrate the peripheral sub-system market. This program was divided into three steps:

1) Bringing together the essential system skills and expertise to design a peripheral display subsystem centered about a small processor with a mass memory.
2) Assembling the peripheral display sybsystem and preparing the necessary software to demonstrate various off-line formats and data storage and retrieval systems.
3) Demonstrating and marketing the developed system.

The program was assigned to the EASD Systems Programming group, who worked with potential customers in defining system operational requirements. As more was learned about the operational characteristics required by a typical customer, it became evident that from a system technique point of view there was nothing new about a peripheral processor supporting several peripheral devices (in this case, displays). However, it was observed that the distribution of data processing resources was not always in the users' best interests.

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Display terminals have been available in one form or another for the past 14 years. As depicted in Fig. 1, their application has been to provide the interface between man and his data base, rather than "man/machine" as the interface is often called. During that time period, the application of data processing resources to various points between the CRT and the data base has varied dramatically with the technology.

Fig. 2 shows one of the earliest configurations. Here, most of the support functions required by the terminal were provided by the computer. These included refresh, key recognition and translation, and cursor positioning. The next variation on this approach is depicted in Fig. 3. The terminal support functions were relegated to a front-end processor, thus reducing the overhead in the central computer and allowing the system to support more display terminals.

At about the same time that the front-end processor came into vogue, some highly sophisticated command and control display terminals were built. Each of these terminals contained its own stored program computer; however, these devices were very expensive.

The terminal support functions had travelled from the central processor to the terminal in software form. The next evolution was the hardware implementation of the support functions in the terminal itself. These included refresh memory, key recognition, and cursor positioning.

As hardware became less expensive, more and more functions were designed into the terminal hardware, until economic considerations forced the manufacturers to return selected terminal functions back towards the data base. For example, refresh memories, character generators, and most of the display support logic was time shared between two or more CRT's.

Today, there is a good deal of activity in both directions. Many support functions are best implemented in a front-end processor (peripheral processor). Other functions are best implemented in the terminal. However, user requirements are so diverse, that a general purpose terminal often does not satisfy the requirements. Thus, the terminal micro-processor has come into its own, and once again the application of data processing resources is moving back and forth between the terminal and the data base.

Today's peripheral processor is significantly less expensive and more powerful than its predecessors. Thus, it can also be used to perform pre-application

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received his education in Glasgow, Scotland, and is pursuing a business administration major at Los Angeles City College and at Valley State College. Mr Goodman has more than 15 years experience in all areas of information systems. He has also had management experience at the project, group and company level, in management consultation, and in marketing. Prior to joining RCA, Mr Goodman was president of Programming Research, Inc., a California-based software firm. Mr Goodman's most recent project concerns the extensive firmware programming for EASD's new FLEXIMITE micro-processor now under development for special-purpose data terminals. He is a member of ACM and two of its special-interest groups SIGTIME and SIGBDP.

processing and other functions that are more appropriately relegated to a peripheral processor. Further, by adding a simple interface device, the peripheral processor and its associated terminal and memory devices can be connected to almost any central computer. The peripheral processor software can compensate for any format and sequence considerations, allowing the user to expand an existing on-line system, or convert to an on-line system using foreign terminal devices, without modifying his existing operating system.

The effort at EASD led to the development of a Peripheral Data Management System (PDMS) concept. The basic premise of this concept is that the cost and risk of implementing or expanding on-line systems can be reduced significantly by properly distributing data processing resources between the man and his data base.

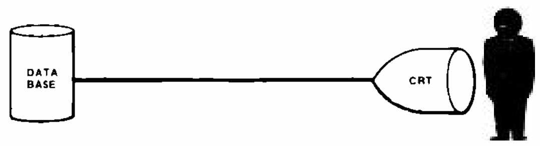

Fig. 1—Man/data-base interface.

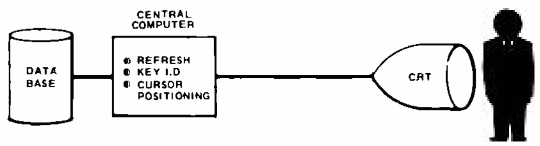

Fig. 2—Central computer support CRT.

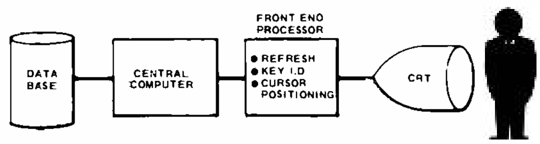

Fig. 3—Use of front-end processor.

PDMS concept

The first important characteristic of the PDMS is that it can be "plugged into" an existing computer system without disrupting or in any significant way changing the existing operation. Another equally important characteristic of the PDMS concept is that it implicitly provides for an improved distribution of the processing load. The best example is the cost of core space and overhead time associated with terminal input/output (I/O) processing, a task which can be appropriately relegated to a peripheral subsystem.

When a computer user adds on-line terminals to his existing system, he is usually confronted by the following hardware, software, and operational problems:

1) Core expansion.
2) Mass storage expansion.
3) Software changes to enable the operating system to handle the new core and the new equipment.
4) Increased software overhead as a result of a more complex operating system.
5) Being forced into buying terminals sold by the mainframe manufacturer rather than risk operating system changes if third-party terminals are used.
6) General disruption of operational activities.
7) Increased response time, caused by increased overhead and loss of effective core space.
8) Failure to achieve proportionate increase in throughput after adding core.

In contrast, the PDMS concept eases the technical and economic problems facing the prospective on-line terminal user:

1) The addition of a PDMS does not require core expansion in the primary computer. In fact, cost effective distribution of processing tasks conserves primary core.
2) PDMS does not create a requirement for primary mass storage expansion. The subsystem has its own mass storage, thereby providing for a priority-oriented hierarchical data base.
3) The primary computer's operating system does not have to be regenerated to accommodate PDMS.
4) PDMS provides for a relative reduction in overhead, in sharp contrast to the typical effect of adding large numbers of terminals.
5) In planning his system or system enhancement, the user can consider the product of any peripheral manufacturer without risking the integrity of his primary system.
6) "Plugging in" a PDMS does not interrupt the existing operation.
7) Since overhead is reduced, response time is enhanced.
8) The peripheral system handles all of the new terminal overhead. Thus, if the user wishes to add core to his primary computer, he can expect a proportionate increase in throughput.

The PDMS handles all of the buffering, I/O, and interrupt processing overhead; character conversion; and format manipulation; while at the same time providing off-line management and inter-operator communications facilities. Other peripheral processing applications include:

Data editing
Data verification
Security procedures
Indicator processing
File preprocessing
Program compilation
Keypunch replacement
General data entry
Test manipulation
Display format generation
Transaction logging
Bulk media processing
Tape-to-print, etc.
On-line programming

A distinct PDMS advantage to the "new system" designer is the opportunity to consider cost effective distribution of the processing load from the start, rather than having to adapt the system after the fact. Using the PDMS concept to add on-line terminals and distribute the overhead burden offers a low-risk, fixed-cost, technically advanced solution to a high-risk problem with the potential for runaway costs.

PDMS application

The knowledge gained during the initial phases of the development effort contributed to EASD winning a contract for a PDMS application. The system was operational during the first quarter of 1971, demonstrating the 'plug-in' concept described earlier. This PDMS system is a 32-terminal extension of the customer's primary system.

Fig. 4 depicts the overall system configuration. It includes a GE-635 computer with a core memory of 256 k, a multibillion character data base, and 16 Bunker-Ramo BR-90 display consoles for on-line information retrieval and maintenance. In this application, there are several user groups. Each one is interested in a different facet of the same data base. Further, each group uses one or more BR-90's to access and update the common data base.

The BR-90 is a highly sophisticated display device. The unit contains its own program computer with an 8 k, 12-bit word capacity, graphics, marker and cursor, off-line text and graphic editing functions, rear view slide projection, and light pen. It was decided that the primary system should be expanded to allow additional users to access the data base. Since most of the additional users would not require graphics or slide projection, the customer could not justify the cost of additional BR-90's. The PDMS was sold to provide the required additional text capability. Thus, each of the RCA terminals functions as a miniature text-only BR-90.

A PDP-15 mini-computer is utilized as a peripheral processor to functionally interface the RCA displays with the existing system. The software in the PDP-15 provides compatibility with the BR-90.

In addition to the GE-635 interface and BR-90 compatibility, the PDMS also provides a variety of off-line capabilities:

1) A console-to-console communications system.
2) A secretarial file system.
3) Various editing capabilities including:

Page save	Character insert
Page restore	Character delete
Line insert	Format generation
Line delete	Line and field erase

Software organization

The PDMS software operating in the PDP-15 has three major components: operating system; task processors; and background monitor and utility system.

The operating system (OS) provides for multi-programming. It allows any practical number of tasks to be processed concurrently. The OS provides for all physical resource allocation, interrupt processing, scheduling, and includes I/O handlers for all I/O devices, including the GE-635/PDP-15 interface. The OS design philosophy is similar to a process control operating system; low space and time overhead, immediate processing rather than queueing whenever possible, and modularity as a product requirement rather than a design constraint. The OS program design is directly re-usable on any other comparable computer and would require only recoding.

The task processors (TP's) support the system's functional requirements. For example, there is a unique task processor for the execution of each I/O command from the GE-635. Thus, to interface with another computer and/or system, a new TP is written for each command and the command interpretation in the OS is modified. All TP's are core resident. Each TP is re-entrant. Thus, all 32 terminals can concurrently use the same TP without requiring 32 copies in core. All OS/TP communication is accomplished via standard software interfaces.

The background monitor can be used concurrently with the rest of the system. It supports a complete debugging and utility system for magnetic tape, paper tape, teletype, disk, and core. The design is directly re-useable on any other comparable system.

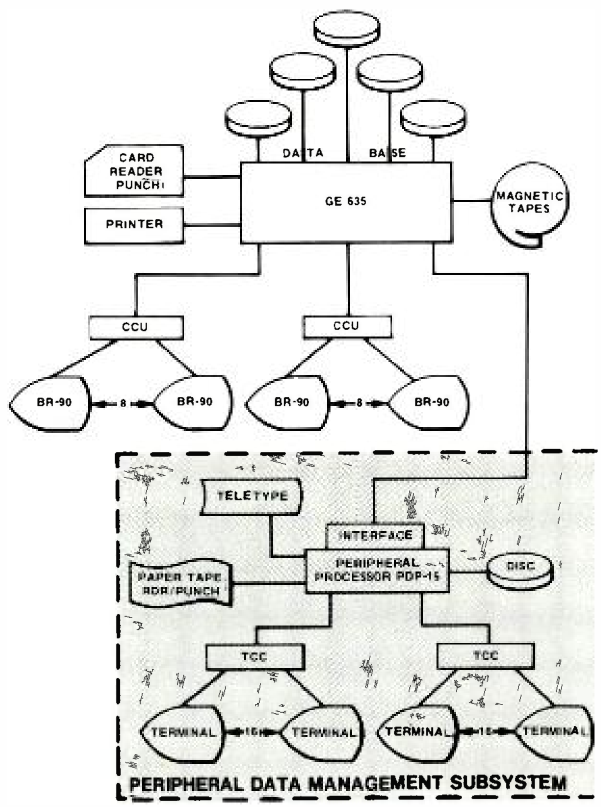

Fig. 4—Peripheral data management system (PDMS).

Hardware organization

Fig. 4 depicts the PDMS hardware configuration. It includes a GE-635/PDP-15 interface; a PDP-15; a core of 16 k, 18-bit words; two teletypes; three DEC tape drives; two console controllers; 16 generators and 32 video terminals, each with an alphanumeric keyboard, a fixed function keyboard, and two sets of variable function keys.

The PDP-15/GE-635 interface is particularly flexible and allows the PDP-15 to terminate all I/O transfers. Thus, the amount of data, the speed with which it is transferred, and the status sent to the GE-635 at termination is under program control.

A chaining facility, functionally comparable to command and data chaining in the RCA Spectra 70 IOC, was implemented in each terminal subsystem. It has two important benefits: (1) software overhead as the result of termination interrupts is reduced to one interrupt processing sequence per I/O request, independent of the number of commands and data sequences that are sequentially transmitted to a given console; and (2) chaining has been implemented independent of the PDP-15. Thus, the system has the same capability no matter what computer is used.

Video data terminals

The video data terminals used in the system are the RCA Spectra 70/751 displays designed and manufactured at EASD. They were modified to provide special features not available on the original terminal. The computer-to-display communication capability is provided by two units. One is a modified version of the RCA Spectra 70/759 video data controller. The other is a new and advanced version of a processor I/O peripheral equipment controller.

The PDMS video data terminal is depicted in Fig. 5. Each terminal includes an alphanumeric keyboard with extra data editing keys and both fixed and user software dependent variable function keys. Controls are also provided to aid in communicating with the processor to allow it to interactively assist the operator with information retrieval and maintenance tasks. The display tube is a 12-inch rectangular CRT, capable of 70° deflection, and coated with a P4 phosphor. The display format consists of 960 characters, at 64 characters per line and 15 lines per page. A display refresh memory provides storage for locally generated data and/or data received from the processor. Display refresh is at 60 Hz, for flicker-free viewing. The monoscope character generator provides a repertoire of 96 USASCII characters that are bright and appear as highly legible closed curves.

There are four functional subdivisions of the keyboard on each video data terminal. The first two units are the four-row typewriter style alphanumeric keyboard and the system status indicator panel. The alphanumeric keyboard contains extra keys to permit control of the positions of the editing cursor, activation of certain off-line editing functions, and call-up of the fixed on-line editing and system control functions. The status indicator panel is a square array of 25 processor controlled lights. The array is provided with a plastic overlay to permit custom identification of the light's function.

The second two units are two-column switch and indicator variable function key arrays which are also provided with a plastic overlay for customized usage. These are used for activating on-line, program state dependent functions.

Fig. 5—PDMS video data terminal.

Operator cursor controls include UP, DOWN, LEFT, RIGHT, HOME, TAB, SKIP, CARRIAGE RETURN, BACKSPACE, and ADVANCE. The computer can control and interrogate the cursor position.

Special display features

Format data feature

The display presentations may be configured so that all character positions may be controlled by both the computer and the operator, or selected data locations may be reserved for operator changes. When mixed data is displayed, those character positions whose contents may be controlled by the operator are underlined on the display presentation. Editing functions including ENTER, ERASE, CHARACTER INSERT, CHARACTER DELETE, LINE INSERT, LINE DELETE, PAGE INSERT, PAGE DELETE, NEXT PAGE, PREVIOUS PAGE, SAVE, RESTORE, SEND, and RESET are included with the format data feature.

Blank field feature

Under control of the processor, individual or groups of character locations on the display may have their contents hidden from view, so that data entered into the system by an operator cannot be seen by unauthorized people. This feature is independent of, but most effective when used in conjunction with, the format data feature.

Data blink feature

Under control of the processor, individual characters and/or fields of characters may be caused to blink at a 2-Hz rate. Data blink is independent of the format data feature. It is typically used to emphasize the significance of a particular data string.

Audible alarm feature

An audible alarm is provided with the viewer for several purposes. It sounds once when the editing cursor approaches the end of each line (like a typewriter carriage bell). It sounds once when the editing cursor enters the last line of the display. It may also be sounded by the processor. In this function, the alarm is used to indicate such system conditions as message waiting and error.

Pseudo light pen

A system key is provided that allows the terminal operator to tell the processor to take note of the position of the editing cursor by causing a unique status message to be transferred from the terminal to the processor.

Connectability

Two video data terminals are connected to each video data generator. These terminals can be installed via cable by as much as 1000 feet from the video data generator.

Current PDMS activity

As a result of this program, a concept was developed, a capability created, a market aperture identified, a contract won and completed, and a new business area developed. These successful activities reaffirm EASD's position as the corporate skill center for terminal engineering and production. EASD is aggressively pursuing the PDMS market. Follow-on work is anticipated in the near future, and several marketing targets with high return probability have been identified.

Monte Carlo techniques for use in upper atmosphere problems

R. R. McKinley | S. M. Siskind | Dr. G. K. Bienkowski

The so-called transitional flow region of the atmosphere, *i.e.* the zone between 100 and 150 kilometers, can be described neither as a mixture of gasses in hydrostatic equilibrium nor as a mixture in diffusive equilibrium. Monte Carlo simulation techniques furnish a model of the system that renders satellite-gathered information intelligible and allows designers to optimize satellite design.

NOW THAT MAN has flown around and set foot on the moon, the National Aeronautics and Space Administration (NASA) is directing more of its effort towards increasing our knowledge of the earth and its atmosphere. Probably the least understood region of the earth's atmosphere is the zone between 100 and 150 kilometers, yet an understanding of the processes taking place in this region is necessary to provide accurate boundary conditions for both the lower and higher atmosphere.

To obtain more information about this region, NASA intends to launch a series of Atmosphere Explorer satellites to gather data in the region near 135 kilometers. However, scientific interpretation of this data may be a problem. The program described below, which was done for NASA on Contract NAS5-11241, is one attempt to aid in interpretation of the data.

Transitional flow region

Below about 100 kilometers, the atmosphere can be treated as a continuum-fluid with a density equal to the mean density of its constituent species of particles (*i.e.*, the gas is in hydro-static equilibrium). Above 150 kilometers, the atmosphere mixture can be treated by considering its individual components separately, since each type of particle behaves the same as it would if the other species were not present (*i.e.*, the mixture is in diffusive equilibrium). If a satellite is flown in either of the above regions, the flow field of the gases (as they "flow around" the

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assumed stationary satellite) can be adequately described by current theory, and data taken by the satellite is relatively easy to relate to the required free-stream condition, *i.e.* the state of the atmosphere if the satellite were not present to distrub it.

If however, a satellite is flown between 100 and 150 kilometers in the so-called "transitional flow region" of the atmosphere, the flow field around it cannot be accurately described by equations governing either the diffusive or hydrostatic regions. Indeed, there now exists no sound theoretical basis for describing the flow field in this region of the upper atmosphere due to the fact that in the transitional flow region, the physical state of the atmosphere is changing from a hydrostatic to a diffusive equilibrium. In this zone, the mere presence of a moving satellite or rocket causes the build-up of tremendous shock waves which drastically affect the measurements of the surrounding flow field. In order to correctly interpret such measurements, it is necessary to independently solve for the physical parameters (such as average density and mass ratios of various species,) in the flow field disturbed by the passage of the satellite and to compare these results with those from the free-stream undisturbed flow field. Until recently, techniques for obtaining these parameters in the transitional flow region were virtually non-existent. Now however, Monte Carlo methods appear to give valid solutions for the parameters.

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received the BS in Physics from the University of Southern California in 1965 From 1965 to 1969 he attended graduate school at the University of Illinois where he received his MS in astronomy and completed course work for the PhD Also during this period he was employed by Jet Propulsion Laboratory as a research assistant. Mr McKinley joined RCA in 1969 to work orbital dynamics problems in the Advanced Mission Planning Group. He has worked on problems such as determination of best fit satellite orbits for tracking, station data, long term perturbation effects of the solar wind for the ERTS satellite and a computer program to determine the position and dynamics of a launch vehicle after first stage burn. He has also done work on several classified projects and has done various projects related to the development of the Atmosphere Explorer Satellite While at RCA Mr McKinley attended a summer course on Advanced Orbital Dynamics at UCLA. He has previously published two technical papers.

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History of Monte Carlo methods

Before presenting the specific use of these Monte Carlo methods in the current program, some general background information may be helpful. The original use of these methods as a research tool was in the development of the atomic bomb, in the early 1940's. Faced with the problem of examining random neutron diffusion in an atomic pile, early experimenters tried direct duplication methods. Ulan and von Neumann improved the accuracy of these methods with several techniques for reducing the scatter around the mean value, in particular with what they called "Russian Roulette" methods of using random numbers. This laid the ground work for present day Monte Carlo techniques.

