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features

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the cover

Test socket display associated with Project FIST: an NBS-developed maintenance system for modularized noncomputer electronic equipment. Shown is a test socket arrangement that guides the technician through a logical testing routine. Sockets are arranged in two ranks. The first rank (dark blue areas) consists chiefly of group tests; the second (gold areas) comprises individual module tests. Each socket has either a REPLACE or a TEST instruction. Sockets are tested sequentially proceeding from left to right and top to bottom; when a bad indication is encountered, the instruction above the "bad" socket is followed. No socket in gold area is tested unless the instruction on a bad socket in blue area so directs. Article on Project FIST begins on page 98 of this issue.

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In this issue Z. H. (Herb) Heller of AIL's Central Research Group describes an interesting parallel between the Raman laser and an early parametric, electromechanical oscillator first described by R. V. L. Hartley in the twenties.

The Raman Laser

An Electromechanical Parametric Oscillator

The advent of high-power lasers has given new impetus to studies of the Raman effect. In the early twenties C. V. Raman discovered that light waves scattered by vibrating molecules are weakly amplitude-modulated at the vibrational frequency. The "Raman spectrum," produced by incoherent monochromatic light, contains the exciting line plus characteristic "sidebands," which have been used by chemical physicists in determining molecular symmetry and structure.

In 1962, G. Eckhardt *et al.*[1], operating a Q-spoiled ruby laser containing a cell of nitrobenzene in the optical cavity, discovered the stimulated Raman laser. An intense Raman line, exhibiting spatial coherence and linewidth narrowing appeared in the output together with the primary laser line. Their frequencies were 402 and 432 terracycles respectively, the difference being the principal C-C bond stretching vibration frequency. Only the strongest vibration contributed, but several sidebands appeared. Current interest in the Raman effect is due to the possibility of generating coherent sidebands and millimeter waves.

The vast increase in Raman intensity is caused by spontaneously scattered Raman light fed back into the highest Q optical cavity mode within the Raman linewidth. It mixes with the powerful laser field through nonlinear molecular polarizability in the nitrobenzene to introduce a driving force at the natural molecular frequency, causing larger amplitude vibrations and coherent stimulated optical scattering.

The stimulated Raman laser is strongly analogous to a circuit, first investigated theoretically by R. V. L. Hartley[2] and experimentally by E. Peterson[3], which is an early ancestor of today's microwave paramps. A variable capacitor whose plates were the prongs of a tuning fork vibrating at frequency $f_v = 600$ cps was resonated electrically at $f_R = 1600$ cps with an inductance in a circuit driven by a generator at frequency f_L. Electrostatic forces between the tines coupled the mechanical and electric circuits.

Hartley predicted, and Peterson observed, that both the mechanical and electrical circuits exhibited negative resistance at f_v and f_R when the generator was driven at $f_L = 2200$ cps = $f_v + f_R$. Moreover: "When the impressed voltage was increased beyond a critical value, mechanical vibration suddenly built up, and current of the difference frequency, larger in amplitude than the current of the impressed frequency, appeared in the electrical system."

Hartley pointed out the similarity to Raman scattering in 1929, anticipating the Raman laser. Figure 1 displays the analogy pictorially. The ruby laser is analogous to the electrical generator, the electromagnetic cavity resonance at the Raman frequency to the electrical circuit, and the molecule (whose polarizability varies with vibrational displacement) to the tuning-fork capacitor. In each case, electrical and mechanical linear systems coupled by a nonlinear driving term are made to exhibit gain and oscillation. The threshold for stimulated Raman effect phonon or photon emission at the molecular resonance frequency, dc and harmonic generation, higher-order Stokes and anti-Stokes lines, all of which are observed, could have been predicted from Hartley's 1936 paper.

The author thanks Dr. Bernard Salzberg, AIL's Chief Scientist, for stimulating this study by recalling Hartley's papers and their applicability to the Raman process.

A complete bound set of our eighth series of articles is available on request. Write to Harold Hechtman at AIL for your set.

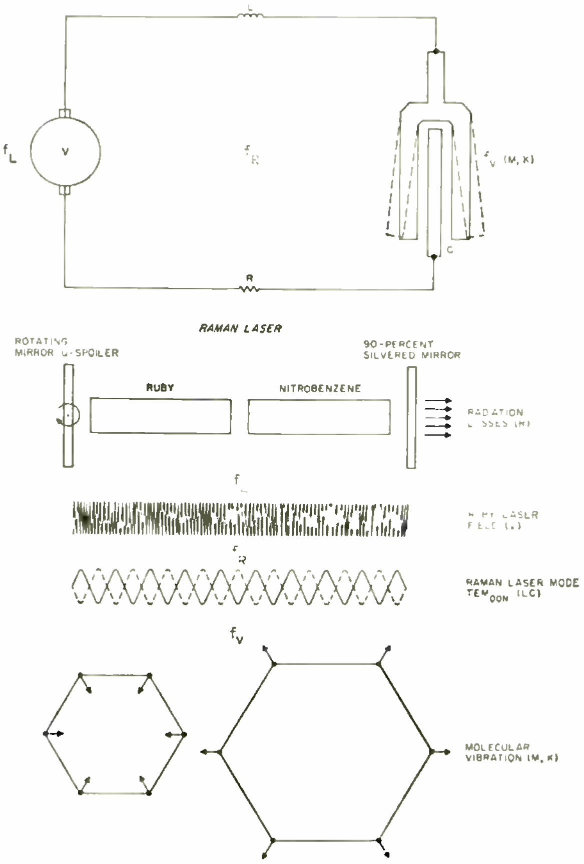


Figure 1.

ELECTROMECHANICAL OSCILLATOR

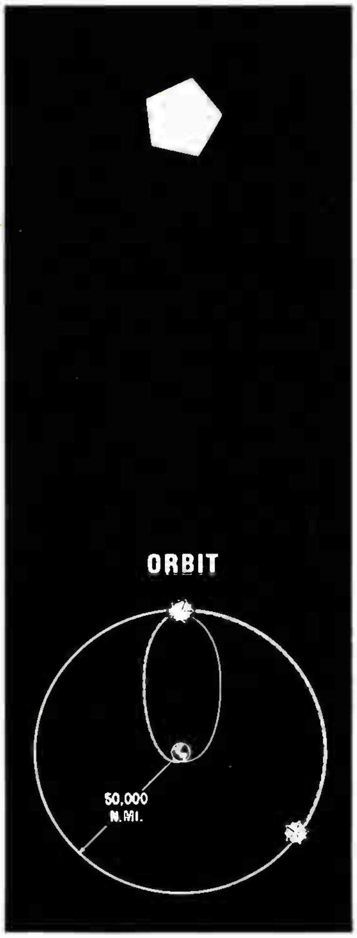
References:

[1] G. Eckhardt *et al.*, Phys. Rev. Letters, **9**, 455 (1962).

[2] R. V. L. Hartley, Phys. Rev., **33**, 289 (1929).

R. V. L. Hartley, B.S.T.J., **15**, 424 (1936).

[3] Described by: L. W. Hussey and C. R. Wrathall, B.S.T.J., **15**, 441 (1936).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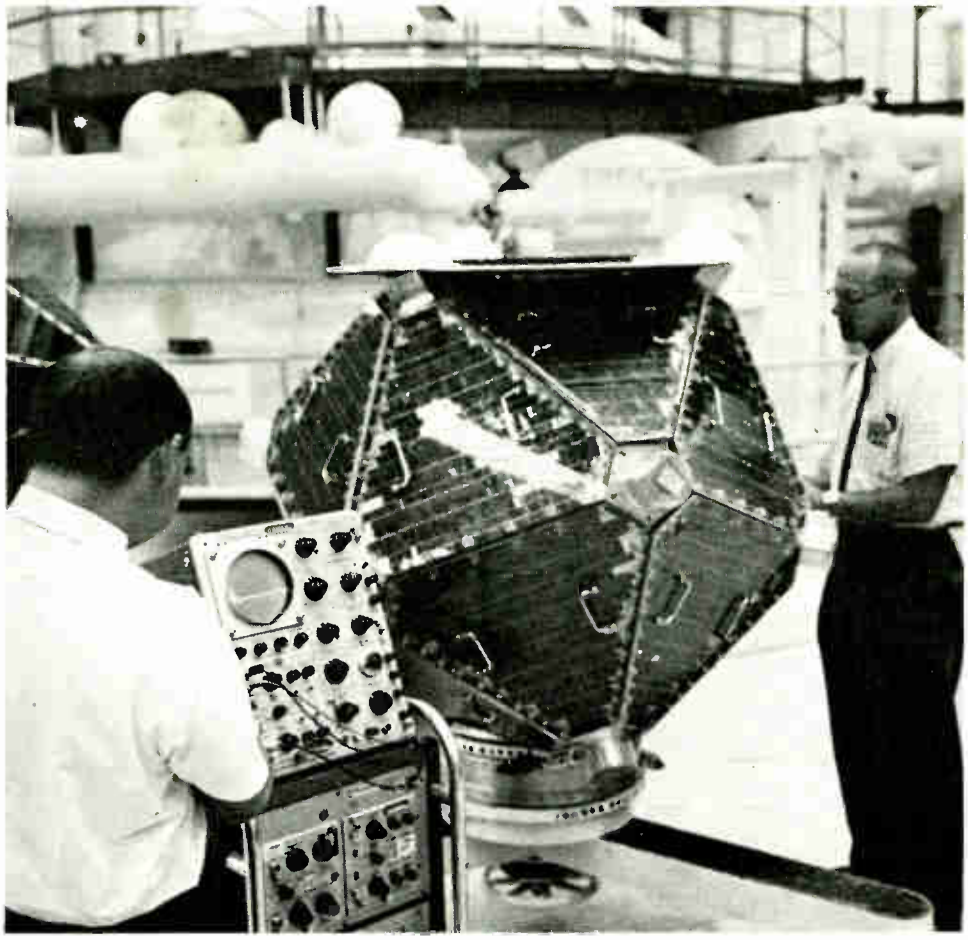
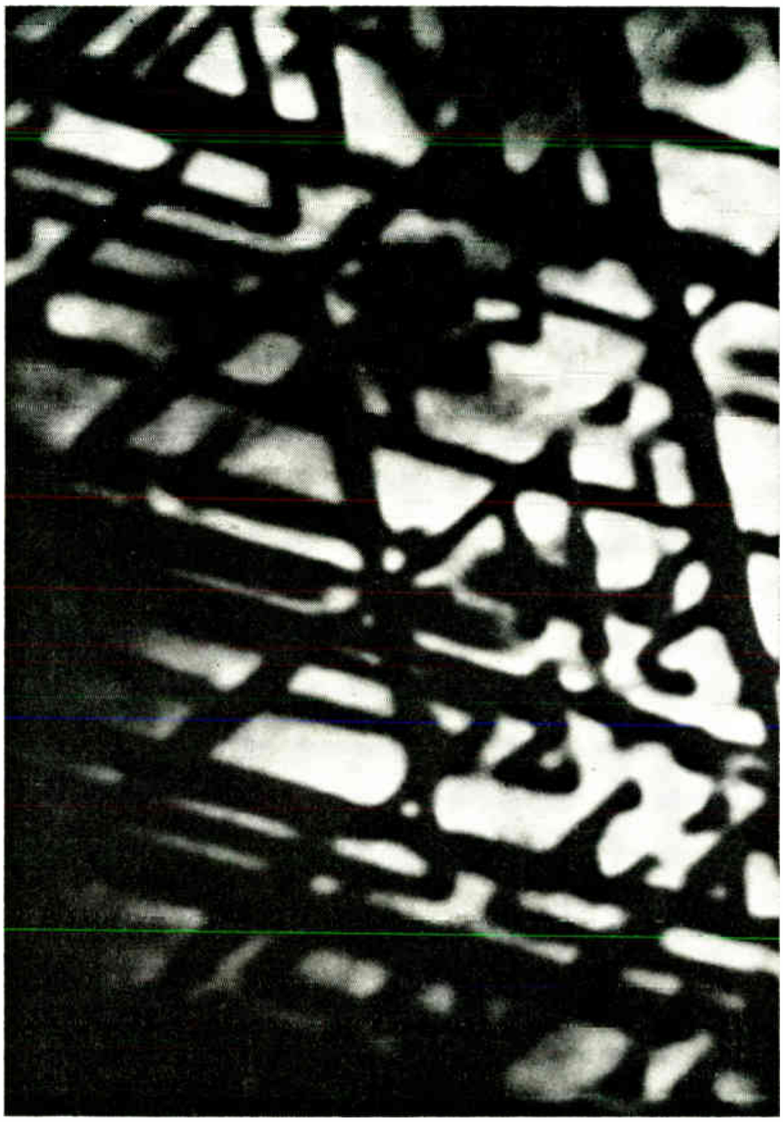


The ART of engineering

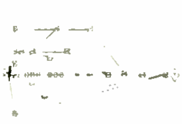


Photomicrograph of an internal view of crystal imperfections in a silicon diode. The photomicrograph was taken with a scanning electron microprobe at a magnification of 620. This new technique in microscopy developed at Bell Telephone Laboratories enables semiconductor diodes to be studied without damaging the specimens or using special treatment. The electron beam penetrates the material under study and a picture is produced by collecting the charges generated in the material by the beam. In this manner, opaque materialscan be examined. Beam energies from 4 to 50 keV are used with currents from 4 nanoamperes to 4 microamperes.

Computer Output Questionnaire

Test your knowledge of the latest methods available
for displaying and recording the
output of large-scale digital computers.

Questions



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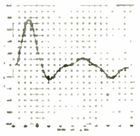

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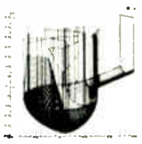

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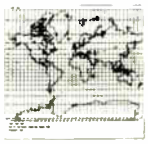

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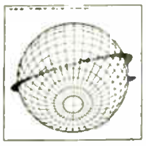

f

1 How much time was required to record the above output sample "b" on film.

a. One hour ☐ b. One minute ☐
c. One second ☐ d. One-half second ☐

2 How much time was required to print all of the above samples from tape transport start to delivery of finished paper to the engineer?

a. Thirty seconds ☐ b. Six minutes ☐
c. Twenty-five minutes ☐ d. One hour ☐

3 How much time was required to write the computer program for producing sample "b"?

a. One minute ☐ b. Five minutes ☐
c. One hour ☐ d. Four hours ☐

4 How much large-scale computer time (IBM 7090 class) was required to prepare tape for output sample "b" shown above?

a. Less than three seconds ☐ b. One minute ☐
c. Five minutes ☐ d. Ten minutes ☐

5 How many of the following output types can be produced by one versatile computer recorder already in commercial operation? (1) 16mm microfilm for automatic storage and retrieval; (2) 35mm microfilm; (3) quick-look paper copy; (4) high-quality paper copy for reports and distribution; (5) vellums; (6) page-size film negatives; (7) animated motion picture strips.

a. (1) through (3) ☐ b. (1 through 4) ☐
c. All except (7) ☐ d. All of these ☐

6 Each of the six samples above represents a specific computer output application. Match correct letter code of above samples to each of the applications listed below.

Curve Plotting ______
PERT Charts ______
Tool Path Drawings ______
Orbital Plotting ______
Mapping ______
Alphanumeric Line Printing ______

7 What is the minimum number of hours of daily usage required to justify economically an output device capable of producing all of the above samples in a matter of seconds?

a. Sixteen hours ☐ b. Eight hours ☐
c. Three hours ☐ d. One hour ☐

(Answers may be found on following page)

GENERAL DYNAMICS | ELECTRONICS GD SAN DIEGO

Answers

1 Answer: "d"—The annotated graph sample was recorded in one-half second on a General Dynamics S-C 4020 computer recorder which plots at 10,000 points/second and prints at 7,000 lines/minute. Even the most complicated sample, the map, took only six seconds.

2 Answer: "a"—Using S-C 4020's quick-look printing capability, an impatient engineer could have page-size paper output in less than 30 seconds after computer-generated tape is placed on the tape transport.

3 Answer: "b"—If x, y values of points to be plotted are stored in arrays X and Y; and titles for the graph, its x axis, and its y axis are stored in alphanumeric arrays PGTITL, XTITLE, and YTITLE, respectively, the single statement CALL AICRT3(1,X,Y,NOPNTS, 1,2,2,42, PGTITL, XTITLE, YTITLE, 1,1,32.0,1, DUMMY1, DUMMY2,1, DUMMY3, DUMMY4) will produce a labeled grid, the desired titles and the plotted curve.

4 Answer: "a"—Using the AICRT3 subroutine and its high density tape capability, S-C 4020 accepts data at input rates up to 62,500 six-bit characters per second, economizing on valuable computer time.

5 Answer: "d"—The versatile S-C 4020 produces all these types of output, including computer-generated movies. Movies are produced by creating slightly varying drawings which can be viewed with a motion picture projector.

6 Answers: Curve Plotting, b; PERT charts, a; Tool Path Drawing, c; Orbital Plotting, f; Mapping, d; Alphanumeric Line Printing, e; S-C 4020 allows organizations to use computers to translate output into graphic form for many different departments and groups.

7 Answer: "d"—In many centers where S-C 4020s are in operation, one hour or less of use per day justifies the cost. One user performs a complex plotting job for engineering, in a few minutes, which previously took a large drafting department several days. The same highly precise annotated charts are now produced simultaneously on paper and on microfilm.

For information on S-C 4020, write Dept. E-35, General Dynamics | Electronics, P.O. Box 127, San Diego, Calif.

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Reflections

75 years ago

Underground Distribution. "In referring to overhead electric light work I am speaking rather of the past than of the future, because I think you are aware the commission appointed by the Board of Trade, which has lately gone into the whole matter, has formed a set of regulations under which the whole of the electric lighting in London is to be placed underground as soon as possible. No additional overhead wires are allowed to be placed, except such as may be agreed upon between the inspectors and the various companies, and the central station companies in London are now very hard at work laying down mains. However, there is no doubt a good deal of overhead work will be required for various purposes, and as you have so much overhead work here perhaps it might be worth while to explain our practice. First of all, we have not been allowed to plant posts in the streets at all, except in country roads. Within the boundaries of towns it is an absolute rule that no posts can be fixed in the streets. If we want posts we must put them in people's back gardens and in vacant lots, etc. Of course this has required that the majority of posts be placed on the tops of the houses. In foreign towns they have also had to go on the tops of the houses very largely. They have adopted one construction; we have adopted another. On the Continent most of the roofs have a very steep slope, and are tiled so that it is quite impossible to walk on them, and, of course, people do not put up stronger roofs than they can help—only strong enough to support the tiles and stand the wind, but not strong enough to support telephone posts. On such buildings they use two long pieces of timber, and form what they call a horse. That consists of a number of uprights and a lot of cross frames. I think you have some of them here. Nearly the whole of the work is done in that way. In England we went to work in quite a different way. As Mr. Lockwood said, it is not unusual in London, at any rate, in overhead work on houses, to have wires arranged horizontally. As a rule there is but a single span. We have first of all what we call a chair. That is an iron casting weighing from fifty to sixty pounds that goes on the top of the roof. From this rises a wrought-iron tubular pole. These tubes are carefully made to specification; they are about three inches internal diameter. It is usual to put up a pole of not less than 18 feet, but they range as high as thirty. In such cases as the latter, it is usual to have two or three poles, one inside the other, each pole having a collar and a bolt going through. These poles are simply stayed to the brickwork. Heavy spikes are driven into the brickwork, and it is rather an agonizing process for the house as you may imagine, but somehow men have a way of doing it, and they drive spikes eight inches long into the brickwork. It is wonderful how the masonry stands it. I may say I have seen some very large cracks occasionally. The wall itself will sometimes split out in the plaster joint. Each pole will have at least four of those stays under ordinary circumstances, and then of course it has to be stayed in accordance with the rules.

"When I came to America and saw the mass of wires running in all directions, it reminded me of what we call the early days of telephones in London, and we had so many faults with wires then that I could not understand how things worked. So I looked about me and I find apparently the difference is that we think nothing of a span of 120 yards. Sometimes in telephone work we go 200 yards, and 150 yards is considered very little for a span of wires. Of course in running wires that distance there is a very considerable amount of sagging, and in a wind they are liable to come in contact with each other, and they are also apt to get out of regulation; that is, wires put in when the weather is hot, and wires put in when it is cold, and brought into unison, will get out of unison occasionally. So that, perhaps, accounts for the reason why you are able to run such a mass of wires about the streets and yet get along at all." (G. L. Addenbrooke, discussion of T. D. Lockwood's paper, "Electrical Notes of a Transatlantic Trip," *Trans. AIEE*, vol. VI, Nov. 1888–Nov. 1889, pp. 428–429.)

50 years ago

A Young Man's Game. "Several persons have suggested that the law should specify a minimum age limit for commercial radio operators, especially for shipboard work. Such a law might have certain advantages but would be difficult to enforce.

"If, for instance, a minimum age of 18 were fixed, we all know that a great many excellent operators would be disqualified, and many undesirable candidates would not hesitate to overstate their age, even under oath. This latter statement is known to be a regrettable fact and is substantiated by statistics of services in which a minimum age is specified, even tho a severe penalty for false statement of age is provided. It is not practicable to search out birth certificates of several thousand men per year.

"After all, so far as existing conditions are concerned, the question of age seems to have adjusted itself quite satisfactorily, and in this, as before, the person employing an operator may be expected to employ older men for the more responsible positions.

"There are a few boys 15 years of age holding commercial first-grade licenses, but from a search of inspection records on file in the Bureau of Navigation it does not appear that any of these are employed at commercial stations or on ships as senior operators.

"We give herewith a chart showing the ages of licensed operators, commercial first and second grades.

DEPARTMENT OF COMMERCE

Bureau of Navigation, Radio Service.
Washington, February 28, 1914.

COMMERCIAL WIRELESS OPERATORS

The following tables show the number of commercial radio operators and their

ages at the time licenses were issued by the Secretary of Commerce.

Of the first-grade operators 57 per cent. were 21 years of age or older, while 83 per cent. were 18 or older.

Of the second-grade operators 49 per cent. were 21 years of age or older, while 75 per cent. were 18 or older.

Of both grades 82 per cent. were 18 years of age or older.

First-grade Operators.

Ages	Number
21 or older	1,197
20	244
19	293
18	197
17	119
16	36
15 or under	13
Total	2,099

Second-grade Operators.

Ages	Number
21 or older	120
20	29
19	38
18	23
17	18
16	13
15 or under	6
Total	247
Grand total both grades	2,346

"It is interesting to note that most of the operators are 19 years of age. This is true of both the first and second grades. It is assumed that if the number 21 years of age and above were shown, the curve would drop down from 19 as indicated at 20.

"The maximum at 19 may be accounted for if we assume that "wild oats" are usually ripe at about that age. I think that most young men who are suddenly imbued with a desire to leave home for a career at sea as radio operators are about 19 years of age. (Such was my own personal experience and while I do not advocate or approve of young men leaving school at this age, unless necessary, I believe the radio operating field offers such young men much better opportunities than many other lines of work that they might follow.) There may be other interesting psychological reasons accounting for this age maximum." (V.F. Greaves, "The Radio Operator Problem," *Proc. IRE*, September 1914, pp. 195–210.)

Railway Electrification. "Of a total of ten notable instances of steam railway electrification in this country, the Butte, Anaconda & Pacific was the first if not the only one in which the prime cause for the change in motive power was an expected decrease in operating expenses sufficient to give immediately a satisfactory earning on the new investment of capital required for the improvement.

"The preliminary investigations and estimates had indicated a probable annual saving amounting to about 17.5 per cent on the total investment, of which 11 per cent was expected to result from the partial substitution of electrical energy, costing about 0.552 cent per kw-hr. at the secondaries of the substation transformers, for coal of 12,250 B.t.u. calorific value and costing $4.25 per ton delivered. The remaining 6.5 per cent was expected from reduced cost of locomotive maintenance, engine house expense and enginemen's wages.

"On this prospect, an expenditure of $1,201,000 was made in the electrification of 90 miles of track and in replacing 22 steam locomotives by 17 electric locomotive units which now operate about 80 per cent of the total locomotive-miles.

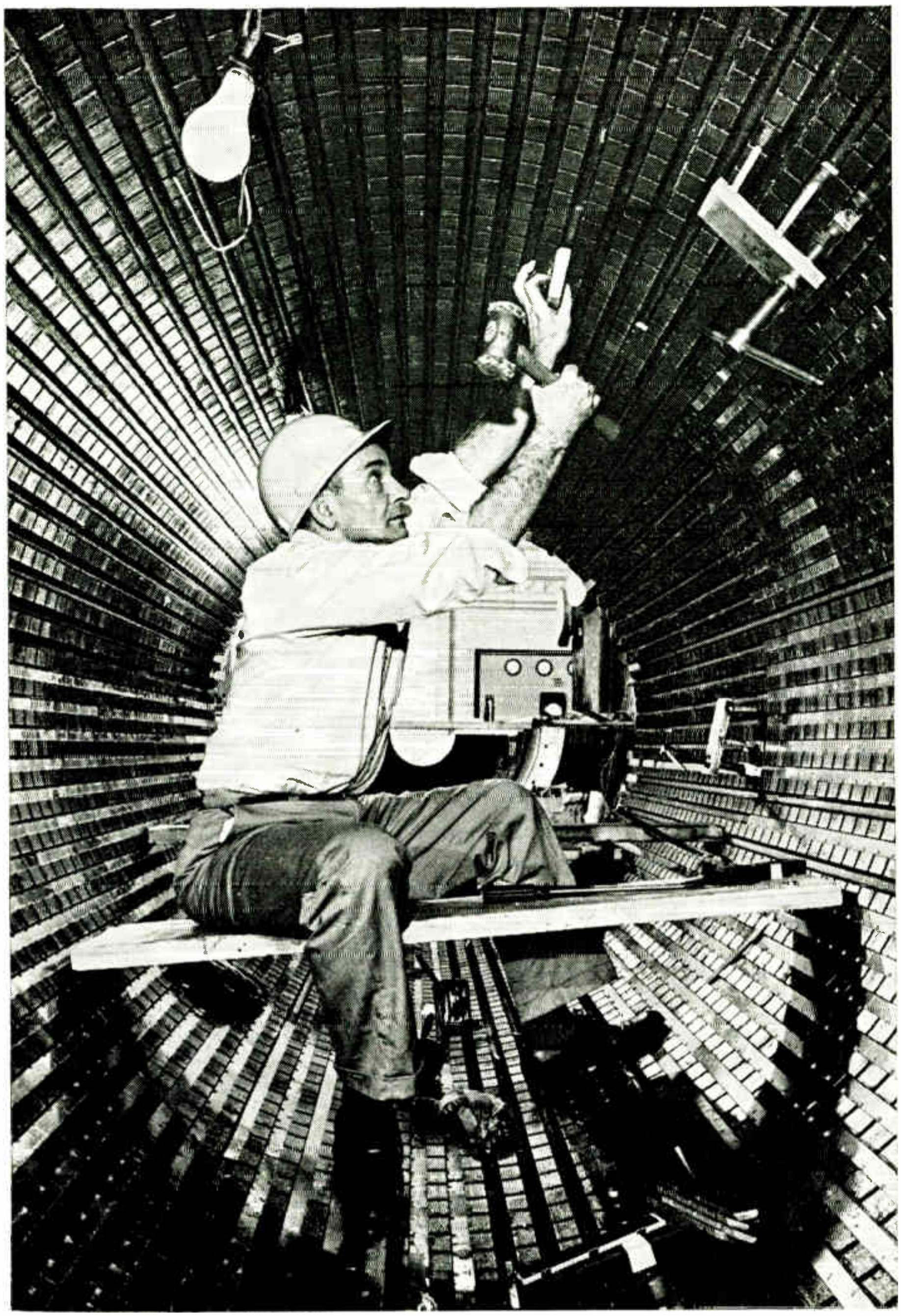
"The actual results as indicated by the first six months of full electrical operation show the total net saving in operating expense to be at the rate of $242,299.12 per year or an earning of 20.02 per cent on the investment, of which the decrease in the cost of coal and power is 12.5 per cent.

"Other savings are due to decreased cost of locomotive maintenance, engine house expenses, lubricants, supplies and trainmen's wages.

"The average tons per train hauled by the electric locomotives has increased 33 per cent, the average time per trip decreased 30 per cent, the delays to traffic decreased 41 per cent, the number of trains decreased 25 per cent and the number of engine and train crews decreased 25 per cent." (J. B. Cox, "The Electrical Operation of the Butte, Anaconda & Pacific Railway," *Trans. AIEE*, vol. XXXIII, Part II, 1914, pp. 1369–1403.)

25 years ago

Supersonic TV. "This paper is the first of a series of four giving an account of the Scophony system of television reception. There appears to be a popular misconception that the Scophony receivers represent the application of the mechanical methods used for the low-



definition television of a few years ago to modern picture standards. It cannot be emphasized too clearly that the Scophony system is based on the principle of the temporary storage of picture signals, made possible by the supersonic cell, and its conception has nothing in common with the mechanical television of the past.

"The method has been developed to the stage where pictures of the highest quality up to fifteen feet wide are available for use in cinemas, while 18- and 24-inch pictures are produced for the domestic market.

"It is significant that in a world of television research on electronic lines, Scophony stands alone in using entirely optical methods, and by employing these means it has actually set the pace for large-screen television in England.

"The demonstration by Debye and Sears of the diffraction of light by supersonic waves in a liquid (see Fig. 1) opened up new possibilities and in 1934 Jeffree first showed how this effect could be used as the basis of a light control of negligible inertia and power consumption and with reasonable light efficiency up to the highest picture definition. With this supersonic light control it is possible to modulate a beam of light from an independent light source and the latter, therefore, can be chosen solely on its merit as a bright, efficient, and suitably colored source.

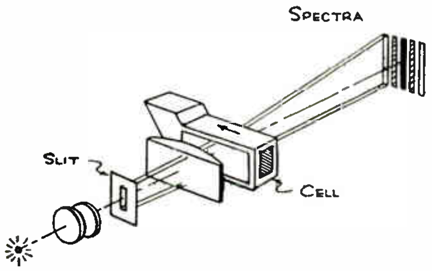


Fig. 1—Diffraction of light by supersonic waves in liquid showing the first-order (shaded) and second-order (unshaded) diffraction spectra, and the normal position of the image of the slit (black).

Moreover the beam so controlled can be projected directly on to a screen to give large pictures without the necessity for an expensive lens of high aperture. The cell is extremely simple in construction, has unlimited life, is robust and stable, and can be driven from a normal receiver-type output tube, the driving power being independent of the size of the picture.

"The supersonic light control consists

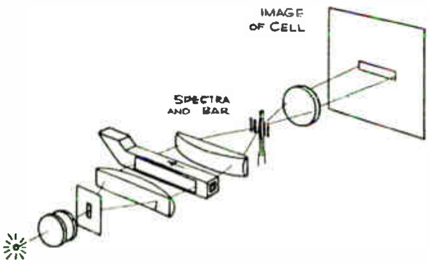


Fig. 2—The supersonic cell as a light control for television. The lens between the slit and cell insures that the light in the latter shall be parallel, while the similar lens on the far side of the cell brings this parallel beam to focus at the bar. The central image is stopped out by the bar and the diffracted light passes on to a further lens, which is arranged so as to form an image of the liquid column on the screen.

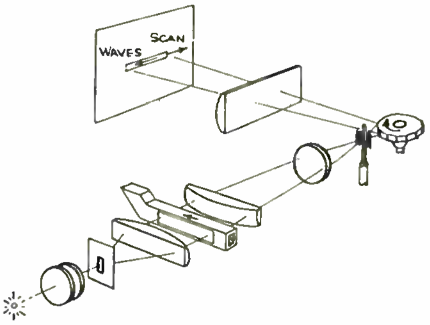


Fig. 3—Immobilization of the supersonic shadows on the screen. A high-speed scanner polygon is placed behind the stop bar and the whole is so arranged that the scan and wave motions cancel each other on the screen. The required width of picture line is obtained by a cylindrical lens which forms an image of the scanner surface on the screen in the direction perpendicular to the scanning direction.

of a glass-sided cell filled with a transparent liquid with a piezoelectric crystal having a natural frequency between 5 and 30 microseconds immersed in the liquid or inserted in one wall of the cell. The crystal is provided with electrodes on opposite faces and these electrodes are fed by a high-frequency carrier the frequency of which is approximately that of the crystal, and the amplitude of which may be modulated by the video-frequency signal received from the transmitter.