In the 1950's, Monte Carlo methods became a panacea for all manner of physical problems, without consideration as to which of these problems could be handled efficiently. These methods fell into disfavor when they proved to be inefficient on some problems and markedly inferior to other numerical analysis techniques on other problems. However, in recent years Monte Carlo methods have returned to favor, primarily due to a better understanding of those problems in which they are the best, and sometimes the only, available technique.

As used today, Monte Carlo methods (or methods of statistical trials) are a numerical means of solving various physical and mathematical problems. Statistically valid solutions can be obtained by the construction of some random process for each problem, with the parameters in the process equivalent to the required quantities of the problem. The required quantities can then be determined approximately by computing the statistical characteristics from the random process.

Because of their inherently statistical nature, problems related to the kinetic theory of gases are especially well suited to Monte Carlo treatment. A number of these problems has been successfully attacked by Monte Carlo techniques. However, only recently have attempts been made (by Bird and other workers) to apply this method to rarefied flow problems where the Knudsen number (the ratio of molecular mean-free-path to satellite size) is of the order of unity.

Atmosphere simulation

In the altitude range of 100 to 150 kilometers, the state of the flow field changes and Knudsen number goes from less than one to more than one. To investigate the effects the flow field of a satellite has on measurements taken at its surface (or interior to its surface in a cavity corresponding to some sort of measuring instrument), it is necessary to numerically simulate the steady-state velocity and position distributions of the various species of gases present in the atmosphere. These distributions are obtainable only if both particle-particle and particle-satellite collisions are considered in the proper amounts and at the proper positions. In problems such as this, a Monte Carlo direct simulation technique is ideally suited for obtaining statistically valid distribution functions.

In such a direct simulation, the gas is represented by a large number of particles whose velocity components and position coordinates are continuously monitored. If the properties of each particle are randomly selected from the known properties of the gas, the results obtained should be meaningful for the gas as a whole. In such an approach, due to the tremendous amount of data which must be handled, the entire simulation and calculation of results must be done on a large computer.

At AED, the initial effort in the computer simulation field (done under a NASA contract) was a feasibility study and survey of applicable simulation techniques. During this study a basic computer program was written and parametric data were generated for the case of an infinite cylinder and for a sphere, using a two-dimensional program and a two-species gas mixture. Under a second NASA contract, the efficiency and usefulness of the two-dimensional program was improved and it was extended to more general situations.

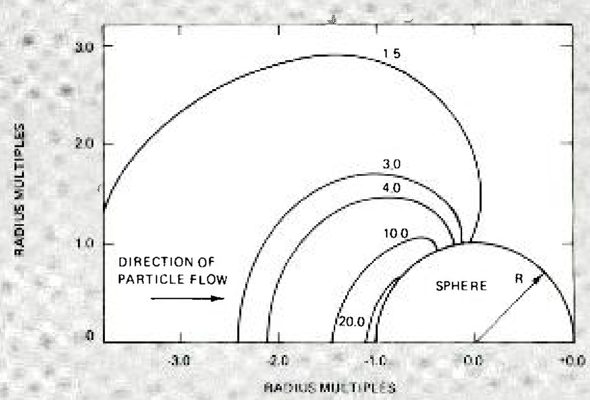

Fig. 2—Density contours for flow around a sphere at an altitude corresponding to approximately 150 kilometers. Completely diffuse reflection is assumed at a body temperature equal to the free stream gas temperature. All density levels are normalized to the free-stream values. Note the tremendous increase in density at the leading edge of the body.

Three-dimensional simulation

Upon successful completion of the generalized two-dimensional case, the effort turned to a three-dimensional simulation, again using a two-species gas (which can be arranged to duplicate the upper atmosphere quite accurately). In this program, the following process takes place. Initially, an unperturbed thermal velocity distribution function is selected for initialization purposes. This function depends on the Mach number, Knudsen number, particle mass ratio and a number density ratio, and body-gas temperature ratio, relevant to the conditions being tested. The physical volume surrounding the test body, which is generally a typical satellite geometry, is divided into about seven hundred test cells of several sizes, the smaller cells being nearer the body and on its "leading edge" in order to give better resolution. A representative satellite geometry is shown in Fig. 1.

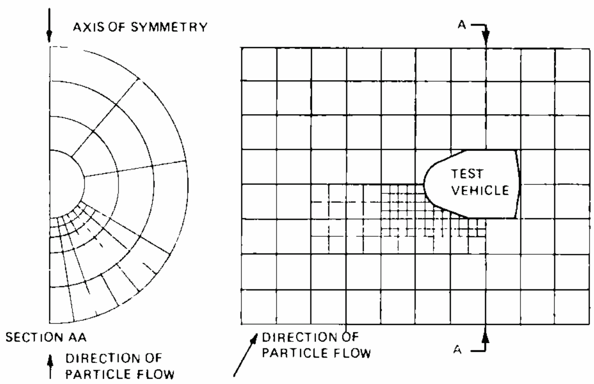

Fig. 1—Typical three-dimensional geometry for a test vehicle, showing three levels of cells. Cells also are divided angularly by planes coming radially outward from the axis of rotation of the vehicle. Note that more of the smaller cells are placed on the leading edge of the body, where more interaction is expected.

Particles of the two species, whose mass and number density are generally different, are then introduced into the sample space. The initial spatial distribution of about five thousand particles of each species is made by random selection within each cell. The initial thermal velocities of the particles are also randomly selected from the above described velocity distribution function. In order to simulate motion through the atmosphere, the satellite's velocity is subtracted from the initial velocity of each particle, thereby giving the particles a net translational motion through the sample space. The test body is then inserted into the free stream and "time" begins.

At this point, the particles are allowed to move and interact with each other and the body. Each individual cell is considered to be a point in space. In a preselected, short interval of time (a small fraction of the expected mean time between collisions), the particles within a single cell randomly collide with each other. The collision probability of any pair of particles within a cell is made to simulate the physical

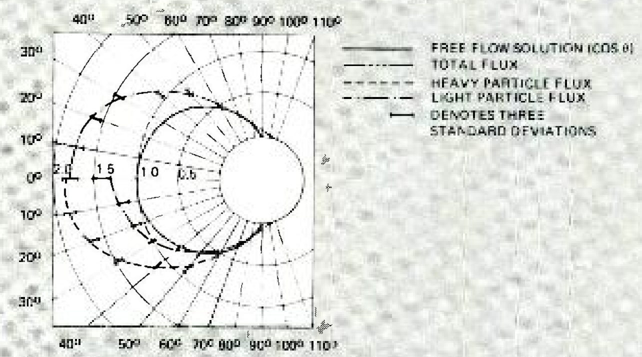

Fig. 3—Angular distribution of particle fluxes per unit area on a sphere. Total flux along with the individual flux of a heavy and a light species are indicated. Other conditions are the same as in Fig. 2. Note the large increase at the leading edge of the test satellite. Also note that the flux of the heavy species increases much more dramatically than that of the light species.

laws of probability applicable in this region of the atmosphere. After each collision, the new velocity of each particle is again randomly chosen, but with the provision that momentum be conserved.

After the required number of collisions has occurred (corresponding to the expected number of collisions which would occur in the given fraction of expected mean collision time), all particles are allowed to advance in space according to their latest velocities. Particles with the appropriate velocities may leave the sample space through any of the boundaries. To compensate for this, other particles are added to the sample space by means of distribution functions on all boundaries. Particles are, of course, allowed to collide with the body when such an encounter is indicated.

For those particles colliding with the body, a preselected fraction between zero and one can be diffuse collisions, while the remainder are specular. The diffuse portion of reflection can be either elastic or non-elastic. In all of the test runs completed to date, totally diffuse, non-elastic collisions have been assumed. Using this model, particles encountering the body are, in effect, absorbed and then re-emitted at the same position with random velocities whose magnitudes are typical of the temperature of the test body (an imput to the program) and whose directions relative to the local body surface normal are randomly selected from a cosine law distribution function.

In a typical run of the program, as time increases from zero, particle densities tend to increase on the leading edge of the test body and decrease on the trailing edge, and the total number of particles in the sample space increases over the original free-stream density. The total number of particles reaches a maximum and then decreases slightly as the equilibrium shock waves are formed. After this equilibrium condition is reached, useful data can be obtained about the specific test geometry and the flow field.

Information obtainable

The number flux, momentum transfer, and energy transfer to the surface of the body are accumulated and used to compute aerodynamic data. The data of interest include total particle flux to the body, heat transfer to the body, and aerodynamic drag and lift. Total magnitudes of these parameters as well as their components from each of the two species of particles can be obtained.

The body surface of the satellite is divided into segments so that the same aerodynamic quantities can be computed as a function of location on the surface. In addition, the overall velocity distribution of the impinging particles can be obtained for any body surface segments. These parameters are important to the experimenter who wishes to place a sensor or sensor orifice on the surface of the satellite because they provide him with a basis for correcting his measurements.

Flow field properties are also computed. Instantaneous values are sampled at appropriate time intervals after equilibrium and these are time-averaged for greater accuracy. Number density, flow velocity, and temperature can be obtained at each cell location (Fig. 1). As an indication of non-equilibrium, the temperatures based on the three individual velocity components are also calculated. Some typical results for density and average particle fluxes around a spherical body at Mach 25 are shown in Figs. 2 and 3 respectively.

Even a cursory glance at these two figures gives ample evidence that measurements of the environment taken by satellite or rocket borne instruments in this region of the upper atmosphere are not indicative of the nondisturbed atmosphere conditions. Obviously, some means for correcting the observations must be used. Studies such as this will eventually yield a series of correction curves relating the observed data to the unperturbed atmosphere.

Conclusions

The usefulness of the data obtained from a satellite or rocket in the transitional flow regime of the upper atmosphere can be greatly enhanced by this use of the Monte Carlo technique. In the near future, a direct application of this process will be the correction of measurements taken by NASA's Atmosphere Explorer satellites. Prior to flight, the current program can be used to optimize the placement of various instruments on the satellites. As man continues his incursions into the upper atmosphere, Monte Carlo techniques may well be used to solve more of his complex problems.

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Error rate of multiple PSK signals through a hard limiter

B. E. Tyree | J. Bailey

This paper describes an investigation* of channel spacing for multiple binary phase-shift-keyed (BPSK) signals accessing a hard-limiter satellite. The effects of intermodulation and modulation spectrum interference on the bit error rate of the active channels were considered. Results and conclusions of experimental error rate data are presented for various channel spacing arrangements. Of major significance is the formation of rules for spacing of active channels when six or more BPSK signals are accessing the hard limiter.

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received the BEE from the University of Florida in 1957 and the MSEE from Drexel University in 1963. He joined RCA in 1957 participating in the Engineering Training program and then the PRC-35 transceiver program during 1958. Other major program responsibilities from 1959 to 1964 include the GKA-5 Data Link project, classified VLF program, the Dyna Soar X-20 SHF Ground Receiver and the AN/TRC-97 Troposcatter Communications Equipment. In November of 1964 he became project engineer for the development of an FDM equipment to meet DCA requirements and continued on this program through 1967 when he received the RCA Professional Excellence Award. He was promoted to Engineering Leader in June of 1967 on the TACSAT I program, responsible for developing two of a family of five Tactical Satellite Terminals, including a high speed Differential Encoded PSK Modem. In 1970 he was responsible for three other TACSATCOM programs including a simulation of FDMA accesses to a hard limiter resulting in the formation of spacing allocations based on intermodulation distortion. During 1971, he performed further work in the satellite terminal area, high speed modems, and error correction devices. He is a member of the IEEE and the Communication Technology group.

Ben Tyree (Mr. Bailey was not available for photograph)

THREE COMMON TECHNIQUES are used for multiple-user access in communicating through a satellite channel: 1) frequency-division multiplex (FDMA), 2) time-division multiplex (TDMA), and 3) code division multiplex (CDMA). This paper is concerned with the most commonly employed satellite-access technique, FDMA, in which multiple signals access the satellite at different frequencies. In this technique, the satellite RF channel bandwidth is divided into a number of non-overlapping frequency slots (contiguous channels) which determine the number of accesses. In general, any type of angle modulation such as FM, PM, FSK, or PSK can be used on the multiple carriers. In the use of FDMA, the most serious problem lies in the intermodulation products formed when multiple signals are simultaneously present in the non-linear satellite channel. This intermodulation noise subtracts from the power available to the desired signals at the satellite channel output, and results in interference in the active channels unless proper spacing is employed. In addition, suppression effects occur when one of the accessing signal levels becomes higher than the other accesses resulting in further degradation.

An investigation was conducted to determine how these effects and others influence the bit error rate of multiple PSK signals through a hard limiter. A simulated system model of a satellite communication channel was conceived and used to perform error-rate measurements with various channel spacings. The ultimate goal of the investigation was to establish rules for placement of the active channels and arrive at an arrangement which would provide 14 active channels from a 60-channel-capacity system. The figure of merit used in determining a usable configuration was a 1×10^{-5} bit error rate (from intermodulation and modulation spectral interference) with an allowable power-level variation of -3 dB relative to the normal channel level.

Intermodulation effects

Intermodulation distortion (*IM*) is a long standing problem in radio systems which process multiple signals, either on single or multiple RF carriers, because of non-linearities in the transmitter and/or receiver. In a hard-limiting type of satellite, the *IM* product content is of greater magnitude than that commonly encountered with multiplexed signals since the non-linear element is in series with the communications path.

The hard-limiter model is considered to be a symmetrical clipper with an odd-order transfer function. This type transfer function generates intermodulation products when multiple signals are simultaneously present which fall into discrete portions of the frequency spectrum.[7] The low-frequency area is

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designated the *zero zone*, while the input frequency range is designated as the *fundamental zone*. Harmonics of the fundamental frequency range are denoted as *higher order zones* (second, third, etc.). A bandpass filter is used after the hard limiter to restrict the desired output signals and undesired *IM* products to the fundamental or first zone. The location and magnitude of these products depend upon the number, spacing, and format of the signals accessing the satellite. When blocks or groups of contiguous channels are operated simultaneously, odd-order products are generated which fall into the operating channels, with the third and fifth order being the most significant contributors.

These products were summarized by Babcock[3] and are tabulated below:

Third order
1) $f_A+f_B-f_C=f_{111}$
2) $2f_A-f_B=f_{21}$

Fifth order
1) $f_A+f_B+f_C-f_D-f_E=f_{11111}$
2) $2f_A+f_B-f_C-f_D=f_{2111}$
3) $f_A+f_B+f_C-2f_D=f_{1112}$
4) $2f_A+f_B-2f_C=f_{212}$
5) $3f_A-f_B-f_C=f_{311}$
6) $3f_A-2f_B=f_{32}$

The frequency designations, such as f_A, contain a band of frequencies in channel *A* of bandwidth, Δf, and likewise for channel *B*, *etc*. Babcock arrived at channel spacing arrangements empirically and performed analysis for equally spaced channels which show that the third-order *IM* products occupy a bandwidth of nearly three times that of the active channels.

Similarly, the fifth-order *IM* products occupy a bandwidth of nearly five times that of the bandwidth of the active channels. These analyses may be generalized to conclude that n^{th}-order *IM* products, having equally spaced channel widths, are spread over a bandwidth which is *n* times as large as the channel width of the active channels.

However as Sevy[2] indicates, Babcock's spacing arrangements are valid only for CW signals through a hard limiter since they do not take into a account the effect of spectrum spreading (Babcock's study did not consider the effects of hard limiting). Sevy discusses the effects of *multiple FM signals* passing through a hard limiter with the resultant spectrum spreading effect, and the *IM* and channel spacing arrangements for four channels necessary to have third- and fifth-order *IM*-free channels.

Table I—Maximum number of interference-free channels with capacity *n*.

Total channel capacity=n	*Number of third-order IM-free channels*
4	3
6	3
10	4
15	5
20	6
30	7
40	8
50	9
60	10
100	13

Total channel capacity=n	*Number of third- and fifth-order IM-free channels*
13	4
26	5
50	6
100	7

Table II—Babcock third-order *IM*-free channels.

Channel Capacity=n	*No. of IM-free channels*	*Use channels*
4	3	1,2,4
7	4	1,2,5,7
12	5	1,2,5,10,12
18	6	1,2,5,11,13,18
26	7	1,2,5,11,19,24,26
35	8	1,2,5,10,16,23,33,35
46	9	1,2,5,14,25,31,39,41,46
62	10	1,2,8,12,27,40,48,57,60,62
137	8*	1,2,8,12,27,50,78,137

*These channels free from both third and fifth.

In the case of conventional bi-phase PSK signals passing through a hard limiter, other factors must be considered. The spectrum of the bi-phase modulated signal is of the form $(\sin x/x)^2$. When this signal is hard limited, the output spectral density from the limiter consists of:

1) Signals at the carrier frequency of the form $(\sin x/x)^2$ with a bandwidth equal to the input signal bandwidth.
2) Signals of the form $(\sin x/x)^2$ at odd harmonics of the carrier frequencies with a bandwidth equal to the input signal bandwidth.
3) Spectral lines at even-order harmonics of the carrier frequencies.

Intermodulation distortion produced from using the odd-order harmonics of the carrier band ($3\omega_c$, $5\omega_c$, *etc*.) result in normal spreading in relation to the order of the product. However, *IM* produced from the even-order products of the carrier band (such as $2A-B$) are restricted to a single-channel bandwidth equal to the bandwidth of *B*. This means that *IM* of the $2A-B$ category is not as predominant a factor as the $A+B-C$ products. Shaft[4] shows that the $(2A-B)$ *IM* quickly diminishes after ten signals. This leads to the conclusion that for the bi-phase signal case, the *IM* from the hard limiter is primarily associated with products produced from the fundamental carrier frequencies (*e.g.*, $A+B-C$).

Both Babcock and Edwards, et al,[5] determined the maximum number of interference-free channels for third-order and fifth-order products for *n* contiguous channels. Some of Babcock's cases (up to a 100-channel-capacity system) are given in Table I where it can be seen that interference-free channel spacing does not allow economic utilization of the transmission bandwidth.

Shaft[4] shows, for accesses (number of simultaneous signals) between 10 to 100, that the signal to total intermodulation, S/IM_{total}, in a given channel lies between 9 to 8.5 dB for random selection of channel frequencies, thereby establishing a lower bound on the *S/IM* ratio. Shaft points out that through computer analyses, the *S/IM* ratio can be increased above the lower bound.

Channel spacing arrangements

A number of investigators have done work on channel-spacing arrangements. Babcock's approach was to select operating channels from a block of *n* contiguous channels so the difference between any pair of channels is unlike the difference between any other pair of channels as given in Table II.

Shaft[1] extended one of Babcock's spacing arrangements (1, 2, 5, 10, 12) to a six-access case where he considered: a) 6 accesses in 6 contiguous channels, b) 6 accesses in 12 contiguous channels, and c) 6 accesses in 15 contiguous channels. His approach to the assignment problem was to use the Babcock spacing for the first five slots and place the sixth channel in some acceptable left-

Definition of terms

IM = Intermodulation distortion; intermodulation power level
S = Signal power
I = Sidelobe spectrum interferance level
N = Noise power
E = Energy per bit
N_o = noise-power spectral density (noise level per Hz of bandwidth)
dBr = dB below reference level

Table III—Sidelobe interference summary.

Configuration	*Active channels*	*Total channel capacity*	*Signal-to-interference in 2× data-rate bandwidth channel No.*	*S/I (dB)*
Equal data rate				
1) One adjacent	1,2	2	1,2	14.5
2) Two adjacent	1,2,3	3	1,3	13.7
			2	11.5
3) Six contiguous			1,6	13.0
			2,5	10.8
			3,4	10.6
4) One chan. guardband	1,3,5,7,9,11	12	1,11	19.7
			3,9	17.4
			5,7	17.2
Multiple data rate				
1) Contiguous case	1,2,5,6	—	1,6	17.7
	3-4		2,5	10.8
1,2,5-6 } @ BR=1 @ Power=1			3-4	12.7
3-4 } @ BR=2 @ Power=2				
2) 1 chan. guardband	1,3,8,10	—	1,10	18.5
	5-6		3,8	15.6
1,3,8,10 } @ BR=1 @ Power=1			5-6	18.6
5-6 } @ BR=2 @ Power=2				

over slot using a computer program to determine the number of *IM* products (both third and fifth order) and then computing the signal-to-*IM* ratio of each active channel.

Askinazi and Subbotina[6] recommended the use of channel spacing according to an arithmetical progression. This is accomplished by progressively increasing the guardband between the active channels, for example, a typical channel spacing would be 1, 2, 4, 7, 11. In using the arithmetical spacing, some third-order *IM* falls into the active channels, but with significantly less magnitude than that of uniform (equal) spacing arrangements. Where a large number of active channels are needed, Askinazi and Subbotina suggest breaking the total bandwidth into equally spaced groups and then using unequal spacing of channels within each group. The *IM* produced for this case is greater than that produced where unequal spaced channels are used, but the advantage over equal spacing is still significant.

Edwards, Durkin, and Green[5] established a method for calculation of third- and fifth-order *interference free* channels through the use of Difference Sequence Theory. They developed rules for the selection of third and fifth order mutually compatible channels and present tabulation of channel difference sequences for direct application to channel selections free of third- and fifth-order *IM*.

Bi-phase modulated signal spectrum interference effects

Little, if any, treatment is given in the literature of the effects of modulation spectrum interference upon the bit error rate where multiple bi-phase modulated signals are present in a communication channel.

At a first look, one might tend to ignore the spectral sidelobe energy as being insignificant. However, upon closer inspection it is found that 10% of the total energy in a bi-phase modulated signal is in the spectral sidelobes with the remaining 90% in the main lobe. Where several signals are closely spaced, the sidelobe energy is a significant interference factor.

In evaluating sidelobe interference, two generalized cases were analyzed: 1) channels having equal data rates, and 2) channels having unequal data rates where each channel bandwidth is made equal to twice the data rate. Fig. 1 illustrates the case for three active channels with equal data rates and indicates the sidelobe interference contributors for each of the channels.

To evaluate the two cases, the energy levels for the main lobe and sidelobes of the $(\sin x/x)^2$ function were obtained by computer runoff and used to calculate the sidelobe interference factors. In each case under consideration, the sidelobe contributors were determined, the energy of the contributors added on a power basis, and the interference level determined with respect to the main lobe (desired channel information). These data are summarized in Table III.

It is evident from these analyses that adjacent-channel operation should be avoided since the sidelobe interference is a major contributor to the channel bit error rate.

In addition, when data rates other than one to one are being used, additional spacing constraints must be imposed due to high sidelobe levels from the higher-data-rate channels. Channel arrangements must be based on sidelobe interference as well as *IM* considerations.

Thermal noise and power control effects

Another effect controlling the error rate of digital transmission through a channel is thermal noise. In general, performance of a satellite communication system is limited by the down-link noise. This should be the controlling element for determining the error rate of a particular channel. However, as we have seen from the previous discussions of intermodulation distortion and sidelobe interferences (from bi-phase modulated signals), all three of these factors will have a pronounced effect on the bit error rate of a given channel.

The other factor to be considered is the degree of power control required on the signals accessing the satellite. Shaft[1] concluded for signal variations of less than 2 dB (for the equal-power, equal-data-rate case) that the resulting *S/IM* ratio varies approximately linearly with the power change. However, when the power of one signal becomes much larger than the remaining signal access levels, the effect becomes two fold: 1)

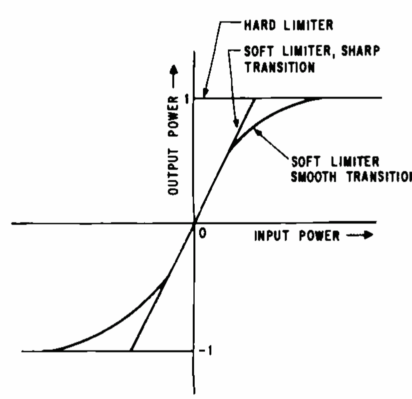

Fig. 3—Transfer function of limiter models.

signal suppression occurs to the weaker signal (for the extreme case, 5-6 dB), and 2) the *S/IM* decreases for the weaker signals because of the signal suppression, and possibly higher *IM* contributions from the larger signal.

System model

Initially, effort was extended toward establishment of a system model which in general would represent any operational hard-limiting satellite system. A functional block diagram of a typical hard-limiting satellite communication channel is shown in Fig. 2.

The channel is operated so that the limiters are the major non-linear elements in the communications channel. This allows the channel to be represented (simulated) at a more convenient frequency range, such as 70 MHz, since exact duplication of the system model at *X*-band or UHF frequencies is not readily achieved. The limiter characteristic determines the input-output transfer function of the system model.

The literature concerning limiter operation is quite extensive with three basic types of mathematical models being used. Shaft[1] summarizes the models as:

1) Hard limiter,
2) Soft limiter—sharp transition,
3) Soft limiter—gradual transition,

Fig. 3 illustrates the transfer function of each of these three models. The limiter models are represented mathematically by an odd-order transfer function given by Sevy[2] of the form:

$$y=g(x),$$

where for *hard limiting*,

$$g(x)=\begin{cases} a & x>0 \\ 0 & x=0 \\ -a & x<0 \end{cases}$$

for *soft limiting*,

$$g(x)=\begin{cases} ax^{\nu} & x>0 \\ 0 & x=0 \\ -a(-x)^{\nu} & x<0 \end{cases}$$

where $\nu<1$

In actual operation, the gradual-transition type limiter most closely approximates a practical limiter.

A block diagram of the implemented system simulation model is given in Fig. 4 which includes the test equipment needed for making test measurements. The system model was designed to provide the capability of fifteen active accesses in the bandwidth of 20 MHz over the frequency range of 60 to 80 MHz.

Fourteen signals with a 63-bit pseudorandom modulation (bi-phase PSK) are used with the fifteenth signal being generated by a TACSATCOM differentially-encoded PSK modem.

A test message generator supplies a data stream consisting of eight-bit periodic sequences to the differential-encoded PSK modem transmit section where the information is differentially encoded and bi-phase modulated on an RF carrier. The fifteen bi-phase modulated signals are fed to individual attenuators which provide proper loading for the modulators and are routed to the hybrid combiner where the fifteen signals are combined in the 60 to 80 MHz frequency range. The combined signal is fed to a high gain amplifier and variable attenuator prior to being

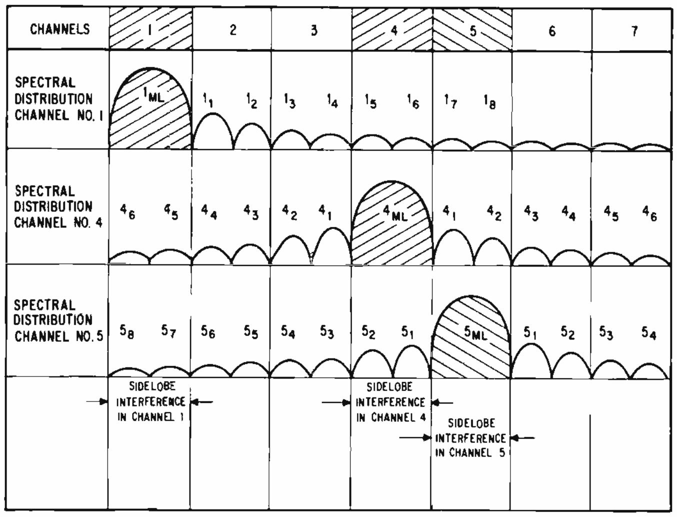

Fig. 1—Sidelobe interference.

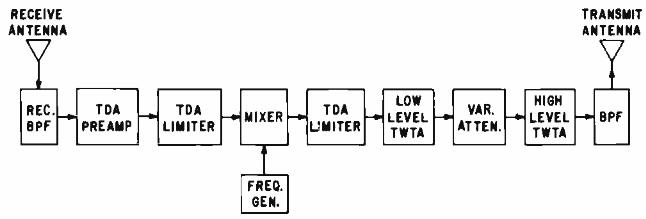

Fig. 2—Satellite-communication channel.

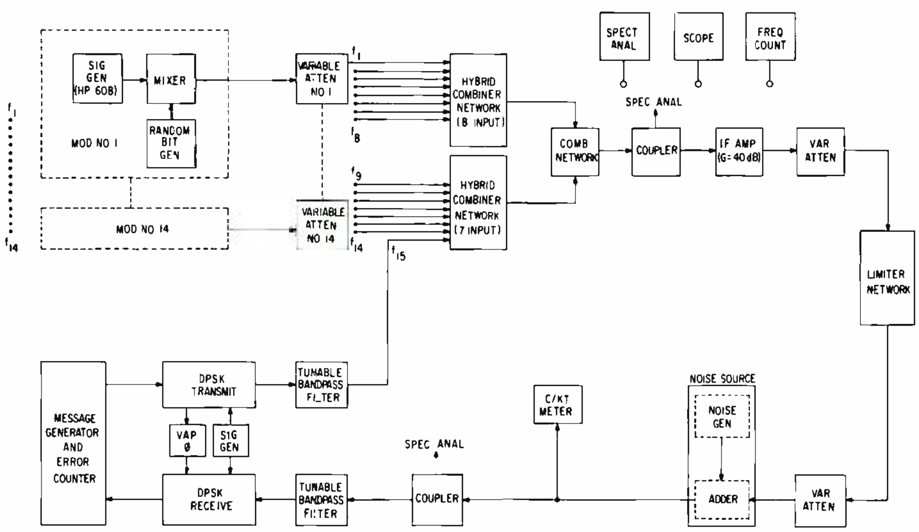

Fig. 4—FDMA simulation system test setup.

limited. The variable attenuator is used to set the operating input power level and the operating point of the limiter. The operating point of the limiter is maintained at a constant power level (full limiting) by adjusting the individual carrier levels by $P_C=P_T-10 \log n$ where n=number of signals.

After limiting, the combined signals are passed to a receive tunable bandpass filter which restricts the output of the limiter to the fundamental zone of operation and limits the total noise bandwidth to the receive section of the differential-encoded PSK modem. The filter is tunable across the 60- to 80-MHz frequency range with a noise bandwidth of approximately 3.0 MHz. The output of the tunable filter is processed by the receive section of the modem which provides an output digital stream to the error detector unit in the test message generator. The error detector unit compares the transmitted information (via a delay line) with that from the receiver and provides a visual readout of the received signal errors.

Provision for inserting wideband noise before or after limiting or at both points simultaneously is included.

The differential-encoded phase-shift-keying modem unit was designed on Army Contract DAAB07-67-C-0495 and was modified to operate over the 60- to 80-MHz frequency range using an external signal generator injection so error-rate measurements could be made in any slot selected within that frequency range.

During the test program, error-rate measurements were made with the modem operating at 288 kilobits and 144 kilobits. Operation at 144 kilobits was achieved through modification to three removable modules. Typical error rate. E/N_o (energy-per-bit to noise-spectral-density ratio) curves for the two data rates are shown in Fig. 5. No attempt was made for complete optimization of the modem at the 144 kilobit rate.

Since economic useage of the transmission bandwidth does not permit the use of third-order interference-free channels, selection of channel spacing arrangements must be based on accepting some degree of IM degradation, but retaining a useable channel bit error rate. Spacing arrangements were, therefore, selected to minimize the third-and fifth-order products while allowing the

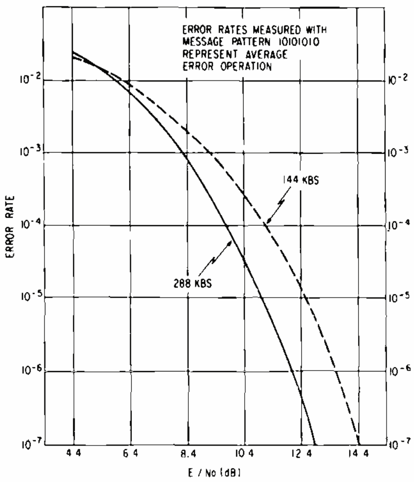

Fig. 5—Error rate *vs.* E/N_o.

maintenance of a channel bit error rate of 1×10^{-5} over a power level variation of -3 dB relative to the normal channel signal level without the influence of noise. With this criterion, the ultimate objective of the test program was to find a useable arrangement which provides fourteen active channels from a 60-channel system.

Several tests were conducted to supply a data baseline for comparing subsequent data taken on the program. Two series of contiguous channel configurations, six and fifteen channels, were tested to determine worst-case operation for the 100% occupancy case, as well as providing data for comparison to Shaft's[1] predictions in the six-contiguous-channel case. Tests were conducted for comparison with the theoretical predictions of two of Babcock's third-order IM-free arrangement and several of Shaft's six access configurations of twelve and fifteen channel capacity cases. The odd (even) spacing arrangements were tested using both single-channel guard bands, as well as a two-channel guard-band spacing.

Several arithmetical progression spacings were used, and at the conclusion of the 288- to 144-kilobit series, two sets of two-group arrangements were tested in an effort to obtain a higher occupancy. The final series of tests, the multiple-bit-rate cases, were conducted to determine the effects of different channel bandwidths and power upon the error rate.

Performance of spacing arrangements

To consolidate the measured data for easy use, the spacing arrangements were grouped into the following categories:

1) Babcock and Shaft
2) Uniform-spaced arrangements
3) Non-uniform spacing—arithmetical progression
4) Grouping arrangements
5) Multiple-bit-rate spacings

Babcock and Shaft spacing

To simplify the analysis of the Babcock (1, 2, 5, 10, 12) and Shaft spacing configurations, Table IV was constructed to enable quick comparisons between theoretical and measured results. This table presents comparisons for the equal-power and unequal-power cases based upon achieving error rates of 1×10^{-5}

The Babcock configuration provides the better spacing arrangement (as would be expected), however, it is limited to an unequal-power variation of -3 dB in channel 2 and -4 to -5 dB in channel

Table IV—Comparison of Babcock and Shaft's channel-spacing arrangements.

Spacing	*% Occupancy*	*Error rate vs. I+IM equal power* 1×10^{-5}	*Error rate vs. I+IM unequal power* 1×10^{-5}	*Agrees with Shaft**
Babcock 1,2,5,10,12	41.5	Yes	Thru −2.4 dBr	Yes
Shaft's 6 of 12				
1,2,5,8,10,12	50	Yes	−2 dBr	Yes
1,2,4,5,10,12	50	Yes	−1 dBr	Yes
1,2,5,9,10,12	50	Yes	−1 dBr	Yes
1,4,8,9,10,12	50	No	No	Yes
1,2,5,7,10,12	50	Yes	−1 dBr	Yes
3,4,5,9,11,12	50	No	No	Yes
1,2,4,8,9,12	50	Yes	−1 dBr	—
Shaft's 6 of 15				
1,2,5,10,12,15	40	Yes	−2 dBr	Yes
1,2,5,11,13,15	40	Yes	−1 dBr	Yes
3,4,5,8,11,15	40	No	No	Yes
2,7,9,12,14,15	40	Yes	No	Yes
1,2,4,7,14,15	40	Yes	−2 dBr	—

Notes

*When sidelobe interference is considered and its contribution removed, the test results agree with Shaft's predictions. Any adjacent channel arrangement of two or more channels results in higher IM and sidelobe interference and, as a consequence, more stringent power control.

1 for $1x10^{-5}$ error rate. This error-rate degradation is caused by sidelobe interference between two adjacent channels as previously discussed.

Shaft predicted the following four arrangements to provide the better error rate performance:

a) 6 of 12; 1, 4, 8, 9, 10, 12
b) 6 of 12; 1, 2, 5, 8, 10, 12
c) 6 of 15; 1, 2, 5, 10, 12, 15
d) 6 of 15; 1, 2, 5, 11, 13, 15

Selections b) and c) do indeed provide the better bit-error-rate performance; however, they are limited in unequal power operation to −2 dBr because of sidelobe interference while selection d) is usable through −1 dBr. Spacing a) is unusable even at the equal-power level because of the adjacent channels, 8, 9, 10, 12. In general, when the effects of sidelobe interference are considered, the measured data agree with Shaft's predictions.

Uniform-spaced arrangements

The even-spaced arrangements tested consisted of the following:

Contiguous
6 of 6; 1, 2, 3, 4, 5, 6
15 of 15; 1, 2, 3, 4 . . . 15

One-channel guardband
6 of 12; 1, 3, 5, . . . 11
8 of 16; 1, 3, 5, . . . 15
15 of 30; 1, 3, 5, . . . 30

Two-channel guardband
6 of 16; 1, 4, 7, 10, 13, 16

The test results of these configurations are summarized in Table V.

Table V—Comparison of uniform spacing arrangements.

Spacing	*% Occupancy*	*Error rate vs. I+IM equal power* 1×10^{-5}	*Error rate vs. I+IM unequal power* 1×10^{-5}	*Comments*
Contiguous				
6 of 6; 1,2,3,4,5,6	100	No	No	Sidelobe interference predominates.
15 of 15; 1,2,3. . . 15	100	No	No	
*One-channel guardband**				
6 of 12; 1,3,5. . . 11	50	Yes	No	Unequal operation limited by *IM* of $A+B-C$
8 of 16; 1,3,5. . .16	50	Marginal	No	
15 of 30; 1,3,5. . .30	50	No	No	
Two-channel guardband				
6 of 16; 1,4,7. . .16	37.5	Yes	−1 dBr	Unequal operation limited by *IM* of form $A+B-C$

*These configurations are identical to spacing arrangements using even-number channels and represent a 50% occupancy factor.

The contiguous-channel cases are limited in operation due to the high level of spectral sidelobe energy from the densely packed channels. The single-channel guardband arrangements offset the sidelobe interference effects, but the *IM* distribution ($A+B-C$) falls into the active channels since the spacing is still uniform. The data indicates that the six-of-twelve case is the only possible useable arrangement and that, only at equal power.

Another form of an even-spacing arrangement, the two channel guardband, was selected to try to achieve a better average error rate than that of the single channel guardband arrangement. Again, an even-spacing arrangement is being employed; thus the $A+B-C$ intermodulation falls back into the active channels.

The two-channel guardband configuration is usable from equal power through −1 dBr, unequal power, thereby making it the most desirable of the equal spacing arrangements.

Thus, uniform spaced arrangements are limited to less than 37.5%, occupancy (two-channel guardband) for obtaining a 1×10^{-5} error rate and some allowable power variation (1 dB). Better arrangements may be selected from Shaft's spacings which yield the same percent occupancy, the same number of active channels, and allowable power variations of −2 dB.

Non-uniform spacing—arithmetical progression

Four arithmetical-progression spacing arrangements were tested as detailed below and the results tabulated in Table VI:

a) 6 of 16; 1, 2, 4, 7, 11, 16
b) 8 of 29; 1, 2, 4, 7, 11, 16, 22, 29
c) 8 of 36; 1, 3, 6, 10, 15, 21, 28, 36
d) 12 of 78; 1, 3, 6, 10, 15, 21, 28, 36, 45, 55, 66, 78

The arithmetical progressions were selected to offset the $A+B-C$ products resulting from uniform-spacing arrangements. The first two configurations have adjacent channels (1, 2) and as would be expected, these channels limit operation in both cases. In the 6-of-16 case, channel 2 restricts unequal power operation through −1 dBr with all other channels usable through −3 dBr.