"The electrical excitation at the natural frequency of the crystal causes the latter to vibrate mechanically; it dilates and contracts in the direction of its thickness. These vibrations are transferred to the liquid as a series of compressions and rarefactions which move forward from the crystal at the

Marconi Self-Tuning H.F system—
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An h.f linear amplifier transmitter
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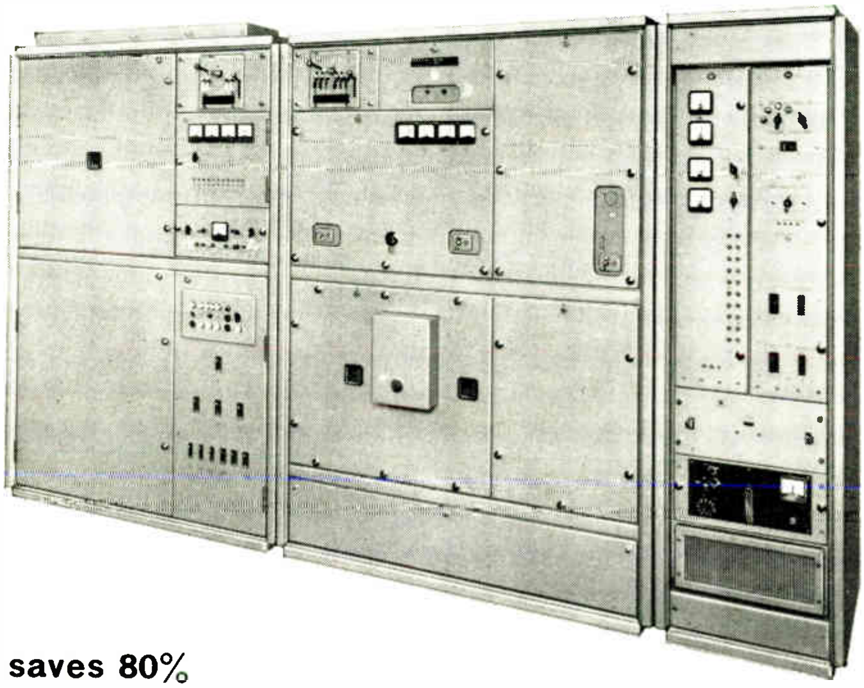
Frequency range: 4-27.5 Mc/s.
Output power: 30 kW p.e.p, 20 kW c.w.
Meets all CCIR Recommendations.



saves 80% floor space

Transmitters can be mounted side by side and back to back or against a wall. Floor-ducts are eliminated and all power supply components are built-in. These features lead to smaller, simpler, cheaper buildings or more services in existing buildings.

rugged reliability

R.F circuits have been simplified and the number of mechanical parts reduced to a minimum. Highest engineering standards are applied to the design of these parts: stainless steel shafts in ball-bearings in heavy, rigid, machined castings; stainless steel spur gears meshing with silicon bronze; heavy r.f coil contacts with high contact pressure. Specified performance is maintained with ample margins.

simplicity

MST reliability allows continuous unattended operation with extended or remote control, saving maintenance and operating staff. Any fault in the servo control circuits can quickly be located with simple test routines. Transistors and printed wiring give these circuits maximum reliability.

self-tuning

The H1200 has a frequency following servo tuning system. Any frequency may be selected on the synthesizer decade dials in the associated MST drive equipment; the unattended transmitter automatically tunes itself in an average time of twenty seconds. Final stage tuning and loading servos continuously ensure automatic compensation for changes in aerial feeder impedance caused by weather conditions. Self-tuning gives *one-man* control of an entire transmitting station.

Marconi telecommunications systems

The Marconi Company Limited, Communications Division, Chelmsford, Essex, England LTD/H51

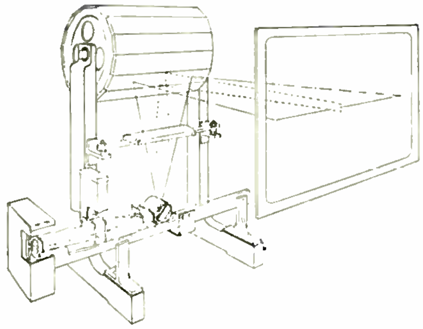
World Radio History

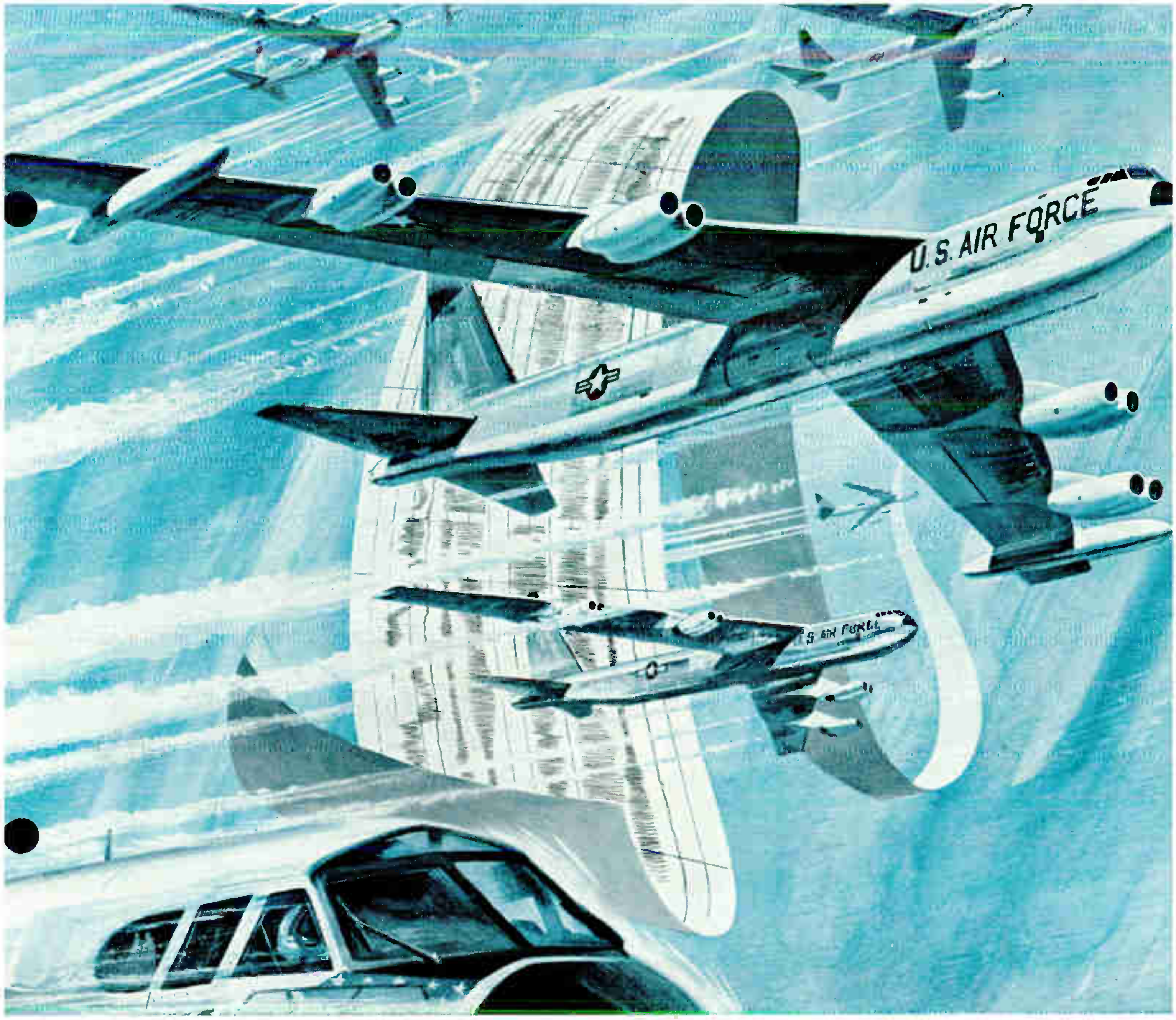
speed of sound in the liquid, forming a train of supersonic waves. Thus the density of the liquid varies periodically in the direction of travel of the wave train and the index of refraction varies with it. Light passing through the layer of waves perpendicular to the direction of motion of the waves is retarded by the compressive and accelerated by the rarefied half waves and since the supersonic wavelength is small (of the order of 0.1 millimeter) interference of the emergent light takes place and diffraction spectra are produced.

"The intensity of the light deflected from the normal beam into the diffraction spectra is proportional to the amplitude of the high-frequency carrier applied to the crystal. It is a simple matter to arrange that the normal beam shall be stopped out, and the light from the side images utilized on the screen to give an intensity proportional to the received vision signal.

"Scophony has developed a home receiver giving a two-foot picture and a picture 18×14 inches for the smaller-size living room. These receivers use a superpressure mercury lamp. This lamp, of the air-cooled type, has been especially developed in the Scophony Laboratories. Its brightness when consuming 300 watts is about 30,000 to 35,000 candles per square centimeter. The brightness of the 18-×14-inch picture is between 6 and 10 foot-candles measured in the high lights, representing peak white. This brightness is essential for home-receiver requirements, since it may in some cases be desirable for the receiver to be used in a room with a considerable amount of daylight or artificial light. Six to ten foot-candles is ample. The receiver often has been demonstrated with full daylight falling directly on the front of the screen from a near-by window. The picture was still clearly visible for the translucent rear-

Fig. 4—Optical chassis of home receiver giving a picture 18 inches wide, by back projection.





How Lockheed helps keep aircraft on full combat status

A revolutionary monitor developed by Lockheed now gives military aircraft the important capability of performing extra missions. By detecting, locating and predicting malfunctions during flight this Lockheed monitor, called MADREC, substantially reduces downtime. Already in use on B-52's, B-47's and presently being adapted to P-3A's and F-4B's, it has established an enviable record of keeping these aircraft on full operational status a greater percentage of time.

MADREC (Malfunction Detection and Recording Equipment) graphs a continuous record of the performance of the plane's electronic systems. Either during, or after, a mission, the graph is matched against a test pattern. Malfunctions show up clearly as deviations, eliminating many hours of trouble-shooting to isolate the defective items. MADREC was developed by the Lockheed-Georgia Company and incorporates major sub-systems designed and built by the Lockheed Electronics Company.

In the missile field, where instant readiness is critical and in-flight procedures not practical, Lockheed Electronics developed simulators which duplicate electronically exact operating conditions. One such system now in use is TRACE, developed in conjunction with other Lockheed divisions for use with the Polaris missile. It keeps the launch and flight systems of Polaris meticulously checked out and always in instant readiness.

If you have a simulation or checkout problem which needs to be solved fast, and with a minimum of red tape, look to Lockheed Electronics for leadership.

LOCKHEED ELECTRONICS COMPANY
PLAINFIELD, N. J. / A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

RADAR • ASW • TELEMETRY • OPTICS • TRAINERS • CHECKOUT EQUIPMENT • R & D • ENGINEERING SERVICES

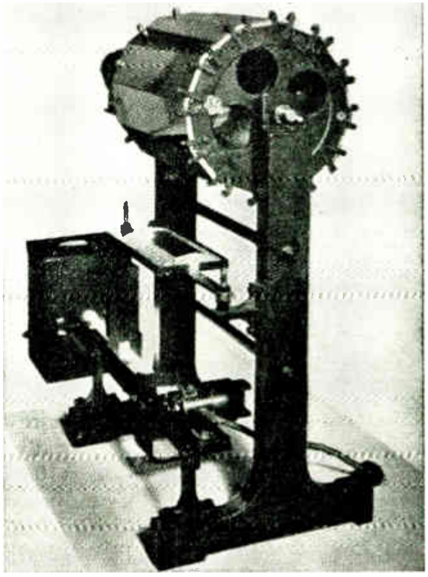


Fig. 5—Optical chasis of home receiver showing high- and low-speed scanners and supersonic light-control cell.

projection screen made this advantage possible.

"In the large-screen television apparatus up to 6- to 8-foot pictures, for new cinemas, schools, etc., exactly the same optical and electrical system is used with a high-intensity arc lamp as the light source, and a different number of mirrors in the low-speed drum to correct for the increased projection distance.

"The screen used is of plate glass suitably sandblasted or special translucent screens made in the laboratories.

"The peak-white screen illumination on a 6-foot picture is in the region of 3 foot-candles and this has been found the minimum necessary for cinema projection where the usual auditorium lights are left burning.

"In the larger picture apparatus up to sizes of 15 feet, a screen illumination of 3 foot-candles is retained using improved optical and electrical systems.

"The reliability of the apparatus is very gratifying, and the installations carried out at the world's first Television News Theatre at Marble Arch, London, and the Odeon Theatre, Leicester Square, where a 15- by 12-foot screen is used have been absolutely trouble-free.

"It may be of interest to state that, although this and other related papers deal with apparatus for the British television standard of 405 lines, 50 frames a second, receiving and transmitting apparatus has already been designed by Scophony for the proposed American Standard of 441 lines, 60 frames a second." (D. M. Robinson, "The Supersonic Light Control and Its Application to Television With Special Reference to the Scophony Receiver," *Proc. IRE*, August 1939, pp. 483–486. Also, J. Sieger, "The Design and Development of Television Receivers Using the Scophony Optical Scanning System," *ibid.*, pp. 487–492.)

Why Are You an Engineer? "If our daily jobs, if our purposes for this American Institute of Electrical Engineers, if our conduct as citizens are to be more than a perfunctory performance of ritual, a mechanical service of institutions, we must know what we are after. It is not enough that a more abundant supply of cheap electricity, a more perfect art of communication, a national system of broadcast of television, more efficient motors, or more dependable circuit breakers should be built by us; it is not enough that stockholders should receive a more nearly adequate return because of our employment; it is not enough that our Institute be larger or financially sounder or that its publications represent a higher level of scientific and literary contribution; it is not enough that our nation shall be secure against enemies at home and abroad or that prosperity shall return to the land. These things are good; they are the things that we must bring about; but we must know in our several jobs, in our professional organization, in our operations as citizens, what we individually have in mind as the ultimate reason for the sacrifices that we are prepared to make and to ask of others. . . "

"There is a quality in men as they work at their jobs; there is a quality in professions as such; there is a quality in the citizenship of each nation that inevitably is expressive of inner light which unconsciously, unobtrusively gives direction to specific acts of performance and which in the aggregate accomplishes the greatest influence in human affairs. It may defy definition, but it is patent to all. . . "

"I recommend to the membership of the Institute individual responsibility, individual work, and an organization developed along representative lines, but above all else that, in the odd moments between wakefulness and breakfast, we occasionally give some thought to why we are engineers and why engineering should be a part of the processes of human life." (J. C. Parker, "Responsibilities in the AIEE," *Electrical Engineering*, vol. 58, 1939, pp. 330–332.)

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Spectral lines

Those Happy Days Are Gone Forever. Once upon a time, during the reign of good King Steady-State, when the technical world was young, our engineering campuses were happy places. The ivy grew undisturbed on those classrooms and shops down by the power plant, and in their offices the faculty maintained a serenity engendered by their certainty of what they would teach next year—and the next, and the next. A summer vacation was to be enjoyed at the cottage on the lake, not sandwiched between summer institutes, research conferences, and a graduate class. In that day the curricula were planned to graduate engineers, and the faculty were very sure of that. The technical world was bounded and almost complete; had not Newton, Bernoulli, Carnot, Faraday, and their kind established all the rules?

And then came the electron, the quantum, and wave mechanics, the overdue realization that mathematics was for use, the discovery that new knowledge could be found through organized research.

The electrical engineering field can be thankful for the fact that electric charge and current are invisible. In the early days their conceptual nature forced the use of analytic methods as against the touch-and-see approach of other fields. Electrical science became the field of the theoretician whose tool was mathematics; the electron's uncertainties and its place in the wave-mechanical structure of matter strengthened this alliance with the basic sciences. Electrical education was thus directed along the theoretical and mathematical road; it has also profited from the stimulus of a new field, electronics. Electrical industry has contributed unity and foresight, has long advocated the teaching of more fundamental material, and has accepted as its own burden much additional teaching not possible in the schools.

Even so, came the 1940s and World War II, electrical education was not ready for change. Other engineering fields, not so fortunate in character of subject matter or in choice of forebears, or lacking in major industry leadership, were even less ready to prepare engineers for the new technical world. Only a few schools showed, through their development of graduate study and research programs, that they were aware that the technical world was no longer static—that change was to be a normal pattern; that the technical world was no longer bounded—that we faced new problems on which no practical experience existed; that an engineer would often be a team worker—and required depth in his own field, and breadth in many fields; and that engineers must serve as useful members of society—that they must be recognized by the world as educated men and women.

Most of the major educational change has occurred in the last 15 to 20 years. What of the vast number of engineers graduated pre-1950 who had no opportunity to know of the changes in education? Can we provide them with an awareness of modern mathematical methods, quantum concepts of materials, an appreciation of the importance of transient analysis, or of system views instead of component details? Can they be made knowledgeable of modern computer and numerical methods?

These men can turn the indicated technical corners, but only as a result of monumental individual effort and strong industry support of widespread programs of continued education. Such programs are being developed by some schools, or are being worked on cooperatively between schools and particular industries. The schools can usually supply the teaching, but industry will have to supply most of the classroom time, much motivation, and the financing as well.

Let it first be recognized that these men are primarily employees, and students only secondarily. Standards of academic work accomplished after an eight-hour workday will not equal those set by the usual on-campus full-time student. Graduate degrees should not, perhaps, be the usual objective; motivation may have to be supplied more directly by the employer.

So far it seems that the most powerful stimulus to employee participation is given by programs not only subsidizing the teaching costs, but which arrange for teaching on company time and, where feasible, on company property. Such plans range from a contribution of a few hours per week to several days per week, and even to full time allowances for study; the latter are usually reserved for formal graduate programs leading to degrees.

Some schools are arranging special courses directly intended for the re-education function; other industries are planning to teach their own programs which range from six-week courses at company educational centers to monthly one- or two-day seminars. Research-based industries seem more aware of educational need than are production-oriented companies. Their attitudes are reflected in ability or inability to hire current graduates—the better students are nearly always interested in opportunities to continue learning—and opportunities for company-sponsored programs leading to advanced degrees are powerful sales tools.

Not all companies are located on university doorsteps, and not all companies are large enough to give supervisors free time at random. For such cases, the professional society publications can partially fill the need—thus TRANSACTIONS, SPECTRUM, and PROCEEDINGS.

The ivy is off the walls—the classrooms and faculty must go where the educational need exists—those past happy and soporific days on campus will not return.

J. D. Ryder

Proposed automatic calculating machine

Here presented is the memorandum that 20 years ago initiated a series of events whose revolutionary implications are only beginning to manifest themselves—a description of the first large-scale general-purpose automatic digital computer

Howard Aiken *Harvard University and University of Miami*

A Note on the Twentieth Anniversary of the MARK I Computer—Aug. 7, 1964

Twenty years ago, on August 7, 1944, MARK I, the first large-scale general-purpose automatic digital computer ever to be put in operation was dedicated at Harvard University by James B. Conant, then president of Harvard, and the late Thomas J. Watson, founder of IBM.

Howard Aiken, now Professor of Applied Mathematics, Emeritus, had already put MARK I, fully named the "IBM Automatic Sequence Controlled Calculator," to work several months earlier, in May 1944.

These events were the culmination of an effort begun by Aiken seven years earlier and brought to fruition through his collaboration with IBM.

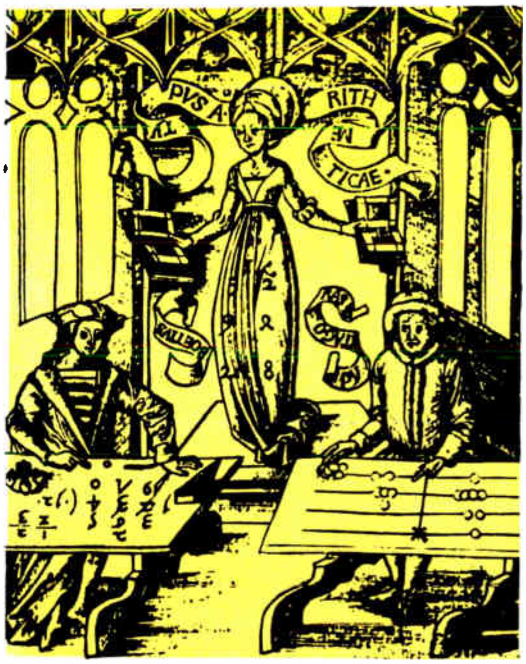
A copy of the unpublished memorandum in which Aiken first outlined his conception of MARK I was recently discovered in Professor Aiken's Harvard files by Mrs. Jacquelin Sanborn Sill, and through her efforts is presented here with the author's permission. The memorandum itself is undated, but an unknown recipient's handwritten notation "Prospectus of Howard Aiken, November 4, 1937" puts an upper bound on the date for its preparation.

The memorandum is remarkable not only for the insight it gives into an historic event and for its historical value, but also for its clear style, its depth and breadth of scholarly perception, and its startling freshness after over a quarter of a century. The careful referencing of the work already done by others, and the conservative, accurate estimate of the potentialities of the machine to be constructed, place Aiken's initial contribution as precisely as is possible, even at this late date.

The MARK I computer was constructed during the period 1939 to 1944. MARK I was synchronous and parallel; numbers were represented as using 23 decimal digits plus sign. As the memorandum also prescribes, MARK I could perform addition, subtraction, multiplication, and division directly. Subroutines using special registers provided values for sines, logarithms, and antilogarithms. The input devices were punched cards and the output devices punched cards and electric typewriters. The actual sequencing of operations was controlled by perforated paper tape in order that the machine "should be fully automatic in its operation once a process is established."

A large percentage of MARK I's operating time during the early years of operation was for classified Navy projects. The machine further produced a number of standard tables of values for mathematical functions, the principal tables being published in the *Annals of the Computation Laboratory of Harvard University*. Various other studies at Harvard made use of the machine, including some well-known work on systems of linear equations directed by Professor Wassily Leontief of the Department of Economics.

MARK I was retired in July 1959. One half of the machine now resides in the Harvard Computation Laboratory, and the remaining part is on display



in the Smithsonian Institution in Washington, D.C.

The original of the memorandum, which is now deposited in the Harvard University Archives, is a draft bearing a few erasures, corrections, queries, etc. A version amended in accordance with these corrections is presented here.

Further material on the Mark I and Howard Aiken may be found in the references following. The biographical data on Professor Aiken on the "Authors" page was prepared by Mrs. Jacquelin Sanborn Sill.

A. G. Oettinger
T. C. Bartee
Computation Laboratory, Harvard University, Cambridge, Mass.

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The desire to economize time and mental effort in arithmetical computations, and to eliminate human liability to error, is probably as old as the science of arithmetic itself. This desire has led to the design and construction of a variety of aids to calculation, beginning with groups of small objects, such as pebbles, first used loosely, later as counters on ruled boards, and later still as beads mounted on wires fixed in a frame, as in the abacus. This instrument was probably invented by the Semitic races and later adopted in India, whence it spread westward throughout Europe and eastward to China and Japan.

After the development of the abacus, no further advances were made until John Napier devised his numbering rods, or Napier's Bones, in 1617. Various forms of the Bones appeared, some approaching the beginning of mechanical computation, but it was not until 1642 that Blaise Pascal gave us the first mechanical calculating machine in the sense that the term is used today. The application of his machine was restricted to addition and subtraction, but in 1666 Samuel Moreland adapted it to multiplication by repeated additions.

The next advance was made by Leibnitz who conceived a multiplying machine in 1671 and finished its construction in 1694. In the process of designing this machine Leibnitz invented two important devices which still occur as components of modern calculating machines today: the stepped reckoner, and the pin wheel.

Meanwhile, following the invention of logarithms by Napier, the slide rule was being developed by Oughtred, John Brown, Coggeshall, Everard, and others. Owing to its low cost and ease of construction, the slide rule received wide recognition from scientific men as early as 1700. Further development has continued up to the present time, with ever increasing application to the solution of scientific problems requiring an accuracy of not more than three or four significant figures, and when the total bulk of the computation is not too great. Particularly in engineering design has the slide rule proved to be an invaluable instrument.

Though the slide rule was widely accepted, at no time, however, did it act as a deterrent to the development of the more precise methods of mechanical computation. Thus we find the names of some of the greatest mathematicians and physicists of all time associated with the development of calculating machinery. Naturally enough, in an effort to devise means of scientific advancement, these men considered mechanical calculation largely from their own point of view. A notable exception was Pascal who invented his calculating machine for the purpose of assisting his father in computations with sums of money. Despite this widespread scientific interest, the development of modern calculating machinery proceeded slowly until the growth of commercial enterprises and the increasing complexity of accounting made mechanical computation an economic necessity. Thus the ideas of the physicists and mathematicians, who foresaw the possibilities and gave the fundamentals, have been turned to excellent purposes, but differing greatly from those for which they were originally intended.

Few calculating machines have been designed strictly for application to scientific investigations, the notable exceptions being those of Charles Babbage and others who followed him. In 1812 Babbage conceived the idea of a calculating machine of a higher type than those previously constructed, to be used for calculating and printing tables of mathematical functions. This machine worked by the method of differences, and was known as a difference engine. Babbage's first model was made in 1822, and in 1823 the construction of the machine was begun with the aid of a grant from the British Government. The construction was continued until 1833 when state aid was withdrawn after an expenditure of nearly £20 000. At present the machine is in the collection of the Science Museum, South Kensington.

In 1834 George Scheutz of Stockholm read the description of Babbage's difference engine and started the construction of a similar machine with the aid of a governmental grant. This machine was completed and utilized for printing mathematical tables. Then followed several other difference engines constructed and designed by Martin Wiberg in Sweden, G. B. Grant in the United States, Leon Bolleé in France, and Percy Ludgate in Ireland. The last two, however, were never constructed.

After abandoning the difference engine, Babbage devoted his energy to the design and construction of an analytical engine of far higher powers than the difference engine. This machine, intended to evaluate any algebraic formulae by the method of differences, was never completed, being too ambitious for the time. It pointed the way, however, to the modern punched-card-type of calculating machine since it was intended to use perforated cards for its control, similar to those used in the Jacquard loom.

Since the time of Babbage, the development of calculating machinery has continued at an increasing rate. Key-driven calculators designed for single arithmetical operations such as addition, subtraction, multiplication, and division, have been brought to a high degree of perfection. In large commercial enterprises, however, the volume of accounting work is so great that these machines are no longer adequate in scope.

Hollerith, therefore, returned to the punched card first employed in calculating machinery by Babbage and with it laid the groundwork for the development of tabulating, counting, sorting, and arithmetical machinery such as is now widely utilized in industry. The development of electrical apparatus and technique found application in these machines as manufactured by the International Business Machines Company, until today many of the things Babbage wished to accomplish are being done daily in the accounting offices of industrial enterprises all over the world.

As previously stated, these machines are all designed with a view to special applications to accounting. In every case they are concerned with the four fundamental operations of arithmetic, and not with operations of algebraic character. Their existence, however, makes possible the construction of an automatic calculating machine specially designed for the purposes of the mathematical sciences.

The need for more powerful calculating methods in the mathematical and physical sciences

It has already been indicated that the need for mechanical assistance in computation has been felt from the beginning of science, but at present this need is greater than ever before. The intensive development of the mathematical and physical sciences in recent years has included the definition of many new and useful functions, nearly all of which are defined by infinite series or other infinite processes. Most of these are inadequately tabulated and their application to scientific problems is thereby retarded.

The increased accuracy of physical measurement has made necessary more accurate computation in physical theory, and experience has shown that small differences between computed theoretical and experimental results may lead to the discovery of a new physical effect, sometimes of the greatest scientific and industrial importance.

Many of the most recent scientific developments, including such devices as the thermionic vacuum tube, are based on nonlinear effects. Only too often the differential equations designed to represent these physical effects correspond to no previously studied forms, and thus defy all methods available for their integration. The only methods of solution available in such cases are expansions in infinite series and numerical integration. Both these methods involve enormous amounts of computational labor.

The present development of theoretical physics through wave mechanics is based entirely on mathematical concepts and clearly indicates that the future of the physical sciences rests in mathematical reasoning directed by experiment. At present there exist problems beyond our ability to solve, not because of theoretical difficulties, but because of insufficient means of mechanical computation.

In some fields of investigation in the physical sciences as, for instance, in the study of the ionosphere, the mathematical expressions required to represent the phenomena are too long and complicated to write in several lines across a printed page, yet the numerical investigation of such expressions is an absolute necessity to our study of the physics of the upper atmosphere, and on this type of research rests the future of radio communication and television.

These are but a few examples of the computational difficulties with which the physical and mathematical sciences are faced, and to these may be added many others taken from astronomy, the theory of relativity, and even the rapidly growing science of mathematical economy. All these computational difficulties can be removed by the design of suitable automatic calculating machinery.

Points of difference between punched card accounting machinery and calculating machinery as required in the sciences

The features to be incorporated in calculating machinery specially designed for rapid work on scientific problems, and not to be found in calculating machines as manufactured for accounting purposes, are the following:

1. Ordinary accounting machines are concerned almost entirely with problems of positive numbers, while machines designed for mathematical purposes must be able to handle both positive and negative quantities.

2. For mathematical purposes, calculating machinery should be able to supply and utilize a wide variety of transcendental functions, as the trigonometric functions; elliptic, Bessel, and probability functions; and many others. Fortunately, not all these functions occur in a single computation; therefore a means of changing from

one function to another may be designed and the proper flexibility provided.

3. Most of the computations of mathematics, as the calculation of a function by series, the evaluation of a formula, the solution of a differential equation by numerical integration, etc., consist of repetitive processes. Once a process is established it may continue indefinitely until the range of the independent variables is covered, and usually the range of the independent variables may be covered by successive equal steps. For this reason calculating machinery designed for application to the mathematical sciences should be fully automatic in its operation once a process is established.

4. Existing calculating machinery is capable of calculating $\phi(x)$ as a function of x by steps. Thus, if x is defined in the interval $a < x < b$ and $\phi(x)$ is obtained from x by a series of arithmetical operations, the existing procedure is to compute step (1) for all values of x in the interval $a < x < b$. Then step (2) is accomplished for all values of the result of step (1), and so on until $\phi(x)$ is reached. This process, however, is the reverse of that required in many mathematical operations. Calculating machinery designed for application to the mathematical sciences should be capable of computing lines instead of columns, for very often, as in the numerical solution of a differential equation, the computation of the second value in the computed table of a function depends on the preceding value or values.

Fundamentally, these four features are all that are required to convert existing punched-card calculating machines such as those manufactured by the International Business Machines Company into machines specially adapted to scientific purposes. Because of the greater complexity of scientific problems as compared to accounting problems, the number of arithmetical elements involved would have to be greatly increased.