In arrangement b), channels 1 and 2 remain at the highest error rates with the error rate in channel 4 higher than in the 6-of-16 case. Since the adjacent channel interference limits the allowable power-level variation of the first two cases, arrangement c) was tried to obtain better error rates in the first two active channels.

The 1, 3, 6, 10, 15, 21, 28, 36 arrangement provides usable error rates through a −3 dBr power variation with channels 1, 3, and 6 limiting the allowable power variation. This arrangement gives a 22% occupancy factor and eliminates the need for any elaborate power control on the accesses.

The fourth arithmetical progression was tried to achieve more accesses, some 12 of 78 which yields a 15.4% occupancy factor and provides error rates approximately the same as for the 36-channel-capacity system.

Grouping arrangements

To achieve a higher percent occupancy and maintain a $1x10^{-5}$ error rate, two grouping arrangements were selected to be tested. The method of implementing

Table VI—Comparison of arithmetical-progression spacing.

Spacing	*% Occupancy*	*Error rate vs. I+IM equal power* 1×10^{-5}	*Error rate vs. I+IM unequal power* $1x10^{-5}$	*Comments*
Spacing				
a) 1,2,4,7,11,16	37.5	Yes	−1	Chan. 2 limits all others −3 dBr Chan. 2, $5x10^{-5}$
b) 1,2,4. . .29	27.6	Marginal	None	
c) 1,3,6. . .36	22	Yes	−3	
d) 1,3,6. . .78	15.4	Yes	−3	

the grouping arrangements was to divide the system bandwidth into two equal segments and then place individual channel-spacing configurations in each group.

In the first arrangement, the two-group arithmetical arrangement used was: 1, 3, 6, 10, 15, 21, 28, 33, 40, 46, 51, 55, 58, 60. This provides two equal-spaced groups from each end of the band and provides a guardband between the two groups of 4 channels.

The advantage of having a guardband between the two groups is that the intermodulation products tend to be more concentrated in the center of the operating bandwidth. This particular grouping arrangement yields excellent error-rate operation from equal power to −3 dBr with channel 3 restricting operation. With corrected error rates (i.e., assuming error rate operation of 144 kilobits equal to 288 kilobits) unequal power operation through −4 dBr can be achieved in all channels except channel 3.

The second group arrangement consisted of channels 1, 3, 11, 17, 22, 26, 29, 31, 34, 41, 49, 54, 58, 60. The advantage of using this arrangement is that each group is interference-free in itself. The channel differences of group one being 2, 8, 6, 5, 4, 3 and those of group two being 3, 7, 8, 5, 4, 2.

This case provides excellent error-rate operation through −2 dBr unequal power operation with channel 29 being the restricting channel. Channel 31 allows operation through −3 dBr. However, all other channels permit unequal power operation of −3.5 dBr for the 1×10^{-5} error rate.

Either of the two grouping arrangements can be used since usable error rate performance is obtained through a −3 dB relative power variation. The arithmetical arrangement gives slightly better performance on an average channel basis. In assignment of channel spacings, the grouping technique appears to be the best approach since the occupancy factor is higher for a given bandwidth compared to either the basic third-order *IM*-free approach (Difference Theory Technique) or the basic arithmetical progression approach.

Multiple-bit-rate spacings

Tests were conducted to determine the effects of multiple-data-rate signals on the hard-limiter operation.

The two-group arrangement of arithmetical progressions (14 of 60 channels) used in the previously described series of tests were used for the multiple-data-rate tests. Three data rates (72, 144, and 288 kilobits) were used with error-rate measurements conducted in the 144- and 228-kilobit accesses.

Four different arrangements were tested:

a) 288 kilobits; channels 10, 15, 21, 28, 33, 40, 46
144 kilobits; channels 1, 3, 6, 51, 55, 58, 60

b) 144 kilobits; channels 1, 3, 6, 51, 55, 58, 60
72 kilobits; channels 10, 15, 21, 28, 33, 40, 46

c) 72 kilobits; channels 1, 3, 6, 51, 55, 58, 60
288 kilobits; channels 10, 15, 21, 28, 33, 40, 46

d) 288 kilobits; channels 10, 15, 21, 28, 33, 40, 46
144 kilobits; channels 1, 6, 51, 55
72 kilobits; channels 3, 58, 60

As can be noted, the higher data-rate channels were placed in the center of

Table VII—Multiple-data-rate comparisons.

Signal case (kilobits)	*No. of Chan.*	*Number of Effective 144-kb Chan.*	*% Occupancy*	*Effective bandwidth factor (dBr) From % Occup.*	*Equal power operation* 1×10^{-5}	*Unequal power operation* 1×10^{-5}
1) 144 (all-equal case)	14	14	23.3	0	Yes	−4 dBr all channels except #3, −3 dBr
a) 288 144	7 7	21	35	−1.8	Yes	2 dBr
b) 144 72	7 7	10.5	17.5	+1.2	Yes	−4 dBr all channels
c) 72 288	7 7	17.5	29.2	−1.0	Yes	−3.5 dBr
d) 288 144 72	7 4 3	19.5	32.5	−1.4	Yes	−3 dBr for 144 kilobits −3.5 dBr for 288 kilobits

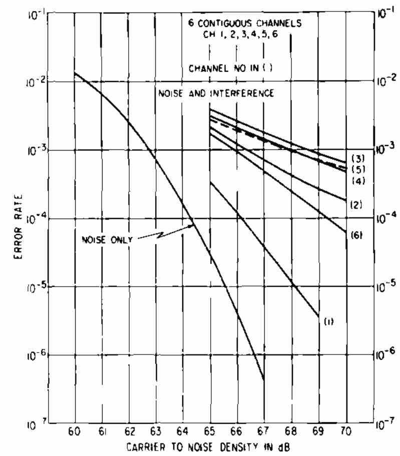

Fig. 6—Error rate *vs.* $L+N_o$ without limiter.

the spectrum where wider spacing was available to avoid adjacent-channel sidelobe interference to the degree possible. Channels 1, 3, and 58, 60 are the closest spaced arrangements, wherein a single channel guardband is employed. Analysis of these four tests is based upon the 14-of-60-channel equal-data-rate case and is summarized in Table VII.

It is to be noted from this data that the variation of the bit rates and the corresponding increase and decrease in power and bandwidth clearly demonstrates that: 1) *IM* can be increased or decreased by corresponding increase and decrease in bandwidth; 2) The energy/Hertz constancy factor holds in practical applications.

Noise considerations

Throughout the test series, error-rate measurements were conducted under noise-loaded conditions to simulate the actual communications-link environment. Of major interest is how the intermodulation *(IM)*, sidelobe interference *(I)*, and gaussian noise (N_o) combine to affect the channel error rates. The six contiguous-channel-case with 576-kHz channel spacings was selected for determining how the three contributors affect the channel error rates.

Two sets of data were taken—with and without limiting. Without limiting, the effects of the sidelobe interference on the error rate can be determined; while, with the limiter, the combined effects of *IM* and *I* can be determined. Two curves relating error rate to (N_o+I) and (N_o+I+IM) were constructed and are shown in Figs. 6 and 7. These curves show that the interference and

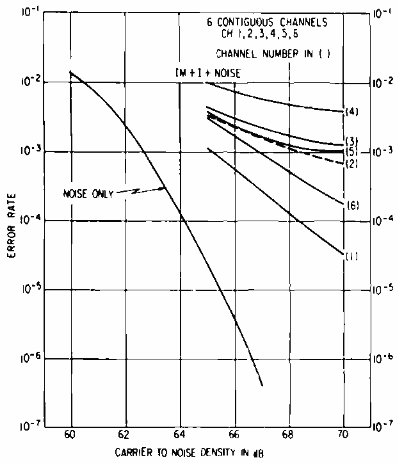

Fig. 7—Error rate *vs.* *IM+I+N*.

IM tend to produce a flaring-up or flattening-out effect on channels with high intermodulation and sidelobe interference.

Analysis with and without limiting indicates that the distributions of the three factors, *I*, *IM*, and gaussian noise do not combine on an RMS basis.

The sidelobe interference contributions appear to add together on a peak basis while the *IM* products tend toward a gaussian distribution. Therefore, where sidelobe energy(s) predominate, they must be considered as a peak interference.

Conclusions

Since the intermodulation products generated when multiple signals are present in a hard limiter depend upon the number, type, spacing of the signals, the primary concern of the test program was to find channel spacing configuration(s) which provide usable error rates, less than 1×10^{-5}, with unequal power capability of -3 dB relative to the equal power case. The conclusions given here are based upon IM and spectral sidelobe interference without the influence of gaussian noise. [To include the effects of gaussian noise, an equivalent E/N_0 for the 1×10^{-5} error rate due to *IM* can be determined for the particular modem used and then a system *C/KT* determined to maintain that error rate assuming the noise and *IM* contribution add on an RMS basis.]

Analysis of the data obtained for the single-grouping arrangements allow formation of rules concerning placement of active channels. A summary of these rules are contained in the following paragraphs. They are applicable to placement of active channels for PSK signals when six or more active accesses are used for the equal-power, equal-data-rate, and equal-bandwidth case.

1) Any contiguous channel case, 100% occupancy, is unusable.
2) Use of adjacent channel assignments should be avoided unless some form of power control is used. For a large number of accesses, unusable error rates occur at 0 to -1 dBr power levels
3) Uniform spacing arrangements should not be used:
   a) One-channel-guardband cases are limited to 6 of 12 channels with absolute power control required in all channels (3, 5, 7, 9, 11) except channel 1.
   b) Two-channel-guardband case is limited to 6 of 16 channels which permits operation through unequal power of -1 dBr.
   c) Any higher-channel guardbands result in inefficient use of bandwidth and other (more efficient) non-uniform spacing arrangements should be used.
4) Non-Uniform Spacing Arrangements should be used with adjacent channels *prohibited:*
   a) *Babcock and Shaft*—Babcock and Shaft's spacing arrangements are restricted in unequal power operation since adjacent channels (1, 2) are used since their analysis does not consider the sidelobe interference of PSK signals.
   b) *Arithmetical progressions*—When a higher number of active accesses, other than six is desired, the non-adjacent channel arithmetical progression should be used. This configuration permits unequal operation through -3 dBr and gives the best average-error-rate performance for a large number of accesses within a given bandwidth.
   c) *Interference-free arrangements*—Interference-free arrangements which prohibit adjacent channel placement provide the best error rate performance, but are limited in the number of active accesses. For a small number of accesses less than six) the difference sequence technique is recommended.
5) Grouping arrangements:
   a) Higher bandwidth occupancy over that of the single grouping arrangements can be obtained with usable error rate and unequal power operation by using multiple grouping arrangements.
   b) The grouping arrangement of two, employing arithmetical progressions (1, 3, 6, 10, 15, 21, 28, 33, 40, 46, 51, 55, 58, 60; 14 of 60), yields the best average error rate and unequal power operation (-3 dBr in channel 3, -4 dBr in all other channels) of the configurations tested.
   c) The grouping arrangement of two, employing third order *IM*-free spacing (1, 3, 11, 17, 22, 26, 29, 31, 34, 41, 49, 54, 58, 60; 14 of 60), permits operation of -2 dBr in channel 29, -3 dBr in channel 31, and -3.5 dBr in all others.
6) *Multiple-data-rate Arrangements*—Assignments of multiple data rate channels required consideration of sidelobe distributions. With intelligent placement of low and high data rate channels within an acceptable spacing arrangement, no appreciable degradation should be noted.
7) *General spectral sidelobe interference considerations*—Depending upon the number of signals and their spacing arrangement, sidelobe energy from PSK signals are inherent interference when using a hard-limiter repeater, and as such, effect the error rates of the active channels.

As such, the following conclusions and rules are formulated:

a) Adjacent channel spacing should be avoided.

b) If adjacent channel spacing is used, some form of power control is required in the adjacent channels.

c) A minimum of one channel guardband should be used for channel spacings where equal, power, data rate, and bandwidths are employed.

d) Where multiple data rate signals having a constant power bandwidth ratio are employed, channel spacings must be assigned with respect to sidelobe interference. Where data-rate ratios of the accesses are greater than 2 to 1, guardbands greater than one channel bandwidth must be used.

e) In any channel spacing arrangement with equal or unequal data rates, the sidelobe interference places a lower bound on the error rate performance.

Acknowledgments

The authors acknowledge the contribution of G. Cicero and R. Maddox who patiently conducted the test program and accumulated the data which form the basis of the conclusions of this paper. In addition the authors express their thanks to Dr. T. T. N. Bucher for his suggestions concerning the manuscript.

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Computer solution of general sets of simultaneous nonlinear equations

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A short Fortran program for an interactive time-sharing system solves sets of simultaneous linear or nonlinear equations using the Newton-Raphson method.

ENGINEERING DESIGN PROBLEMS often include sets of simultaneous non-linear equations. These are usually solved (or avoided) as they arise with specific approximations. This paper describes a relatively short Fortran program which solves general sets of simultaneous linear or nonlinear equations. The user must only supply the equations as Fortran statements along with an initial guess at the solution; the program determines the variables within a pre-established tolerance.

Linearization: the Newton-Raphson method

The basis of the program is the well-studied Newton-Raphson method,[1] where the nonlinear equations are linearized about a point near the solution. By successive iterations this point is converged to the exact solution. The method is described here for a three-equation set. Extension to higher (or lower) order should be apparent.

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received the BSEE from the University of Florida in 1959 and the MSEE from New York University in 1961. He joined Bell Telephone Laboratories at Murray Hill, New Jersey after graduation. Two years later he joined the Martin Company, Orlando, Florida where he worked in various areas of computer magnetics. Mr. Singleton joined RCA in 1964 as a member of the Memory Engineering group. In 1970 he was promoted to his present position at the Palm Beach Gardens plant. This is his sixth published technical paper. He holds one patent.

Assume that we are given a set of three equations in three unknowns:

$$A(x,y,z)=0 \qquad (1)$$
$$B(x,y,z)=0$$
$$C(x,y,z)=0$$

Assume that the point (x_i, y_i, z_i) is near the solution. If the equations are expanded into a Taylor series about this point and the higher-ordered terms are neglected, then

$$A(x,y,z) \cong A_i + \Delta x \frac{\partial A_i}{\partial x} + \Delta y \frac{\partial A_i}{\partial y} + \Delta z \frac{\partial A_i}{\partial z}$$

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$$B(x,y,z) \cong B_i + \Delta x \frac{\partial B_i}{\partial x} + \Delta y \frac{\partial B_i}{\partial y} + \Delta z \frac{\partial B_i}{\partial z}$$

$$C(x,y,z) \cong C_i + \Delta x \frac{\partial C_i}{\partial x} + \Delta y \frac{\partial C_i}{\partial y} + \Delta z \frac{\partial C_i}{\partial z}$$

where

$$\Delta x = x - x_i \qquad (2)$$
$$\Delta y = y - y_i$$
$$\Delta z = z - z_i$$

and

$$A_i = A(x_i, y_i, z_i)$$
$$B_i = B(x_i, y_i, z_i)$$
$$C_i = C(x_i, y_i, z_i)$$

The exact solution of this set of equations occurs when

$$-A_i = \Delta x \frac{\partial A_i}{\partial x} + \Delta y \frac{\partial A_i}{\partial y} + \Delta z \frac{\partial A_i}{\partial z} \qquad (3)$$

$$-B_i = \Delta x \frac{\partial B_i}{\partial x} + \Delta y \frac{\partial B_i}{\partial y} + \Delta z \frac{\partial B}{\partial z}$$

$$-C_i = \Delta x \frac{\partial C_i}{\partial x} + \Delta y \frac{\partial C_i}{\partial y} + \Delta z \frac{\partial C}{\partial z}$$

The above set of equations may be solved using linear simultaneous techniques for Δx, Δy, and Δz. With Δx, Δy, Δz known, x, y, z may be found from Eq. 2. These values for x, y, z are a closer approximation of the solution; the solution of Eq. 3 may then be repeated using these values as a new starting approximation for x_i, y_i, z_i. This iteration may be repeated as many times as required to obtain the desired degree of accuracy.

Partial derivatives and convergence

In order to use the Newton-Raphson method for solution of non-linear simultaneous equations, all partial derivatives must be known. For a specific set of equations these may be found explicitly,[2] but the partial derivatives must be found within the program if general equations are to be solved. These derivatives may be found by parabolic numerical differentiation[3] where

$$\partial A_i/\partial x \cong \left[A(x_i+\Delta x) - A(x_i - \Delta x)\right]/2\Delta x, \qquad (4)$$

and similarly for other derivatives.

It is important to make the Δx in Eq. 4, equal to the Δx of the Newton-Raphson linearization, Eq. 3. This forces the differentiation and the Newton-Raphson iterations to converge simultaneously.

The partial derivatives are required to make the first Newton-Raphson iteration, which in turn produces the step size for the next differentiation. The initial step size is arbitrarily chosen to be a percentage of the variable in question.

Determination of completed solution

The method of solution of nonlinear simultaneous equations outlined above can proceed in several directions. When the initial guess is too far from the final solution and severe nonlinearities exist, the iteration may diverge. The program detects this occurrence as follows. At each iteration, the *error distance*, E_i, from the actual solution of Eq. 3 is computed as

$$E_i=(A_i^2+B_i^2+C_i^2)^{1/2} \qquad (5)$$

This distance is compared with the error distance of the prior iteration, and if the distance has not diminished, the program assumes that the iteration is diverging and requests a new set of initial conditions.

A second possibility is that during the solution of the linearized equations (Eq. 3) the Jacobian may approach zero. This may or may not indicate a bad solution. When the computer detects this occurrence, it informs the user and causes the values of the variables and their last step sizes to be displayed. The operator can determine whether or not satisfactory convergence has been reached.

On the more optimistic side, the solution may converge rapidly. If the error distance in Eq. 5 falls below a predetermined level, an exact solution is assumed to have been reached.

Frequently the variables can converge to within engineering tolerances before the error distance of the solution reaches zero. If all variables have been found within a given percentage, the program eliminates further iterations to minimize running time.

Finally, slow convergence may make the number of iterations required to reach a satisfactory solution excessive. The program keeps count of the iterations and when a preset maximum is reached, the fact is noted and resultant variables and last step sizes are displayed.

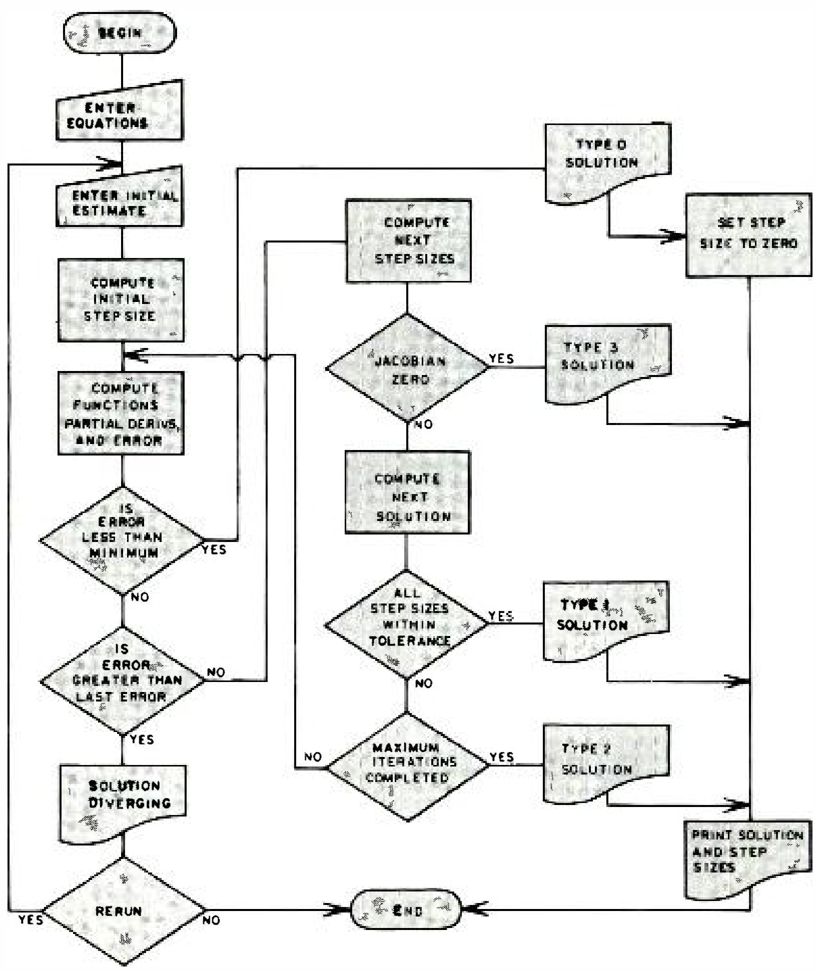

Fig. 1—Program flow.

```
HØW MANY EQUATIØNS?
N=3
EQUATIØN(1)=X(1)**2+X(2)**2+X(3)**2-1.
EQUATIØN(2)=X(1)-X(2)**2
EQUATIØN(3)=X(1)+X(2)+X(3)-1.

 ENTER ESTIMATED SØLUTIØN VECTØR
X(1)= 1
X(2)= 1
X(3)= -1
 TYPE 1 SØLUTIØN
X(1)=      0.5698 +ØR-     0.0000
X(2)=      0.7549 +ØR-     0.0000
X(3)=     -0.3247 +ØR-     0.0000
```

Fig. 3—Interactive program run.

Program

Fig. 1 shows the flowchart of a program which implements the techniques described above. The flowchart is generalized so that coding may be done in any desired language, and tolerances, error values, and maximum iterations may be varied. The solution types are:

Type 0: convergence to within assigned error.
Type 1: all variables found within engineering tolerance.
Type 2: maximum number of iterations completed.
Type 3: Jacobian zero in linearization.

Fig. 2 shows the Fortran program which was written for interactive time-sharing on an RCA Spectra 70/45. Comments have been inserted to make the listing self-explanatory.

In this program, the numerical differentiation is explicitly coded, and the linearized equations (Eq. 3) are solved by a standard subroutine, SIMQ.[4] The equations to be solved are entered as a subroutine. Tolerances are selected as follows: initial step size, 0.1 percent of the given variable; error distance for satisfactory solution, 1×10^{-6}; acceptable engineering tolerance on variables, 0.1 percent; maximum allowable number of iterations, 30.

In this specific program, the number of unknowns is limited to five. This limitation is arbitrary; the number of unknowns can readily be extended at the expense of run time.

A sample run of the above program is shown in Fig. 3 for the set of equations

$$0=x_1^2+x_2^2+x_3^2-1$$
$$0=x_1-x_2^2$$
$$0=x_1+x_2+x_3-1$$

where the initial guess was $(1,1,-1)$.

This was an interactive session; user inputs are underlined. The total processor time used, including program compilation, was 5.4 seconds on an RCA Spectra 70/45. The solution converged in five iterations.

Conclusion

The program outlined above is short and straightforward and requires very little computer time. At the same time it is general enough to solve the wide variety of simultaneous nonlinear equations that might occur in engineering design problems.

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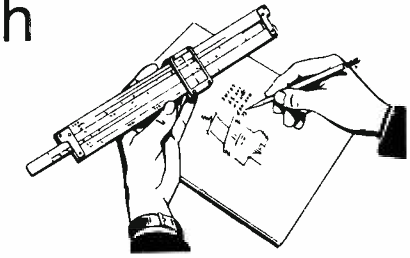
```
      REAL F(5),X(5),P(25),G(5),H(5),DX(5),LE
C ENTER NUMBER ØF EQUATIØNS,N
      INCLUDE37(A1)
C ENTER INITIAL ESTIMATE
5     PRINT" ENTER ESTIMATED SØLUTIØN VECTØR"
      JCØUNT=0
      LE=1.E70
      DØ20 J=1,N
      PRINT10,J
10    FØRMAT(' X(',I1,')= ',N)
      READ11,X(J)
11    FØRMAT(F10.4)
C CØMPUTE INITIAL STEP SIZES
      DX(J)=ABS(.1*X(J))
20    CØNTINUE
22    CALLEQNS(F,X)
      M=1
      DØ30 J=1,N
      X(J)=X(J)+DX(J)
      CALLEQNS(G,X)
      X(J)=X(J)-(2*DX(J))
      CALLEQNS(H,X)
      X(J)=X(J)+DX(J)
      DØ25 I=1,N
      IF(DX(J).LT.1.E-10)GØTØ25
      P(M)=(G(I)-H(I))/(2*DX(J))
25    M=M+1
30    CØNTINUE
C CØMPUTE ERRØR DISTANCE,E
      E=0.
      DØ40 K=1,N
      F(K)=-F(K)
      E=E+F(K)**2
40    CØNTINUE
C CHECK FØR CØNVERGED SØLUTIØN
      IF(E.LT.1.E-12)GØTØ60
C CHECK FØR DIVERGENCE
      IF(E.GT.LE)GØTØ56
      LE=E
C CØMPUTE NEXT STEP SIZES
C P ARE PARTIAL DERIVATIVES
C F ARE FUNCTIØNS ØN INPUT AND STEP SIZES ØN RETURN
      CALL SIMQ(P,F,N,KS)
C CHECK FØR ZERØ JACØBIAN
      IF(KS)42,42,41
41    PRINT" TYPE 3 SØLUTIØN"
      GØTØ46
42    ICØUNT=0
      DØ44 I=1,N
      X(I)=X(I)+F(I)
      DX(I)=ABS(F(I))
C CHECK FØR STEP SIZE WITHIN ENGINEERING TØLERANCE
      IF(DX(I).LT.1.E-10)GØTØ43
      IF(DX(I).LE.ABS(.001*X(I)))GØTØ43
      GØTØ44
43    ICØUNT=ICØUNT+1
44    CØNTINUE
      IF(ICØUNT.EQ.N)GØTØ45
      JCØUNT=JCØUNT+1
C CHECK FØR MAXIMUM ITERATIØNS
      IF(JCØUNT.EQ.30)PRINT" TYPE 2 SØLUTIØN"
      IF(JCØUNT.EQ.30)GØTØ46
      GØTØ22
45    PRINT" TYPE 1 SØLUTIØN"
C PRINT SØLUTIØN AND STEP SIZES
46    DØ50 J=1,N
      PRINT47 J,X(J),DX(J)
47    FØRMAT(' X(',I1,')= ',F10.4,' +ØR- ',F10.4)
50    CØNTINUE
55    PAUSE
56    PRINT57
57    FØRMAT(' SØLUTIØN DIVERGING. RERUN WITH NEW
      ESTIMATE? ',N)
      READ58,ANS
58    FØRMAT(A1)
      IF(ANS.EQ.'Y')GØTØ5
      GØTØ55
60    PRINT" TYPE 0 SØLUTIØN"
      DØ61 I=1,N
      DX(I)=0.
61    CØNTINUE
      GØTØ46
C ENTER EQUATIØNS AS SUBRØUTINE EQNS(F,X)
      INCLUDE37(A2)
      SUBRØUTINE SIMQ(A,B,N,KS)
      DIMENSIØN A(25),B(25)
      TØL=0.0
      KS=0
      JJ=-N
      DØ65 J=1,N
      JY=J+1
      JJ=JJ+N+1
      BIGA=0
      IT=JJ-J
      DØ30 I=J,N
      IJ=IT+I
      IF(ABS(BIGA)-ABS(A(IJ))) 20,30,30
20    BIGA=A(IJ)
      IMAX=I
30    CØNTINUE
      IF(ABS(BIGA)-TØL) 35,35,40
35    KS=1
      RETURN
40    I1=J+N*(J-2)
      IT=IMAX-J
      DØ50 K=J,N
      I1=I1+N
      I2=I1+IT
      SAVE=A(I1)
      A(I1)=A(I2)
      A(I2)=SAVE
50    A(I1)=A(I1)/BIGA
      SAVE=B(IMAX)
      B(IMAX)=B(J)
      B(J)=SAVE/BIGA
      IF(J-N) 55,70,55
55    IQS=N*(J-1)
      DØ65 IX=JY,N
      IXJ=IQS+IX
      IT=J-IX
      DØ60 JX=JY,N
      IXJX=N*(JX-1)+IX
      JJX=IXJX+IT
60    A(IXJX)=A(IXJX)-(A(IXJ9*A(JJX))
65    B(IX)=B(IX)-(B(J)*A(IXJ))
70    NY=N-1
      IT=N*N
      DØ80 J=1,NY
      IA=IT-J
      IB=N-J
      IC=N
      DØ80 K=1,J
      B(IB)=B(IB)-A(IA)*B(IC)
      IA=IA-N
80    IC=IC-1
      RETURN
      END
```

Fig. 2—The NONLIN program as written for the BTSS system consists of two programs. The program INPUT prepares the input equations into a subroutine on a tape file (TAPE 37) and the program RUN calls the subroutine (using the INCLUDE command) and solves the equations.

Engineering and Research Notes



Brief Technical Papers
of Current Interest

Frequency comparator

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The frequency comparison circuit shown in Fig. 1 is especially useful for speed-control purposes. The input at *A* may be pulses derived from a piece of rotating machinery such as a magnetic drum and the input at *B* may be pulses produced by a frequency standard. The direct voltage output signal V_{OUT} has a value indicative of the difference in frequency between f_A and f_B.

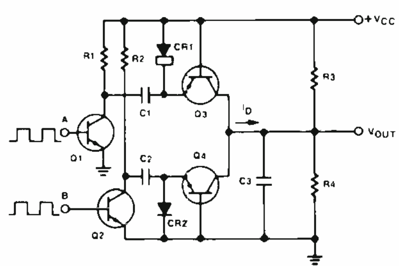

Fig. 1—Frequency comparator.

In the operation of the circuit, during the positive pulse at *A*, capacitor C1 charges through the emitter-to-collector path of transistor Q1 and diode CR1. During the negative-going part of the wave at *A*, capacitor C1 discharges through resistor R1 and the emitter-to-collector path of transistor Q3, charging capacitor C3 in the process. During the positive pulse at *B*, capacitor C2 discharges through the emitter-to-collector path of transistor Q4, capacitor C3, and the emitter-to-collector path of transistor Q2. During the negative-going portion of the wave at B, capacitor C2 charges through the path including resistor R2 and diode CR2.

A characteristic of the circuit of Fig. 1 which is of special importance in speed-control applications is that the transfer function, shown in Figure 2, is linear. In other words, between the clamping limits *O* and V_{CC}, the current I_D is directly proportional to the difference in frequency between the waves at *A* and *B*. The

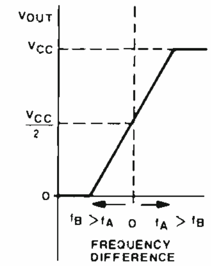

Fig. 2—Transfer characteristic.

linear transfer characteristic obtained in the present circuit is due to the charge control properties of capacitors C1 and C2.

The slope of the transfer characteristic is determined by the current I_D (the difference in currents passing through transistors Q3 and Q4) and the effective resistance of R3 paralleled with R4. The slope of the transfer characteristic may be altered by changing the values of capacitors C1 and C2 and/or resistors R3 and R4. Changing the ratio between resistors R3 and R4 will change the value of the output voltage for $f_B = f_A$. Fig. 2 illustrates the case in which R3 = R4.

Frequencies of other than unity ratio may be compared by appropriate scaling of capacitors C1 and C2. Zero error ($I_D = 0$) will be indicated whenever $f_A C1 = f_B C2$.

Changing the supply voltage levels will change the clamping levels from V_{CC} and ground to other values. The signals at *A* and *B* may be pulses, as shown, or may be waves of sinusoidal or other shape.

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New technique for measuring thermal resistance of integrated circuits

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Integrated-circuits must be properly cooled; electrical parameters degrade and failure rates rise as the semiconductor junction temperature rises. A fundamental parameter to be considered is the thermal resistance from junction to ambient of the IC as mounted in the system. This parameter, Θ_{JX}, can be either calculated using many assumptions; or it can be measured as in this study.

Thermal resistance equation and electrical analog

Thermal resistance of the mounted IC is related[1] to the junction temperature by:

$$T_J = \Theta_{JX} P_D + T_A \quad (1)$$

where T_J is junction temperature (°C); Θ_{JX} is thermal resistance (°C/watt); P_D is power dissipation (watts); and T_A is ambient temperature (°C).

An electrical analog to the thermal heat flow problem is shown in Fig. 1.

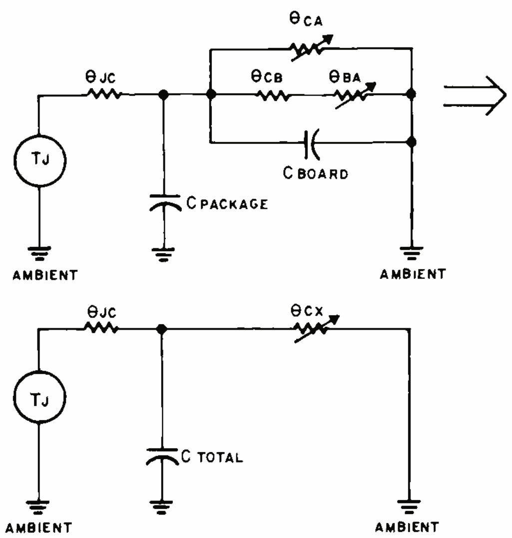

Fig. 1—Electrical analog to thermal heat flow. Θ_{CB} is thermal resistance from case to board; Θ_{JC} is thermal resistance from junction to case; Θ_{BA} is thermal resistance from board to ambient; and Θ_{CA} is thermal resistance from case to ambient.

From Fig. 1, the thermal resistance is

$$\Theta_{JX} = \Theta_{JC} + \Theta_{CX} \quad (2)$$

and the total thermal capacitance is

$$C_{TOTAL} = C_{PACKAGE} + C_{BOARD}$$

The thermal capacitance of a solid is the specific heat (at constant pressure) multiplied by the mass.

The simplified circuit (Fig. 1) reduces to one fixed resistor Θ_{JC} and one variable resistor Θ_{CX} with the total heat capacity connected between them. The variable resistor is a result of variations in coolant specific heat, coolant thermal conductivity, coolant rate of flow, and external heat-sink connections to the board. Radiation is neglected as a major heat-transfer mechanism at the temperatures involved.

Generally, measurement involves calibration of a temperature-sensitive parameter (such as a diode forward voltage drop) which is then used to monitor junction temperature. Special test chips are used; or power is dissipated in a diode in the circuit, power is switched off, and the forward voltage is then measured. Inaccuracy results from making measurements as the IC is cooling.

The measurement technique described in this note depends upon finding a temperature-sensitive electrical parameter which is dependent only on junction temperature. The IC's are soldered onto a circuit board and placed in an oven. A temperature-sensitive voltage or current is plotted *vs.* power dissipation ($V_{CC} \times I_{CC}$). The oven temperature is then changed, and the measurements repeated. A family of curves, each at a constant ambient (oven) temperature, is obtained.

If the temperature-sensitive voltage is a single-valued function of temperature only:

a) $V_1 = f(T_{J1})$, but $T_{J1} = \Theta_{JX} P_{D1} = T_{A1}$
b) $V_2 = f(T_{J2})$ but $T_{J2} = \Theta_{JX} P_{D2} + T_{A2}$

and if $V_1 = V_2$, then $T_{J1} = T_{J2}$, and subtracting b) from a) gives

$$\Theta_{JX}(P_{D1} - P_{D2}) = (T_{A2} - T_{A1})$$
$$\Theta_{JX} = (T_{A2} - T_{A1})/(P_{D1} - P_{D2}) = \Delta T_A/\Delta P_D$$

This is the essence of the method; at constant voltage, the thermal resistance can be calculated using only power *dissipation* and *oven temperature*. Thermal resistance is assumed constant. If Θ_{JX} is constant, the graph consists of parallel curves. (Parallel *straight* lines were actually obtained.)

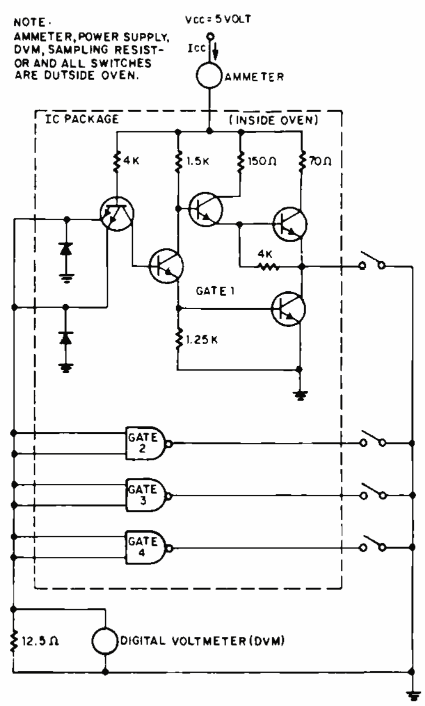

Fig. 2—Measurement circuit for T^2L.

A typical measurement circuit is shown in Fig. 2. The integrated circuit is a T^2L quad dual-input NAND gate. The T^2L gates are well adapted to this method since a high impedance exists between input and output. The output can float or be shorted with-

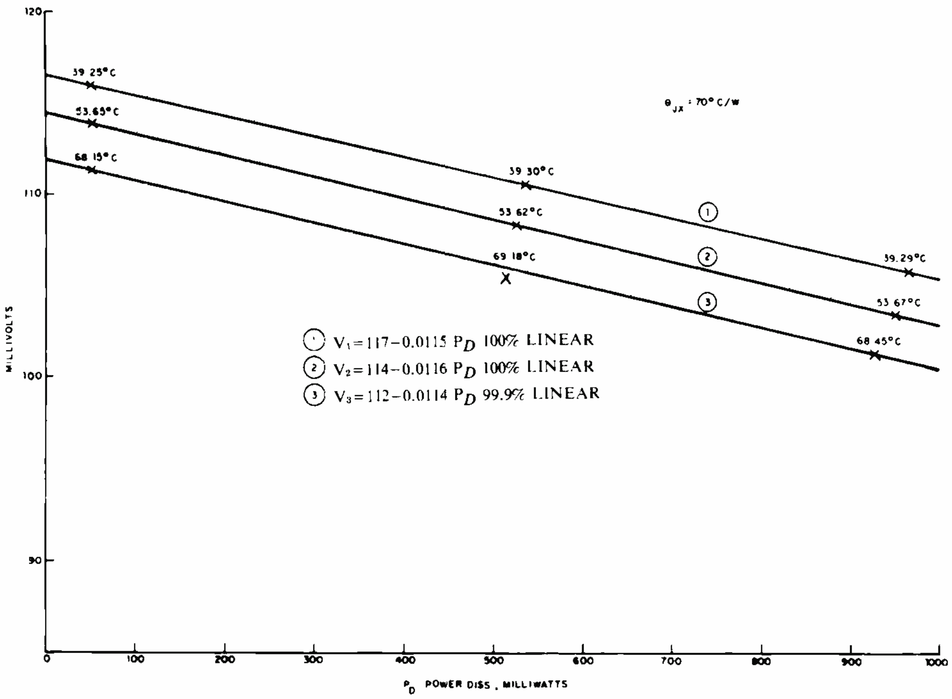

Fig. 3—V_t vs. power dissipotion for a 198601 integrated circuit (epoxy package).

out electrically affecting the input current. The current and power in the sampling resistor (or ammeter shunt) are negligible compared to I_{cc} and total power dissipation. The temperature sensitive components are the 4 kilohm base resistors and forward voltages of the base-emitter junctions of the input transistors. As the temperature of the IC varies, the current from the inputs changes the voltage across the sampling resistor (12.5 ohm). The power dissipation is changed by successively shorting the output pins to ground. The current through the sampling resistor decreases with increasing chip temperature.