Mathematical operations which should be included

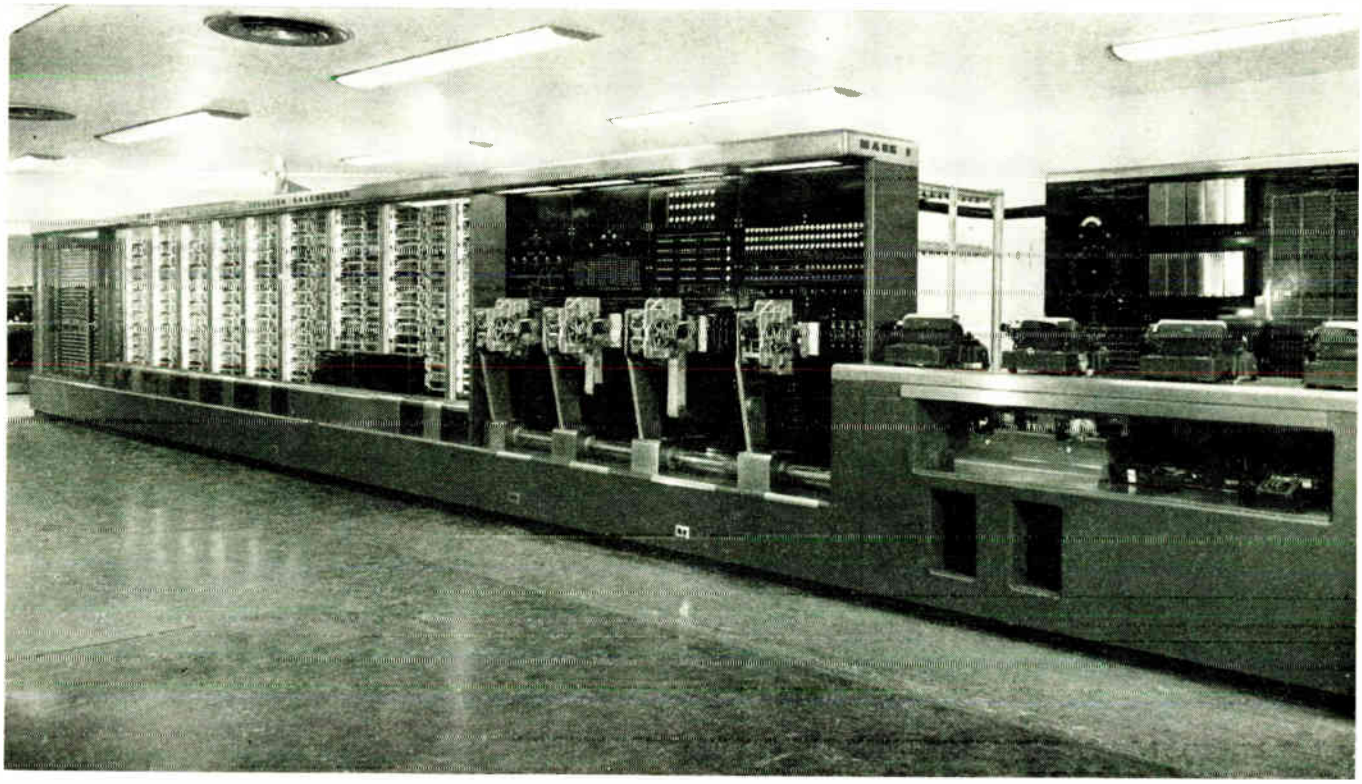
The mathematical operations which should be included in an automatic calculating machine are:

1. The fundamental operations of arithmetic: addition, subtraction, multiplication, and division
2. Positive and negative numbers
3. Parentheses and brackets: ( ) + ( ), [( ) + ( )]·[( ) + ( )], etc.
4. Powers of numbers: integral, fractional
5. Logarithms: base 10 and all other bases by multiplication
6. Antilogarithms or exponential functions: base 10 and other bases
7. Trigonometric functions
8. Antitrigonometric functions
9. Hyperbolic functions
10. Antihyperbolic functions
11. Superior transcendentals: probability integral, elliptic function, and Bessel function

With the aid of these functions, the processes to be carried out should be:

12. Evaluation of formulae and tabulation of results
13. Computation of series
14. Solution of ordinary differential equations of the first and second order
15. Numerical integration of empirical data
16. Numerical differentiation of empirical data

The "IBM automatic sequence-controlled calculator" (MARK I), dedicated Aug. 7, 1944.



The mathematical means of accomplishing the operations

The following mathematical processes may be made the basis of design of an automatic calculating machine:

1. The fundamental arithmetical operations require no comment, as they are already available, save that all the other operations must eventually be reduced to these in order that a mechanical device may be utilized.

2. Fortunately the algebra of positive and negative signs is extremely simple. In any case only two possibilities are offered. Later on it will be shown that these signs may be treated as numbers for the purposes of mechanical calculation.

3. The use of parentheses and brackets in writing a formula requires that the computation must proceed piecewise. Thus, a portion of the result is obtained and must be held pending the determination of some other portion, and so on. This means that a calculating machine must be equipped with means of temporarily storing numbers until they are required for further use. Such means are available in counters.

4. Integral powers of numbers may be obtained by successive multiplication, and fractional powers by the method of iteration. Thus, if it is required to find $5^{1/3}$,

$$y = f(x) = x^3 - 5 \qquad \text{(a)}$$

and

$$x_n = x_{n-1} - \frac{f(x_{n-1})}{f'(x_{n-1})} \qquad \text{(b)}$$

$$x_n = x_{n-1} - \frac{x^3_{n-1} - 5}{3x^2_{n-1}} \qquad \text{(c)}$$

or

$$x_n = \frac{2}{3}x_{n-1} + \frac{5}{3x^2_{n-1}} \qquad \text{(d)}$$

Let

$$x_0 = 2$$

$$x_1 = \frac{4}{3} + \frac{5}{12} = \frac{21}{12}$$

$$x_2 = \frac{42}{36} + \frac{5 \times 144}{3 \times 441} = 1.166 + 0.544$$

$$= 1.710 \qquad \text{(e)}$$

which is the cube root of 5 to four significant figures. In general the rth root of θ is given by the iteration of the expression

$$x_n = \left(1 - \frac{1}{r}\right)x_{n-1} + \frac{\theta}{rx^{r-1}_{n-1}} \qquad \text{(f)}$$

Finally, if r is not an integer, recourse may be had to the mechanical table of logarithms later to be described.

5. To supply a mechanical device with a complete mathematical function over a wide range of values would require an impossible amount of apparatus. To avoid this difficulty several artifices may be employed. In the case of logarithms, let it be required to find

$$y = \log_{10} x \qquad \text{(a)}$$

Then

$$x = 10^y$$

$$= 10^{a+b/10+c/100+d/1000+\ldots} \qquad \text{(b)}$$

where $a, b, c, \ldots$ are all integers. If x is restricted to have values no larger than 10^{10}, then

$$0 \leq a, b, c, \ldots \leq 9 \qquad \text{(c)}$$

Equation (b) may then be written

$$x = 10^a \times (10^{1/10})^b \times (10^{1/100})^c \times (10^{1/000})^d \times \ldots \qquad \text{(d)}$$

We may now form a table consisting of 100 numbers

	0	1	2	3	4	5
10	1	10.000	100.00	1000.0	...	
$10^{1/10}$	1	1.2589	1.585	1.995	...	
$10^{1/100}$	1	1.0238	1.0471	1.0715	...	
$10^{1/1000}$	1	1.0023	1.0046	1.006	...	
$10^{1/10000}$	.	...	...	...	...	

giving the integral powers from 0 to 9 inclusive of 10, $10^{1/10}$, $10^{1/100}$, etc. Then, if it is required to find $\log_{10}$ 2104, for instance, choose the largest number in the first row which, when divided into 2104, still leaves a result greater than unity. Thus

$$\frac{2104}{1000} = 2.104\ldots3$$

where 1000 was taken from the 3rd column. Continuing,

$$\frac{2.104}{1.995} = 1.054\ldots3$$

$$\frac{1.054}{1.0471} = 1.006\ldots2$$

$$\frac{1.006}{1.006} = 1.000\ldots3$$

Hence,

$$\log_{10} 2104 = 3.323 \qquad \text{(e)}$$

This is correct to the last figure.

Thus it is seen that the computation of ten significant figure logarithms may be reduced to ten discriminations, each in a field of ten, and eight divisions: eight because the first consists of moving the decimal point, a process as effortless in mechanical as in mental computation, and the last division need not be carried out.

6. The process of finding antilogarithms may be reduced to a reversal of the logarithmic process. Thus, if

$$y = 10^x \qquad \text{(a)}$$

then

$$y = 10^{a+b/10+c/100+\ldots} \qquad \text{(b)}$$

$$= (10)^a \times (10^{1/10})^b \times (10^{1/100})^c \ldots \qquad \text{(c)}$$

and repetitive discrimination and multiplication suffices.

7. The trigonometric functions most commonly used are the sine and cosine, and from these all other trigonometric functions may be computed easily. Either of these functions may be computed from the other, but in the expansion of Fourier series both sines and cosines are required. Therefore, it seems worth while to consider mechanical means of computing both the functions.

On expanding sin $(a + h)$ by MacLauren's theorem,

$$\sin (a + h) = \sin a + \frac{\cos a}{1} h - \frac{\sin a}{2} h^2 - \frac{\cos a}{6} h^3 + \frac{\sin a}{24} h^4 - \ldots \qquad \text{(a)}$$

If, now

$$\theta = a + h \qquad \text{(b)}$$

and

$$-\pi/2 \leq \theta \leq \pi/2 \qquad \text{(c)}$$

20 values of a may be chosen, as

$$a = \pi/2, 9\pi/20, 4\pi/5, \ldots -9\pi/20 \qquad \text{(d)}$$

Then the maximum value of h is

$$h = \pi/20$$
$$= 0.15729\ldots \qquad \text{(e)}$$

and ten terms of the series suffice for determining sin θ to ten significant figures, at most. On the average, approximately five terms are sufficient. The process of computing sines is thus reduced to discriminations of 1 number in a field of 20, and the computation of a series of at most 10 terms.

The process for computing the cosine is exactly the same, and from these all other trigonometric functions may be determined arithmetically by

$$\csc \theta = 1/\sin \theta \qquad \text{(f)}$$

$$\sec \theta = 1/\cos \theta \qquad \text{(g)}$$

$$\tan \theta = \sin \theta/\cos \theta \qquad \text{(h)}$$

Thus a field of 200 numbers is sufficient to supply all trigonometric functions.

8. The inverse trigonometric functions may also be determined by MacLauren's theorem, but since $\sin^{-1} \theta$ and $\tan^{-1} \theta$ occur more often than any other inverse trigonometric function, these should be selected and any others computed from them.

9. Similar methods might be applied to the computation of the hyperbolic functions, but it is questionable if special apparatus should be initially installed for their determination since the hyperbolic functions may all be defined in terms of exponentials computable from the logarithmic device already suggested.

10. Similar comments apply to the inverse hyperbolic functions.

11. A great many functions may be similarly treated, and if the design of the automatic calculating machine proceeds so that a given device can be changed from one function to another rapidly, all such functions may be included in the scope of the machine. Means of accomplishing this will be suggested later.

12. Given a suitable supply of transcendental functions, the evaluation of formulae is reduced to arithmetic. If a formula is to be evaluated for a wide range of the independent variable, the process becomes repetitive. Means for accomplishing this will be discussed later.

13. The computation of closed series such as

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 \qquad \text{(a)}$$

is most easily accomplished by the sequence

$$\begin{aligned}
&a_3\\
&a_3x\\
&a_3x + a_2\\
&a_3x^2 + a_2x \qquad \text{(b)}\\
&a_3x^2 + a_2x + a_1\\
&a_3x^3 + a_2x^2 + a_1x\\
&a_3x^3 + a_2x^2 + a_1x + a_0 = y
\end{aligned}$$

In the case of infinite series the computation may be reduced to successive multiplications and additions. Thus, if

$$y = a_0 + a_1x + a_2x^2 + a_3x^3\ldots \qquad \text{(c)}$$

$$\begin{aligned}
&= a_0\\
&\quad + \frac{a_1}{a_0} x \cdot a_0\\
&\quad + \frac{a_2}{a_1} x \cdot \frac{a_1}{a_0} x \cdot a_0\\
&\quad + \frac{a_3}{a_2} x \cdot \frac{a_2}{a_1} x \cdot \frac{a_1}{a_0} x \cdot a_0\\
&\quad + \frac{a_4}{a_3} x \cdot \frac{a_3}{a_2} x \cdot \frac{a_2}{a_1} x \cdot \frac{a_1}{a_0} x \cdot a_0\\
&\quad + \ldots \qquad \text{(d)}
\end{aligned}$$

and

$$\begin{aligned}
y &= A_0\\
&\quad + A_1x \cdot A_0\\
&\quad + A_2x \cdot A_1x \cdot A_0\\
&\quad + A_3x \cdot A_2x \cdot A_1x \cdot A_0\\
&\quad + A_4x \cdot A_3x \cdot A_2x \cdot A_1x \cdot A_0 \qquad \text{(e)}
\end{aligned}$$

where

$$A_0 = a_0;\ A_1 = a_1/a_0;\ A_2 = a_2/a_1;\ldots \qquad \text{(f)}$$

Thus each term of the series is obtained from the last through multiplication by a coefficient and the value of the independent variable.

14. Any mechanical device that can evaluate formulae can also determine the real roots of algebraic and transcendental equations provided only that in the evaluation of the formulae the successive values of the independent variable are the successive values of the dependent variable computed; thus, consider

$$x + \log_{10} x = {}^1/_2 \qquad \text{(a)}$$

given that x is in the neighborhood of ${}^1/_2$. A succession of 11 approximations suffices to give

$$x = 0.672384 \qquad \text{(b)}$$

Or, letting the equation be the famous cubic of Wallis,

$$x^3 - 2x - 5 = 0 \qquad \text{(c)}$$

the iterative equation is

$$x_n = x_{n-1} - \frac{x^3_{n-1} - 2x_{n-1} - 5}{3x^2_{n-1} - 2} \qquad \text{(d)}$$

Three approximations serve to give

$$x = 2.09455148\ldots \tag{e}$$

The root of this equation has been computed to 150 significant figures. Note that again the process is purely repetitive after being started.

15. The solution of ordinary differential equations of any order can usually be accomplished to any degree of accuracy by expansion into infinite series by MacLauren's theorem for any specified boundary demands. Under certain circumstances the series may be rapidly convergent and the method offers excellent means for numerical solution.

However, when the equation has complicated functions of x as coefficients of the various derivatives of y, and the independent variable itself occurs in complicated functions, the various successive derivatives necessary to the series expansion may involve a prohibitive amount of labor. For such cases, various methods of numerical solution have been devised, such as those of Adams, Runge-Kutta, and others.

Of these, the method of Runge-Kutta is probably best adapted to mechanical computation because the method of solution depends entirely on the evaluation of a repetitive sequence. Thus, if

$$\frac{dy}{dx} = f(x, y) \tag{a}$$

and

$$\begin{aligned} K_1 &= f(x_0, y_0)\Delta x \\ K_2 &= f\left(x_0 + \frac{\Delta x}{2}, y_0 + \frac{K_1}{2}\right)\Delta x \\ K_3 &= f\left(x_0 + \frac{\Delta x}{2}, y_0 + \frac{K_2}{2}\right)\Delta x \\ K_4 &= f(x_0 + \Delta x, y_0 + K_3)\Delta x \end{aligned} \tag{b}$$

Then,

$$\Delta y = (x_0 + \Delta x, y_0 + K_3)\Delta x$$

and

$$\begin{aligned} y_1 &= y_0 + \Delta y \\ x_1 &= x_0 + \Delta x \end{aligned} \tag{c}$$

The process may now be repeated to find x_2, y_2, and so on. The inherent error of this process is of the order of Δx^5; hence, if Δx is taken as 0.1, the solution will be correct to the fourth place of decimals, and doubtful in the fifth.

The method can be applied to simultaneous equations of the first order, and hence to second-order equations.

Since the method involves nothing other than the evaluation of formulae, a mechanical device suitable for such evaluation is prepared to perform this type of numerical integration.

16. The numerical integration of empirical data may be carried out by the rules of Simpson, Weddle, Gauss, and others. All these rules involve sums of successive values of y multiplied by specified numerical coefficients. Hence the only new mechanical component involved is a means of mechanically introducing a list of numbers. Means of accomplishing this will be discussed later.

17. Numerical differentiation of empirical data is best accomplished by means of a difference formula. Most experimental observations are of such an accuracy that fifth differences may be neglected by taking observations sufficiently close together. If, then, all differences above the fifth may be neglected, the process of numerical differentiation may be carried out by a fifth difference engine such as originally designed by Babbage. Such a device can, however, be assembled from standard addition–subtraction machines with but a few changes. The differentiating apparatus would also be applicable to many other problems. In fact, most of the problems already discussed may under certain circumstances be solved by application of difference formulae.

Mechanical considerations

In the last section it was shown that even complicated mathematical operations may be reduced to a repetitive process involving the fundamental rules of arithmetic. At present the calculating machines of the International Business Machines Company are capable of carrying out such operations as:

$$\begin{aligned} A + B &= F \\ A - B &= F \\ AB + C &= F \\ AB + C + D &= F \\ A + B + C &= F \\ A - B - C &= F \\ A + B - C &= F \end{aligned} \tag{a}$$

In these equations A, B, C, D are tabulations of numbers on punched cards, and F, the result, is also obtained through punched cards. The F cards may then be put through another machine and printed or utilized as A, B, ... cards in another computation.

Changing a given machine from any of the operations (a) to any other is accomplished by means of electrical wiring on a plug board. In the hands of a skilled operator such changes can be made in a few minutes.

No further effort will be made here to describe the mechanism of the IBM machines. Suffice it to say that all the operations described in the last section can be accomplished by these existing machines when equipped with suitable controls, and assembled in sufficient number. The whole problem of design of an automatic calculating machine suitable for mathematical operations is thus reduced to a problem of suitable control design, and even this problem has been solved for simple arithmetical operations.

The main features of the specialized controls are machine switching and replacement of the punched cards by continuous perforated tapes. In order that the switching sequence can be changed quickly to any possible sequence, the switching mechanism should itself utilize a paper tape control in which mathematical formulae may be represented by suitable disposed perforations.

Present conceptions of the apparatus

At present the automatic calculator is visualized as a switchboard on which are mounted various pieces of calculating machine apparatus. Each panel of the switchboard is given over to definite mathematical operations.

The following is a rough outline of the apparatus required:

1. IBM machines utilize two electric potentials: 120 volts ac for motor operation, and 32 volts dc for relay operation, etc. A main power supply panel would have to be provided including control for a 110-volt-ac/32-volt-dc motor generator and adequate fuse protection for all circuits.

2. Master control panel: The purpose of this control is to route the flow of numbers through the machines and to start operation. The processes involved are: (a) Deliver the number in position (x) to position (y); and (b) start the operation for which position (y) is intended. The master control must itself be subject to interlocking to prevent the attempt to remove a number before its value is determined, or to begin a second operation in position (y) before a previous operation is finished.

It would be desirable to have four such master controls, each capable of controlling the entire machine or any of its parts. Thus, for complicated problems the entire resources could be thrown together; for simpler problems fewer resources are required and several problems could be in progress at the same time.

3. The progress of the independent variable in any calculation would go forward by equal steps subject to manual readjustment for change in the increment. The easiest way to obtain such an arithmetical sequence is to supply a first value, x_0, to an adding machine, together with an increment Δx. Then successive additions of Δx will give the sequence desired.

There should be four such independent variable devices in order to (a) calculate formulae involving four variables; and (b) operate four master controls independently.

4. Certain constants: many mathematical formulae involve certain constants such as ϵ, π, $\log_{10} \epsilon$, and so forth. These constants should be permanently installed and available at all times.

5. Mathematical formula nearly always involve constant quantities. In the computation of a formula as a function of an independent variable these constants are used over and over again. Hence the machine should be supplied with 24 adjustable number positions for these constants.

6. In the evaluation of infinite series the number 24 might be greatly exceeded. To take care of this case it should be possible to introduce specific values by means of a perforated tape, the successive values being supplied by moving the tape ahead one position. Two such devices should be supplied.

7. The introduction of empirical data for nonrepetitive operations can be accomplished best by standard punched-card magazine feed. One such device should be supplied.

8. At various stages of a computation involving parentheses and brackets it may be necessary to hold a part of the result pending the computation of some other part. If results are held in the calculating units, these elements are not available for carrying out succeeding steps. Therefore it is necessary that numbers may be removed from the calculating units and temporarily stored in storage positions. Twelve such positions should be available.

9. The fundamental operations of arithmetic may be carried on three machines: addition and subtraction, multiplication, and division. Four units of each should be supplied in addition to those directly associated with the transcendental functions.

10. The permanently installed mathematical functions should include: logarithms, antilogarithms, sines, cosines, inverse sines, and inverse tangents.

11. Two units for MacLauren series expansion of other functions as needed.

12. In order to carry out the process of differentiation and integration on empirical data, adding and subtracting accumulators should be provided sufficient to compute out to fifth differences.

13. All results should be printed, punched in paper tapes, or in cards, at will. Final results would be printed. Intermediate results would be punched in preparation for further calculations.

It is believed that the apparatus just enumerated, controlled by automatic switching, should care for most of the problems encountered.

Probable speed of computation

An idea of the speed attained by the IBM machines can be had from the following tabulation of multiplication in which 2 × 8 refers to the multiplication of an 8 significant figure number by a 2 significant figure number, zeros not counted.

	Products per hour
2×8	1500
3×8	1285
4×8	1125
5×8	1000
6×8	900
7×8	818
8×8	750

In the computation of 10 place logarithms the average speed would be about 90 per hour. If all the 10-place logarithms of the natural numbers from 1000 to 100 000 were required, the time of computation would be approximately 1100 hours, or 50 days, allowing no time for addition or printing. This is justified since these operations are extremely rapid and can be carried out during the multiplying time.

Suggested accuracy

Ten significant figures have been used in the above examples. If all numbers were to be given to this accuracy it would be necessary to provide 23 number positions on most of the computing components, 10 to the left of the decimal point, 12 to the right, and one for plus and minus. Of the twelve to the right, two would be guard places and thrown away.

Ease of publication of results

As already mentioned, all computed results would be printed in tabular form. By means of photolithography these results could be printed directly without type setting or proof reading. Not only does this indicate a great saving in the publishing of mathematical functions, but it also eliminates many possibilities of error.

dated by unknown recipient:
Prospectus of Howard Aiken
Nov. 4, 1937.

The changing market for electrical engineers

It is becoming increasingly important for government and industry, as well as for many engineers and scientists, to examine the implications of present and future changes in defense requirements

Guy Black *Massachusetts Institute of Technology*

At a time when the electronics and aerospace industries are undergoing an "agonizing reappraisal" of the future requirements of their chief customer, many companies and many engineers and scientists are beginning to think more intently about the prospects before them.

The public statements of industry and government leaders indicate that we are just beginning to give thoughtful attention to the implications of a changing view of the future. For example, at a recent defense marketing conference, one industry vice president recommended salvation through sharpening up marketing skills, through generally improved planning and management, and through more cost-conscious engineering. The trouble with such statements is that narrowly conceived remedies are not adequate to cope with industry-wide problems. As any market shrinks, companies must sharpen their skills and deficient companies will fail; but it does not follow that total sales will increase.

Deputy Assistant Secretary of Defense Arthur Barber has said that there are many unexploited opportunities that have not materialized because the electronics industry has lacked willingness to risk product development funds. At least on the level of intellectual speculation, there are certainly many electronic products that have not yet been offered for sale—products that undoubtedly will find their way into our lives some day.

Present prospects

What precisely is happening in the defense market? First, the customer is managing his own affairs somewhat differently than before. The emphasis on developing a wide variety of new weapons has lessened considerably as major defense requirements have been met. There is less pressure for further weapons development from our foreign adversaries except in the limited war area, and probably the prospects for a substantial upgrading in military capability through exploitation of available technology are lower than they were a decade ago. The burst of activity to build up certain capabilities—which followed the Eisenhower years—is rapidly dissipating.

Basically, there has been a minor decline in the actual level of defense spending, but a major decline in expectations for a continued increase in spending. So far the decline has been only a few per cent, but at worst a continuing slow decline can be expected. Even in the event of international arms agreements, a fairly remote possibility, the rate of decline would be modest. However, the ultimate effect might be very great indeed.

These facts have been well publicized. In the fall of 1963 defense officials alerted industry to the changing patterns of procurement, and by the spring of 1964 the significance of their statements had been recognized. Interest in readjustment planning reached a new high.

Slight impacts on the scientific community have occurred to date. New engineering graduates are still collecting higher starting pay than graduates of the previous year (*New York Times*, April 14, 1964), although the job market is reported to be softening. By now, every major defense-oriented region of the country has gone through a period of stress resulting from contract cancellations and cutbacks, but almost invariably the laid-off workers have been absorbed in one way or another. A prominent journal warns that "the high life" is over (*Electronics*, May 18, 1964), and others note that there is increased interest in refresher courses and retraining (*Wall Street Journal*, February 20, 1964).

It must be understood, however, that there is and will continue to be substantial governmental procurement of products with a high research and development content, in the areas of defense, space, and atomic energy.

The market for engineers and scientists

The current cry in the trade press is about an impending job shortage for engineers and scientists, even though only a few years ago predictions of a shortage of engineers were regular features. The rapid reversal in the

I. Federal and private* funds for R & D by industry, 1957–1962

	Millions of Dollars											
	1957		1958		1959		1960		1961		1962	
Industry	Fed.	Pri.	Fed.	Pri.	Fed.	Pri.	Fed.	Pri.	Fed.	Pri.	Fed.	Pri.
Food	—	67	—	79	5	84	9	94	4	101	5	103
Paper	—	45	—	50	—	48	—	53	—	60	—	65
Industrial chemicals	80	423	110	443	114	485	128	538	137	556	158	572
Drugs	0	104	2	126	3	151	4	159	3	177	3	192
Other chemicals	9	89	14	97	34	105	50	107	83	118	95	130
Petroleum	16	212	12	229	25	251	26	271	19	275	20	281
Rubber	33	74	23	66	39	72	37	79	36	90	31	94
Primary metals	6	110	13	112	13	123	16	143	16	144	14	152
Fabricated metals	45	65	57	64	43	59	38	73	33	86	32	100
Machinery	264	426	316	462	413	511	372	572	292	603	310	633
Communications	1199	576	1331	616	810	284	892	352	784	400	867	413
Other electrical					787	379	725	456	749	472	745	474
Motor vehicles	212	492	318	531	222	622	211	640	192	611	183	675
Aircraft and missiles	2266	327	2276	361	2769	386	3180	405	3537	420	3787	412
Scientific instruments	82	57	92	63	116	64	138	74	109	81	131	87
Optical–surgical instr.	29	81	40	93	50	104	64	120	67	127	93	144
All industry	4340	3390	4760	3600	5640	3970	6080	4330	6310	4960	6729	4831

Based on National Science Foundation Reports 60-35, 60-81, 63-7, 63-19, 63-37, 63-40, and 63-41.

* Includes company-funded R & D performed for account of company by outside organizations on a contract basis.

general tenor of remarks is a good object lesson in the superficiality of the statements that many industry spokesmen have written for them by their public relations departments. Many speeches are compiled from a collection of press clippings. The speeches generate new press clippings in turn, so that a mass of predictions in general agreement may be only a feedback phenomenon, with very few exogenous inputs or hard-thinking analyses. This situation is by no means confined to the electronics industry; for example, an equally cynical view of the forecasts of the business cycle by economic analysts is fully warranted. Surveys of official opinion and of projected future employment suffer from the same faults. Even governmental publications appear to be heavily influenced by opinion surveys.

When the ultimate sources for predictions are tracked down and examined, often their methodology does not inspire much confidence. Of course, forecasts must be based on such imponderables as the defense budget of the future, for which the only possible procedure is to make some reasonable assumption.

With regard to Department of Defense spending, for example, one government publication says "first, a least squares straight line was fitted to DOD electronics expenditures for the years 1955 to 1963 and extrapolated to 1970 . . . " and so on (Bureau of Labor Statistics Bulletin 1363, p. 43). Some curious liberties were taken, in another government publication, that seem to reflect wishful thinking. It said, "Although DOD officials have indicated in public statements that future DOD expenditures are not expected to rise significantly, at least through fiscal year 1967, it appears likely that such statements are somewhat conservative and that the increasing costs of new weapon systems and rising production of ever more complex military items currently in the R & D stage will tend to increase DOD expenditures somewhat between 1963 and 1970."

It seems worthwhile to assume an alternative defense budget and trace through the implications for requirements for engineers and scientists. The published data are not set up for the purpose. To make a really good projection of the industry-wide significance of cutbacks in defense demand would require more detailed knowledge of interindustry relationships than is presently available. The effects would probably be more widely felt in the aerospace and electronics industry than published data suggest. Component manufacturers and instrument manufacturers may sell only a small portion of their products directly to the government or on subcontract to prime contractors, but a substantial proportion may actually be defense-derived demand. Even governmental employment of engineers and scientists is closely linked with government funding of R & D by industry, although there is a crosscurrent resulting from shifting emphasis from in-house contracting to R & D by industry.

With the published data the most feasible alternative assumption is that the level of defense spending will remain as it was in 1962. Today, although this appears to be an optimistic assumption, some defense market analysts might still consider it pessimistic.

A revised estimate

I have revised the forecast for demand for engineers and scientists issued by one of the government agencies. This revision is based on the assumption that the level of defense demand, both R & D and production, would remain at the 1962 level, but that the growth of private industry and commercially oriented research and development would continue apace—in short, that the leveling off of defense demand would not adversely affect the national growth rate. Table I shows how R & D expenditure has been increasing in industry in recent years. The average increase of private funds has been $288 million per year—about 7 to 8 per cent per year. Interestingly enough, the rate of increase of private funds in the heavily defense and R & D oriented industries is almost identical to the rate in industries in which both Federal and private R & D spending is low. There is some evidence that private spending in the defense industries might be higher if the amount of Federal funds available were not so great. There is also some evidence that the rate at which R & D spending increases depends very much on the amount of funds companies have available, derived from undistributed profits or depreciation allowances. That is, R & D spending increases when firms prosper. Taking these factors into account, I have assumed a $300 million a year increase in the level of private R & D funding. By 1970 an additional $2.4 billion will be spent, bringing total R & D expenditures—private and Federal—to $13.9 billion.

To determine the amount of employment that this level of funding will provide, we can divide by the average expenditure per R & D scientist. The amount was about $35 000 in 1962. The average has shown a somewhat irregular upward trend. If we take a value of $40 000 per person, industry will then increase the number of engineers and scientists working on private R & D, an average 7500 per year, with its $300 million. Without any increase in Federal R & D funds for industry, this would be the total increase in R & D, except for a small amount in colleges and nonprofit institutions.

However, there are many non-R & D jobs in industry, especially for engineers. In 1960 there were in industry a total of 859 000 engineers and 148 000 scientists. About one third of this total were engaged in R & D. In the metal products industries the portion was only 15 per cent, but in the electric machinery industry it was 70 per cent.[1,2] A great proportion of non-R & D employment, especially for electrical engineers, is in nonmanufacturing situations (communications and public utilities) where there is very little R & D.

Table II, from the 1960 Census, is an interesting indicator of where the jobs are. All told, there were about 599 thousand non-R & D jobs for engineers and scientists in industry.

The number of non-R & D jobs is probably geared to the general level of economic activity, so employment will probably increase about equally to the level of industrial production. The economy is now in high gear, and 1970 industrial production will probably be 75 per cent greater than in 1960 (20th Century Fund, *U.S. and its Economic Future.*) Allowing something for the shift toward more automation and more skilled employment, I predict 1.1 million non-R & D jobs in industry for engineers and scientists by 1970.

On this basis, the industrial employment of engineers and scientists in 1970, assuming no increase in defense demand, can be taken as follows:

R & D employment in industry	382 thousand
Other employment in industry	1078 thousand
	1460 thousand

II. Employed scientists and engineers in the United States, 1960[2]

Industry	Total number, thousands Scientists	All Engineers	Electrical Engineers
All industries	148.2	859.5	181.9
Agriculture, forestry, and fisheries	1.9	1.4	—
Mining	13.5	14.5	0.8
Construction	1.0	91.5	3.7
Manufacturing, total	68.5	472.4	99.0
Manufacturing, durable goods	21.8	397.9	96.6
Lumber, wood, furniture products	0.2	2.9	0.1
Glass, stone, clay products	1.9	9.7	0.5
Primary ferrous metals	3.0	17.8	0.7
Primary nonferrous metals	1.7	8.9	0.7
Fabricated metals	3.3	52.6	8.7
Office, computing, and acctg. machinery	0.8	11.4	4.4
Other machinery (nonelectric)	0.9	54.9	2.0
Electric machinery	3.8	103.2	59.5
Motor vehicles and parts	0.8	20.8	1.0
Aircraft and parts	2.2	81.3	11.4
Shipbuilding and repairing (govt. and priv.)	0.4	5.6	1.1
Railroad and misc. transportation equip.	—	1.4	0.2
Professional, photographic equipment, etc.	2.2	23.7	6.8
Miscellaneous manufacturing of durables	0.5	3.0	0.2
Manufacturing, nondurable goods	46.7	74.4	3.4
Chemicals	24.5	32.4	1.5
Petroleum and coal	4.6	11.7	0.3
Transportation	0.7	10.4	3.9
Communications, radio broadcasting	—	6.5	6.1
Communications, telephone and telegraph	0.1	26.3	22.8
Utilities, government and private	0.6	22.9	14.5
Wholesale and retail trade	2.7	27.5	1.8
Insurance, real estate, finance	0.4	7.6	2.0
Business and repair services	7.2	24.8	8.3
Entertainment, recreation, personal services	—	0.6	0.3
Professional and related services	27.1	21.3	10.0
Engineering and architectural services	2.1	54.8	6.2
Educational services	1.9	6.9	1.8
Federal government administration	18.1	51.3	10.0
State government administration	2.7	4.2	0.2
Local government administration	0.9	15.0	0.5

NOTE: Figures given include mathematicians but not statisticians.

This contrasts with the original prediction of 1.9 million in industry, based on the assumption of a continuing upward trend in defense spending, using the definition of the original source, which did not include education or government.

Other major employment for engineers is in education and government. In 1960 about one billion dollars was provided to the universities and colleges by the Federal government for R & D. This was three quarters of all of their R & D budgets (NSF Reports 63-40 and 63-11). Almost all of the funds going to university-operated special research centers came from the DOD, NASA, or AEC—about $420 million. About 40 per cent ($218 million out of $540 million in the fiscal year 1961) of the funds of the education institutions proper are from the same agencies. The full-time equivalent of about 50 000 engineers and scientists are performing R & D in the universities and colleges, and a slightly larger number are engaged in teaching.[3] Although no increase in engineering student enrollment is forecast, science student enrollment is expected to double. If faculty were increased proportionately, an additional 55 000 would be employed by 1970. Engineering colleges may seek to push up the faculty-to-student ratio, which currently stands at 23 students for every engineering faculty member. Educational requirements were not, however, included in the forecast I am using.

I am not projecting any increase in government employment of engineers and scientists, which is about 170 000. There may be some increase in state and local employment which may offset decline in Federal employment closely related to defense–space activities.

As a result of the changes based on these assumptions, the difference between projections of demand for engineers and scientists, on the basis of an assumed increasing and an assumed stable defense budget, is the difference between a 1970 total of 2 million and 1.5 million. A reduction in demand by half a million can spell the differences between a shortage of personnel and a surplus. Converted to a per-year basis, the requirement for the remaining years of the 1960s is as shown in Table III. In comparing these figures with projections of the supply of engineers and scientists, I have not attempted to forecast the impact that changing requirements might have on the supply, although in the past there has been a tendency for the selection of undergraduate majors to reflect economic opportunities. Converted to annual averages, the supply is as shown in Table IV.

III. Projected annual average demand for engineers and scientists

	Personnel Required	
	With Stable Defense Budget	With Increasing Defense Budget
Increased requirements	30 000	80 000
Losses due to death and retirements	16 000	16 000
Transfers out of the profession	6 000	6 000
Total yearly requirements	52 000	102 000

The situation for electrical engineers

In the fall of 1962 there were 57 000 undergraduates with electrical engineering majors out of a total of 229 000 engineering undergraduates in the schools accredited by the Engineers' Council for Professional Development, and about 9000 graduates a year with electrical engineering degrees. In recent years about one third of all engineering graduates have been electrical engineers. That this emphasis is responsive to industry demand is suggested by the continued increases in starting salaries for graduates. Since the proportion of electrical engineers in industry as a whole is only 21 per cent, the net effect is to increase the proportion of electrical engineers in industry. If the present rate of graduation continues, the number of electrical engineers graduated in the 1960s will equal one half of all those employed in 1960.

The most detailed information on where electrical engineers find employment is the 1960 Census, from which Table II was extracted. It shows that about half of electrical engineers work for manufacturing industries and that although 73 per cent of these are in electric machinery or aircraft manufacturing, a few electrical engineers are found in every industry. Outside of manufacturing, the largest employers of electrical engineers are the communications industries and the utilities. Professional engineering services and business and repair services are also important sources of employment, as is the Federal government.

The ability of industry to absorb all electrical engineering graduates, even in the event of a stable rather than increasing defense budget, is marginal at best. The Bureau of Labor Statistics' estimate is that 85 per cent of engineering graduates actually enter the profession—less than 8000 per year. Electric machinery manufacturing is of special interest. The 40 per cent of this industry that is electronic in nature is one of our more striking growth industries. This growth is characteristic even of the nondefense portion. As reported by the

IV. Average annual supply of engineers and scientists

	First Degrees Awarded	Per Cent To Enter Profession	Entrants with Engineering or Science Degrees	Entrants with Other Degrees	Other Entrants	Net New Supply
Engineering	34 700	85	29 500	7300	10 500	45 100
Science	71 200	36	25 600	6100	800	31 400
						76 500

Source: Bureau of Labor Statistics, for the National Science Foundation's "Scientists, Engineers and Technicians in the 1960's, Requirements and the Supply."

Electronic Industries Association, the rate of growth of sales (compound, from 1959 to 1962) of nondefense electronics was 7 per cent per year for consumer products, 17 per cent per year for industrial products, and 11 per cent per year for both combined. Together, these two product groups provide a $5 billion base for future growth. They provide markets in turn for the products of other parts of the electrical and electronics industry. An 11 per cent per year rise in the entire electric machinery industry not devoted to defense would provide employment for about 2200 additional engineers per year. By my estimate, about 20 000 of the engineers in the electric machinery industry are engaged in nondefense work.

However, two thirds of all electrical engineers are employed elsewhere than in the electric machinery industry. If other industries increase employment by about 3.5 per cent per year, 4200 electrical engineers will be absorbed yearly. This leaves slightly under 2000 graduates per year to be accounted for. Retirements and deaths, transfers out of the profession, and transfers in from other sources and unusual employment associated with automation or installation of new equipment are among other factors that might be taken into account.

From the foregoing it appears that electrical engineers will share, although to a lesser degree, any problems that result from reduced defense demand. Though electronics is growing rapidly, most electrical engineering employment is elsewhere, and is more closely keyed to the general economic situation than to the state of defense business.

The manner in which demand shifts from one product to another has special significance. In military and industrial electronics about one third of personnel are engineers, scientists, technicians, or draftsmen. In consumer electronics—and probably in electric machinery generally—these groups amount to about one tenth.[4] The electronics industry could maintain its sales volume or even increase it, but by shifting from R & D to production it would provide fewer jobs for technical personnel. Trends toward automation and microminiaturization may partly offset such effects.

What happens to engineers when there is an oversupply

If defense electrical engineering does not decline, it might be expected that those who have defense jobs will stay in them, and that new graduates will seek out newly created employment. Although a tendency in this direction is quite likely, I believe that there would be a substantial movement of recent graduates into defense work, and a corresponding movement of older engineers out of defense work even with no net change in engineering employment in defense work. The search for better opportunities would cause some movement. Job jumping has been an electronics industry tradition ever since the earliest days of radio. Also, the more up-to-date engineering knowledge and the lower salaries of recent graduates will give them a competitive advantage. Thus, the number of ex-defense-industry electrical engineers moving to other industries may be 2000 or 3000 a year if defense industries take their share of the new graduates. If there were actually a decline in defense electronics, the movement would be much greater.

Where those who move would be likely to find employment is reasonably well suggested by Table II, but I have provided Table V as an independent indicator of the industries where engineering employment is expected to increase most sharply over a 1959 base. This table was prepared from an industry-by-industry adjustment of an official forecast of engineer and scientist requirements that was based on an assumption of increasing defense R & D efforts. Table V was prepared by reducing the increases originally projected by the portion of each industry's R & D that was financed by the Federal government. In this table, government employment and education are excluded.

Tables II, V, and VI suggest that the type of work that may be found by persons moving out of the defense industry will necessitate some personal adjustments. First of all, it is doubtful that much of the burden of readjustment can be carried on within the framework of present company organizations. Defense business will continue to be substantial, although reduced, and companies that have specialized in this work will probably continue to do so. Attempts at product diversification, which would enable them to continue their interrupted growth rate and provide nondefense employment for their personnel, have had limited success in the past, and I see no evidence that much has been learned. Most companies find substantial impediments in changing their focus from one product or market to another. About half of electrical engineering employment is in nonmanufacturing industry anyway, and few additional companies will combine communication or public utility operation with manufacturing. These major areas of employment are not likely to be opened by diversification of manufacturing companies.

A characteristic of electronics technology is the ease with which a company in another industry can develop an in-house capability. The widespread employment of electrical engineers is evidence of the extent to which this has been done in the past. The output of a machine tool manufacturer may vary from zero to a very high percentage of electronic products (which is one reason it has been so difficult to define the electronics industry). The engineer may find job opportunities in manufacturing industries into which traditional electronics or electrical companies find it impossible to move.

With regard to relocation, the geographic pattern of defense electronics is quite different from that of components manufacturing, consumer electronics, and electric equipment manufacturing. Much of it is concentrated in regions where nondefense jobs for electrical engineers are limited. Relocation by defense-industry engineers has been so common that it is hard to see this as a problem. Surveys have shown that most engineers are willing enough to relocate for better jobs, and it is difficult to imagine that many would balk if the choice were a job elsewhere or no job at all.

Changes in type of work and working behavior may be critical problems for some. Consider the following points:

1. Many in defense work have learned to approach problems in a way appropriate for R & D on major weapons, but with little civilian application.

2. Military projects are often very large and lead to specialization that has little counterpart in civilian applications, and to types of specialists for which there is no nondefense demand.

3. The balance of emphasis between cost, meeting schedules, and quality is very different in commercially

oriented industry, despite recent emphasis on cost in defense procurement.

4. The tendency for military R & D to be kept separate from commercially oriented R & D means that many engineers and scientists have never had the experiences of working on commercial projects.

That the differences between defense-oriented and commercially oriented R & D are significant is part of the folklore of the industry. Most companies keep commercial work and defense work separate, and some have made such separations after attempting combined operations. It is claimed that government-sponsored R & D requires a framework of bureaucracy that is inconsistent with good commercial practice, that governmental paperwork routine is extreme, and that the environment so impinges on the engineer who has been in defense work as to incapacitate him for commercial work. Other differences exist. One is the difference between military and commercial secrecy; another is the instability of employment in defense business, and the rapid drastic reorientation of direction of work that goes with it. It may be the bookkeeper and not the engineer who makes defense and commercial R & D incompatible. None of these viewpoints has been well documented, and I am personally skeptical that differences are as important as some claim them to be. If defense R & D has emphasized anything it is the successful adaptation to changing product requirements. On the other hand, differences in management practice may be very significant.

V. Projected employment of engineers and scientists in selected industries*

Industry	Employment, thousands 1957	Employment, thousands 1970
Food and kindred products	10.2	12.9
Textile mill products and apparel	5.4	6.5
Lumber, wood products, and furniture	2.9	3.9
Chemicals and allied products	83.1	136.3
Petroleum refining and products, coal	28.0	37.5
Rubber products	7.3	9.5
Primary-metal products	33.2	63.1
Fabricated metal products, ordnance	34.7	63.8
Machinery, nonelectric, but including office machinery	67.4	101.8
Electric machinery	92.7	132.6
Motor vehicles, ships, and transportation equipment, except aircraft	23.4	45.2
Aircraft and missiles	107.4	120.3
Instruments, professional and scientific	23.7	31.5
Miscellaneous	29.7	—
All manufacturing	568.0	900.0
Nonmanufacturing†	240.1	384.0
Total	808.1	1284.0

* Assuming no further increase in government R & D funding.
† Includes mining, construction, transportation, communications, public utilities, engineering and architectural services, medical and dental laboratories, miscellaneous business services, nonprofit organizations, and others.

Based on National Science Foundation Reports 61-65 and 63-7.

VI. Characteristics of industrial research and development, 1960

Industry	R & D Cost per Scientist or Engineer, thousands of dollars	Engineers and Scientists per 1000 employees	Total Funds for R & D, millions of dollars	Private Funds for R & D, millions of dollars	R & D Engineers and Scientists per Average Company with Over 5000 Employees
R & D oriented:					
Industrial chemicals	32.5	42	664	536	860
Drugs	27.4	43	171	167	340
Communications	32.5	62	1249	357	1920
Other elec. machinery	37.7	42	1184	459	1290
Aircraft and missiles	26.7	92	3621	434	2880
Scientific instruments	36.4	65	215	77	1280
Optical–surgical instr.	—	32	184	120	481
			7288	2158	
Other:					
Food	19.6	7	104	95	105
Textiles, apparel	30.5	3	32	29	37
Lumber, wood furniture	28.9	4	13	10	50
Paper	21.6	7	54	—	72
Other chemicals	24.4	29	165	116	290
Petroleum	32.9	17	298	272	376
Rubber products	29.5	18	119	82	650
Primary ferrous	30.0	4	93	91	113
Primary nonferrous	28.8	9	69	55	183
Fabricated metals	26.0	11	112	74	218
Nonelectric machinery	30.6	25	949	577	411
Transportation, except aircraft	46.4	16	852	641	700
			2860*	2091†	

Based on National Science Foundation Report 63-7, pp. 51, 64, 74, 86, and 87.
* Total for all industry is $10.546 billion.
† Total for all industry is $6.117 billion.

Employment outside of defense or electronics

The engineer whose career has been entirely in the defense industries will be surprised when he becomes acquainted with engineering practices elsewhere. Despite the increased popularity of R & D, the National Industrial Conference Board reports that only one in 25 manufacturing companies, and only about one in 2000 nonmanufacturing companies, conducts any R & D at all.[5] Still, these small proportions add up to about 12000 companies. About half of all engineers and scientists are employed in manufacturing industries and about half of these are engaged in R & D. In general, R & D is a characteristic of the larger manufacturing companies. Less than 4 per cent of companies with less than 1000 employees conduct any R & D whatever. Over 90 per cent of companies with over 5000 employees have R & D programs, but there are only 350 such manufacturing companies in the United States. The electronics and aerospace industries are excluded; about 29 per cent of engineers and scientists in manufacturing industries are engaged in R & D (NSF Report 61-75, p. 25).

Privately financed R & D programs are often far from grandiose even for the large companies. As of 1960, 115 companies in the United States had programs of over $10 million yearly, and 500 had programs costing $1 million to $10 million yearly. About 70 per cent of R & D personnel are employed by the 100 largest companies—a concentration that far exceeds the concentration of total employment or total sales.[5] In the rubber industry, for example, 86 per cent of the R & D was done by four companies. Table VI shows some characteristics of R & D in various industries. The proportion of research and development personnel is much lower in the "other" group in the table, but surprisingly, perhaps, the amount of private R & D money in each group is about equal, and the cost per scientist or engineer is only slightly lower in the "other" group. The average number of R & D personnel in this group is significantly smaller.

For industry as a whole, privately borne R & D expense as a per cent of sales is a surprisingly low 1.8 per cent among the companies that do any R & D.[2] Less than one quarter of these companies spend as much as 2.5 per cent of sales on privately financed R & D.

Engineers moving out of defense work will very likely find themselves in work groups that are smaller and in which there is less demand for narrow specialization. Engineers who have concentrated on such military-oriented specialties as contract administration, reliability, and standards work can probably find comparable non-R & D employment in nondefense industry. In other industries non-R & D positions outnumber R & D positions by nearly two to one. However, because there are relatively fewer R & D positions in other industries than in defense work, some persons who prefer R & D may be obliged to perform other duties if they move to other industries.

In many cases salary adjustments are likely to accompany changes in employment. It is difficult to make comparisons, as often relocations involve somewhat different positions. Significant salary differences are associated with various industries, which tend to become greater the longer engineers have been out of school. However, there is also considerable overlap. For exexample, as of 1962 median starting salaries for communications industry engineers ran about $900 a year below starting salaries for electric machinery–electronics manufacturing, but one quarter of the 1953 graduates who were in communications were receiving salaries above the median for their counterparts in electrical manufacturing. Because each industry represents a different mix of engineering skills, there are limits to the conclusions that can be drawn from published data for all engineering combined.

The problem of the defense-oriented firm

It is entirely practical for a defense-oriented firm to make an estimate of the impact on the company of a leveling out or actual reduction in defense spending. Tailor-made estimates are highly desirable, since the average impact for an entire industry will seldom exactly apply. A useful approach is to analyze a number of alternative assumptions, and then develop suitable compensatory programs with full consideration of the sales, profits, investment, and employment under each. If these analyses are sufficiently extensive, the sensitivity of the company to changing defense budgets can be made clear and a rational decision can be made as to what immediate program is warranted and feasible.

The calculated effects of two alternative policies were carried out for one electronics firm. The first policy was to do nothing expensive in advance of an actual reduction of defense procurement, and the second was to develop a fairly costly compensatory program in advance. The proper choice among these policies depended on the odds that there would be a reduction in defense procurement. In this particular case, it turned out that the expected profit (using "expected" in the statistical sense) would be greater with the compensatory program only if the chance of the reduction was greater than one in four.

This exercise demonstrated the feasibility of a straightforward approach to advance planning to compensate for somewhat unlikely contingencies, and it gave some indication of the types of compensatory programs needed. Of greatest significance is the time lag between the conception of a new commercial product and an eventual net profit position. Even when the product is eminently successful, there is likely to be a long period during which considerable costs are incurred. Only firms with substantial financial reserves can afford the transition. It is popular to say that the coming shakeup in electronics will eliminate the smaller firms, but my analysis indicates that firms maintaining a strong financial position relative to the size of business they undertake will be the survivors, whether they are big or small. In sizing up a financial position, it is well to consider the probably unfavorable attitude of the financial community at a time when the entire defense electronics industry may be undergoing a difficult period. A cash reserve must be very substantial to finance product development to the extent that sales will offset lost defense business. Profits foregone by maintaining such a reserve are in fact one of the major costs of a strong defense against business adversity. The need for a reserve can be materially reduced by initiating diversification well in advance of the time when defense business starts to fall off.

When sales drop precipitously, no firm can continue to provide employment in anticipation of future work except for a few key employees. Companies will surely exercise the option of shifting the burden of readjustment to their employees. For this reason, the current attention to reconversion planning seems to miss the point. A firm may make a substantially successful readjustment, but its ex-employees may be faced with a difficult period. If the transition involves a shift from R & D-oriented to production-oriented work, many of the most skilled employees will be permanently dislocated. Successful reconversion may actually take the form of a reorganization of former defense-contractor employees in a new group of business firms.

Identifying nondefense markets for electronics

Inadequate market analysis has probably been the chief reason for the failure of many defense contractors to develop commercial products. Since the personal future of many engineers will be intimately involved with the success of new commercial products, it behooves them to understand the ingredients of a workmanlike market analysis for a new product.

To use education by way of illustration, there is a solid basis for student enrollment projections from population statistics. Expenditures on education per pupil can be projected. The opportunities for electronic techniques, such as teaching machines and computerization of administrative paper work can be identified. It is always worth remembering that potential customers are not likely to have the same interest in new gadgetry as are engineers and scientists. Basically educators will adopt electronic devices only if there is a worthwhile saving in administrative or teaching costs.

Good market analysis will always consider the customers' decision-making processes. When industrial equipment is under consideration, criteria such as return on investment will be applied—frequently by the company controller. It is surprising how little interest there is in a device that will not pay for itself quickly. A successful new industrial product is a device that will pay for itself in three years or less for a large enough number of buyers that the company developing and marketing it can recover its own investment in three years or less.

Consumer decision making is a somewhat different story. Who, for example, knows the return on investment in an electric toothbrush? But there are well-defined patterns of consumer buying. Almost any electronic device can be classified as a "consumer durable," along with automobiles, household appliances, and heavy recreational equipment. Only about 15 per cent of consumer income is spent on consumer durables. There has been an encouraging increase in demand for electronic consumer durables in recent years, largely in such relatively new products as electronic organs, tape recorders, phonographs, and color television.

An assessment of competition is part of any market analysis. Although many markets may be new to defense-oriented companies, they are the established markets for others, who have reputations, customer contacts, and an appreciation of what is desired in products. These companies have geared themselves to the prevailing rate of increasing demand. Their reaction to new competition may provide some interesting episodes in business history.

Despite the necessity for looking at particular product and market opportunities, the position of the industry as a whole is the key question today. Companies assessing their future must take a broad-gauge look before narrowing down their market analysis. Too commonly a company that recognizes a need for a greater role in nondefense markets draws the blissful conclusion from the market potential of a few new products that they are adequate to solve the company's problem. Dozens of other companies may be zeroing in on the same markets. Thus, a group of "experts" can get together and conclude that each has solved the problems of his company, and never realize how incompatible their plans are with each other's.

The role of government

Government is actually ahead of industry in studying the potential problems of changing patterns of defense procurement. Surveys of industry have shown a general tardiness in responding to the urgings of governmental officials. Studies sponsored by the Arms Control and Disarmament Agency, one of which is concerned specifically with the electronics industry, should be generally applicable to the less severe readjustment problems. A start has been made at tracing through the economy-wide implications of disarmament. Already a number of compensatory programs have been suggested by governmental and private groups. These include retraining, employment services, stimulation of demand for skills developed in defense work by other industries, financial assistance, and stimulation of the economy by public works, private construction, or foreign aid. Most of these programs emphasize impacts on the broad mass of unskilled and semiskilled work forces. Engineers and scientists, a highly paid, youthful and mobile group are apparently expected to solve their problems individually in their own way. That is probably the way most of them would want it.

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Adaptive antenna arrays

The entire course of antenna development appears to have been altered by the rapid evolution of the self-phasing principle. Salient characteristics of adaptive, or self-phasing, antennas are described by means of a semiquantitative approach

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Antenna research is considered by some shortsighted individuals to be a "dead field." The statement has been repeated many times since the end of World War II, but fortunately for those who make a living in this field, the body shows a great reluctance to lie down for the burial. While a quick perusal of the popular antenna publications indicates a great deal of "rediscovery" in progress, the relatively small number of researchers responsible for most of the progress are still pushing back the frontiers. Recent antenna developments, in fact, occasionally have bordered on the glamorous.

Background

Antenna arrays are as old as the antenna art itself. The familiar form of antenna array, in which coherent signals from the various elements interfere within the confines of the feed system and appear at an output terminal pair, represents what may be considered one extreme of a wide spectrum of possible directivity-enhancement methods. In this case, the entire burden of enhancement is placed upon the antenna system proper. Therefore, its characteristics can be specified without regard to the electronic system in which it may be used. One might regard the feed system as an ingenious and efficient analog computer that properly combines the element signals so as to enhance the directivity, as well as the signal-to-noise ratio, of the received signal. In the transmit mode, it supplies each element with precisely the correct signal in both amplitude and phase.

One might also envision the opposite extreme in which each element feeds its information to a data processor. Here it becomes the task of the processor to provide the equivalent of directivity enhancement and signal-to-noise ratio enhancement in addition to providing pointing information, etc., depending upon the system in which the antenna is to be used.

Since each element functions independently of its neighbors, a dynamically programmed computer could, in theory, learn the relative physical position of each element and adjust for mutual interaction of elements. It could be calibrated to indicate pointing direction, and even adjust for a change in frequency. The system would be as broadband as any of the individual elements.

It is, of course, not surprising that engineering and economic considerations have necessitated a temporarily stable compromise position between the two aforementioned extremes of the enhancement spectrum.

Adaptive antennas

There have been a number of developments in the field of adaptive antennas or, more properly, self-phased antennas. Three of the most noteworthy are:

1. Automatic beam steering and focusing
2. Retrodirective steering
3. Adaptive radar arrays

It was the writer's privilege to witness the initial tests of the Van Atta retrodirective reflector[1] about nine years ago at the Hughes Aircraft Company. In his patent disclosure, Dr. L. C. Van Atta proposed the array equivalent of the Luneberg lens or corner reflector. In addition, he proposed the use of amplifiers to make the array an active reflector. Shortly thereafter, the work of Lehan and Hughes[2] at Space-General Corporation made possible the application of phase-locked loops to adaptive arrays. These pioneering efforts together with the circuit developments of Margerum[3] and Lees of Electronic Specialty Company provided the basis for a substantial amount of effort that has since been applied in the field of adaptive antennas by numerous other workers.

An adaptive array may be defined as an antenna in which each of the elements is independently phased, based on the information obtained from signals received. Each element phases itself without regard to a priori knowledge of its relative position or of the path length to the source. A formal system of phasing is not used. No beams are formed in preselected directions. Instead, the adaptive array automatically adjusts each element to the proper relative phase in order to form a beam or beams on the targets or sources. Adaptive arrays compensate for changes in propagation path length to each element position and thereby optimize both the linear component of phase (scan) and the quadratic component of phase (focus). The semanticist might wish to differentiate between the adaptive array and the self-phased array; however, the terms are generally used interchangeably.

In the adaptive array only one phase shifter per element is needed, and the only requirement is that it cover a range of ±180 degrees with a monotonic response. Since each phase shifter is adaptively adjusted to the proper value, nonlinearities in the response, variation with temperature, hysteresis effects, and dependence on operating frequency are unimportant in focusing both receiving and transmitting radiation patterns on the source. If, however, the direction angle of the source is to be measured, then the phase shift at each element must be known.

Because the adaptive array requires some complexity at each element, most applications involve elements of considerable size, particularly when the elements themselves are steerable. However, the pointing accuracy of the element is associated only with the beam width of the element and not that of the array. Therefore, adaptive arrays are attractive when (1) the cost of larger and more accurately pointed conventional antennas becomes prohibitive, (2) physically separated elements are required, (3) the narrow beam widths of single large antennas limit the surveillance volume that can be scanned in the available time, or (4) large amounts of power are to be transmitted, and thus multiple transmitters are required.

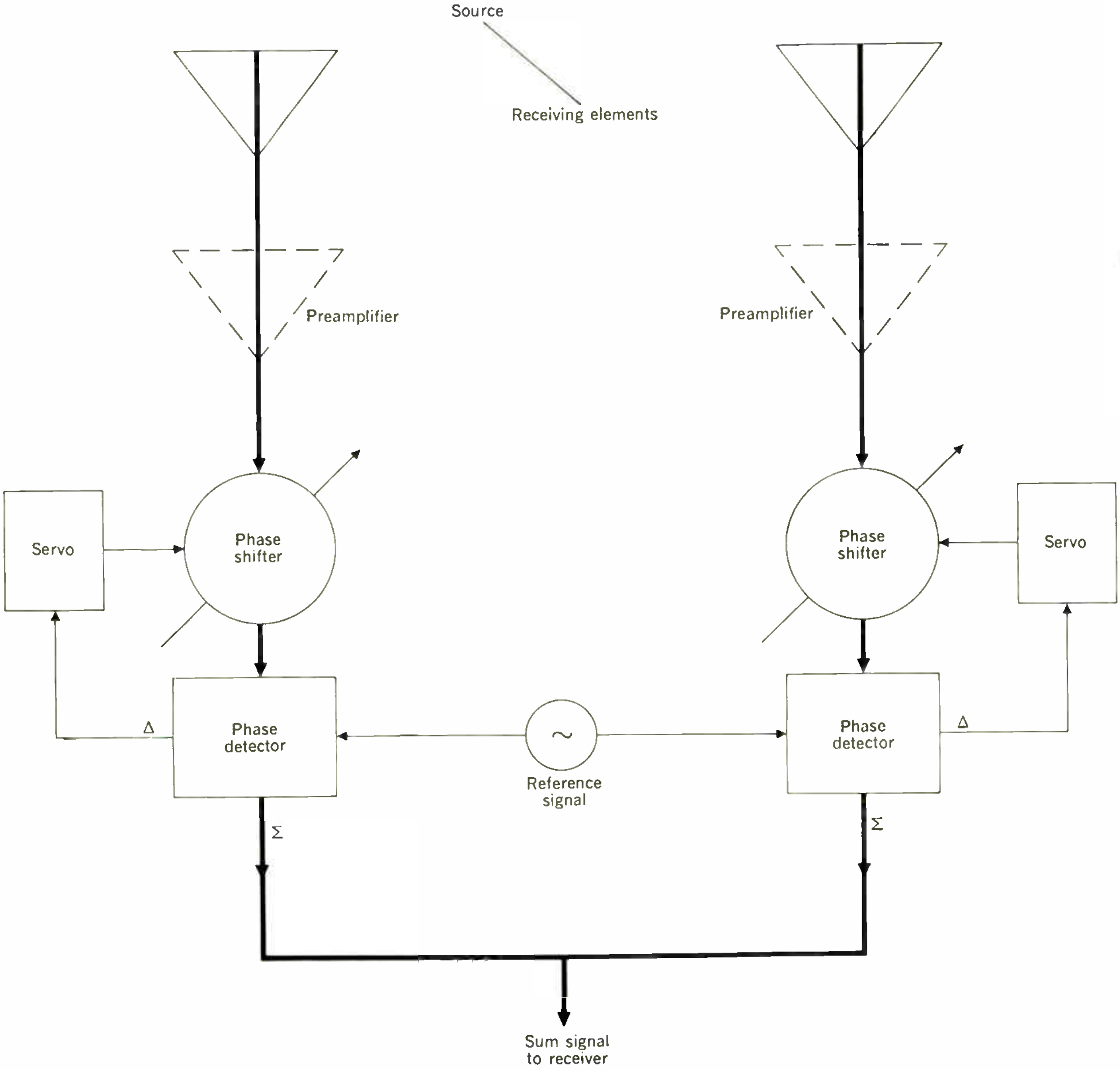
It is not difficult to imagine several more specific examples of ways in which the adaptive array principle may be usefully employed. For instance, several large dish-type receiving antennas with slaved steering can be self-phased, on received signals from satellites or space vehicles, so that the effective receiving aperture is the sum of the apertures of the dishes. Once the target is acquired and self-phasing is accomplished, the resultant increase in the overall signal-to-noise ratio can be traded for additional bandwidth and, consequently, greater information capacity. Advantages include flexibility, portability, and lower cost per square foot of effective aperture, especially when very large collecting areas are involved.

The adaptive array is well suited to applications that require transmissions to be directed back toward the source of a received signal, with very short response times. Such applications as time-shared communications between a number of remote points or transmission of prime power via microwave energy are served by retrodirective antennas.

Adaptive arrays can be designed to operate in pulsed, low-duty-cycle radar systems where they provide collecting aperture and transmitting gain, and also ultraprecise information on target direction. High precision can be achieved by utilizing multiple interferometer techniques in conjunction with special data processing for the elimination of ambiguities in angle-of-arrival determinations.

The three aforementioned applications represent three levels of sophistication required in system design. As will be seen presently, the receiving array requires only that frequency-locked reference signals be provided at each element so that the necessary signals may be derived for self-phasing at a common point. However, a retrodirective array generally requires that not only frequency-locked but also phase-locked reference signals be provided at each element. Moreover, the received signals for phasing may be present only intermittently, whereas a continuous phasing control for transmission may be required. In addition, a radar array must provide readout of angular direction, and therefore accurate measurement of the phase between pulsed signals at the various elements and an exact knowledge of the position

Fig. 1. Typical adaptive receiving array.



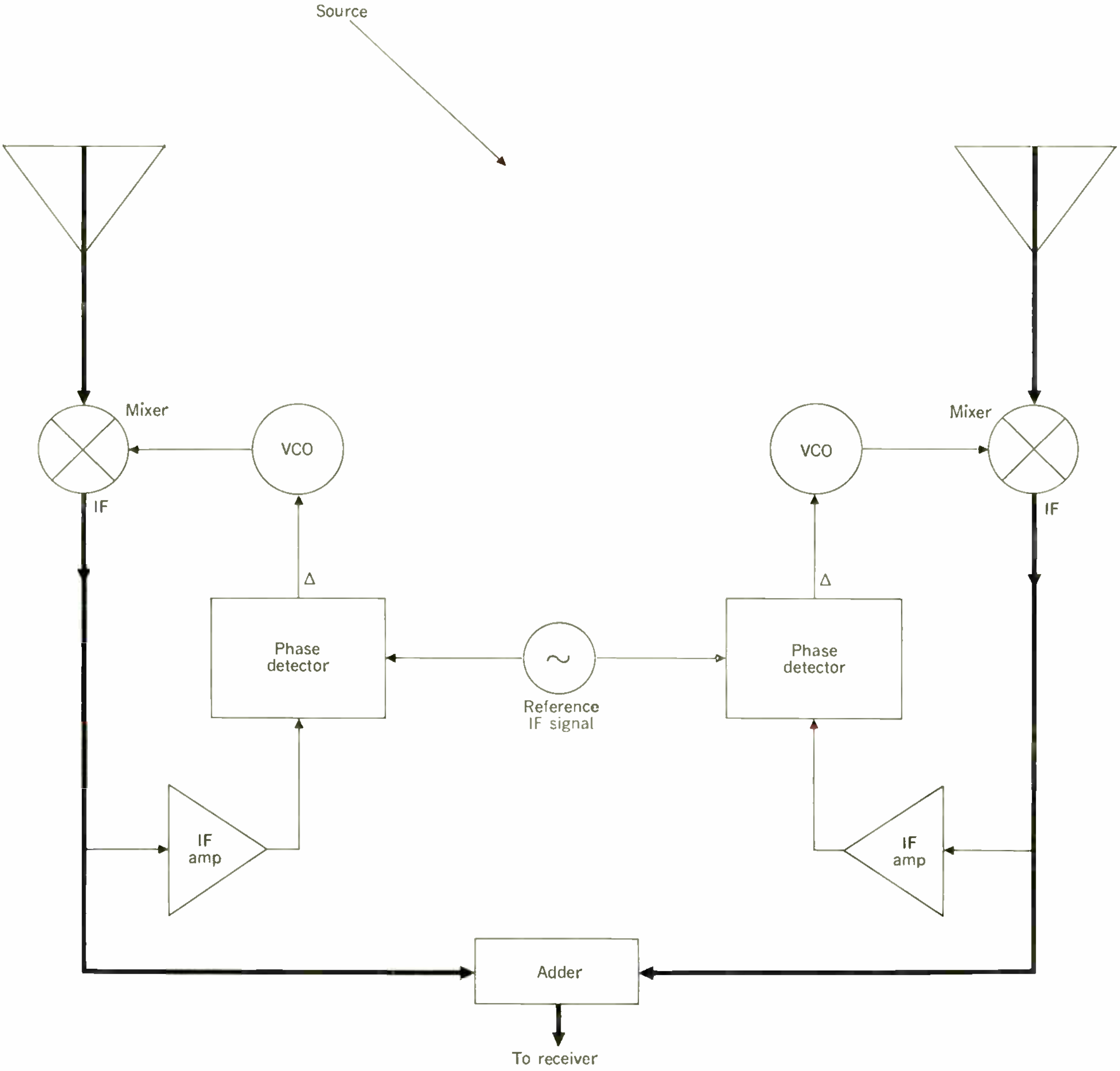
of each of the elements are required.