After the IC is wired as in Fig. 2, the board is placed in an environmental chamber whose temperature is monitored by a quartz crystal thermometer (Hewlett-Packard, Model 2801A). The environmental chamber is controlled to $\pm 0.5°C$, and the board is protected from direct air flow. Kelvin connections were used in the test circuit. The power supply and test circuit are outside the oven. Outputs of the gates are successively shorted to provide different power dissipations. The temperature-sensitive voltage across the sampling resistor is plotted *vs.* power dissipation ($V_{CC} \times I_{CC}$). The oven temperature is then changed and the measurements repeated. Parallel straight lines are obtained of voltage vs. power, each line representing one oven temperature. The thermal resistance is calculated as Δ Oven temp./ΔP_D at constant voltage.

A difference of 1.0°C in oven temperature causes noticeable variation in linearity. Five minutes between different power dissipations was sufficient for thermal equilibrium to be reached. The board used was 1/16×5.0×5.75 inch glass-filled epoxy with no large ground planes or heat sink pads.

Other IC's were treated similarly. A T^3L IC which consists of three dual-input NAND gates and two inverters was measured by monitoring the gate inputs and shorting the inverter outputs in turn to change the power dissipation from the standby level.

From a plot of data obtained from an epoxy-packaged T^3L integrated circuit (Fig. 3), the thermal resistance is calculated to be 70°C/watt, between the two upper lines and 69°C/watt between the two lower lines. Linearity of the curves was found to be 100% for the upper curves and 99.9% for the bottom curve (determined as correlation coefficient in RCA POLYFIT Computer Program). The middle point of the lower curve is below the the line because the oven was slightly hotter during this measurement. The equation of the lines was provided by the computer program from the raw data. The equation for T_J *vs.* V_T was obtained by using the 70°C/W number for Θ_{JX} and calculating T_J from Eq. 1 for points on the graph of Fig. 3. This procedure gives $T_J = 754 - 6.12V_T$ which is 99.9% linear using seven data points.

This relationship is independent of system air flow or heat sinking (changes in Θ_{CX}). Therefore, a board could be used to monitor junction temperature in any system environmental condition even though it is calibrated under laboratory conditions. Others[2] have calculated the effect of forced air cooling and other heat sources on the board.

Good agreement was obtained between these thermal resistance measurements and those of the vendor. The vendor used special test chips with isolated diodes and resistors fabricated and calibrated especially for the measurements. The resistors were used to heat the chips and the calibrated diodes to monitor T_J. Maximum power ratings for no forced-air flow were calculated to 125°C junction temperature using the vendor's worst case data (Table I).

Table I—Maximum power ratings.

Package	*Vendor guaranteed avg $\Theta_{JX} \pm 2\sigma$*	*Our measurement*	*Calculated Max. power at +2σ*
14-pin epoxy	85±12°C/W	95°C/W	.570W
16-pin epoxy	80±12°C/W	70°C/W	.600W
24-pin epoxy	57± 9°C/W		.840W

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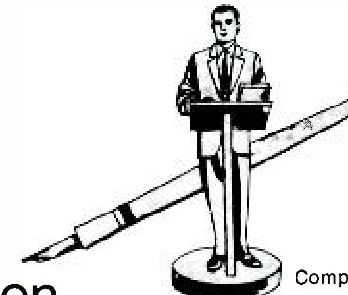

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TV CAMERA, Improvements in the Dynamic Resolution Capabilities of a—C. L. Olson, N. P. Kellaway (CSD, Camden) B/C Symp., Washington, D.C.; 9/23/71

TWO-INCH RBV Performance Evaluation—B. P. Miller, G. A. Beck, J. M. Barletta (AED, Pr) SMPTE 110th Semi-Annual Technical Conf., Montreal; 10/4/71

245 Displays

. . . equipment for the display of graphic, alphanumeric, & other data in communications, computer, military, & other systems, CRT devices, solid state displays, holographic displays, etc.

HOLOGRAPHIC MOTION PICTURES for Home TV Playback—M. Lurie (Labs, Pr) Optical Society of America, Pittsburgh Section; Pittsburgh, Pa.; 12/8/71

MATRIX DISPLAYS, Liquid Crystal—B. J. Lechner, F. J. Marlowe, E. O. Nester, J. Tults (Labs, Pr) *Proc. of IEEE*, Vol. 59, No. 11; 11/71

255 Audio Components & Applied Acoustics

. . . microphones, loudspeakers, earphones, etc., sound transmission & control; ultrasonic equipment. (excludes: sonar & audio recording)

SEQUENCE GENERATOR/CORRELATOR, Switchable Acoustic Surface Wave—G. D. O'Clock, Jr., C. L. Grasse, D. A. Gandolfo (EASD, Van Nuys) IEEE Ultrasonics Symp., Miami, Florida; 12/71

280 Thermal Components & Equipment

. . . heating & cooling components & equipment, thermal measurement devices, heat sinks.

HEAT PIPE RADIATOR for Cooling a Klystron Collector, The Development of a 30 Kilowatt—W. E. Harbaugh, R. A. Freggens (EC, Lanc) IEEE Electron Devices Mtg., Washington, D.C.; 10/11-13/71

HEAT TRANSFER Panel NAAC Report: Computer Analysis of Complex Thermal & Air Flow Systems—F. Gorman (M&SR, Mrstn) Naval Aeroballistics Advisory Committee Mtg. at NRL; 10/12/71

SERIES 300 SYSTEMS, EQUIPMENT, & APPLICATIONS

305 Aircraft & Ground Support

. . . airborne instruments, flight control systems, air traffic control, etc.

SHORT-HAUL AIR NAVIGATION, The Satellite's Role in Domestic—R. Buntschuh (AED, Pr) RTCS Annual Assembly, Washington, D.C.; 11/17-18/71

310 Spacecraft & Ground Support

. . . spacecraft & satellite design, launch vehicles, payloads, space missions, space navigation.

AEROSPACE to Urban Technology—What's the Hangup—G. Barna (AED, Pr) 8th Annual AIAA Mtg., *Conf. Proc.*, Washington, D.C.; 10/26-28/71

COLOR TELEVISION for Apollo 15 and Beyond, Development and Application of—S. Russell (AED, Pr) Space for Mankind's Benefit—A Space Congress for Non-Aerospace People, Huntsville, Alabama; 11/15-19/71

GEOSTATIONARY SPACECRAFT, Propulsion for—Y. Brill, R. Lake, J. Mavrogenis (AED, Pr) 1971 JANAF Combined Propulsion Meeting, Chem. Propulsion Info Agency Journal, Las Vegas, Nevada; 11/3/71

ITOS, The Evolution of the TIROS Operational Environmental Satellite—A. Schanpf (AED, Pr) 5th Hawaii Int'l Conf. on System Services, Honolulu, Hawaii; 1/11-13/71

LASER ALTIMETER for Apollo Lunar Orbit—J. H. Woodward (ASD, Burl) IEEE NEREM, 11/71; NEREM Record

MARINE AND TRAFFIC SURVEILLANCE and Marine Users, Advanced Satellite Technology for Broad Area—R. Buntschuh (AED, Pr) National Electronics Conf., Chicago; 10/18/71

SHORT-HAUL AIR NAVIGATION, The Satellite's Role in Domestic—R. Buntschuh (AED, Pr) RTCS Annual Assembly, Washington, D.C.; 11/17-18/71

320 Radar, Sonar, & Tracking Systems

. . . microwave, optical, & other systems for detection, acquisition, tracking, & position indication.

AMPLITUDE MONOPULSE OFF-BORESIGHT RADAR, Angular Accuracy of—S. Sherman (M&SR, Mrstn) *IEEE Proc.*, 11/71

IFF ANTENNA AN/TPQ-27 & 10 kW ISIS Switch—E. M. Brown (M&SR, Mrstn) NATO Mark XII IFF Cooperative Proj. Mtg., NRL: 10/15/71

WIDEBAND RADAR, Testing & Alignment of—J. Christensen, T. Maggio (M&SR, Mrstn) EASCON, Washington, D.C.; 10/6/71; Conf. Record

MONOPULSE TRACKING ERRORS Due to Multipath: Causes & Remedies—J. Nessmith, S. Sherman (M&SR, Mrstn) EASCON, Washington, D.C.; 10/6/71; Conf. Record

MONOPULSE Radar Measurements of Two Unresolved Targets, Information Derivable from—S. Sherman (M&SR, Mrstn) IEEE Trans.; 9/71

325 Checkout, Maintenance, & User Support

. . . automatic test equipment, (ATE), maintenance & repair methods, installation & user support.

AUTOMATIC TEST SYSTEMS. Dedicated or Integrated?—A. M. Greenspan (ASD, Burl) IEEE Trans. on Instrumentation and Measurement; 12/71

340 Communications Equipment & Systems

. . . industrial, military, commercial systems, telephony, telegraphy, & telemetry, (excludes: television, & broadcast radio).

MESSAGE SWITCHING—An Overview and New Directions—I. Susskind (CSD, Camden) Mohawk Valley Chapter of IEEE, Rome, New York, 12/22/71

MICROWAVE SYSTEM for Distress Signaling by Disabled Motorists—H. Staras, L. Schiff (Labs, Pr) 22nd IEEE Vehicular Technology Conf., Detroit, Mich.; 12/7-9/71

345 Television & Broadcast Systems

. . . television & radio broadcasting, receivers, transmitters, & systems, television cameras, recorders, studio equipment; closed-circuit, spacecraft, & special purpose television.

BROADCASTER and the Cassette, What the Future Holds—E. L. Bidun (CSD, Camden) CCBA Convention, Ottawa, Canada; 10/26/71

COLOR TELEVISION for Apollo 15 and Beyond, Development and Application of—S. Russell (AED, Pr) Space for Mankind's Benefit—A Space Congress for Non-Aerospace People, Huntsville, Alabama; 11/15-19/71

HOME TV PLAYBACK, Holographic Motion Pictures for—M. Lurie (Labs, Pr) Optical Society of America, Pittsburgh Section; Pittsburgh, Pa. 12/8/71

360 Computer Equipment

. . . processors, memories, & peripherals.

INFORMATION STORAGE in Magnetic Holography—R. S. Mezrich, H. Schachter (Labs, Pr) Israel J. of Technology, Vol. 9, No. 3; 1971

365 Computer Programming & Applications

. . . languages, software systems, & general applications (excluding: specific programs for scientific use).

COMPUTER PERFORMANCE EVALUATION, A Data Base for—R. O. Winder (Labs, Pr) The Workshop on System Performance Evaluation, Argone, Ill.; 10/7/71

370 Computer Programs (scientific)

. . . specific programs & techniques for scientific use, computation, simulation, computer aided design, etc. (entries in this category generally consist of program documentation, listings, decks, etc.)

DESIGN AID COMPUTER PROGRAMS Using Consistent Mass Matrix Approach, NMODES A Package of—C. H. McKee, R. C. Bauder, (EC, Lanc) Air Force 3rd Conf. on Matrix Methods in Structural Mechanics, Wright-Patterson Air Force Base, Ohio; 10/19-21/71

HEAT TRANSFER Panel NAAC, Report: Computer Analysis of Complex Thermal & Air Flow Systems—F. Gorman (M&SR, Mrstn) Naval Aeroballistics Advisory Committee Mtg. at NRL; 10/12/71

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Subject numbers listed opposite each author's name indicates where complete citation to his paper may be found in the subject index. An author may have more than one paper for each subject category.

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RCA Records

Patents Granted

to RCA Engineers

As reported by RCA Domestic Patents, Princeton

Advanced Technology Laboratories

Operation of Field-Effect Transistor Circuit Having Substantial Current Source with Positive Feedback—D. D. Harbert (ATL, Cam) U.S. Pat. 3629612, December 21, 1971

Article Labeling and Identification System—J. F. Schanne (ATL, Camden) U.S. Pat. 3622758; November 23, 1971

Aerospace Systems Division

Interpulse Time Interval Detection Circuit—C. Y. Hsueh (ASD, Camden) U.S. Pat. 36344869; January 11, 1972

Autocollimator Including a Retroflector Element—B. R. Clay, W. A. Strickland (ASD, Burlington) U.S. Pat. 3628869; December 21, 1971

Orthogonal Filters—W. F. Fordyce, E. J. Mitchell (ASD, Burlington) U.S. Pat. 3629721; December 21, 1972

Astro-Electronics Division

Frequency Modulated Phase-Locked Oscillator Having Low- and High-Frequency Response—D. G. Shipley (AED, Princeton) U.S. Pat. 3622913; November 23, 1971

Electromagnetic and Aviation Systems Division

Magnetic Drum System—A. Lichowsky (EASD, Van Nuys) U.S. Pat. 3623120; November 23, 1971

Current Repeater—R. B. Boyer (G&CS EASD, Van Nuys) U.S. Pat. 3629692; December 21, 1972

RCA Laboratories

Magnetic Head—J. J. Hanak (Labs, Pr) U.S. Pat. 3634933; January 18, 1972.

Heat Seal of a Glass Member to another Member—A. I. Stoller, W. H. Schip, Jr. (Labs, Pr) U.S. Pat. 3635510; January 18, 1972

Epitaxial Semiconductor Device Having Adherent Bonding Pads—J. R. Burns, J. H. Scott, Jr. (Labs, Pr) U.S. Pat. 3636412; January 18, 1972

Partially Overlapping Hologram Motion Picture Record—R. A. Bartolini, M. J. Lurie (Labs, Pr) U.S. Pat. 3632869; January 4, 1972

Holographic Scan Converter—I. Gorog (Labs, Pr) U.S. Pat. 3630594; December 28, 1971

Electrically and Optically Accessible Memory—W. F. Kosonocky (Labs, Pr) U.S. Pat. 3631411; December 28, 1971

Hologram Memory—D. I. Bostwick (Labs, Pr) U.S. Pat. 3628847; December 21, 1971

Digital Synchronization System—L. A. Rempert (Labs, Pr) U.S. Pat. 3629503; December 21, 1971

Magnetic Heads with Poles Joined by Molecular Transport Bonding—J. J. Hanak (Labs, Pr) U.S. Pat. 3629519; December 21, 1971

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Electrophotographic Recording Elements with Halftone Screen Coatings Thereon—P. J. Donald (Labs, Pr) U.S. Pat. 3627526; December 14, 1971

Electrophotographic Recording Element Having Photoconductor with Quenched Luminescence during Charging and Method of Making the Photoconductor—E. C. Giaimo, Jr., S. Larach (Labs, Pr) U.S. Pat. 3627528; December 14, 1971

Method of Applying an N,N'Diallylmelamine Resist to a Surface—J. E. Goldmacher, O. E. Dow (Labs, Pr) U.S. Pat. 3627599; December 14, 1971

LSA or Hybrid Mode Oscillator Started by Series connected Gunn or Quenched Mode Oscillator—M. C. Steele (Labs, Pr) U.S. Pat. 3628170; December 14, 1971

Optical Modulation System—J. M. Hammer (Labs, Pr) U.S. Pat. 3628177; December 14, 1971

Electrical Control of Light Polarization Utilizing the Optical Property of Fluids—G. W. Taylor (Labs, Pr) U.S. Pat. 3625593; December 7, 1971

Magnetic Recording Medium wtih Lubricant—M. Slovinsky (Labs, Pr) U.S. Pat. 3625760; December 7, 1971

Thyristor Controlled Power Supply Circuits and Deflection Circuitry Associated with a Kinescope—G. Forster (Labs, Zurich, Switz.) U.S. Pat. 3626238; December 7, 1971

Digital Light Deflector Using Electro-Optic Grating—J. M. Hammer (Labs, Pr) U.S. Pat. 32626511; December 7, 1971

Method for Isolating Semiconductor Devices from a Wafer of Semiconducting Material—A. I. Stoller, W. H. Schilip (Labs, Pr) U.S. Pat. 3623219; November 30, 1971

Electro-Optical System—G. W. Taylor, A. Miller (Labs, Pr) U.S. Pat. 3623795; November 30, 1971

Noise Cancellation in Video Signal Generating Systems—D. R. Bosomworth, Z. J. Kiss (Labs, Pr) U.S. Pat. 3624286; November 30, 1971

Balanced Optically-Settable Memory Cell—W. F. Kosonocky (Labs, Pr) U.S. Pat. 3624419; November 30, 1971

Electric Signal Processing Circuit Employing Capacitively Scanned Phototransistor Array—P. K. Weimer, F. V. Shallcross (Labs, Pr) U.S. Pat. 3624428; November 30, 1971

Heterojunction Semiconductor Transducer Having a region which is Piezoelectric—R. M. Moore (Labs, Pr) U.S. Pat. 3624465: November 30, 1971

Liquid Crystal Cells in a Linear Array—D L. Matthies (Labs, Pr) U.S. Pat. 3622226; November 23, 1971

Zinc Oxide and Titanium Oxide Sensitized by AZO Dyes—W. M. Lee (Labs, Pr) U.S. Pat. 3622341; November 23, 1971

Electronic Scanner Utilizing a Laser for the Simultaneous Scanning and Reproducing of Images—A. W. Stephens, J. J. Walsh (Labs, Pr) U.S. Pat. 3622690; November 23, 1971

Device Employing Selenium-Semiconductor Heterojunction—R. M. Moore, C. J. Busanovich (Labs, Pr) U.S. Pat. 3622712; November 23, 1971

Amplifiers and Oscillators Comprised of Bulk Semiconductor Negative Resistance Loaded Slow-Wave Structure—J. M. Hammer, B. Vural (Labs, Pr) U.S. Pat. 3621462; November 16, 1971

Digital Scanning Mosaic Photosensing System—P. K. Weimer (Labs, Pr) U.S. Pat. 3,603,731; September 7, 1971; Assigned to U.S. Government

Computer Systems

Apparatus for Handling Endless Tape—M. C. Guerrero, R. E. Justice, R. M. Rudy (CS, Fla) U.S. Pat. 3,613,976; October 19, 1971

Optical Card Reading Apparatus—J. G. Hoehn, R. A. Mancini (CS, Fla) U.S. Pat. 3,619,569; November 9, 1971

Signal Detecting and Latching Circuit—J. J. Yorganjian (CSD, Palm Beach) U.S. Pat. 3634876; January 11, 1972

Apparatus for Contact Printing—R. A. Rubenstein (CSD, Framingham) U.S. Pat. 3625147; December 7, 1971

Communications Systems Division

Drift-Compensated Average Value Crossover Detector—R. L. Giordano, D. J. Poitras (CSD, Camden) U.S. Pat. 3,610,-956; October 5, 1971

Servo System for Recorder-Reproducer Apparatus Utilizing Frequency and Phase Synchronizing—K. Sadashige, M. Horii (CSD, Camden) U.S. Pat. 3,611,096; October 5, 1971

Squeeze Film Bearing Servosystem—L. H. Sulton (CSD, Camden) U.S. Pat. 3,614,579; October 19, 1971

Edge Connector with Polarizing Member—N. B. Silverstein (CSD, Camden) U.S. Pat. 3,614,714; October 19, 1971

Thermoelement Array Connecting Apparatus—M. S. Crouthamel (CSD, Camden) U.S. Pat. 3,615,870; October 26, 1971

Frequency Shift Oscillator Which Avoids the Generation of Transients—W. F. Hingston (CSD, Camden) U.S. Pat. 3,618,132; November 2, 1971

Broad Slope Determining Network—J. R. Barger, P. B. Scott (CSD, Camden) U.S. Pat. 3,619,509; November 9, 1971