Automatic beam steering and focusing. A block diagram of a typical self-phased receiving array is shown in Fig. 1. The reference signal, against which each received signal is compared, is usually at or near the frequency of the received signals. The reference signals at each phase detector must be in phase. This requirement, in turn, implies that the lines between each detector and the source are of equal length if the system is not to be frequency sensitive. For receive-only arrays, all of the phase-lock circuitry can be installed in one location, but the remote antenna elements (without phase-stable transmission lines) can be widely dispersed. Each phase shifter compensates for both the phase differences associated with the angle of arrival and the phase shift in the transmission lines from the antennas. If unsynchronized pump oscillators are used in parametric preamplifiers, phase and frequency errors are introduced. These errors, in principle, can also be compensated by the phase shifters in the central unit. In practice, although synchronization in frequency is easily accomplished, absolute synchronization in phase is more difficult.

A method of directing a purely transmitting array on to a cooperative receiver has been described by R. T. Adams.[4] Each transmitting element has a different auxiliary modulator (AM or PM), which provides beam tagging. Therefore, at the receiving site, the amount of phase adjustment per transmitting element can be ascertained and relayed to the transmitter site.

The simplified diagram of the self-phased receiving array shown in Fig. 1 is adequate for operation with a stationary source when speed of acquisition is not of great importance. However, when high-velocity sources are involved, even the difference in Doppler shift between widely spaced elements may be significant, and response time is quite important. Consequently, the type of phase shifter and reference signal generator must be selected with due consideration.

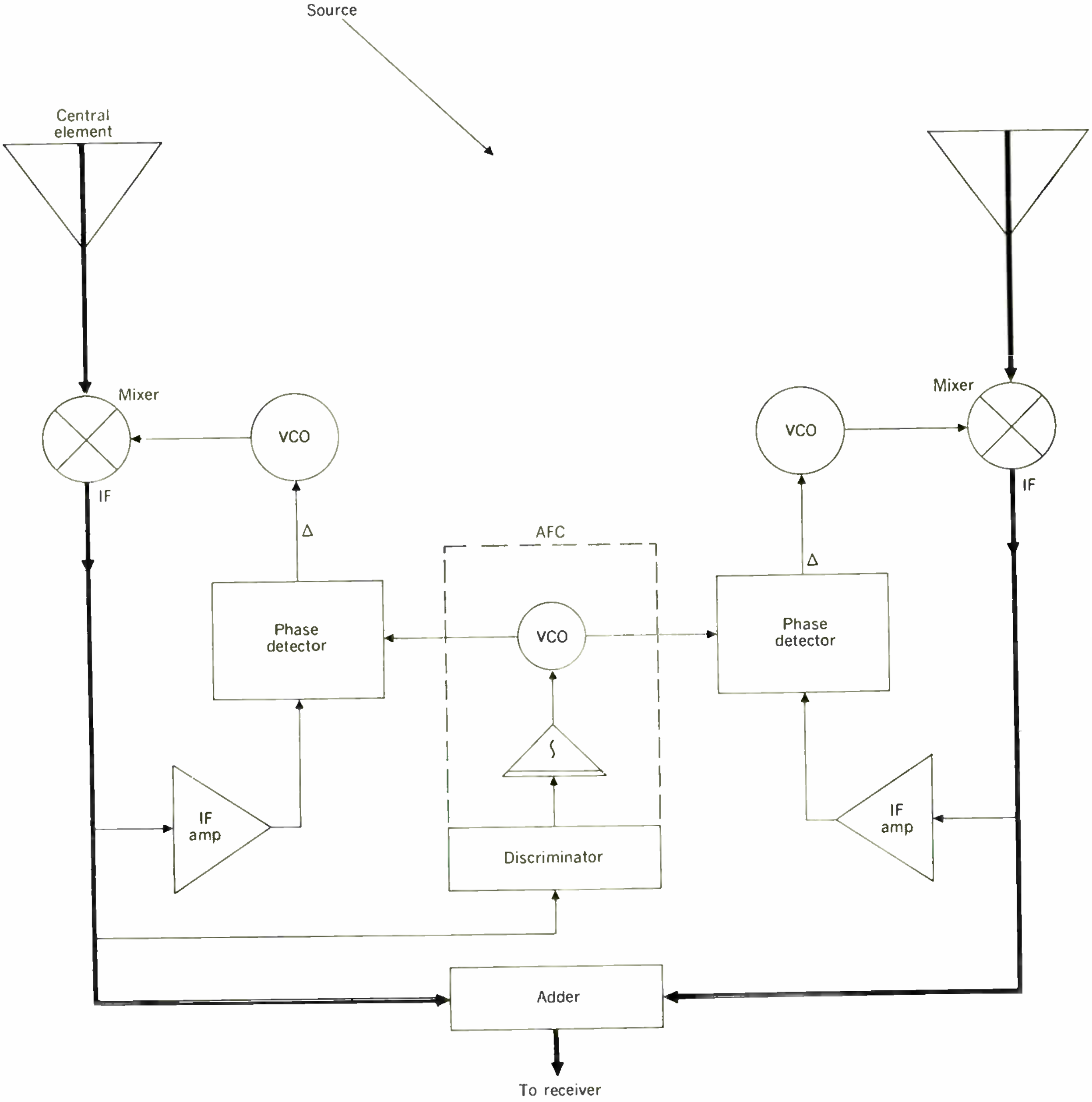
Fig. 2. Basic heterodyne phase-tracking circuit.



Doppler shifts at X-band frequencies, resulting for example from the velocities of satellite-borne transmitters, might require the phase shifters to introduce phase at rates up to the order of 10^8 degrees per second. Obviously, mechanical and most electronically controlled phase shifters are not suitable. Therefore, the reference signal must be slaved to the received signal frequency by an AFC (automatic frequency control) circuit. However, even when the reference signal tracks the received frequency at the central element in the array, those elements on either side of the central element may require continuous phase shifts of many cycles per second. Two techniques for accomplishing the phase tracking are (1) heterodyne phase tracking and (2) serrodyne phase tracking. The word "heterodyne," a familiar one in electronics, is derived by combining *hetero* (meaning different) with *dyne* (meaning power). Serro is derived from *serra* (meaning saw) and, therefore, serrodyne refers to a sawtooth form of power. As will be seen, the sawtoothed quantity is actually the relative phase.

The heterodyne phase-tracking circuit utilizes a voltage-controlled local oscillator driven by the difference output of a phase detector, which compares the phase of the received IF signal with that of a reference signal, as shown in Fig. 2. The RF signal is nominally at the transmitter frequency but is shifted in phase angle in propagating to the antenna element. The rate of change of range determines the Doppler shift to the central element, whereas the rate of change of projected aperture determines the differential Doppler shift. Unfortunately, the acquisition time is excessive for a system that must operate over the entire Doppler range. Therefore, it is preferable to use the circuit which is shown in Fig. 3, where the reference signal can be at the nominal

Fig. 3. Basic heterodyne phase-tracking circuit with automatic frequency control.



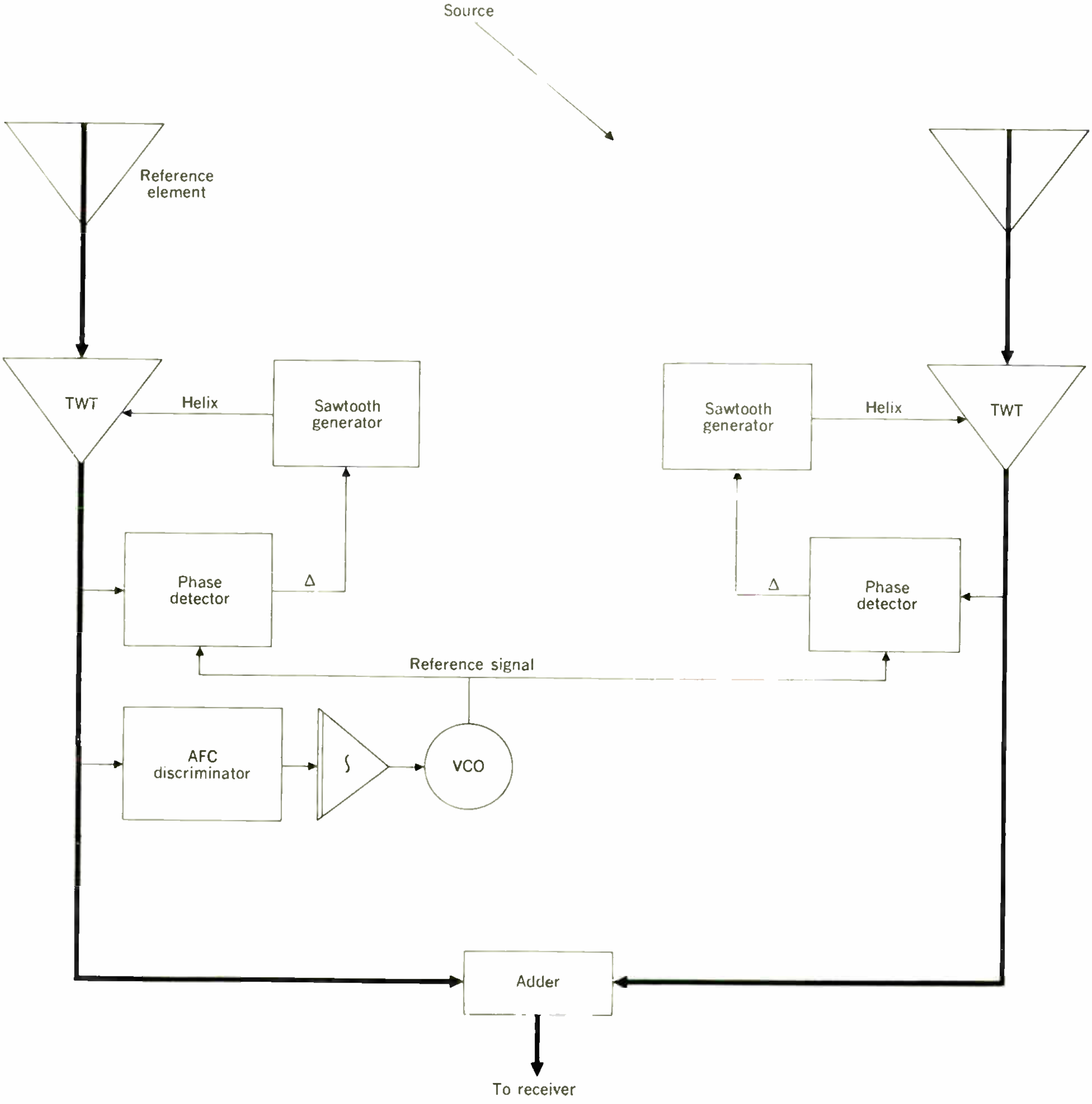
Doppler-shifted frequency, due to the use of an AFC circuit.

The reference signal is supplied by an AFC circuit operating on the received signal at the central element. The necessary frequency range of the local VCO (voltage-controlled oscillator) is restricted and its response is slow compared to that of the AFC loop, which provides a reference signal shifted by approximately the central-element Doppler shift. The Doppler tracking need be only approximate as long as the reference signal is distributed to all elements. The control voltage to the local VCO can be held at the most recent input in the case of intermittent signals, so a linear extrapolation of phase shift as a function of elapsed time is provided until the signal is received once more.

In the serrodyne method, signals received at the various elements are brought into phase coincidence by the use of phase shifters that are fast enough to account for the Doppler shifts involved. Since the phase shifters are generally electronically controlled and limited to a few cycles of phase shift, the virtually unlimited phase deviations demanded in a self-phased array, operating with a moving source, must be achieved by applying a sawtooth waveform that periodically inserts or withdraws phase shifts of 2π. Figure 4 is a block diagram of an adaptive array using traveling-wave tubes as serrodyned phase shifters.

The sawtooth generators can provide linear extrapolations of phase shift as a function of time during the absence of received signals for intermittent operation. The TWT (or any other type of electronically controlled phase shifter) need not provide gain, but should have a linear, or at least a well-known, monotonic transfer characteristic.

Fig. 4. Basic serrodyne phase-tracking circuit.



The time required to achieve phase-lock operation of each element in an adaptive array depends upon the uncertainty in the knowledge of the frequency to be received (usually due to Doppler effects), the spread in frequencies received (differential Doppler effects), and the signal-to-noise ratio at each element. The AFC circuit that locks the reference-signal oscillator to the mean Doppler-shifted frequency contributes delay in the acquisition process, as does the self-phasing loop at each element.

Typically, 20 microseconds are required for an adaptive array to acquire a signal within a ±15 kc/s range.[3] The sum of the AFC error and differential Doppler shift across the array may produce up to 100 c/s errors at each element.

It is evident that with a dwell time of only 20 μs required in each beam position (for a receiving array), the acquisition time may well be limited by mechanical sluing of the elements in the array rather than by its adaptive characteristics. But it is still a great improvement over the conventional antenna, which is even more restricted mechanically because of its larger mass and more critical tolerances.

Retrodirective steering. When RF amplifiers are employed, the central phasing unit approach can also be applied to retrodirective arrays—that is, arrays that focus transmitted energy back in the direction of arrival of the received signals. Both transmitting self-phased arrays and passive arrays that focus outgoing waves back at the source of incident waves are retrodirective arrays. The best-known passive retrodirective antennas are the corner reflector, shown in Fig. 5(A), and the Luneberg lens. The passive array equivalent of these is the Van Atta array.

The one-dimensional Van Atta array shown in Fig. 5(B) provides equal-length bilateral transmission lines connecting elements equally spaced from the center of the array. The incoming signal on elements to the left of center (solid arrow) are retransmitted (through a common transmission-line delay) to their mirror images at the right of center. Thus the advanced signals on reception are transmitted as delays and vice versa. The sum of the retransmitted signals add coherently in the direction of the source, provided that the energy emanating from each antenna in the array is assumed to be only that which was intercepted by its image and transmitted over the interconnecting cable. Therefore, it is desirable to minimize the scattering cross section of the installation.

For element spacings greater than λ/2, more than one beam will be formed, but without degradation in gain since the beam width will be inversely proportional to the spacing and the resulting higher directivity in each beam will compensate for the power division between beams. In applications in which multipath or secure communication are not involved, wider spacings offer practical advantages. Van Atta reflectors lend themselves to stripline construction for lightweight encapsulated units and may be stacked to make two-dimensional arrays.

Active Van Atta arrays may be employed with the use of either bilateral or two unilateral amplifiers in each interconnecting transmission line. Circulators are used to separate signals traveling in the two directions. Both of these active methods are limited, however, by the mismatch reflections from the antenna elements, whose impedance changes with angle of arrival of incident energy when the elements are closely spaced. Because of the

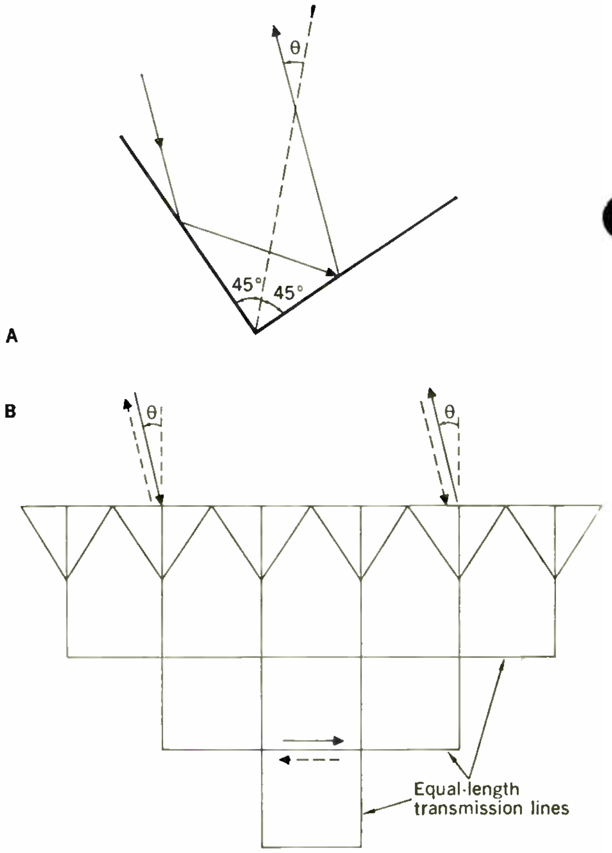
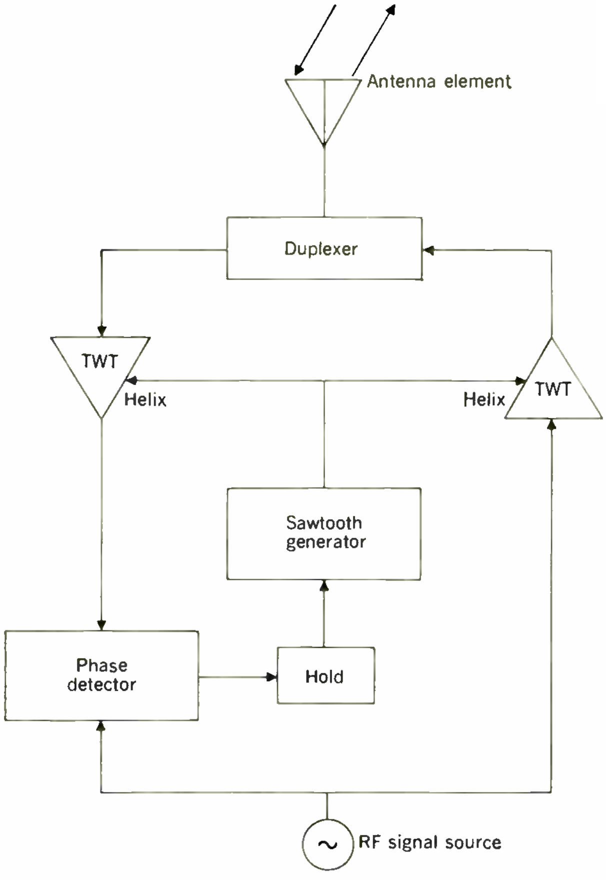


Fig. 5. Passive retrodirective reflectors. A—90° corner reflector. B—Six-element Van Atta reflector array.

Fig. 6. Serrodyne phase-conjugation circuit.



change in impedance of the elements with angle of arrival, negative-resistance types of amplifiers cannot be easily employed. Therefore, to achieve high amplification figures in active Van Atta arrays, frequency-offset techniques must be employed. The percentage difference between input and output frequencies must be kept small, however, because of the occurrence of a beam shift, which is a function of the frequency offset and the entrance angle.

Principle of phase conjugacy. The conditions for self-phasing can be generalized so that they may be applied to any arrangement of phasing devices. The requirement for common transmitting and receiving phase shifters is thereby avoided. The fundamental requirement for retrodirectivity is that each element in the array have an outgoing wave that is delayed (with respect to a given reference element) by exactly as much as the incoming wave was advanced. If this requirement is satisfied, the total path length from the source to the array element and back to the source will be constant for all elements in the array. Consequently, back at the source the fields will add in phase. At a given frequency, time delay usually may be simulated by a phase shift, which may be ambiguous to within $\pm 2n\pi$. Thus at any element in the array the outgoing wave must lag in phase by exactly the lead in phase (with respect to the reference element) observed at that element; that is, the phase of the transmitted signal from any element in a retrodirective array must bear a conjugate relationship to the phase of the received signal at that element relative to a common reference signal. It is to be noted that the phase, or even the frequency, of the reference signal is completely arbitrary, although in many cases it is convenient to choose the received signal from one of the elements or a combination of received signals as the reference.

An array of elements transmitting conjugate-phased signals will be retrodirective regardless of the disposition of the elements. Thus elements spaced randomly over any surface will allow retrodirective operation.

The phase conjugation required for retrodirectivity may be obtained by driving receiving and transmitting phase shifters in parallel while servoing the receiving phase shifter to compensate for the phase shifts caused by the angle of arrival. Because mechanical phase shifters cannot perform adequately over the large dynamic range of phase rates required for fast targets, electronic phase shifters are used. The latter cannot supply an infinite phase deviation, so multiples of 2π are added or withdrawn as required by the previously mentioned serrodyne circuit.

The traveling-wave tube is an excellent phase shifter as well as a high-gain preamplifier or driver for a power amplifier. A circuit showing the employment of TWTs in a serrodyne phase conjugation application is outlined in Fig. 6. The "hold" circuit enables the transmitting TWT to provide continuous conjugate phasing even though the received signals may be intermittent, since the sawtooth generator acts as a flywheel.

The helix of the receiving TWT is driven to produce a phase shift, which compensates for the angle-of-arrival phase shift, by a comparison of RF phases in the phase detector. Thus it is part of a phase-locked loop. If the transmitting TWT is of the same type, its helix may be driven directly in parallel with the receiving-tube helix. If the tubes are of different types, the linear characteristics of phase shift versus helix voltage allow a simple voltage division to account for the difference in phase sensitivity.

It is also possible to use the upper and lower sidebands from a balanced modulator for the local oscillator signals of the receive and transmit systems, respectively. The two sidebands bear a conjugate phase relationship with respect to the carrier signal.

Adaptive radar arrays. An adaptive array may be operated as a radar by utilizing the phase-shift information available at each element in conjunction with an accurate knowledge of the physical position of each element. To achieve maximum accuracy the elements must be widely spaced, but not so widely as to prevent resolution of angular ambiguities.

A knowledge of the total phase difference Φ_1 of a wave incident on two widely spaced elements permits an accurate determination of the angle of incidence. However, the relationship of the angle to the measured phase ϕ_1 is ambiguous, since only the principal part of the total phase can be measured ($-\pi \leq \phi_1 \leq \pi$). Figure 7 shows the direction-finding geometry.

Fig. 7. Pointing direction geometry.

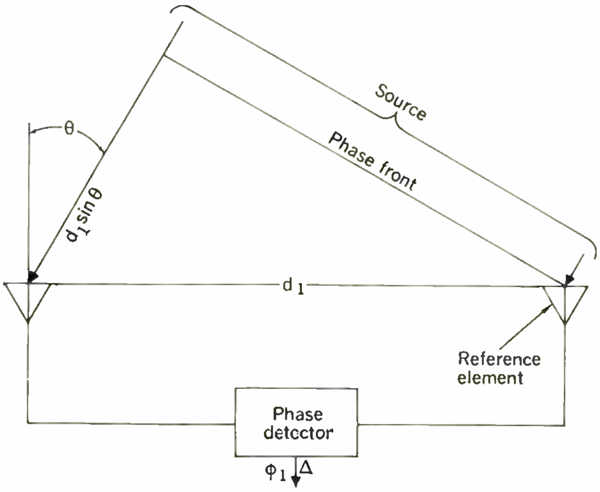
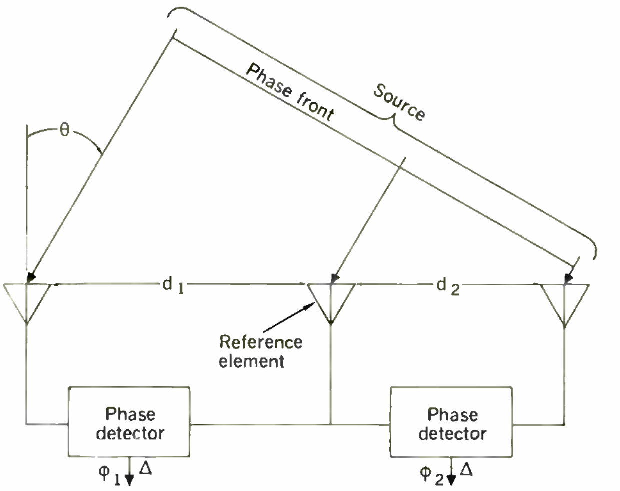


Fig. 8. Three-element direction finder.



The total phase angle between the received signals is given by

$$\Phi_1 = \frac{2\pi}{\lambda} d_1 \sin \theta \tag{1}$$

This total phase can be obtained from the measured phase, but the relationship is ambiguous. The set of possible Φ values corresponding to a measured ϕ_1, is denoted by Φ_{1n}. This set, which includes the true Φ_1, is defined by

$$\Phi_{1n} = \phi_1 + 2n\pi \qquad |n| \text{ is an integer} \leq \frac{d_1}{\lambda} \tag{2}$$

Consequently, a measured phase difference corresponds to a family of possible arrival angles θ_n.

$$\sin \theta_n = \frac{\lambda}{d_1}\left(\frac{\phi_1}{2\pi} + n\right) \tag{3}$$

An approximate value of θ may be obtained from the pointing direction of the steerable antenna elements. The accuracy is not sufficient to resolve the ambiguities but it does limit the range of possible values of n. However, the correct value of n sometimes can be determined and the ambiguities resolved by the use of an additional element with a different spacing; see Fig. 8. Expressions similar to equations (1) and (2) exist for the measured difference phase between the reference element and this additional element, and are given by

$$\Phi_2 = \frac{2\pi}{\lambda} d_2 \sin \theta \tag{4}$$

$$\Phi_{2m} = \phi_2 + 2m\pi \qquad |m| \text{ is an integer} \leq \frac{d_2}{\lambda} \tag{5}$$

$$\sin \theta_m = \frac{\lambda}{d_2}\left(\frac{\phi_2}{2\pi} + m\right) \tag{6}$$

The correct value of θ occurs when $\theta = \theta_n = \theta_m$. If $\sin \theta_n$ is set equal to $\sin \theta_m$, the following relation is obtained:

$$m = \left(\frac{d_2}{d_1}\right)n + \frac{1}{2\pi}\left(\frac{d_2\phi_1}{d_1} - \phi_2\right) = K_1 n + K_2 \tag{7}$$

where K_1 and K_2 are known from the measurements. Therefore, if d_1 and d_2 are properly chosen, it may be possible to obtain unique values of m and n by applying the conditions that both are integers.

For example, assume

$$\phi_1 = \phi_2 = 0$$

$$d_1 = 3.2\lambda$$

$$d_2 = 5.2\lambda$$

Then $-5 \leq m \leq 5$, $-3 \leq n \leq 3$, and $m/n = 5.2/3.2 = 1.625$. A quick run-through of the possible combinations of m and n readily indicates that the unique solution is $m = n = 0$. Consequently, in this example, $\theta = 0$ (broadside). A sevenfold and an elevenfold ambiguity have been combined to produce an unambiguous result.

Similarly, for $\phi_1 = \phi_2 = -0.8\pi$, it is found that $\theta = +\pi/6$ unambiguously.

Any errors introduced in the phase-measuring device are either inherent systematic errors or random errors due to noise. The systematic errors vary with environmental changes but are constant from pulse to pulse, so they cannot be decreased by pulse-to-pulse integration.

When the signal-to-noise ratio is high (20 dB), the noise errors are typically about 4°. These random errors can be decreased significantly by pulse-to-pulse integration.

The phase errors resulting from atmospheric fluctuations are random with respect to both time and position. Near broadside they usually will not exceed ±5°, according to Margerum.[3]

If ambiguities are to be resolved satisfactorily, it is necessary to have an accurate knowledge of the position of the antenna phase centers. A displacement Δy of the phase center, perpendicular to the line of elements, corresponds to a phase shift proportional to the cosine of the angle off broadside.

$$\Delta\phi_y = \frac{2\pi}{\lambda} \Delta y \cos \theta \tag{8}$$

A colinear displacement Δx corresponds to a phase shift proportional to the sine of the angle off broadside.

$$\Delta\phi_x = \frac{2\pi}{\lambda} \Delta x \sin \theta \tag{9}$$

A phase accuracy of $\pm\pi/8$ in the X band requires a position accuracy of about $\pm 1/16$ inch.

Position errors may be caused by fluctuations in the towers or by rotation. The towers are supposedly rigid structures, but changes in height due to temperature variations must be considered. These changes are generally small and are controllable. If there is horizontal sway in the towers in heavy winds, monitoring is necessary to permit correction in the data processing.

If all the antenna elements are identical, the rotation errors will be identical as long as the elements are pointed in the same direction. Even though wind may deflect the feeds and bend the antennas slightly, it can be shown that the relative phase shifts are second order and will not fluctuate appreciably if the elements are tracking the target.

Multiple targets

When a number of sources illuminate the array simultaneously, each element will detect the phase of the vector sum of the received signals with respect to a reference signal. The self-phasing process acts to provide retransmitted signals, which have the conjugate phase of the vector sum. It is evident that if several phasing distributions were superimposed, the resultant phase distribution would be the conjugate of the vector sum of the signals received from those points. Therefore, distinct beams would be formed properly directly toward the desired points in space. If target A by itself produces, after self-phasing, a phase distribution a that forms a beam back in the direction of A, and likewise target B by itself produces a phase distribution b that forms a beam back in the direction of B, the superposition of the retransmitted field with phase distributions a and b will result in beams directed at both A and B. Essentially this superposition occurs when simultaneous phasing signals are received from more than one target.

When the number of elements is large, multiple target focusing can be achieved with constant power output from each element. It should also be noted that the received signals need not be at the same frequency. When the received signals are not at the same frequency the

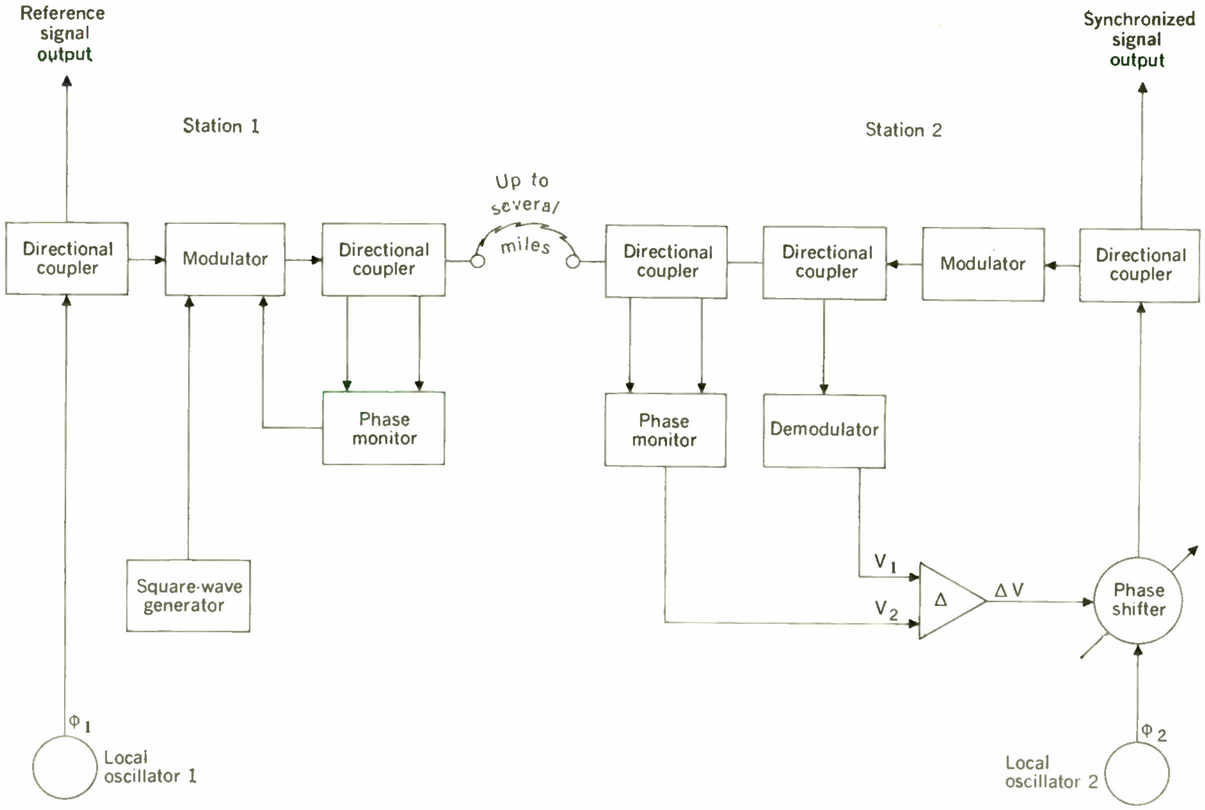


Fig. 9. Phase-synchronization circuit.

resultant phase distribution changes rapidly at the difference frequencies, but the resultant at any given time produces the proper multiple focusing.

Requirements and limitations

Since the adaptive process depends upon the detection of relative phase between the received signal at each element and a common reference signal, the signal-to-noise ratio at each element is of paramount interest. If the phasing errors are, for example, not to exceed δ radians, then the "uncertainty principle" requires that the noise power should not exceed the value given by

$$N < 2\delta^2 \text{ (signal power)} \qquad \text{for small } \delta \qquad (10)$$

With an array of M elements, a signal-to-noise improvement of M is achieved on reception once the array is phased. This improvement results because the noise contributions from the various receivers add incoherently (the powers add), whereas the signals add coherently (the voltages add). Similarly the retransmitted signals, after self-phasing takes place, add coherently at the origin of the phasing signals. The result is a power gain by a factor of M, the number of elements in the array. The fact that the bandwidth of the phasing signals need be only that necessary to pass the information associated with changes in the position of the "target" or that associated with maximum acquisition time, allows the array to adapt on relatively weak signals by employment of relatively narrow-band receivers.

In some instances the array may be phased in an organized fashion so as to create beams that search for a target, and thus the signal-to-noise ratio requirement at each element may be relaxed. More often, however, the elements are widely spaced, and the propagation path, as well as the exact location of each element, is not known with sufficient accuracy to allow such organized phasing. Then the voltages transmitted from the various elements add vectorially at the target in random phase. It might be suggested that all combinations of phasings (with given increments) be examined so that the proper phasing may be determined. However, the number of possible combinations generally becomes prohibitively large, allowing many opportunities for false alarms from noise during the search for the proper combination of signal phases.

For reasons of economy, adaptive arrays often will consist of elements spaced by many wavelengths, since the complexity and expense of individual self-phasing units can be justified only for relatively large antenna elements. When the spacing of the elements is greater than a wavelength, the phasing at each element may be ambiguous by $2n\pi$ radians at the received frequency. Consequently, even though the array may be properly phased at a single frequency, for proper operation a change in operating frequency would, in general, require a different set of phase shifts at each element. This is true for all arrays when phase-delay scanning, as opposed to time-delay scanning, is employed.

It is true that a phase perturbation occurring over the path from the target to a particular element in an adaptive array will be compensated for during reception, so that upon retransmission the waves traversing the same path will add in phase at the target with the waves from the other elements. However, it must be emphasized that the propagation paths must be (1) linear (independent of amplitude); (2) bilateral (isotropic); and (3) quasi-static (unchanged during the receive–transmit cycle).

Propagation paths are linear and bilateral in the troposphere and also in the ionosphere for operating frequencies above 1000 Mc/s. However, Faraday rotation effects in the ionosphere at lower frequencies are anisotropic, and adaptive arrays will not operate properly as transmitting antenna systems if such effects are to be expected. They will, of course, operate quite successfully as receiving antenna systems, since the signals can always be added in phase regardless of their origin or propagation path.

Satisfaction of the quasi-static path requirement depends again upon operating frequency, with practical difficulties developing only at frequencies well above 10 000 Mc/s. Detrimental effects may be the changes in propagation paths caused by turbulences and by the slight differences in the position of the propagation paths for reception, as contrasted with that for retransmission when a moving target is involved. For a perfectly stratified atmosphere, the rotation in the "line of sight" occurring between reception and retransmission would have no significant effect on the electrical path length; therefore, in both types of path-length variations the effects of atmospheric turbulence are the phenomena of importance.

A considerable frequency band exists wherein the requirements for linear, bilateral, and quasi-static propagation paths are met and the active adaptive (retrodirective) array is feasible. The passive adaptive array can operate independently of propagation considerations.

Remote phase-synchronization techniques

Accurate measurement or control of the relative phase between signals existing at widely separated points requires a means of communicating the phase information that does not in itself introduce errors. This requirement is most difficult to meet when the signals are in the microwave spectrum and the separations are several thousand feet. If temperature-stabilized transmission lines are employed to bring the signals to a common point, small drifts of 0.1°C or so will cause excessive phase shifts. The total phase shift must then be calibrated from day to day, an exceedingly difficult job in itself.

By providing phase-synchronized local oscillators at each point, the received signals can be heterodyned down to intermediate frequencies where the phase errors introduced by transmission lines are negligible. This changes the problem to that of establishing phase-synchronized local oscillators.

The most common approach to establishing phase-synchronized local oscillators is to phase-lock crystal-controlled oscillators at lower frequencies and use local multiplier chains to provide microwave local oscillators at each remote point. However, since the phase errors multiply by the same factor, little is accomplished and, in fact, some ground is lost. The problem is that of maintaining a known time delay in the communication path—and a time delay is, of course, independent of frequency. Whether or not frequency multiplication is used, it is apparent that some sort of feedback is required to maintain phase synchronization.

If exactly the same transmission path is used for sending the reference signal to the remote point as for sending back the feedback signal, only on the bilateral nature of the transmission line rather than its absolute delay is significant. Hence, if the path becomes longer, the reference reaches the point delayed by $\Delta\tau$ and the feedback signal is delayed by $2\Delta\tau$. By sensing $2\Delta\tau$ and servoing a compensating delay line to cancel out the change, it is possible to keep $\Delta\tau$ very small even under dynamic conditions. The essence of the problem now becomes one of distinguishing outgoing signals from incoming signals, even though both use the identical path at the identical frequency. Figure 9 illustrates a system that will provide phase synchronization for separations up to 60 000 feet at X-band frequencies. Each local oscillator transmits signals to the other end of the link through an amplitude modulator, the square wave of which modulates the signal between maximum and typically 50 dB below maximum. A phase-measuring apparatus that has been developed yields analog voltages directly proportional to the phase difference measured over a $\pm\pi$ range. The phase difference measured at station 2, during the interval when station 1 is on, is proportional to

$$V_2 = \phi_1 + \Delta\phi - \phi_2 \tag{11}$$

where ϕ_1 is the phase of the reference local oscillator, $\Delta\phi$ is the phase shift over the path length, and ϕ_2 is the phase of the local oscillator to be synchronized.

Similarly the phase difference measured at station 1, while station 2 is on, is proportional to

$$V_1 = \phi_2 + \Delta\phi - \phi_1 \tag{12}$$

This difference $\Delta\phi$ is transmitted via the microwave link to station 2, where the voltages proportional to the phase differences are subtracted, yielding

$$\Delta V = V_2 - V_1 = (\phi_1 + \Delta\phi - \phi_2) - (\phi_2 + \Delta\phi - \phi_1)$$

or

$$\Delta V = 2(\phi_1 - \phi_2) \tag{13}$$

The difference voltage ΔV is then proportional to the phase differences between the two local oscillators and can be used to drive a phase shifter at local oscillator 2 so that it is brought into phase synchronization with local oscillator 1.

Even stations separated by several miles may be phase synchronized to within a few degrees of phase, with no need for field calibration. The only requirement is that the path between the two sites be bilateral over the transit time (always true, as even multipath propagation is bilateral) and that sufficient local oscillator stability be provided to bridge the time during which the phase measurements are made. The necessary stability is easily achieved with stable microwave cavity references, which are simple, rugged, and highly reliable.

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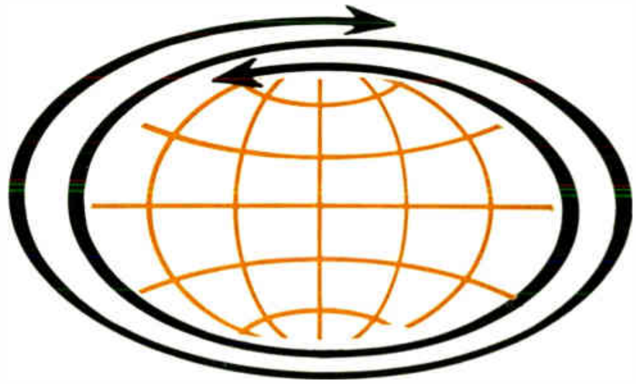


A national science and technology policy

One of our most pressing needs is for a continuous mechanism to assure that the fruits of science and technology are purposefully used for the economic and social benefit of the entire country. Many of the problems discussed apply equally to other nations throughout the world

J. Herbert Hollomon

Assistant Secretary of Commerce for Science and Technology

Science and technology are the dominant influences in our lives, as individuals in a society, and as a nation in a world of other nations. Given this premise, one might assume that there must be a national policy for science and engineering. We have a fiscal policy, a tax policy, a natural resources policy, an agricultural policy, a trade policy, a defense policy, a foreign policy. But as yet we do not have a national policy for science and engineering—at least, we do not have a firm one. We must not adopt a policy of national neglect, or a policy of national indifference toward one of the most significant and far-reaching elements in our society.

Our present attitude toward science and technology began to crystallize during World War II, when the military needs of the nation and the capabilities of science and technology coincided, with dramatic success. Massive programs of applied science and technology were organized. They were aimed at specific objectives—an atomic bomb, radar, guided missiles—not to the general technical advancement of the nation. The question "How much?" was less important than "Will it work?" Money, manpower, and resources for military research were given top priority. The lessons we learned were that huge national programs for specific goals can succeed, and that science and technology are crucial to the fulfillment of certain national objectives. But did we learn that technical resources were becoming at least as important as our natural resources in the development of our economy and the realization of our critical social needs?

Specific research programs

The support of research in the medical and biological sciences at the National Institutes of Health is an example of a broad, public, specific need met by a broad, publicly supported, specific research program. The success of this approach to improving the physical well-being of the nation's population has ranged far beyond the comfort and health of individual citizens. Through the reduction of sickness and prolonging of life expectancy, the size and efficiency of the nation's work force have been greatly increased. The effective utilization of this work force is a new and demanding problem.

The year 1957, and the advent of the space age saw this country embark on a massive, nation-wide scientific and technological effort, an effort in which we are still engaged. For a variety of reasons—national prestige, international competition, the expressed desire of the people to explore outer space, the challenge of discovery—we now give support to many areas of science and technology that relate to this goal.

These spectacular programs and those of the military—such as the one that produced the ballistic missile—arose from a desire to defend ourselves against a potential enemy, or to participate in an intellectual adventure, or to improve our national health. Organized around specific projects, these efforts only incidentally supported basic scientific research or helped build better graduate schools. They supported engineering research in specific fields not related to broad socioeconomic needs. They were directed more to the exploration and application of science for specific national purposes, rather than to meeting the local and sometimes diverse needs of our society.

We must also bear in mind that Federal funds support three fourths of all research and development performed in the country; therefore, public decisions to go to the moon, or to conquer cancer, for example, have largely determined the total national research and development effort.

We provided public support for graduate university education and research primarily because it advanced the objectives of the space program, the national defense effort, and public health. We did not support education to develop and grow new institutions of learning or simply to educate our citizens better. Furthermore, educational support provided by large, goal-oriented programs has had the inevitable effect of biasing faculty, students, and facilities toward a few favored fields of science and engineering—often creating and reinforcing vogues in thinking and interest. The support has made many of our great universities dependent on government research funds of particular mission-oriented agencies. However, this support also gave to scientists and engineers, at least in some fields, all the support that could be intelligently used. And without these programs, graduate education as we need it and American scientific leadership would not exist today, unless substitute programs had been supported—something which probably would not have happened.

On the other hand, a national space program, a national defense research and development program, a national medical research program, and a national policy of support for some kinds of basic research do not constitute a national policy for science and engineering to serve the general welfare. These relatively narrow, goal-oriented R & D programs, no matter how crucial to our nation, do not substitute for a national policy aimed at meeting the country's economic and social needs. Only now are we beginning to appreciate the need for a clearly defined national policy aimed at supporting intellectual activities to assure the health and vitality of our society and our economy. Obviously, there have been side benefits from some of these project-oriented programs. Certain institutions have been strengthened; our national defense has been secured. Certain areas of science were advanced: astronomy because of its relationship to the space program, solid-state physics because of miniaturization and reliability considerations in space and defense projects. But we do not yet have clearly recognized criteria that would help us cope with the problem of allocating technical resources, of deciding which institutions to support, of how to train people, or of how our laws and organizational arrangements should be directed toward making the best use of science for civilian economic purposes.

Before World War II, Federal support for science and technology was opportunistic and had developed largely in response to the demands of the widening frontier—for example, the agricultural programs fashioned under the two Wallaces; the Coast and Geodetic Survey explorations, dating back to the Lewis and Clark expeditions; and the research carried on in the National Bureau of Standards.

Research derived from abroad

A most significant characteristic of the times before World War II was that we drew heavily on the high level of science and technology in Europe. Even the atomic bomb, which was developed in this country, was primarily derived from research performed in Europe and depended upon the guidance of scientists and engineers who had come from abroad.

Three decades ago, therefore, we might seem to have adopted a national policy of borrowing the most advanced science and technology from Europe, adapting it to our mass markets, and making a success out of the process. In effect, this is what we were doing, although not as a matter of announced public policy.

The shift in technological leadership

Today the situation is radically different. We are the wealthiest nation in the world. We are the leaders in science and technology. Just as other nations look to us as a source of capital, they also look to us as a source of scientific and technological knowledge. They can plan, as a matter of *their* national policy, to buy and borrow the know-how from us, even to use it to compete with us in foreign and domestic markets as we did in the 19th century. Where, then, can we turn? Obviously, there are fewer sources from which we can borrow. The alternative, and one which we willingly accept, is to maintain a world lead in science and technology as a matter of public policy, and to use this resource efficiently to achieve social objectives that we consciously choose to pursue. It, therefore, must be developed and conserved.

This policy has certain implications that we must face. First, it is more costly to be the leader than it is to be a follower; it is more expensive to pioneer than it is to copy. Second, we are required to maintain a strong basic research effort in science, as well as a major effort aimed at applying the fruits of science to practical problems and purposes. The latter is particularly important, for we are competing with nations who can choose to devote much of their efforts and resources to practical and profitable applications.

Only a wealthy nation can afford to do well in both of these areas. The very affluence that allows us to support major efforts in these fields raises the question of how we became so wealthy if we had such a casual policy toward science and technology. The fact is that we became leaders in science after we became wealthy, not before. The clear implication, thus, is that we became wealthy for other reasons than science. The answer is found in our history and in our geography, and in the start the young country got from Europe.

We live in a land that was and is abundant in raw materials and natural resources; a country with many natural waterways for transportation and a superabundance of accessible and available land to accommodate the skilled and hard-working people coming here from Europe. Steinmetz, himself, is an excellent example of the wealth we reaped from the investment in education made in Germany. Our country had a single political system, with large, homogeneous markets and free commerce across state borders. We were relatively free from the debilitating effects of wars that ranged across Europe in the 18th, 19th, and 20th centuries. These conditions contributed significantly to our present status but they do not provide a basis for planning for the future.

We must begin with where we are now, what we are doing now. our national posture, the problems that beset us, our technical resources. We must look to the great and pressing social problems of our time: the problem of full employment for all our citizens; the continuing development of new products and services to meet the needs of modern society; increasing urbanization, with new approaches needed for transportation, environmental health and control, and leisure activities; and the extension of the fruits of science and technology to the less-developed nations of the world.

The distinction between science and engineering

In looking at the present situation, we should remind ourselves that science and engineering represent two distinct activities. The distinction becomes very important when Congress examines, as it is now doing, Federal research and development activities. Only about 10 per cent of Federal funds for science are used for basic studies aimed at improving our understanding of nature. The remainder is for development work, engineering, testing, evaluating, etc. Although we support basic research in science, with the expectation that eventually the results will be broadly beneficial, our support for engineering and technology is closely related to specialized goals such as space, defense, or atomic power. Thus we support the discovery of knowledge, but not its broad application; we seize opportunities for new discoveries rather than look for opportunities to meet some need of society.

A notable exception to these generalizations is agriculture. At a current rate representing 1 per cent of the total Federal funds (or $150 million) for research and development, we are supporting, as a matter of public policy, technology designed to advance agriculture. Beginning with the establishment of the land-grant colleges about 100 years ago, then the initiation of agriculture experiment stations, and later, the extension service which brought the results of advanced agricultural technology to the farmer, this program has, in a few decades, reduced the number of people required in farming to one tenth while increasing the amount of agricultural products raised. This has been a truly remarkable demonstration of the effectiveness of a deliberate effort to apply the results of science for the benefit of society as a whole. Agriculture employs today only about 6 per cent of our labor force. We do not provide even a fraction of this support by government either for the application of technology to the service industries, which employ about 60 per cent of the labor force, or to manufacturing, which employs nearly all the rest. And we support practically no science and engineering directed toward improving our educational system, or toward modernizing our overall transportation systems, or toward the many other problems springing from urban living. Relatively little R & D money is provided to guide the progress of foreign aid—and even the need for this is not understood by those who see that great program as a giveaway.

Even during the current economic boom, now the longest lasting in history, unemployment is still high. Much of it is a persistent unemployment, selective in terms of those affected as to race, level of education, and level of skill. New industries have not provided sufficient employment opportunities. New products that would meet many of the important social needs of our people have not been developed. New processes and new services are not being introduced rapidly enough to meet the demands of our urbanized society. Workers have not been educated and trained in the new skills. Many of our people live in poverty—denied the basic necessities of food, clothing, and shelter. This one problem in itself poses a threefold challenge to science and technology: raising the economy to a level that will permit us to alleviate the effects, stimulating industrial expansion so as to provide job opportunities for these people, and devising more efficient and more economical means for satisfying the basic wants of these lowest income groups.

One of the principal obstacles to the use of science and engineering in solving these problems is a widespread lack of understanding of the main characteristic of technology —the fact that technology by its very nature produces change. Science without innovation is a sterile pursuit, a luxurious avocation, and a misuse of technical resources in the face of the challenge facing us as a nation today.

Human resistance to technological change

When new technology is applied to an existing industry, or when the fruits of new technology compete with established products and services, dislocations occur. Old materials may not be needed now. Old skills may be irrelevant to the tasks to be performed now. The people and organizations providing the old materials and the old skills may be asked to bear the heaviest part of the cost burden, while they receive practically none of the benefits of the technological innovation. Their resistance is both predictable and tenacious.

The cost of innovation is rising, both in terms of dollars and in terms of human dislocation. To reduce this high cost we might consider tax and fiscal policies that encourage innovation, such as special measures for inventors to allow them to capture the benefits of their discoveries, pooling arrangements for groups of firms and industries to support research on common technological problems, and many other organizational and administrative devices.

The human cost is less susceptible to settlement by the stroke of a pen. It is commonly believed that the labor problem is the chief stumbling block to the rapid introduction of technological change. Certainly, labor's resistance has been highlighted and made more dramatic through the use of such terms as featherbedding. Now, however, there is considerable resistance to technological change within management and within society as a whole. This resistance is based on a number of factors, such as personal commitment to the accepted way of doing things, heavy investment in one type of material over another, or one type of machinery, or one type of distribution system, or design of product, or method of advertising and selling. Every mature system, whether in the physical world of nature or in the world of human affairs, contains within itself forces that resist efforts to upset its equilibrium, regardless of how irrational that equilibrium may seem to the enlightened outsider. In society as a whole there is also resistance to technological change, to new ways of doing things, and to new ideas, such as investment of public funds in technical resources for the benefit of private industrial sectors of the economy.

This resistance is frustrating to those who would change the system. What is frequently overlooked is that the economic and social cost of adapting to technological change is usually the limiting factor on the rate of its introduction. This cost is not often borne by those people who will benefit most from the innovation. For example, the dispute in the railroad industry over work crews on diesel locomotives has the same elements of imbalance. The country as a whole benefited from the change while the railroads and the firemen particularly bore a disproportionate share of the cost. This is one reason that so much technical change comes about from invasion of an established industry by firms from an outside industry. The invaders have nothing to lose, relatively speaking, and everything to gain.

Private industry's responsibility

The benefits of innovation cannot usually be captured fully by the firm making the change. If it is in the total national interest to have a constantly growing economy, if our wealth derives from increased productivity, if science and technology are key elements in increasing productivity, if innovation is the mechanism by which the results of science and technology influence productivity, then as a matter of national policy we must assure that the innovation process operates to the short-term disadvantage of the fewest people and the long-term advantage of the greatest number. The critical need we now face is to eliminate poverty, and to create the means to prevent its recurrence. We must face up to the hard fact that private industry has not created enough of the additional jobs that our economy has required over the past 20 to 30 years. Government programs, directly and indirectly, have provided the great majority of the new job opportunities in the last decade. This and the high level of unemployment must mean that industry is not producing the products and services that people will buy. New services and new products may call for new types of institutional arrangements in the private sector of our economy. And if private enterprise does not respond to this new challenge, we shall continue to have unnecessarily large unemployment, and government will be required to carry on larger and larger programs to meet the economic and social needs of the country. Identifying the needs of the future and making plans to meet these needs are essential to the optimum utilization of our technical resources. If this trend is to be part of the pattern of the future, our national policy for science and engineering must be shaped to encourage new concepts of industries and the products they can furnish.

We must have new products and new concepts of industry to meet today's needs. The most important new industry to appear in the future may be the creation of cities by the private sector of our economy; the creation and then the selling of these cities for profit to the inhabitants. This concept is completely removed from the mill towns of the last century, and it is far beyond the mere erection of hundreds of houses in a single development. What I am describing is something taking place now on a limited scale: houses, roads, public utilities, recreation areas, business districts, industrial sites, educational facilities, etc., are created under a comprehensive plan for self-sufficiency, and paid for by the homeowners, the businessmen, and the industrial companies making up the community. The concept of cities for sale is, perhaps, a radical development in our thinking, but it may be just the answer to the needs of our urbanized society in the 20th century.

Relationships with other countries

We need not restrict our view to domestic matters. When we look at the competition we face from many other countries, there is little to indicate that we can be fully satisfied with the way we have managed our own scientific and engineering affairs. All too often we hear the complaint that foreign competition is based entirely on lower wage rates, and that the only solution to the problem is in import quotas and high tariffs. Actually, we compete most successfully in foreign markets with high-technology products, which come from high-wage American industries. This situation also applies to imports. Japanese textiles, to cite one example, compete in our domestic market not because the labor that produced it was underpaid by our standards, but because the machinery is of high quality and is efficient in the use of raw materials. We should learn to cope with and to enjoy this sort of competition.

It is no accident of economics that the countries that are growing the fastest—and faster than we are—are the countries that devote a greater relative technological effort to civilian industrial needs. We begin at a higher level, in terms of standard of living and rate of improvement in productivity but, nonetheless, many other industrialized nations are surpassing us in growth rates in both of these important indexes. The conclusion we should draw is not that we will be soon overtaken, or that we are headed for economic disaster. Rather, we should learn the obvious lesson: that public support of activities aimed at stimulating the industrial technological needs of the nation will reap substantial benefits to the entire economy.

The underdeveloped countries of the world, representing a great proportion of the world's total population, are sometimes seen as a gigantic problem for the industrialized nations. In some respects this view is accurate, for obviously the present imbalance in material satisfactions cannot continue indefinitely. These underdeveloped countries will need our assistance for a long time to come, but in the process of building up their own economies they will also become trading partners and markets for our products—on a scale unlike anything we have experienced before in history. This sort of future is clearly recognized by many of the industrialized nations of the world, and their long-range plans take it into account. If we are to participate in this great humanitarian and economic adventure, then science and technology will play a vital role, and our national attitude, our national policy toward science and engineering may be crucial to the outcome of our efforts.

Taking a broader view of the total national picture, we back away from statistics on unemployment, foreign trade, gold balance, and gross national product improvement. It is now apparent that the great social needs today will be met only by a heavy reliance on science and technology. There is a great deal of discussion about transportation problems and about the problems of our physical environment, such as the water we use for drink and recreation and the air we breathe. We read about the problem of moving water from areas where it is in abundance to areas where it is a scarce and expensive commodity, and the problem of developing new sources of energy that will be competitive in the market place. All of these problems have an obvious technological component. However, it is their sociopolitical aspects that are really crucial.

Another element in a national policy concerns the geographical distribution of our technical resources. The beginnings of a significant debate on this subject are now being heard in the nation's capital. On the one hand, the Federal government must place its contract and grant funds for R & D in the location of highest technical competence, to meet properly the requirements of various national programs, such as space and defense. On the other hand, this system tends to make certain parts of the country the centers of excellence, built up in part by Federal funds and in a superior position to justify even quicker grants of more Federal funds. The questions raised touch on quality versus equity, immediate benefit versus long-range benefits. What is really vital to the welfare of the country, however, is to create conditions under which all parts of the country will be able to develop their own technical resources, to create conditions that will enable all industries, all types of firms, all segments of the work force to participate in our imminent technological future. It may be that a part of our present dilemma stems from a lack of understanding of the use of science and technology for the public good.

A rational approach to a technologically based economy would surely include the deliberate policy of building institutions for the optimum development and use of our technical resources. These would be institutions oriented to the broad needs of society, aware of the specific situation in the regions in which they are located, and specifically charged with bringing together people's needs and technology's capabilities. I use the phrase "deliberate policy" because we make a great mistake if we think that the process will come about spontaneously. If we want to explore the moon, or to develop an antimissile defense system, the problem of optimum utilization of science and technology is relatively straightforward, in that the primary limitation is the state of the technical art. The process of applying science and technology to the valid needs of the market place, or of society generally, is vastly different and vastly more difficult. People's needs, recognized and unrecognized, are a factor, as are their ability to pay the necessary cost and willingness to adapt to the changes in their lives that technical changes always bring. To oversimplify the problem, we might say that in some respects it is simpler to orbit a satellite than it is to develop new housing for people in the slums of our cities.

When we look back over the past three decades, when we view the many facets of science and engineering today, the most striking feature is that we have operated to meet specific, individual crises—responding to the needs of the farmer, for example, as though they bore no relation to other scientific or technical problems, responding to technological problems of military defense without regard to the broader needs of basic research, responding to the challenge of space exploration without considering the problems of higher education in science and engineering, responding to human health needs as though there were no other scientific needs in the nation. Only in the last few years has the basic need for education been recognized by our national government. Based on our past history and experience, one can only assume that if we are confronted tomorrow with some new challenge to our prestige or survival, we will once more launch a massive, but specific, program for the solution of the problem.

Needed: an overall policy

Is it not obvious by now that what is needed is a continuous mechanism for assuring that the fruits of science and technology are purposefully used for the economic and social benefit of the entire country? If this is our goal, then a national policy should provide the framework for answering some difficult questions facing us.

First, we must be able to decide what our most important national needs are, and then support the science and technology that will best serve these purposes.

Second, we must increase our support for institutes of learning and research throughout the *whole* of the country.

Third, we must support technology as a national resource throughout the nation, by building local institutions geared to local needs. Organization of our technical resources around large projects, although beneficial to the success of immediate goals, leaves a small legacy of broad technological resources.

Fourth, just as we once had to link the fruits of agricultural science to the working farmers, now we must find better ways to introduce the results of applied science into the offices and shops of our industrial economy.

These major questions dealing with the use of science and technology for the common good are basically not scientific questions. An awareness of the potentials of science and the implications of advanced technology is necessary for understanding, but the basic issues hinge on humanitarian concepts and values. Thus, we must somehow produce people in our country who can assist us in arriving at the judgments that must be made. They will be people who incorporate an appreciation for science and technology as part of their cultural heritage, but who are also attuned to the social, economic, and political needs of our times. And scientists themselves must recognize that science is not just a toy or a challenge but a tool of mature men to be used to fashion the world to purposeful ends. Science must not promise a paradise that it may not be able to deliver to justify society's support, and it must earn whatever support it expects to receive.

One thing is clear. We cannot afford to treat these problems as we have in the past—by ignoring them. If history teaches us anything, it teaches that societies that survive and prosper are those that have met the challenges of their times and have developed institutions to cope with the challenges of the future.

Essentially full text of the 35th Steinmetz Memorial Lecture, presented at the Union College Memorial Chapel, Schenectady, N.Y., May 5, 1964.

Project FIST:
Fault isolation by semiautomatic techniques

Part I—Basic concept and techniques

FIST has been developed for the maintenance of modularized, noncomputer, electronic equipment. Tests are dynamic, meaningful, rapid, and can be performed by an unskilled technician. System flexibility and concepts may well revolutionize maintenance methods for both military and industrial equipment

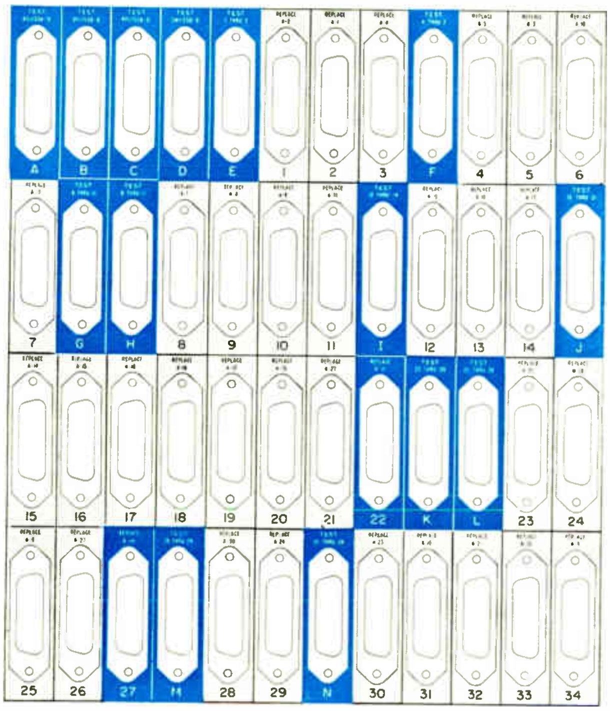
Gustave Shapiro, George J. Rogers, Owen B. Laug,
P. Michael Fulcomer, Jr. *National Bureau of Standards*

The method of fault isolation by semiautomatic techniques developed at the National Bureau of Standards, to which the acronym FIST has been applied, is a diagnostic tool for rapidly isolating faults in modularized, noncomputer-type electronic equipment without removing the modules from the prime equipment. The method is simple and flexible and is orders of magnitude faster than trouble shooting with manual test equipment.

FIST seeks to reduce the maintenance problem by combining modularized equipment, which minimizes the time and skill required to restore system operation, with a rapid, simple means for isolating defective modules. Although it has been devised to permit the novice technician to check module performance without being required to interpret data, it can also be used by the skilled technician to isolate rapidly a malfunctioning module without reference to technical manuals, and without prior knowledge of the equipment being tested.

This article is in two parts. Part I explains the principles upon which the FIST concept is based, describes the features which give the method its flexibility, examines techniques for physically incorporating FIST into the prime equipment, and demonstrates the simplicity with which a complex piece of electronic equipment can be checked.

Part II (which will appear in the September issue) discusses the details of the test equipment, describes the transformation network configurations used in making several types of measurements, and discusses the stimulus generators that are used to furnish the test signal when the normal operating signal is inadequate.



General principles

Project FIST has been conducted at the National Bureau of Standards under the sponsorship of the Department of the Navy, Bureau of Ships. These techniques are applicable in general to shipboard installations, and other areas where small size and weight are not of prime importance. In such installations a moderate increase in size and weight may be justified in the interest of practical maintenance capability. The FIST system must be considered in the initial design of the prime equipment if its full potential is to be realized.

FIST was developed as a solution to the electronic equipment maintenance problem. It has been generally accepted that equipment made up of replaceable plug-in assemblies can rapidly be made operational *after the defective assembly has been identified.* Today, defective replaceable assemblies are identified by using either the substitution method or a module tester. The former requires that a complete set of module spares be on hand at the site of the defective equipment, and the latter requires the existence of numerous special-purpose module test sets to accommodate the wide variety of modules that will always be encountered in the field despite all standardization efforts. Both of these fault identification methods are time consuming, since each module must be removed from its equipment to determine its condition.