Thermoelectric Cooling Device—J. F. Panas (CSD, Camden) U.S. Pat. 3,599,-437; August 17, 1971 Assigned to U.S. Government

Signal Processor for Dropout Correction Before Demodulation—R. N. Hurst (CSD, Camden) U.S. Pat. 3629494; December 21, 1971

Logic One-Shot—G. J. Dusheck, Jr. (CSD, Camden) U.S. Pat. 3,600,687; August 17, 1971 Assigned to U.S. Government

Electronic Components

Lithium Silicate Glare-Reducing Coating and Method of Fabrication on a Glass Surface—G. E. Long 3rd, D. W. Bartch, F. D. Grove (EC, Lancaster) U.S. Pat. 3635751; January 18, 1972

Transferred Electron Amplifier with Oscillation Stabilization Circuit—F. Sterzer (EC, Princeton) U.S. Pat. 3636461; January 18, 1972

Storage Circuit—B. Zuk (EC, Somerville) U.S. Pat. 3636527; January 18, 1972

Identifier Circuits for Color Bar Type Test Generators—W. M. Stobbe (EC, Harrison) U.S. Pat. 3634612; January 11, 1972

Noise Protected AGC Circuit with Amplitude Control of Flyback Pulses—J. R. Harford (EC, Somerville) U.S. Pat. 3634620; January 11, 1972

Method of Producing a Color Kinescope H. B. Law, R. H. Lee (EC, Princeton) U.S. Pat. 3631576; January 4, 1972

Assembly of Filamentary Display Devices—N. L. Lindburg, H. D. Woodland (EC, Somerville) U.S. Pat. 3631593; January 4, 1972

Contact System for Semiconductor Devices—R. Denning (EC, Somerville) U.S. Pat. 3632436; January 4, 1972

Cylindrical Magnetic Memory Construction—W. E. Golder, J. Pellegrino (EC, Needham Hgts., Mass.) U.S. Pat. 3631417; December 28, 1971

Current Source—C. F. Wheatley, Jr (EC, Somerville) U.S. Pat. 3629691; December 21, 1971

Broadband Double Ridge Waveguide Magic Tee—W. W. Siekanowicz, R. W. Paglione (EC, Princeton) U.S. Pat. 3629734; December 21, 1971

Voltage Reference and Voltage Level Sensing Circuit—R. C. Heuner, S. J. Niemiec (EC, Somerville) U.S. Pat. 3628070; December 14, 1971

Linearity Correction Circuit Utilizing a Saturable Reactor—W. F. W. Dietz (EC, Somerville) U.S. Pat. 3628082; December 14, 1971

Power Supply Circuits—S. Reich (EC, Harrison) U.S. Pat. 3626242; December 7, 1971

Visual Displays Utilizing Liquid Crystals—L. A. Boyer (EC, Princeton) U.S. Pat. 3623392; November 30, 1971

Photographic Method for Producing a Cathode Ray Tube Screen Structure—T. A. Saulnier (EC, Lancaster) U.S. Pat. 3623867; November 30, 1971

Very Short Luminescent Decay-Time Phosphor—M. R. Royce, J. S. Martin, Jr. (EC, Lancaster) U.S. Pat. 3623994; November 30, 1971

Photographic Method for Producing a Metallic Pattern with a Metal Resinate—F. W. Brill (EC, Lancaster) U.S. Pat. 3622322; November 23, 1971

Phosphor Screen Comprising Two Kinds of Particles, Each Having Phosphor Core and Phosphor Coating—M. R. Royce (EC, Lancaster) U.S. Pat. 3622826; November 23, 1971

Light-Emitting Diode Array—P. Nyual (EC, Somerville) U.S. Pat. 3622906; November 23, 1971

First-in First-Out Buffer Register—R. A. Mao (EC, Somerville) U.S. Pat. 3623020; November 23, 1971

Mounting Structure for High-Power Semiconductor Devices—D. L. Franklin, L. M. Balents (EC, Somerville) U.S. Pat. 3620692; November 16, 1971

Method for Metallizing a Ceramic Body—M. W. Hoelscher, P. D. Strubhar (EC, Lancaster) U.S. Pat. 3620799; November 16, 1971

Analog Multiplier in Which One Input Signal Adjusts the Transconductance of a Differential Amplifier—H. A. Wittlinger (EC, Somerville) U.S. Pat. 3621226; November 16, 1971

Monostable Multivibrator—J. A. Dean (EC, Somerville) U.S. Pat. 3261297; November 16, 1971

Frequency Multiplier Employing Input and Output Strip Transmission Lines without Spatially Coupling There between—A. Rosen, E. Mykietyn (EC, Princeton) U.S. Pat. 3621367; November 16, 1971

Meterological Device Employing a Temperature Compensated Transmitter—R. E. Askew & H. C. Johnson (ECD, Harrison & Princeton) U.S. Pat. 3577100; May 4, 1971; Assigned to U.S. Government

High-Voltage Transistor Structure Having Uniform Thermal Characteristics—W. G. Einthoven (EC, Hrsn) U.S. Pat. 3,617,821; November 2, 1971

Trigger Circuits Having Uniform Triggering Voltages—A. A. Ahmed, M. B. Knight (EC, Hrsn) U.S. Pat. 3,619,666; November 9, 1971

Electrical Fuse Link—R. R. Soden, W. J. Greig (EC, Hrsn) U.S. Pat. 3,619,725; November 9, 1971

Multiple Pellet Semiconductor Device—L. K. Baker, L. R. Shardlow (EC, Hrsn) U.S. Pat. 3,619,731; November 9, 1971

Semiconductor Device with Multilevel Metalization and Method of Making the Same—W. J. Greig (EC, Hrsn) U.S. Pat. 3,619,733; November 9, 1971

Constant Temperature Output Heat Pipe—W. B. Hall, F. G. Block (EC, Lanc) U.S. Pat. 3,613,773; October 19, 1971

Cathode-Ray Tube With Electrode Supported by Straplike Springs—T. R. Martin (EC, Lanc) U.S. Pat. 3.619,689; November 9, 1971

Gas Laser Tube Mount—D. B. Kaiser, J. A. Powell (EC, Lanc) U.S. Pat. 3,619,-811; November 9, 1971

Consumer Electronics

Oscillator with Variable Reactive Current Frequency Control—S. A. Steckler (CE, Somerville) U.S. Pat. 3636475; January 18, 1972

Signal Seeking System for Radio Receivers with Tuning Indicating Circuitry for Controlling the Signal Seeking—W. W. Evans (CE, Indianapolis) U.S. Pat. 3632864; January 4, 1972

Method of Reconstituting Unfired, Cast, Alumina Scrap—P. Kopko (CE, Indianapolis) U.S. Pat. 3631131; December 28, 1971

Signal Distribution System—W. L. Lehmann (CE, Indianapolis) U.S. Pat. 3631348; December 28, 1971

Electronic Processing Apparatus—A. L. Limberg (CE, Somerville) U.S. Pat. 3629611; December 21, 1971

Television Tuning Circuit Utilizing Voltage Variable Capacitance—D. J. Carlson (CE, Indianapolis) U.S. Pat. 3628152; December 14, 1971

Wide-Band Amplifier—J. R. Harford (CE, Somerville) U.S. Pat. 3628166; December 14, 1971

Color Television Receiver Hue Control—E. W. Curtis (CE, Indianapolis) U.S. Pat. 3624279; November 30, 1971

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Threshold Digital Switch Circuit for Remote Control System—L. B. Juroff (CE, Indianapolis) U.S. Pat. 3624510; November 30, 1971

Automatic Frequency Control System—W. W. Evans (CE, Indianapolis) U.S. Pat. 3624512; November 30, 1971

Dates and Deadlines

As an industry leader, RCA must be well represented in major professional conferences . . . to display its skills and abilities to both commercial and government interests.

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Calls for papers—be sure deadlines are met.

Date	Conference	Location	Sponsors	Deadline Date	Submit	To
JULY 17-19, 1972	**AIAA/NAVY Advanced Marine Vehicles Meeting**	Annapolis, Md.	AIAA	**12-weeks before meeting** **6-weeks before meeting**	abst ms	Don Wendling, Director—Technical Programs, AIAA 1290 Ave. of the Americas, New York, N.Y. 10019
JULY 24-27, 1972	**Conference on Nuclear & Space Radiation Effects**	Univ. of Washington Seattle, Washington	G-NS	**4-3-71**	sum	B L. Gregory, Sandia Labs., POB 5800, Albuquerque, New Mexico 87115
JULY 24-27, 1972	**Nuclear and Space Radiation Effects**	University of Washington Seattle, Washington	IEEE/G-NS Radiation Effects Committee & Univ.	**4-3-72**	sum	B. L. Gregory, Division 1933, Sandia Laboratories, Albuquerque, New Mexico 87115
AUG. 14-16, 1972	**AIAA Guidance and Control Conference**	Stanford, Calif.	AIAA	**12-weeks before meeting** **6-weeks before meeting)**	abst ms	Don Wendling, Director—Technical Programs, AIAA, 1290 Ave. of the Americas, New York, N.Y 10019
AUG. 21-26, 1972	**13th International Congress of Theoretical and Applied Mechanics**	Moscow, USSR		**3-15-72**	sum (5 copies) (500 words)	Professor G. F. Carrier, Pierce Hall, Harvard University, Cambridge, Mass. 02138
SEPT. 10-14, 1972	**Jt. Power Generation Tech. Conference**	Sheraton Boston Hotel Boston, Mass.	IEEE Power Engrg. Soc., ASME, ASCE	**4-28-72**	ms	General Chairman: G. O. Buffington, Stone & Webster Corp., 225 Franklin St., Boston, Mass 02107
SEPT. 11-12, 1972	**AIAA/AAS Astrodynamics Conference**	Cabana Hyatt House Palo Alto, Calif.		**3-27-72**	abst	Dr. Henry J. Kelley, Analytical Mechanics Associates Inc. 50 Jericho Turnpike, Jericho, N.Y. 11753
SEPT. 11-13, 1972	**2nd Atmospheric Flight Mechanics Conference**	NASA Ames Research Center Moffett Field, Calif.	AIAA/NASA	**3-27-72**	abst	General Chairman: Victor L. Peterson, Chief, Aerodynamics Branch, Mail Stop 227-8 NASA Ames Research Center, Moffett Field, Calif. 94035
SEPT. 13-15, 1972	**1972 IEEE International Conference Engineering in the Ocean Environment**	Newport, Rhode Island	OCC/IEEE	**4-15-72**	complete papers	General Chairman: J. J. Greichen, Naval Underwater Sys. Ctr., Newport, R.I. 02840
SEPT 19-22, 1972	**Western Electronic Show & Convention (WESCON)**	L.A. Convention Ctr., Los Angeles, Calif.	Region 6, WEMA	**4-15-72**	abst ms	WESCON, 3600 Wilshire Blvd., Los Angeles, Calif. 90010
SEPT. 26-29, 1972	**Conf. on Metering, Apparatus and Tariffs for Electricity Supply**	London, England	IEE, IERE, IEEE UKRI Section	**3-24-72**	syn	IEE, Savoy Place, London, W. C. 2R, OBL, England
OCT. 18, 19, 1972	**1972 Connector Symposium**	Cherry Hill Inn Cherry Hill, NJ 08034	Electronic Connector Study Group, Inc.	**3-1-72** **7-15-72**	abst ms	Program Chairman, Fifth Annual Connector Symposium, Post Office Box 3104, Philadelphia, PA 19150
DEC. 13-15, 1972	**Conf. on Decision and Control (Inc. 11th Symp. on Adaptive Processes)**	Fontainebleau Motor Hotel, New Orleans, La.	G-CS, G-IT, G-SMC	**5-1-72**	ms	Y. C. Ho, Pierce Hall, Harvard Univ., Cambridge, Mass. 02138
JAN. 28-FEB. 2, 1973	**IEEE Power Engineering Society Winter Meeting**	Statler Hilton Hotel, New York, N.Y.	IEEE Power Engineering Society	**9-15-72**	ms	IEE Hdqs., 345 E. 47th St. New York, NY
APRIL 10-13, 1973	**Conf. on Propagation of Radio Waves at Frequencies above 10 GHz**	London, England	IEE, IERE, Inst. of Phys., IEEE UKRI Section	**5-1-72** **10-20-72**	syn ms	IEE, Savoy Place, London W.C. 2R OBL England

Dates of upcoming meetings—plan ahead.

Date	Conference	Location	Sponsors	Program Chairman
APRIL 4-6, 1972	**Symp. on Computer-Communications Networks and Teletraffic**	New York, N.Y.	PIB, G-Com Tech., coop. of Computer Society	IEEE Hdqs., 345 E. 47th St., New York, N.Y. 10017
APRIL 5-7, 1972	**1972 Reliability Physics Symposium**	Stardust Hotel Las Vegas, Nevada	IEEE Electron Devices & Reliability Groups	D. S. Peck, General Chairman, Bell Telephone Laboratories, 555 Union Blvd., Allentown, PA 18103
APRIL 10-12, 1972	**Int'l Symposium on Accoustical Holography**	Univ. of Calif., Santa Barbara, Calif.	G SU, Univ. of Calif.	Glen Wade, Univ. of Calif., Dept. of EE, Santa Barbara, California 93106
APRIL 10-12, 1972	**Region III Convention**	Univ. of Tenn., Knoxville, Tenn.	Region III, E. Tennessee	W. L. Green, Univ. of Tenn., Dept. of EE, Knoxville, Tenn. 37916
APRIL 10-13, 1972	**Int'l Conference on Magnetics (INTERMAG)**	Kyoto Int'l Conf. Hall, Kyoto, Japan	G-MAG, Japanese Soc. for Promotion of Science et al	C. D. Mee, IBM Corp., Bldg. 015, Monterey & Cottle Rds., San Jose, Calif. 96115
APRIL 10-12, 1972	**AIAA 7th Thermophysics Conference**	San Antonio, Texas		American Institute of Aeronautics & Astronautics, 1290 Ave. of the Americas New York, N.Y. 10019
APRIL 10-14, 1972	**AIAA/ASME/SAE 13th Structures, Structural Dynamics, and Materials Conference/NASA Space Shuttle Technology Conference**	San Antonio, Texas		American Institute of Aeronautics & Astronautics, 1290 Ave. of the Americas New York, N.Y. 10019
APRIL 11-13, 1972	**Conf. on Industrial Measurement & Control by Radiation Techniques**	Univ. of Surrey, Guildford, Surrey, England	IEE, IERE, IPPS, IMC, IEE UKRI Section et al	IEE Office, Savoy Place, London W. C. 2R OBL Eng.
APRIL 11-13, 1972	**Conference on Digital Processing of Signals in Communications**	Univ. of Tech., Loughborough, Leicestershire, England	IERE IEEE UKRI Section	Secretary, IERE, 8-9 Bedford Square, London, WCIB England
APRIL 13-15, 1972	**1972 USNC/URSI-IEEE Spring Meeting**	Statler Hilton Hotel Washington, D.C.	NAS, NRC, URSI, IEEE Groups	Miss A. Wagoner, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418
APRIL 17-19, 1972	**AIAA 9th Electric Propulsion Conference**	Washington, D.C.		American Institute of Aeronautics & Astronautics, 1290 Ave. of the Americas New York, N.Y 10019
APRIL 19-21, 1972	**International Symposium on Circuit Theory**	Sheraton-Universal Hotel, Universal City, Calif.	G-CT	G. C. Temes, Univ. of Calif., Dept. of Elec. Sci. & Engrg., Los Angeles, Calif. 90024
APRIL 19-21, 1972	**Region Six Conference**	Hilton Inn, San Diego, Calif.	Region Six	D. E. Atkinson, Pacific Tele., 525 B. St., Rm. 1458, Box 524, San Diego, Calif. 92112
APRIL 19-21, 1972	**Southwestern IEEE Conference & Exhibition (SWIEEECO)**	Baker Hotel & Dallas Mem. Aud., Dallas, Texas	SWIEEECO, Dallas Section	R. L. Carrel, Electrospace Sys. Inc., POB 1359, Richardson, Texas 75080
APRIL 24-26, 1972	**Int'l Conference on Speech Communications and Processing**	Marriot Motor Hotel Newton, Mass.	G-AE, AF Cambridge Res. Lab.	C. F Teacher, Philco-Ford Corp., 3900 Welsh Rd., Willow Grove, PA 19090
APRIL 24-26, 1972	**Frontiers in Education**	Ramada Inn, Tucson, Arizona	G-Education Tucson Section, Univ. of Ariz.	G. R. Peterson, Dept. of EE, Univ. of Ariz., Tucson, Arizona 85721
APRIL 24-26, 1972	**AIAA 4th Communications Satellite Systems Conference**	Washington, D.C.		American Institute of Aeronautics & Astronautics, 1290 Ave. of the Americas New York, N.Y. 10019
APRIL 25-28, 1972	**Conference on Computer Aided Design**	Univ. of Southampton, Southampton, England	IEE, EEA, IEEE UKRI Section	IEE, Savoy Place, London WC2R OBL England
APRIL 30-MAY 5, 1972	**11th SMPTE Technical Conference and Equipment Exhibit**	New York Hilton Hotel, New York, N.Y.	SMPTE	Society of Motion Picture and Television Engineers, 9 East 41st Street, New York, N.Y. 10017
MAY 1, 1972	**Memory Materials and Devices**	Princeton University McCarter Theatre Princeton, N.J.	American Vacuum Society (Greater N.Y. Chapter)	Dr. W. E. Loeb, Union Carbide Corporation, Chemicals and Plastics Division, 1 River Road, Bound Brook, N.J. 08805
MAY 1-3, 1972	**Offshore Technology Conference**	Astrohall, Houston, Texas	IEEE Ocean. Coord. Comm. et al	Offshore Tech. Conf., 6200 N. Central Expressway, Dallas, Texas 75206
MAY 1-4, 1972	**IES/AIAA/ASTM Joint Space Simulation Conference**	New York, N.Y.		American Institute of Aeronautics & Astronautics, 1290 Ave. of the Americas New York, N.Y. 10019
MAY 6-11, 1972	**74th Annual Meeting**	Sheraton-Park Hotel, Washington, DC	American Ceramic Society	Dr. Alan D. Miller, 325 Roberts Hall, Univ. of Washington, Seattle, Washington, 98195
MAY 7-10, 1972	**Int'l Semiconductor Power Converter Conference**	Lord Baltimore Hotel, Baltimore, Maryland	G-IGA, Baltimore Section	R. C. Whigham, Westinghouse Electric Corp., P.O. Box 100, Youngwood, Pa. 15697
MAY 7-11, 1972	**Int'l Quantum Electronics Conference**	Queen Elizabeth Hotel, Montreal, Quebec, Canada	G-ED, G-MTT, AIP, OSA	B. P. Stoicheff, University of Toronto, Toronto, Ontario, Canada
MAY 7-12, 1972	**SPSE Annual Conference**	San Francisco, Hilton, San Francisco, Calif.	SPSE	Raymond A. Eynard, Public Relations Chairman, SPSE, P.O. Box 2001, Teterboro, N.J. 07608
MAY 8-11, 1972	**ASME Design Engineering Show**	McCormick Place Chicago, IL		A. B. Conlin, Jr., Director Technical Department, ASME, 345 East 47th St., New York, N.Y. 10017
MAY 15-18, 1972	**Spring Joint Computer Conference**	Convention Ctr., Atlantic City, New Jersey	IEEE Computer Soc., AFIPS	AFIPS Hdqs., 210 Summit Ave., Montvale, N.J. 07645

Engineering News and Highlights

Two RCA Men Elected IEEE Fellows

Two RCA employees were recently elected Fellows of the Institute of Electrical and Electronics Engineers. The membership grade of Fellow is the highest attainable in the Institute; election to it is by invitation only. A mark of distinction, it is conferred only upon persons of outstanding and extraordinary qualifications in their particular fields.