The FIST test system has these advantages: (1) plug-in assemblies need not be removed from the equipment, thus permitting rapid identification of defective assemblies; (2) unlike special-purpose module testers, the general-purpose FIST test set is small, man-portable, highly versatile, and easy to use; and (3) an improved general-purpose FIST test set will always completely replace the obsolete versions without adversely affecting the maintenance of the older "FISTed" operational equipment in the field.

A word concerning its ease of application: The technician need have no knowledge of the function or role played by the equipment under test and no decisions are required of him; thus no familiarization period is necessary before an untrained technician can use the FIST test system effectively. All test information is presented clearly and unambiguously, and is virtually impossible to misinterpret. The brief, simple instructions necessary for efficient fault isolation will come as a distinct relief to the senior technician already burdened under an ever-increasing fund of knowledge.

With the FIST system it becomes possible to place the equipment maintenance program under the control of the individual who is best qualified—the prime equipment design engineer. He can perform this function without being required to assimilate a large body of technical information. Thus a radar design engineer who incorporates the FIST program into his equipment will still function basically as a radar design engineer, and not as a test equipment or maintenance engineer.

Although the need for the aforementioned objectives has been apparent for many years, an applicable common sense general approach has been long overdue. The FIST maintenance system, it is believed, may well revolutionize existing maintenance methods.

Guidelines and restraints

In considering fault isolation techniques, it appears logical to divide all electronic devices into two groups: computer systems (both digital and analog), and noncomputer systems. Perhaps the most efficient way to diagnose faults in computer equipment is to program test problems. Much work of this type has been done, but in noncomputer areas such a variety of circuits and functions are encountered that no general method (other than manual) has so far proved useful. Therefore, a decision was made early in this program to concentrate on the development of those techniques that would best fit noncomputer applications.

With the techniques here described, only five or ten minutes of simple instruction will be needed to permit untrained technicians operating under field conditions to make meaningful performance measurements on electronic assemblies. The untrained technician, with the aid of a portable general-purpose test set, should be able to promptly localize a defect in a room full of equipment that has been designed to work with the FIST maintenance system. To permit rapid correction of the defect, the prime equipment must be made up of replaceable plug-in assemblies. Otherwise, the untrained technician, even if he finds the defect, will be unable to take corrective measures. On the other hand, in an equipment built of replaceable assemblies, he should be able to put the equipment back into operating condition quite readily. A major goal of this program was to develop a general purpose test-set concept that would not require the technician to have any knowledge of the kind of test that he was making. This requires an instrument that has no controls to manipulate, that does not require the technician to make diagnostic decisions, and that employs an identical test routine regardless of the type of test being made.

It is not the intent of this program to seek the impossible goal of eliminating the need for trained technicians, but rather to develop maintenance procedures that will permit untrained technicians to assume the routine maintenance tasks. This frees the trained technicians for the more difficult tasks and permits a reduction in the number of highly skilled technicians required.

Throughout the development of the FIST techniques, strong emphasis was placed on the human engineering aspects of the maintenance problem. Because the human being works most effectively when he enjoys the work, the system has been human-engineered to impart to the technician a ready understanding of its basic principles, a trust in its reliability, and an appreciation of its operational ease. Frequently, otherwise adequate technical ideas were put aside because it was felt that the procedures required would evoke an unsatisfactory psychological response from the technician.

Many designers may find some of the techniques so attractive that they will be tempted to retrofit them into existing equipment. In the initial stages of the program, a decision had to be made as to whether the techniques to be used should be such as to permit retrofitting. It was decided that the severe restraints resulting from a retrofitting requirement would bar any novel or imaginative approach to a maintenance program. Therefore no artificial limitations were imposed on what was a techniques program designed to advance the state of the art. The techniques developed are such that they must be designed into the prime equipment during the initial stage of its development.

This approach permits a certain latitude in the physical design of the prime equipment. The equipment obviously must be made up of replaceable assemblies. Normally the decision as to how an equipment should be divided into replaceable assemblies is made on the basis of assembly size. However, when applying FIST techniques to electronic equipment, the circuits must be grouped into assemblies that can be efficiently tested by FIST techniques. For example, two tandem circuits in an equipment might be difficult to test individually but might be very efficiently tested together. Such circuits should be packaged into one assembly rather than two. Conversely, a large assembly that is difficult to test as a unit of equipment might be tested more easily if it were divided into smaller assemblies.

A prime equipment designed for FIST maintenance must have adequate panel space on which to mount the multiple test sockets into which the general-purpose test set can be plugged. These sockets should be mounted on a protected, easily accessible surface.

Basic building block

The keystone of the FIST maintenance system is the two-port measuring device—the comparator. (A voltmeter is a one-port measuring device). A two-port measuring device can be used to make one-port measurements but a one-port measuring device cannot be used conveniently to make two-port measurements. The two-port measurement is a versatile and powerful tool that is not fully appreciated or exploited by electronic instrumentation engineers. Although a few automatic checkout systems use comparators, these can rarely be used in

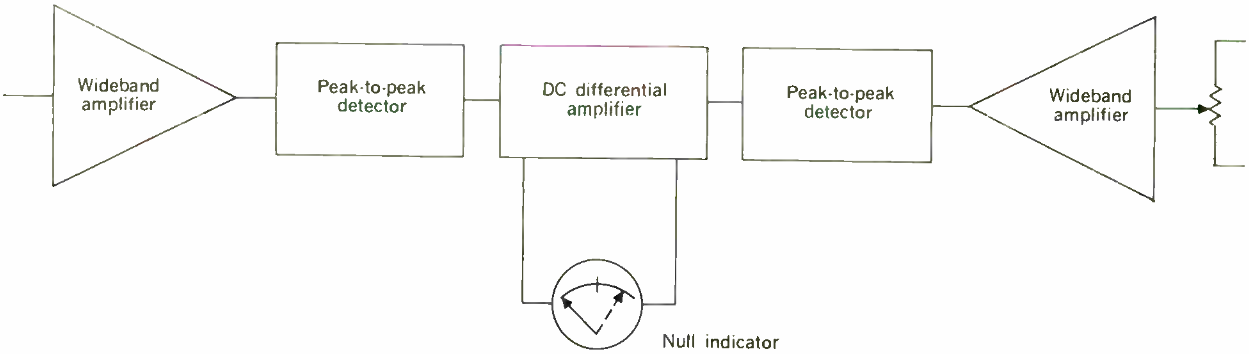


Fig. 1. Basic comparison cell of the FIST test system.

an unconventional manner to locate faults. because of certain restrictions placed on the systems.

The FIST comparator

The two-port measuring cell used in the FIST test system is a special phase- and waveform-insensitive voltage comparator (Fig. 1). For example, an ac signal applied to one port can be compared with a different kind of ac signal applied to the other port. A comparison made of peak-to-peak voltages is unaffected by variations of waveform or phase. For good sensitivity, each side of the comparator incorporates a wide-band amplifier.

The experimental FIST test set contains amplifiers with an upper cutoff of approximately 22 Mc/s. The outputs of the amplifiers drive peak-to-peak detectors. The dc outputs from these peak-to-peak detectors are compared in a dc differential amplifier. The null indicator in Fig. 1 is shown as a meter to permit the basic FIST principles to be most easily comprehended. Another useful null indicator is discussed in Part II, where the test set details are described.

The restraints in many automatic checkout systems are so severe that they permit very few dynamic measurements to be made. The FIST program emphasizes the other extreme; efforts were concentrated on dynamic measurement techniques since these are the most meaningful. Only occasionally can the function of an assembly be evaluated by measuring a key dc or low-frequency ac voltage. More often the only way to assess the performance of a circuit is to measure its ability to provide the function for which it was designed.

Perhaps the simplest introduction to FIST principles is an examination of the technique for amplification measurement. The output signal of the amplifier in Fig. 2 is sampled by an attenuator comprised of two fixed resistors R_1 and R_3, and one variable resistor R_2. The attenuator output is connected to one input of the phase- and waveform-insensitive comparator, and the input signal to the amplifier module being tested is connected to the other input of the comparator. The indicator on the comparator will indicate a null whenever the attenuation or loss is equal to the amplifier gain. In a practical case, one desires to know whether the amplification is within the design limits, for example, 9 to 11. For this example R_1, R_2, and R_3 would be so proportioned that an attenuation of 9 times would be realized when the arm of R_2 is at the upper end of R_2 and an attenuation of 11 times when the arm of R_2 is at the lower end of R_2.

$$\frac{R_1}{R_3} = A_{\max}\left[1 - \frac{1}{A_{\min}}\right] \qquad R_3 = \frac{R_2}{\left[\frac{A_{\max}}{A_{\min}} - 1\right]}$$

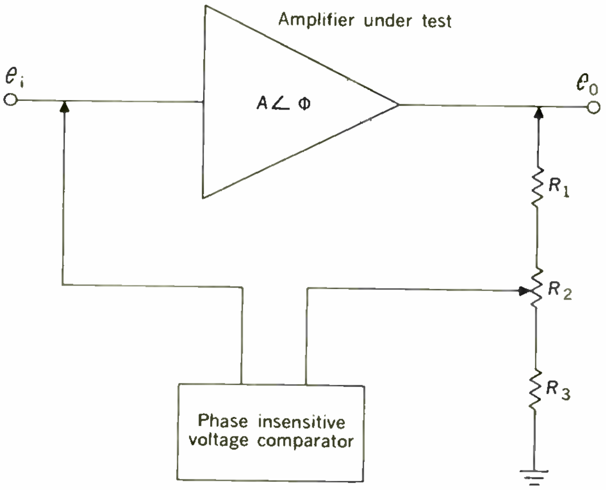


Fig. 2. Comparison method illustrating the basic technique for amplification measurement.

Fig. 3. Practical circuit for amplification measurement.

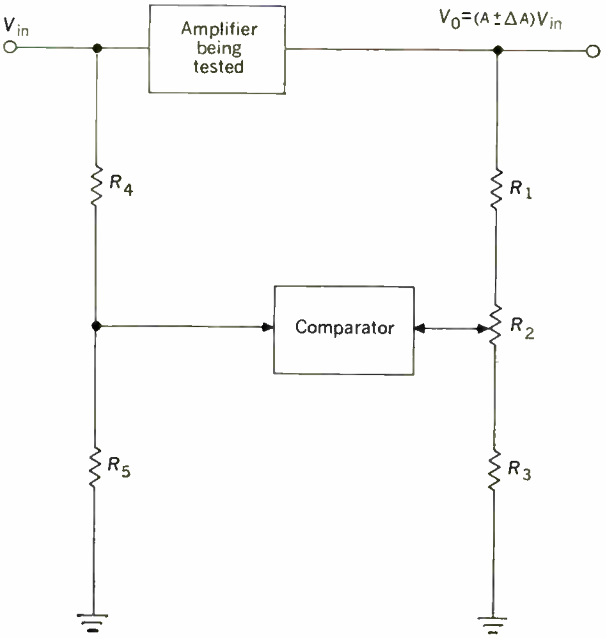
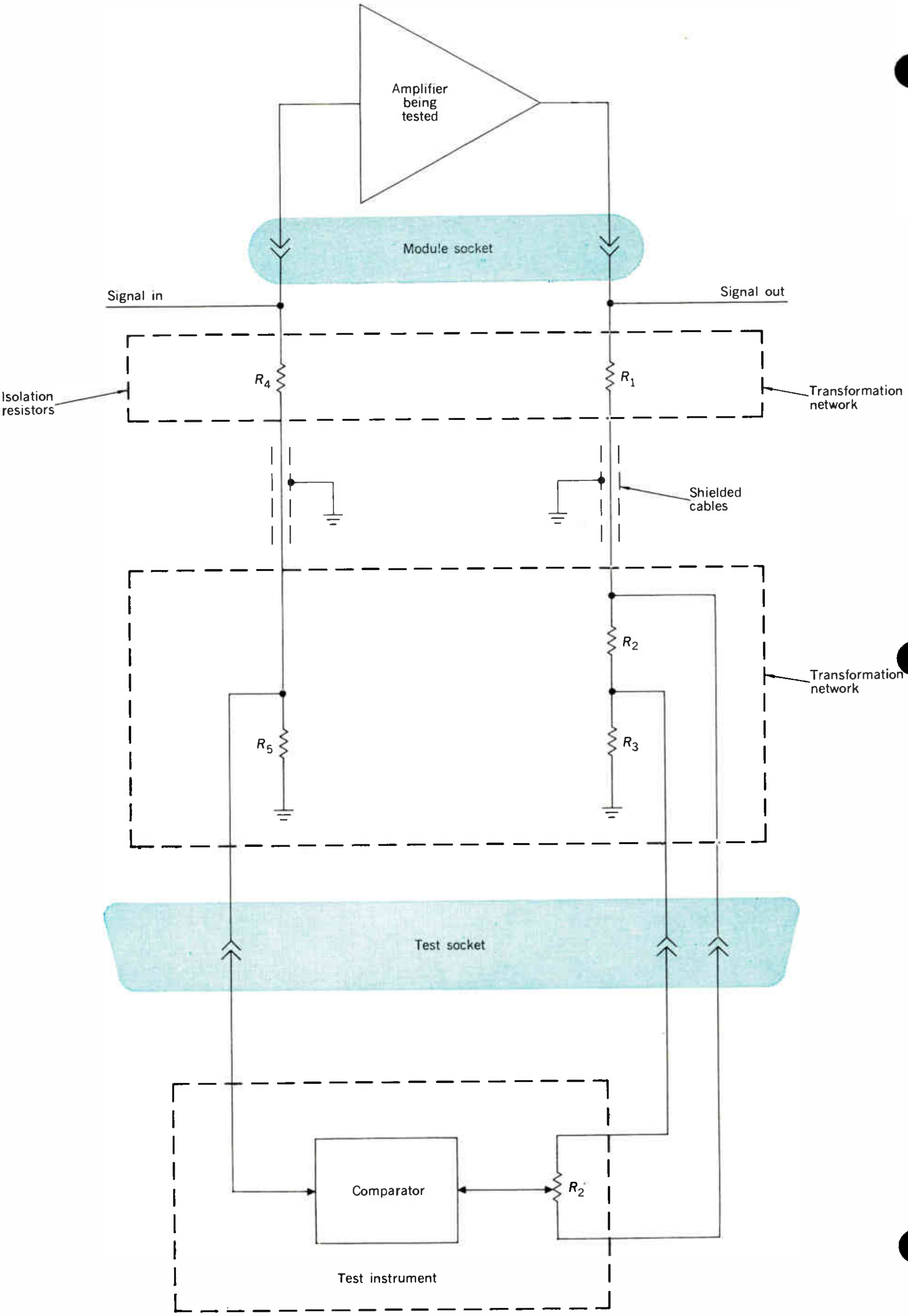


Fig. 4. Schematic view of the physical relationship of the components in a one-cell test.



Thus, some position of the arm of R_2 will permit a null to be obtained if the amplification is within the design limits and, conversely, the inability to obtain a null for any position of the R_2 arm is an indication that the amplifier performance is outside of its design limits and has therefore failed.

It is important that the comparator does not load or degrade the performance of the circuit it is measuring. In Fig. 3, the resistive divider, R_4 and R_5 have been added to minimize any loading effects on the input of the amplifier. If the attenuation supplied by this network is 10, then the attenuation of R_1, R_2, and R_3 should be variable from 90 to 110 to parallel the example discussed in the previous paragraph.

Physical structure

The circuit presented in Fig. 3 is repeated in Fig. 4 but the information is expanded to reveal the physical relations of the various elements. The variable resistor R_2, previously described, has been changed to a fixed resistor R_2, shunted by a much larger variable resistor R_2'. The variable resistor R_2' is located in the test instrument so that the operator can conveniently manipulate it. The test socket is located on a readily accessible panel surface. Since the socket into which a module is plugged can rarely be located in a position adjacent to the test socket, short shielded cables will usually be required to convey the test signals to the test socket. R_1 and R_4 should be mounted on the module socket so that the cable capacitances will not load the module, and must be sufficiently large so that even if their lower ends become grounded, normal function of the module will not be seriously affected. R_2, R_3, and R_5 should be in a cordwood assembly mounted on the back of the test socket.

In the early phases of the program, consideration was given to locating R_1, R_2, R_3, R_4, and R_5 within the module being tested. This was deemed undesirable for many reasons. It would have been necessary to bring out special test leads from each assembly. It was felt that the most desirable sampling points for the test signals were at the input and output pins of the module. Frequently, the same module type could be used in more than one part of an equipment where different performance limits would be tolerable. For example: In a particular equipment, an amplifier module can perform its function satisfactorily provided that its amplification is within the limits of 5 and 11, whereas elsewhere in the same equipment an identical module can perform its function satisfactorily only if its amplification is between the narrower limits of 9 and 11. If the limit-setting resistors are located within the modules, then, for the example cited, the modules cannot be identical. However, if the limit-setting resistors are located external to the module, both of the modules can be identical, thus minimizing the number of module types required. By associating the test limits with the position within the equipment itself, it will sometimes be possible for the knowledgeable technician to make a repair by interchanging the positions of identical modules in wide- and narrow-limit sockets.

Measurements can be made on any kind of amplifier whether it be a low-frequency, high-frequency, or pulse-video amplifier, provided that the frequency components of the signal do not exceed the bandwidth of the comparator amplifiers. Very compact gain-stable amplifiers with pass bands up to 22 Mc/s are used in the FIST test set.

Voltage measurements

It is not practical to make two-port measurements with one-port measuring devices; however, a two-port

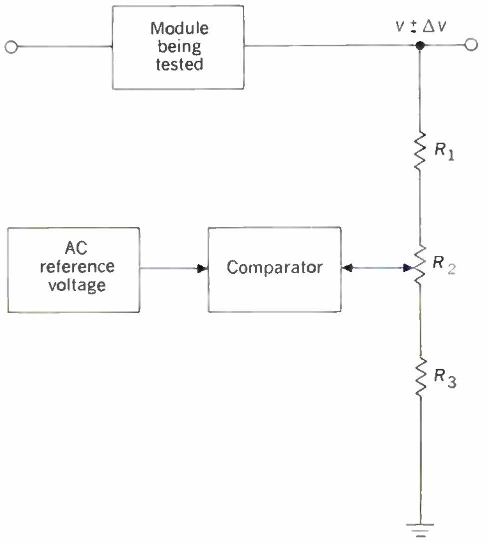


Fig. 5. Block diagram of a basic voltage measurement.

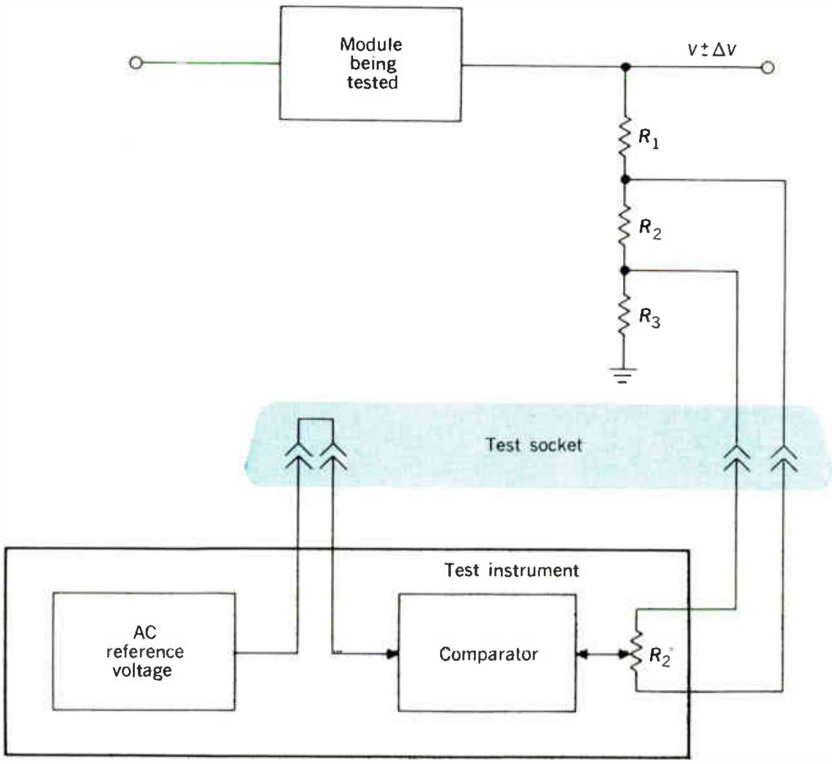


Fig. 6. Transformation network technique used to make a practical ac voltage measurement.

measuring device can readily be used to make a one-port measurement by comparing the unknown with a reference voltage (see Fig. 5). Figure 6 illustrates a practical transformation network technique that would be used to make a voltage measurement. The voltage to be measured may be any periodic waveform that does not have substantial frequency components outside of the comparator pass band. The reference voltage, contained within the test instrument, may be any ac signal of known amplitude. A square-wave reference voltage may be conveniently obtained by regulating a dc voltage with a zener diode and then using this voltage to power a transistor multivibrator whose transistors saturate when turned on. The ac reference voltage output is brought to a pin in the test instrument plug. To set up the test socket for a one-port voltage measurement, a jumper is connected between the pin corresponding to the reference voltage output and the pin corresponding to the reference side of the comparator. When the test instrument is plugged into such a test socket, the jumper functions as a programming connection to set up the test instrument for a one-port measurement. The character of the comparator permits one reference voltage to be used for measuring a wide variety of waveforms.

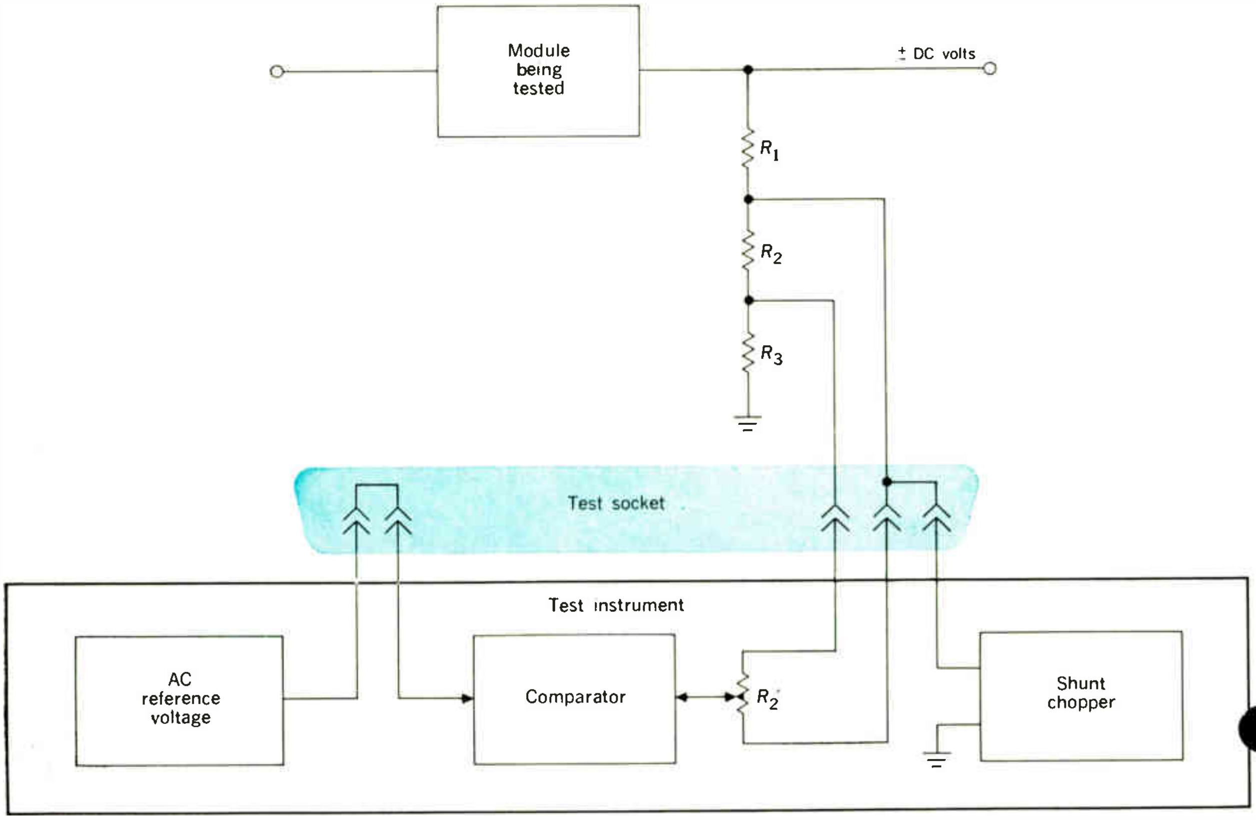
Figure 7 shows how, by adding a shunt chopper to the test instrument, it becomes possible to extend the measurement range of the instrument down to dc. When a dc measurement is to be made, the pin on the test socket that is connected to the junction of R_1 and R_2 is provided with a jumper connecting it to the shunt chopper terminal, thereby permitting the steady dc voltage to be converted into pulsating dc voltage having a peak-to-peak amplitude equal to the dc voltage.

Test sockets and transformation networks

Note that the test socket is not just a convenient terminus for test points but that, together with the transformation network, it supplies a test programming function as well. It programs the test limits, the kind of measurement that is to be made, and the interconnection of the general-purpose FIST test-set elements. While it is possible to eliminate the plug- and test-socket selection hardware and substitute an automatic selecting mechanism, it is not practical to do so. The plug and test socket permit a great many connections to be switched in a very simple fashion. Automatic selection devices having the same switching capacity, whether they are stepping relays, crossbar switches, or semiconductor devices, are comparatively cumbersome and impractical. In addition, most of the practical advantages described later would be lost.

The transformation network assemblies (Fig. 4) should be small enough to be mounted directly on the test socket. Figure 8 shows some details of a versatile cordwood structure that can accommodate switches and a large number of components or a few large components such as RF inductors or piezoelectric crystals. Numerous versions of these assemblies are possible; their structure provides adequate space to accommodate components such as small crystal holders, pulse transformers, etc. The assemblies in the illustration show how transformation networks can range from a single resistor to a net-

Fig. 7. Addition of shunt chopper to test instrument extends measurement range down to a dc level.



work that permits four simultaneous measurements to be made and that can also perform switching functions. Although standard miniature components are used, the assemblies are still small enough to mount conveniently on the rear of the test socket. Until such time as thin-film transformation networks are common and inexpensive, these standard component cordwood assemblies should prove to be quite desirable because of their small size.

The transformation techniques described in this section and in Part II are far from all-inclusive. The initial techniques developed may be considered to be the "work horse" techniques that would be most frequently required. In time it is expected that the library of transformation techniques will be considerably expanded.

Only occasionally will it prove to be either desirable or necessary to include a switch in a transformation network. It should be borne in mind that many of the test sockets will have ac signals present at their terminals and occasionally a situation will arise where, by virtue of the high gain between two sockets, crosstalk or regeneration, or both, can exist. Unfortunately, knowledge of this difficulty comes to the attention of the design engineer at such a late stage in the design that few conventional corrective measures can be taken. When all other practical measures fail, the problem can be overcome by making certain that the "hot" terminals of the sockets involved are normally grounded and are disconnected from ground when the test set plug is inserted into the socket. Although a jumper between two terminals of the test instrument plug is capable of performing a switching function when inserted into a socket, unfortunately it performs the wrong kind of a switching function to correct the crosstalk problem. The jumper functions to complete a connection when the plug is inserted, whereas the required action is that of interrupting a connection when the plug is inserted. There are three possible switching methods that can be used. A jumper on the test-set plug can actuate a relay that in turn disconnects the troublesome socket terminal from ground; a special socket with a built-in switch may be used, or a conventional socket may be modified to accommodate a standard microswitch. The latter solution was deemed to be the most practical. Simple mounting hardware was developed for mounting one to four single-pole, double-throw switches on the transformation network assembly behind a socket. When a plug is inserted into such a modified socket, a plunger is depressed, thereby actuating the switches. The prime equipment manufacturer can inexpensively perform the few drilling operations required to modify the standard sockets.

Test socket hardware costs

In Part II of this article, the techniques for making up to four simultaneous measurements will be discussed. There is no hard and fast rule as to the degree of simplicity or complexity of the transformation networks. The prime equipment design engineer has complete freedom to decide how sophisticated his testing techniques should be and how many simultaneous tests to make with each test socket.

As a laboratory exercise to prove the practicality of FIST techniques, a simple piece of equipment, radar set AN/SPS-46, is being redesigned for FIST maintenance. Based on the experience acquired with this equipment, some rough estimates have been made of the complexity, volume, weight, and cost the FIST would add to a piece of equipment.

Experience with radar set AN/SPS-46 indicates that the average test socket is used to make three measurements, and the associated transformation network contains nine components—six resistors, two capacitors, and a diode. This averages only three components per measurement.

The cost of these components in small quantities, together with the test socket, one foot of coaxial cable, and switching components when required, totals $7.00 when the components are bought in quantities of 100, and $5.00 when they are bought in quantities of 500. This averages between $1.67 and $2.33 per measurement. Original equipment manufacturers could obtain the components for less. This cost is based on components of a size that will permit the cordwood assemblies to be removed with the test sockets.

On the average, each test socket and associated hardware (transformation network, coaxial cable, etc.) increases the weight of the prime equipment by 0.1 pound. The volume occupied by the test socket and transformation network can be as little as 1⅓ cubic inches behind the 1/16-inch test panel. This includes room for cable runs behind the network. The test socket also requires ⅓ cubic inch in front of the test panel.

On the average, for each module of the prime equipment, the FIST system will:

- require 1.2 test sockets
- make 3.6 measurements (three measurements per socket times 1.2 sockets)

Fig. 8. Transformation networks mounted on rear of test sockets.

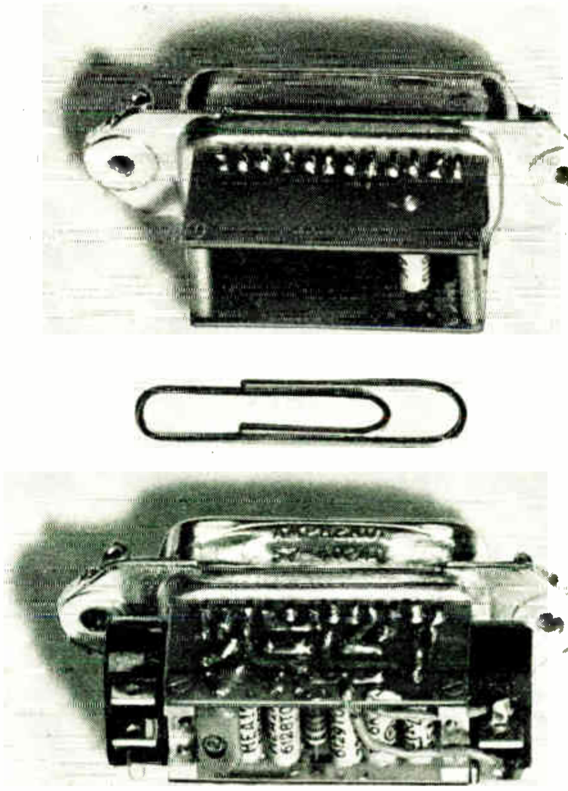
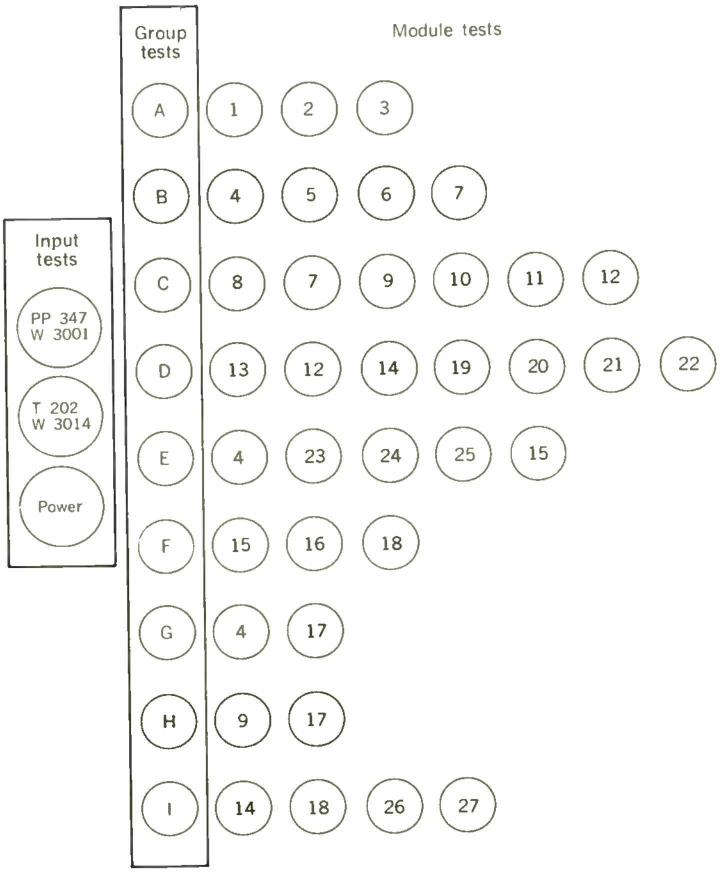


Fig. 9. A typical FIST field modification kit.