Robert D. Lohman . . . "for contributions to discrete-time signal and system theory engineering education."

Ralph E. Simon . . . "for his contributions in the conception and practical development of electron emitters using the principal of negative electron affinity and of low-light-level camera tubes."

ROBERT D. LOHMAN is Head of the Optical Data Storage Research Group, RCA Laboratories, Princeton, N.J. He received the BSEE from Norwich University in 1949 and the MSEE from North Carolina State College in 1951. He joined RCA Laboratories as a Member of the Technical Staff in 1951 and engaged in research in the areas of basic semiconductor noise phenomena, transistor circuit development, color television display systems, and information theory. In 1956, he transferred to the RCA Semiconductor and Materials Division in Somerville, New Jersey, as an Applications Engineer. The next year he was appointed Manager of Applications for computer devices. In 1960, Mr. Lohman was promoted to Engineering Manager, Computer Products, and in 1963 was named Manager, Integrated Circuit Engineering. He returned to RCA Laboratories in 1966 as Head of Integrated Electronics Research and in 1968 was appointed to his present position. He has received 14 U.S. Patents and has published 15 technical papers.

DR. RALPH E. SIMON is Manager of the Electro-Optics Products Department, Electronic Components, Lancaster, Pa. He received the BA in Physics with honors from Princeton University in 1952 and the PhD in Solid State Physics from Cornell University in 1959. He was employed by RCA Laboratories, Princeton, New Jersey, from 1958 until 1968 where he engaged in fundamental studies of electron emission from semiconductors, photoconductivity and surface physics. He is the author of numerous papers in these fields and was the recipient of two RCA Achievement Awards. In April 1968, Dr. Simon was appointed Director, Conversion Devices Laboratories, Princeton, where he directed the development of *GaP* photomultipliers and silicon vidicons and intensifiers. In 1969 Dr. Simon was appointed Manager, Advanced Technology, Conversion Tube Operations, Lancaster, Pa., where he was responsible for research and development of conversion devices. In May 1970, he was appointed to his present position. Dr. Simon is a member of the American Physical Society, IEEE, AAAS, and Sigma Xi. Dr. Simon was a recipient of the David Sarnoff Outstanding Team Award in Science in 1970.

Promotions

RCA Service Company

W. A. Comer from Sys. Svc. Engr. to Mgr., Maintenance Support (W. E. Grundy, Operations Control Center - Atlantic Fleet Weapons Range)

W. Czerwinski from Sys. Svc. Engr. to Ldr., Sys. Svc. Engr. (D. Botticello, Weapons Systems - Systems Engineering, Springfield, Va.)

T. J. Drumm from Assoc. Engr. to Mgr., Air Surveillance Sys. (R. E. L. Fogle, WSMR Radar Project - New Mexico)

L. J. Johnson from Engr. to Ldr., Engrs. (A. T. Miller, STADAN Support - NASA/STADAN Project, Lanham, Md.)

D. A. Kaeding from Engr. to Mgr., Project Support (J. P. Foley, Project Support Operations - Greenbelt, Md.)

Electronic Components

H. Beelitz from Sr. Engr. Product Develop. to Engrg. Ldr., Product Develop. (G. Herzog, Somerville)

Z. Chang from Engr., Product Develop. to Engr. Ldr., Product Develop. (N.C. Turner, Somerville)

E. Helpert, from Sr. Engr., Product Develop. to Engr. Ldr., Product Develop. (J. C. Miller, Somerville)

R. H. Hynicka from Mgr., Color Picture Tube Mfg. to Mgr., Pilot Production Ctr. (D. D. VanOrmer, Lancaster)

J. Koskulitz from Engr., Product Develop. to Engr. Ldr., Product Develop. (R. A. Santilli, Somerville)

Communications Systems

C. P. Paramithas from Ldr., Engrg. Staff to Mgr., Safe Guard Programs (J. L. Santora, Camden)

Missile and Surface Radar Division

L. Campbell from Sr. Mbr. Eng. Staff to Ldr., Eng. Sys. Proj. (W. C. King, Moorestown)

Defense Electronic Products

J. B. Fischer from Sr. Mbr., Engrg. Staff to Mgr., Design Develop. Engrg. (H. Hite, Van Nuys)

Consumer Electronics

E. W. Curtis from Mbr., Engr. Staff to Ldr., Engrg. Staff (P. E. Crookshanks, Indianapolis)

D. H. Willis from Mbr., Engr. Staff to Ldr., Engrg. Staff (P. E. Crookshanks, Indianapolis)

D. F. Griepentrog from Mbr., Engr. Staff to Ldr., Engrg. Staff (E. Lemke, Indianapolis)

N. W. Hursh from Mbr., Engr. Staff to Ldr., Engrg. Staff (E. Lemke, Indianapolis)

T. A. Bridgewater from Mbr., Engr. Staff to Ldr., Engrg. Staff (P. E. Crookshanks, Indianapolis)

L. A. Cochran from Mbr., Engr. Staff to Ldr., Engrg. Staff (J. Stark, Indianapolis)

Licensed Professional Engineers

When you receive a professional license, send your name, PE number (and state in which registered), RCA division, location, and telephone number to: *RCA Engineer,* Bldg. 2-8, RCA, Camden, N.J. As new inputs are received they will be published.

Consumer Electronics

J. B. George, CE, Indianapolis, Ind. PE-14177; Indiana.

S. E. Hilliker, CE, Indianapolis, Ind. PE-14217; Indiana

Aerospace Systems Division

J. H. O'Connell, ASD, Burlington, Mass. PE-24855; Massachusetts.

Service Company creates new post in Data Communications Applications

The appointment of **A. B. Stockton** as manager for Data Communications Applications has been announced by **B. L. Grossman,** sales and merchandising manager, Technical Services, RCA Service Company. Mr. Stockton, who will be headquartered at the company's home office in Cherry Hill, N.J., will be responsible for the evaluation of data communications equipment applications and new types of equipment, and the recommendation of equipment to meet customer requirements.

Mr. Stockton's position is a new management post created by RCA's expansion of activity in the data communications field. Over 20,000 teleprinter units and associated equipment are currently covered by RCA Service Company lease/service programs.

Clarence Gunther receives special award

Clarence A. Gunther recently received a special award from the Philadelphia Section of the IEEE. The award read: "To an 'Engineers' Engineer' Clarence A. Gunther for forty years of Professional excellence and for his leadership in the IEEE." Mr. Gunther retired from RCA last year after more than 40 years' service with the company. His last post at RCA was Division Vice President, Technical Programs, Government and Commercial Systems.

Staff Announcements

Robert W. Sarnoff, Chairman of the Board and Chief Executive Officer has announced the following organization changes: **Anthony L. Conrad,** President and Chief Operating Officer, in addition to his present responsibilities, will assume responsibility for the RCA Staff Research and Engineering, and Marketing functions. **James Hillier,** Executive Vice President, Research and Engineering, and **James J. Johnson,** Vice President, Marketing, will report to Mr. Conrad. **Kenneth W. Bilby,** Executive Vice President, Public Affairs, in addition to his present responsibilities, will assume responsibility for RCA corporate advertising.

President and Chief Operating Officer

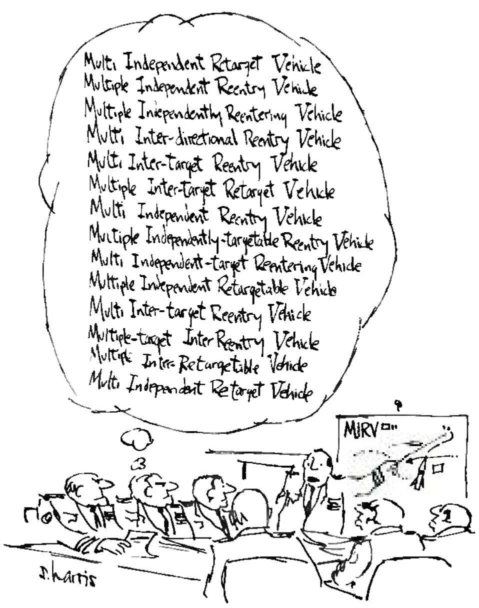
Anthony L. Conrad, President and Chief Operating Officer has announced that **Edgar H. Griffiths,** Executive Vice President, Services, in addition to his present responsibilities, will assume responsibility for Computer Systems; **Julius Koppelman** continues as Division Vice President and will assume responsibility for completing the withdrawal from the general purpose computer business. He will report to Mr. Griffiths. **L. Edwin Donegan, Jr.,** will continue as an RCA Vice President on special assignment.

Finance and Planning

Chase Morsey, Jr., Executive Vice President, Finance and Planning has announced the appointment of **Charles C. Ellis,** Senior Vice President. Finance.

Aerospace Systems Division

John R. McAllister, Division Vice President and General Manager has announced the appointment of **Ernest J. Dieterich,** Manager, Systems Technology, RCA Aerospace Systems Division.



Manufacturing Services and Materials

George A. Fadler, Vice President, Manufacturing Services and Materials has announced the appointment of **Kenneth D. Lawson,** Staff Vice President, Facilities and Real Estate.

Consumer Electronics

Barton Kreuzer, Executive Vice President, Consumer Electronics has announced the Consumer Electronics organization will assume responsibility for the SelectaVision Business Development activity. The activity will continue to provide corporate-wide coordination and control in the development of SelectaVision as a major new business opportunity. **Robert C. Bitting** becomes the Division Vice President, SelectaVision Business Development, and will report to the Executive Vice President, Consumer Electronics.

Missile and Surface Radar Division

Howard G. Stewart, Division Vice President, Marketing announced the appointment of **George B. Johnson** as Manager, Division Program (Air Traffic Systems), RCA Missile and Surface Radar Division; and **James G. Durbin** as Manager, Marketing, Tactical Systems.

Manufacturing

Barnes V. Dale, Director, Manufacturing Systems and Technology has announced his organization as follows: **Henry P. Cichon,** Administrator, Manufacturing Systems and Technology; **Max H. Lazar,** Manager, Systems Programming; **Stuart N. Levy,** Administrator, Manufacturing Systems and Technology; **Donald Mackey,** Manager, New Projects; **James L. Miller,** Manager, International Manufacturing Systems and Technology, **Louis E. Potter,** Administrator, Manufacturing Systems and Technology; **Hemmige V. Rangachar,** Administrator, Manufacturing Systems and Technology.

Electronic Components

John F. Wilhelm, Manager, Commercial Engineering has announced the Commercial Engineering organization as follows: **Norman Erdos,** Manager, Customer Information Programs Commercial Engineering; **Julia Gawruluk,** Manager, Customer Information Services; **Francis P. Lyons,** Manager, Logistics and Reprographic Systems; **Richard C. Garno,** Manager, Publication Services; **Charles F. Rodgers,** Manager, Coordination and Design; **Eleanor M. McElwee,** Manager, Solid State Engineering, Commercial Engineering; **Samuel F. Phillips,** Engineering Leader—IC Products, Commercial Engineering; **Eleanor M. McElwee,** Acting Engineering Leader—Power Products Commercial Engineering; **Arthur P. Sweet,** Manager, Electronic Components Engineering Commercial Engineering; **Charles A. Meyer,**

Administrator, Electronic Components, Technical Services, Commercial Engineering. Miss McElwee and Messrs. Erdos, Garno and Sweet will report to the Manager, Commercial Engineering.

David Sarnoff Research Center

John F. Biewener, Director of Finance and Administrative Services has appointed Craig Havemeyer, Manager, Management Information Systems, David Sarnoff Research Center.

William M. Webster, Vice President, Laboratories has announced the organization as follows: **George D. Cody,** Director, Physical Electronics Research Laboratory; **Nathan L. Gordon,** Director Systems Research Laboratory; **Gerald B. Herzog,** Director, Solid State Technology Center; **Donald S. McCoy,** Director, Consumer Electronics Research Laboratory; **Kerns H. Powers,** Director, Communications Research Laboratory; **Jan A. Rajchman,** Staff Vice President, Information Sciences; **Paul Rappaport,** Director, Process & Applied Materials Research Laboratory; **Thomas O. Stanley,** Staff Vice President, Research Programs; **James J. Tietjen,** Director, Materials Research Laboratory; **Charles A. Hurford,** Manager, Industrial Relations; **Richard E. Quinn,** Manager, Technical Services.

Jerome Kirshan, Manager, Marketing has announced the organization of Marketing as follows: **Harry L. Cooke,** Manager, Technical Relations; **Forrest L. Grimmett,** Manager, Government Contracts; **George C. Hennessy,** Manager, Research Marketing; **A. Pinsky,** Administrator, Scientific Information Services.

Professional Activities

Astro-Electronics Division

B. P. Miller has been reappointed to membership of the AIAA Space Systems Technical Committee for 1972. Mr. Miller is also a member of the AIAA Committee on the Assessment of New Space Transportation Systems.

Government and Commercial Systems

The American Association for the Advancement of Science held its annual meeting in Philadelphia in December. One of the sessions, "Engineering—for the Survival of Man," was sponsored by the AIAA and several RCA engineers participated. **T. Todd Reboul,** Staff Technical Advisor, Government & Commercial Systems organized the session; **Thomas G. Greene,** Administrator, Publications and Presentations, Missile and Surface Radar Division was the session chairman; and **James Vollmer,** Manager, Advanced Technology Laboratories, presented a talk entitled, "The P Requirements."

Advanced Technology Laboratories

Dr. James Vollmer has been appointed to the Air Force Scientific Advisory Board Committee on Laser Technology.

RCA Active in IEEE Professional Communications Group

Sig. Dierk, RCA Laboratories, and **Bill Hadlock,** Editor, *RCA Engineer* were recently elected to the Administrative Committee of the IEEE Group on Professional Communication (formerly Engineering Writing and Speech). Other RCA people active on the Administrative Committee of the Professional Communications Group are **John Phillips,** Associate Editor, *RCA Engineer* (President); **Irv Seideman,** Astro Electronics Division (Publications Chairman and *Transactions* Editor); **Charles Meyer,** Electronic Components (Awards Chairman); **Walt Dennen,** Solid State Division (Newsletter Editor); and **Eleanor McElwee,** Solid State Division.

IEEE to run 1-day courses during International Convention

During the 1972 International Convention (March 20-24) a series of 1-day short courses will be offered. Enrollment in these courses is limited. The fee for each course $20 for IEEE members, $15 for student members, and $35 for non-members. The following courses will be given:

Course title	Date	Contact
Introduction To Modern Control Logic	March 23, 1972	D. C. Hogg Dept. of Electronic Tech. Conestoga College 299 Doon Valley Drive Ditchener, Ontario, Canada (519) 653-2511
Frequency Synthesis-Applications and Techniques	March 20, 1972	Dr. J. Gorski-Popiel MIT Lincoln Laboratory Lexington, Mass. 02173 (617) 862-5500 Ext. 5866
Computer Aided Network Analysis and Design	March 21, 1972	G. Szentirmai School of Electrical Engrg. Cornell University Ithaca, N.Y. 14580 (607) 256-5270
Active Inductorless Filters: Theory and Practice	March 22, 1972	Education Registrar, IEEE 345 East 47 Street New York, NY 10017 (212) 752-6800
Integrated Circuits: A Conceptual Approach	March 24, 1972	D. C. Hogg (Address above)

Dombrosky is new Ed Rep

Richard Dombrosky has been appointed Editorial Representative for Technical Products, RCA Service Company, Cherry Hill, N.J. In this capacity, Mr. Dombrosky is responsible for planning and processing articles for the *RCA Engineer*, and for supporting the corporate-wide technical papers and reports program.

Mr. Dombrosky joined RCA Service Company in Chicago following his graduation from DeForest's Technical Institute in 1949, and was with the Consumer Products Division of RCA Service Company from 1949 to 1957 (except for 1951 and 1952 in the U.S. Army Signal Corps). In 1957, he joined the Government Service Division and was responsible for Communications Engineering at an Air Force facility. He joined the Technical Products Division of RCA Service Company in 1958 as Administrator Mobile/Microwave where he was responsible for the technical support of 150 service technicians. In this capacity, he designed several special test equipments for use by the field technicians. Mr. Dombrosky is currently Manager, Technical Support of the Technical Services Division. He is a Licensed Professional Engineer in New Jersey and also holds licenses as a Commercial Radio Operator, Amateur Radio Operator and Private Pilot. He is a member of the IEEE, the National Society of Professional Engineers, and The Franklin Institute.

Editorial Representatives

The Editorial Representative in your group is the one you should contact in scheduling technical papers and announcements of your professional activities.

Government and Commercial Systems	
Aerospace Systems Division	Engineering, Burlington, Mass.
Electromagnetic and Aviation Systems Division	Engineering, Van Nuys, Calif. Engineering, Van Nuys, Calif.
Astro-Electronics Division	Engineering, Princeton, N.J. Advanced Development and Research, Princeton, N.J.
Missile & Surface Radar Division	Engineering, Moorestown, N.J.
Government Engineering	Advanced Technology Laboratories, Camden, N.J. Defense Microelectronics, Somerville, N.J. Advanced Technology Laboratories, Camden, N.J. Central Engineering, Camden, N.J.
Government Plans and Systems Development	Engineering Information and Communications, Camden, N.J.
Communications Systems Division	
Commercial Systems	Chairman, Editorial Board, Camden, N.J. Mobile Communications Engineering, Meadow Lands, Pa. Studio, Recording, & Scientic Equip. Engineering, Camden, N.J. Broadcast Transmitter & Antenna Eng., Gibbsboro, N.J.
Government Communications Systems	Engineering, Camden, N.J.
Computer Systems	
Systems Development Division	Palm Beach Product Laboratory, Palm Beach Gardens, Fla. Marlboro Product Laboratory, Marlboro, Mass.
	Graphic Systems, Dayton, N.J.
Research and Engineering	
Laboratories	Research, Princeton, N.J.
Electronic Components	Chairman, Editorial Board, Harrison, N.J.
Entertainment Tube Division	Receiving Tube Operations, Woodbridge, N.J. Television Picture Tube Operations, Marion, Ind. Television Picture Tube Operations, Lancaster, Pa.
Industrial Tube Division	Industrial Tube Operations, Lancaster, Pa. Microwave Tube Operations, Harrison, N.J.
Solid State Division	Manager, Solid State Power Devices, Somerville, N.J. Solid State Power Device Engrg., Somerville, N.J. Semiconductor and Conversion Tube Operations, Mountaintop, Pa. Semiconductor Operations, Findlay, Ohio Solid State Signal Device Engrg., Somerville, N.J.
Consumer Electronics	Chairman, Editorial Board, Indianapolis, Ind. Engineering, Indianapolis, Ind. Radio Engineering, Indianapolis, Ind. Advanced Development, Indianapolis, Ind. Black and White TV Engineering, Indianapolis, Ind. Ceramic Circuits Engineering, Rockville, Ind. Color TV Engineering, Indianapolis, Ind. Engineering, RCA Taiwan Ltd., Taipei, Taiwan
Services	
RCA Service Company	Consumer Products Service Dept., Cherry Hill, N.J. Consumer Products Administration, Cherry Hill, N.J. Technical Support, Cherry Hill, N.J. Test Project, Cape Kennedy, Fla.
RCA Global Communications, Inc.	RCA Global Communications, Inc., New York, N.Y. RCA Alaska Communications, Inc., Anchorage, Alaska
National Broadcasting Company, Inc.	Staff Eng., New York, N.Y.
RCA Records	Record Eng., Indianapolis, Ind.
RCA International Division	New York, N.Y.
RCA Ltd.	Research & Eng., Montreal, Canada
Patents and Licensing	Staff Services, Princeton, N.J.

*Technical Publication Administrators listed above are responsible for review and approval of papers and presentations.

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