Fig. 10. Test sequencing by socket positioning.



- add 12 components to the prime system (nine components and a test socket times 1.2 sockets)
- increase the volume of the prime system by 2 cubic inches ($1\frac{2}{3}$ cubic inch per socket × 1.2 sockets);
- increase the weight of the prime system by 0.12 pound (approximately 2 ounces);
- increase the cost of the prime equipment by $6.00 to $8.40.

Field modifications

When the equipment design engineer decides on the types of measurements and measurement limits to be used, he does so in a laboratory atmosphere, and his decisions are, at best, educated guesses. Regardless of ability and maturity of judgment, it will be found that when the equipment goes into the field some of the measurements and measurement limit decisions will prove to be ill-advised. All of the tolerances may not prove to be realistic. It would be unreasonable to expect that all the tests will be meaningful or that all of the meaningful tests will have been employed in the equipment.

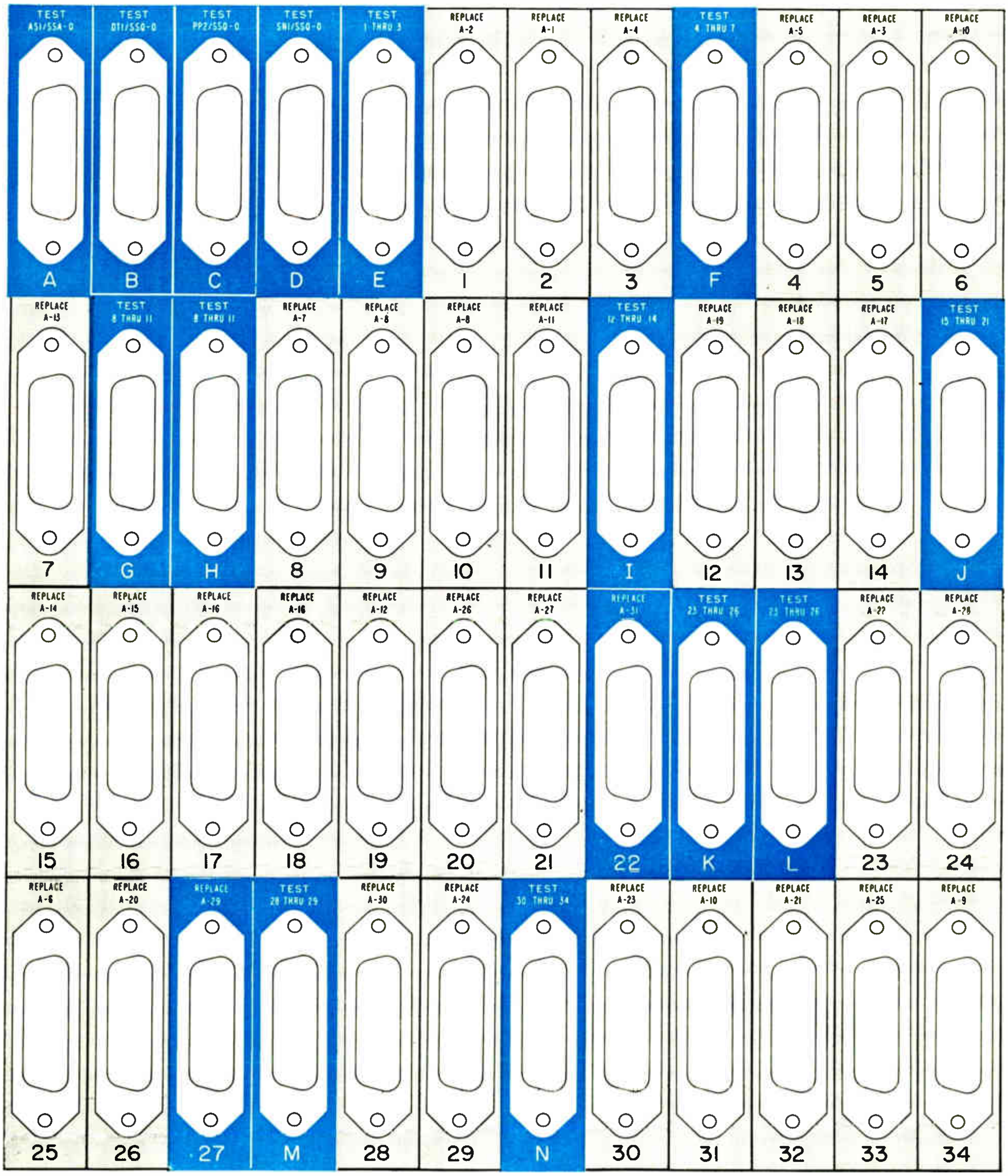
In most automatic testing systems it is difficult and frequently impossible to make a field modification if hardware must be replaced. Figure 9 shows a typical FIST field modification kit, consisting of a replacement socket and transformation network. The technician can readily update a maintenance test in the field by removing the screws that fasten the test socket to the panel, unsoldering a few wires from the obsolete transformation network and socket assembly, reconnecting these wires to the replacement transformation network and socket assembly, fastening the replacement socket to the panel, and discarding the obsolete test socket and transformation network.

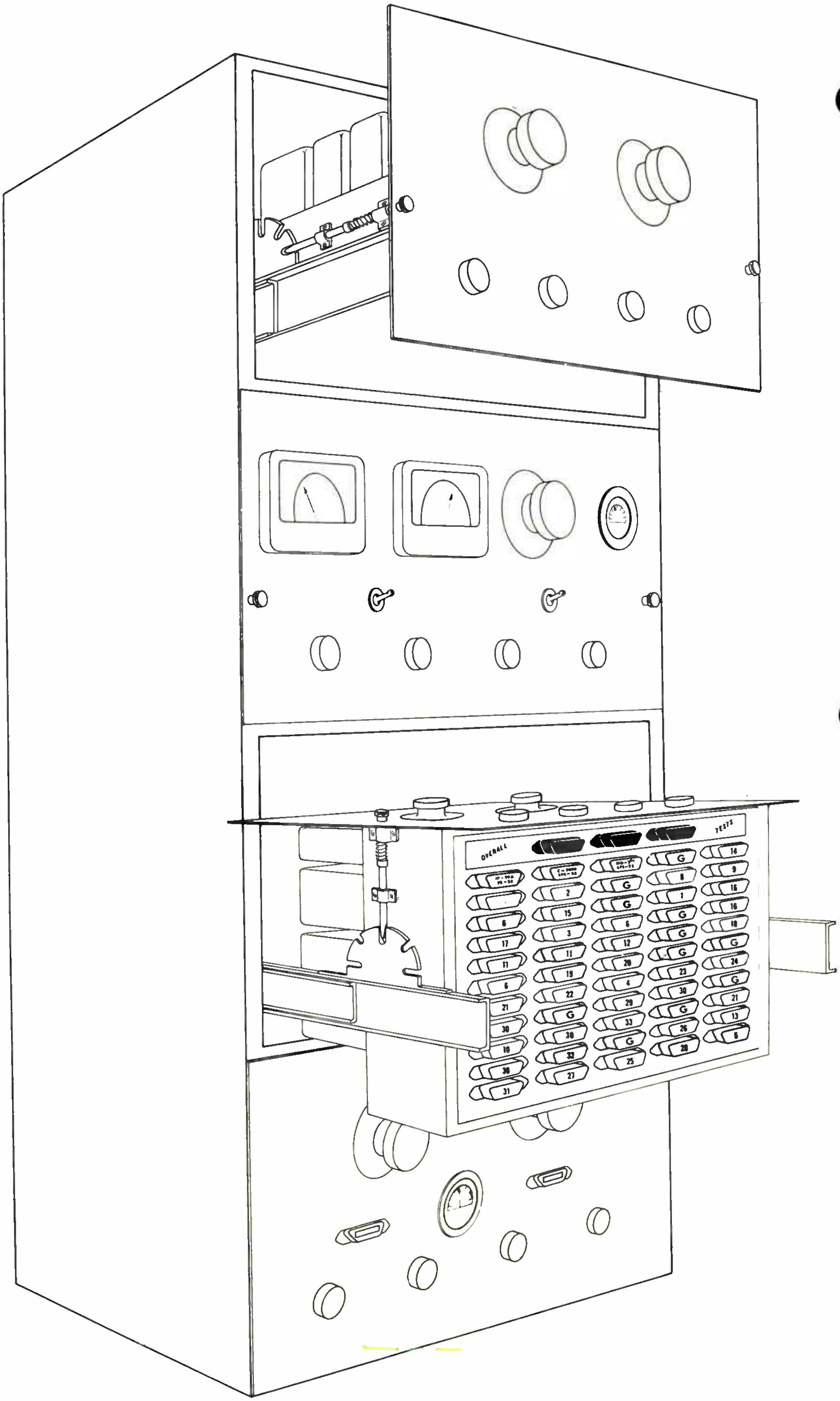
Test socket sequence programming

The FIST techniques can be applied with equal facility to large or small aggregates of circuits. For example, three amplifier modules, each of which is tested individually, can be tested as a group in exactly the same manner. By setting up group tests in a piece of equipment as well as individual module tests, economies in testing time can be realized. The test socket display of Fig. 10 illustrates a socket grouping order that permits efficient and rapid testing. The test sockets are arranged in three ranks. The first rank of tests, signal input tests, are located in the column on the left. These determine the adequacy of the signals that are fed to this equipment from other sources as well as the prime power input. If the first rank of tests is good, the technician proceeds to the second rank of tests, the group tests. The technician goes through the group tests in order—A, B, C, etc.—until he reaches a bad group test (for example, E). At this point he proceeds with the third rank of tests, the module tests, and in the example cited he would measure in turn 4, 23, 24, 25, and 15 until he locates the defective module. The arrangement of the test sockets should be such that the testing order is obvious.

FIST programming is accomplished by a prescribed routine test-socket selection sequence that guides the technician without requiring him to make any decisions, by the transformation networks, and by the programming jumpers on the test sockets. In a completely automatic testing system the procedure is more complex. Thus, the

Fig. 11. Recommended test socket arrangement and instruction markings. Both the input test sockets (A through D) and group test sockets are in blue areas. Sockets in gray areas are for module tests. In the prototype equipment, these areas are in black and white, respectively.




OVERALL
TESTS

combination of simple manual operations involving socket selection and transformation techniques results in a basically simple and readily implemented fault isolation measurement technique.

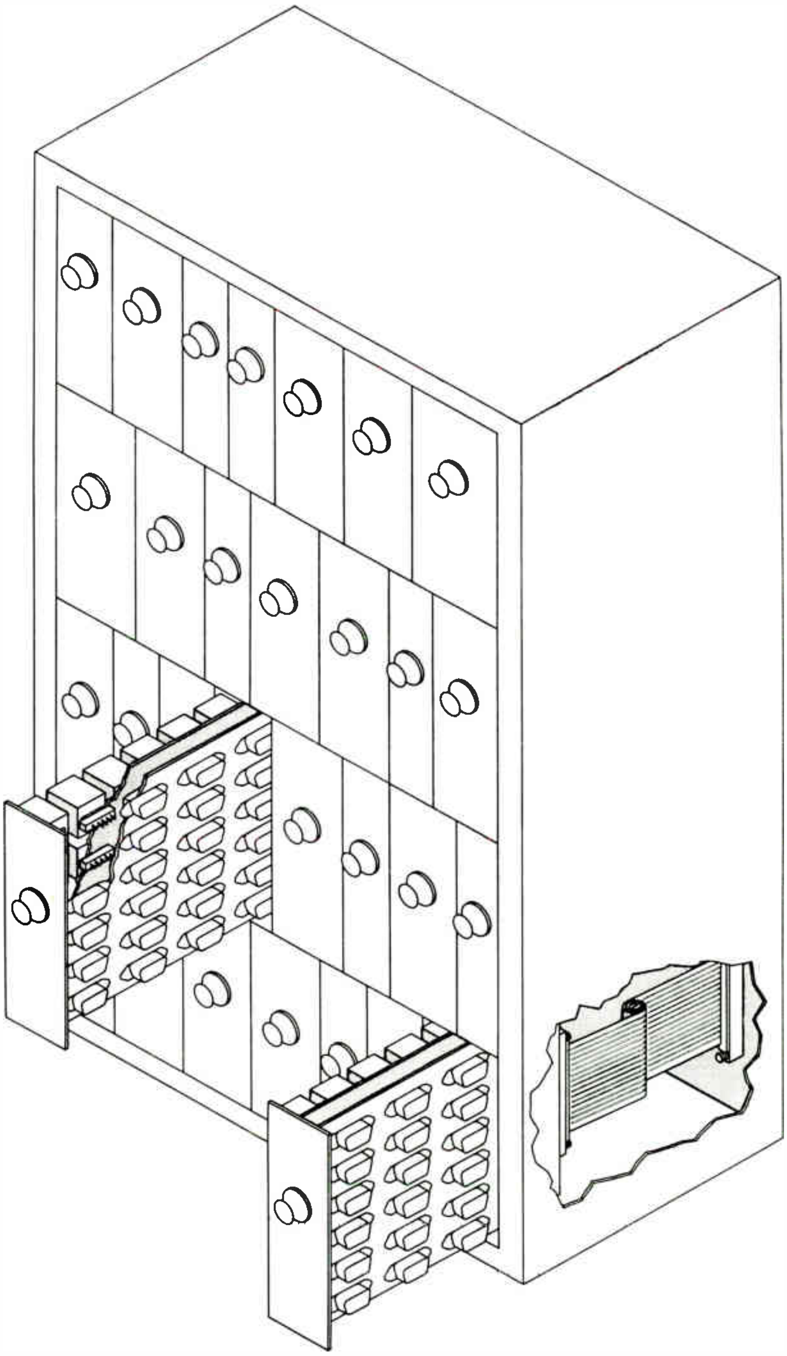
Ideally, the arrangement of test sockets should make the most economical use of panel space. The configuration of Fig. 10 wastes considerable panel area. A superior test-socket arrangement is illustrated in Fig. 11. Here the test sockets are arranged in rectangular array. All input tests sockets (A through D) and group test sockets are in blue areas. Sockets in gray areas are for module tests. If a module is the only member of a group, its test socket is in a blue area. The nomenclature of each socket is below the socket. The module test sockets are given a numerical designation and all other sockets are given a letter designation. Imprinted above each socket will be either a REPLACE instruction or a TEST instruction. The testing sequence is uniform and simple:

- The blue-area sockets are tested sequentially, proceeding from left to right and top to bottom in the manner that a printed page is read.
- When a bad indication is encountered, the instruction above that socket is followed.
- No gray-area socket is tested unless the instruction on a blue-area "bad" socket so directs.

For example, if it is assumed that a fault exists in module A-26, the following test routine will automatically ensue:

- Sockets A through J will be tested in order.

Fig. 12. Suggested physical structures for FIST-maintained equipment: (left) Application to modularized, conventional, rack- and panel-mounted equipment. If equipment is mounted on slides that may be tilted 90 degrees, entire lower chassis surface becomes a convenient plane on which to locate test socket panel; (right) Application to microminiaturized equipment. Both structures were devised with intent of keeping the shielded cable runs between the test sockets and their modules as short as possible.



- Test socket J will indicate "bad" and the instruction above that socket will direct the technician to light-colored sockets 15 through 21.
- By following these instructions the technician will find that test socket 20 indicates "bad." The instruction, located above the socket, will direct the technician to replace module A-26.

It is never necessary to read the socket nomenclature unless a bad indication is observed. Occasionally, more than one test socket is required to test a module completely. This need be no concern of the technician, since his instructions for corrective action are automatically conveyed to him when he observes a failure on a test socket.

The testing sequence is set up so that the first tests are always input tests (Fig. 11, sockets A through D). The instruction above the group test sockets directs the technician to the test sockets of the modules that comprise the group. When there is only one module in a group, its test sockets will be dark colored.

It is not necessary for the technician to be acquainted with the design rules that lie behind the test socket arrangement, since he is required only to follow an invariant testing procedure.

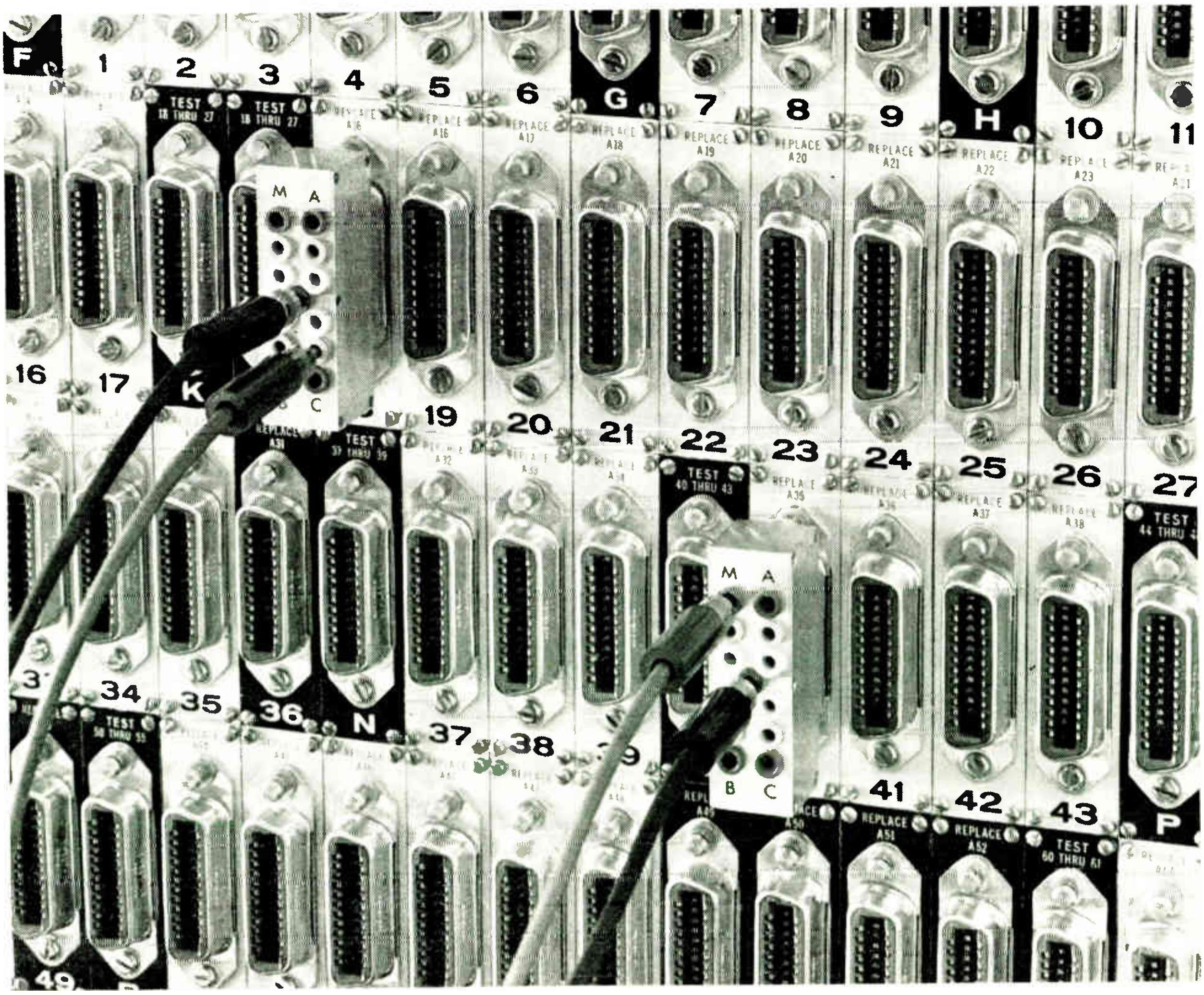
Suggested physical structures

The panel surface on which the test sockets are mounted should be chosen to be readily accessible during a testing sequence yet to provide protection for the sockets between maintenance periods. Figure 12 (*left*) is suggested as one way these objectives can be met in modularized conventional rack-mounted equipment. If the equipment is mounted on slides that may be tilted 90°, the entire lower surface of the chassis becomes a convenient plane on which to locate the test socket panel. When it is mounted in this manner, there is no tendency for the test sockets to collect debris or moisture between maintenance periods.

In the case of microminiaturized equipment, it is expected that each replaceable assembly will contain more than the usual amount of circuitry, so that the size of these replaceable assemblies will be sufficiently large to warrant the allocation of space for FIST test sockets and transformation networks. A suggested physical structure for microminiaturized equipment is illustrated in Fig. 12 (*right*).

The structures in Fig. 12 were devised with the intent of keeping the shielded cable runs between the test sockets and their modules as short as possible. Unless

Fig. 13. Simple test adapters for manual testing.



only low-frequency and dc voltages are being measured, it would not be practical to locate the test socket panel at a point remote from the modules being tested and use long shielded cable runs because of their capacity. This would rule out certain aircraft applications where one might be tempted to place the test socket panel on the external skin of the aircraft.

FIST usage

Occasionally there will be certain defects that the FIST test set cannot identify. For example, if an interconnection between assemblies is discontinuous the FIST test set will not positively identify the defect. Also, if a component such as a potentiometer mounted on the front panel of an equipment is not part of a replaceable assembly, the question of whether or not the FIST test set can identify it as defective is an academic one because the untrained technician can do nothing to correct the problem. The goal of FIST maintenance is to permit the untrained technician to isolate only those faults that exist in replaceable assemblies. The FIST maintenance procedure is not designed to pinpoint a fault that is not located in a replaceable assembly. A knowledgeable technician must be brought in to correct such a defect.

Should the trained technician choose to use conventional test equipment such as multimeters, oscilloscopes, etc., he can make use of the simple test adapters (illustrated in Fig. 13) that when plugged into the FIST test sockets, will provide him with a vast number of readily accessible test points. By reading through the resistive attenuators in the transformation networks, not only can he make voltage, waveform, and signal tracing measurements, but point-to-point measurements as well.

The finite test-point selection capacity of a completely automatic test system determines the depth of testing into a prime equipment that may be accomplished. Since this test point selection capacity must be kept within practical bounds, the usefulness of automatic systems can be greatly enhanced if they are backed up by the FIST maintenance system. Obviously, in addition to this backup ability, the FIST maintenance system is able to furnish a fault isolation function that is self-justifying.

FIST objectives and features

To permit a better understanding of the role that this development might play in the future, it is appropriate to summarize its objectives and features:

1. Emphasis is placed specifically on dynamic tests that will yield meaningful information, and that can measure the effectiveness with which the circuit under test performs the function for which it was designed.
2. The tests are general in nature; equally applicable to high-power transmitting vacuum-tube circuits or low-power transistorized circuits; and equally capable of isolating defects in simple, functional assemblies and in complex assemblies.
3. Emphasis is placed on techniques for diagnosing noncomputer faults, since there already exist programming and test problem techniques for diagnosing computer malfunctions.
4. The system is designed for setup and testing time under field conditions that is orders of magnitude shorter than the set-up and testing time required for conventional test equipment.
5. The FIST techniques are designed for fault isolation in modularized equipment so that the untrained technician can effect a rapid repair by replacing the defective assembly.
6. Faults that the untrained technician cannot correct by replacing an assembly (such as defective interconnection wiring between assemblies) are not isolated by the test system. A trained technician should isolate and correct any faults that cannot be remedied by the simple action of replacing a module. It is the intent of this program to achieve the practical goal of minimizing the required number of trained technicians, not to seek the impossible goal of entirely eliminating the need for trained technicians.
7. In the interest of simplicity, the test system is designed chiefly to make optimum use of the untrained technician (who should not be required to make decisions) but it is also designed for the knowledgeable technician, who will be able to make rapid tests and still use his initiative to improve the efficiency and effectiveness of the test system.
8. The test set is a general-purpose, man-portable, semiautomatic instrument.
9. Operation is simple and uniform. It is not necessary for the technician to have any knowledge of the circuit type being tested or the type of test being performed.
10. The test set incorporates self-testing techniques that are readily comprehended by the untrained technician, thereby enhancing his confidence in the proper functioning of the test set when the self-test so indicates.
11. The system has been human-engineered to impart to the technician a ready understanding of its basic principles, a trust in its reliability, and an appreciation of its operational ease.
12. Simple but efficient test-programming techniques have been developed to obviate the necessity for testing every module.
13. Engineering decisions regarding the desirable types of tests and test tolerances are made in a laboratory atmosphere. If cumulative field reports on the prime equipment should dispute the wisdom of the original testing choices, remedial action may be taken in the field by means of test modification kits.
14. The techniques advanced by the program are not of the "blue-sky" variety, but depend upon current state-of-the-art technology that is ready to be used. Many of the engineering hardware problems that could prevent successful application of the techniques have been investigated and practical engineering solutions to these design problems have been developed.
15. The application of the testing techniques is relatively simple and will be codified in the form of a design manual so that the prime equipment design engineer can incorporate the fault location features in his equipment without requiring either the intervention or cooperation of the test equipment specialist. The intent here is to eliminate the interface problem that exists between the prime equipment designer and the automatic test equipment designer.

More detailed coverage of the material contained in this two-part paper can be found in NBS Monograph 83, "Project FIST: Fault Isolation by Semi-Automatic Techniques," which may be purchased from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.

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Professor Aiken is the recipient of honorary degrees from two universities and has received numerous awards in the United States, Belgium, France, Spain, and Sweden. He is a Fellow of the Association for Advancement of Science, the American Academy of Arts and Sciences, and the Royal Society of Letters and Sciences (Sweden).

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J. Herbert Hollomon, prominent scientist-engineer and administrator, was sworn in as Assistant Secretary of Commerce for Science and Technology on May 14, 1962. In this post, created by Congress on February 17, 1962, he directs the scientific and technical functions of the Department and is the principal adviser to the Secretary on all scientific and technological matters of concern to the Department. He also represents the Department on the Federal Council for Science and Technology and is a consultant to the President's Science Advisory Committee.

Dr. Hollomon received the B.S. and Doctor of Science degrees from the Massachusetts Institute of Technology and taught for a year at Harvard. In 1946 he joined the General Electric Company's Research Laboratory as assistant manager of the Metallurgy Research Department. In 1960 he was appointed general manager of the General Engineering Laboratory.

In the field of education, Dr. Hollomon was an adjunct professor of metallurgy at Rensselaer Polytechnic Institute, and has served in advisory posts at Cornell, Harvard, and MIT. He is the author of a textbook on metallurgy and has written or coauthored more than 50 articles in professional journals.

Robert W. Bickmore (M) has been an independent consultant in the fields of electronics engineering and engineering management since 1962. He also holds the position of assistant to the president of the National Engineering Science Company on a part-time basis.

During World War II he served with the U.S. Army Air Force as a communications chief. He received the B.S., M.S., and Ph.D. degrees from the University of California, Berkeley, in 1948, 1950, and 1953, respectively. In addition, he held a lecturer's appointment at the university from 1950 to 1953. From 1953 to 1960 he held various positions with the Hughes Aircraft Company, including that of senior staff physicist in the Microwave Laboratory. From 1960 to 1962 he served as technical assistant to the president of American Systems, Inc., a subsidiary of Schlumberger, Ltd.

Dr. Bickmore has had more than a dozen papers published in professional journals and has contributed to two books in the scientific field. From 1957 to 1960 he was a member of the United States National Committee of URSI Commission VI. He is the coinventor of time-domain antennas and holds a patent on variable-focus antennas, as well as other patents in electronics.

Gustave Shapiro (F) received the B.S. degree in electrical engineering from the George Washington University. From 1941 to 1947 he was associated with the U.S. Army Signal Corps Engineering Laboratories. He has been with the National Bureau of Standards since 1947, and has held his present position, that of chief of the Engineering Electronics Section, since 1956. He holds nine patents.

Mr. Shapiro has devoted much time to IRE and IEEE activities and holds a number of posts in IEEE Groups. He has been editor of the TRANSACTIONS ON COMPONENT PARTS since 1955 and of the MICROWAVE THEORY AND TECHNIQUES NEWSLETTER since 1957. He also serves on the National Administrative Committees of the Components Parts and Microwave Theory and Techniques Groups. He has been active in program organization for the International Convention since 1956. He currently heads the Secretariat of the International Electrotechnical Commission Committee on Waveguides and Their Accessories.

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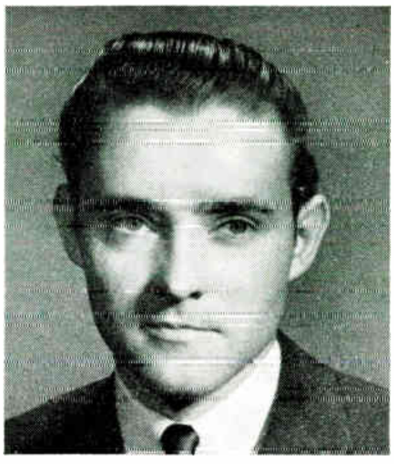
P. Michael Fulcomer, Jr. received the B.S. degree in electrical engineering from Northwestern University in 1957. He joined the National Bureau of Standards in 1957 as an electronics engineer, and has worked chiefly in the area of circuit design. Prior to Project FIST he was involved with a circuit standardization program, which consisted of the design and evaluation of tube and transistor circuits. At present he is responsible for the application engineering of FIST techniques.



IEEE publications

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advance abstracts
translated journals
special publications

Scanning the issues

Distributed Communications. A great deal of thought has necessarily been given in recent years to the question of the survivability of communications systems in the event of attack. Unpleasant though such a prospect may be, the studies themselves have led to some interesting suggestions as to what form our future networks might take.

Of particular interest is the distributed communication network concept in which each station is connected to all adjacent stations rather than to a few switching points, as in a centralized system.

Although one can draw a wide variety of networks, they all factor into two components: centralized (or star) and distributed (or grid or mesh). (See types (A) and (C), respectively in Fig. 1.)

The centralized network is obviously vulnerable, as destruction of a single central node destroys communication between the end stations. In practice, a mixture of star and mesh components is used to form communications networks. For example, type (B) in Fig. 1 shows the hierarchical structure of a set of stars connected in the form of a larger star with an additional link forming a loop. Such a network is sometimes called a "decentralized" network, because complete reliance upon a single point is not always required.

Since destruction of a small number of nodes in a decentralized network can destroy communications, the properties, problems, and hopes of building "distributed" communications networks are of paramount interest.

In a recent study of the effects of an attack on a distributed network, an investigation was made of the percentage of surviving linked stations versus the probability of station destruction for various levels of network redundancy. Redundancy level is a measure of connectivity and is used here as defined in Fig. 2.

A key point revealed by the study is that extremely survivable networks can be built with the use of a moderately low redundancy of connectivity level. Redundancy levels on the order of only three permit the withstanding of extremely heavy level attacks with negligible additional communications loss.

In addition, when one studies what happens when the links rather than the nodes of the network are destroyed, it becomes evident that highly reliable networks can be achieved with low-cost unreliable communication links, even links so unreliable as to be unusable in present networks.

Our future systems design problem is that of building at lowest cost very reliable systems out of the described set of unreliable elements. For communications of the future, digital links appear increasingly attractive by permitting low-cost switching and low-cost links. In any event the network must be built with the expectation of heavy damage. Powerful error removal methods exist.

Some of the communication construction methods that look attractive for the near future include pulse regenerative repeater line, minimum-cost or "minicost" microwave, TV broadcast station digital transmission, and satellites.

In communications, as in transportation, it is most economical for many users to share a common resource rather than for each to build his own system, particularly when intermittent or occasional service is supplied. This intermittency of service is highly characteristic of digital communication requirements. Therefore, we would like to consider one day the interconnection of many all-digital links to provide a resource optimized for the handling of data for many potential intermittent users: a new common-user system.

Fig. 1. (A) Centralized. (B) Decentralized. (C) Distribution networks.

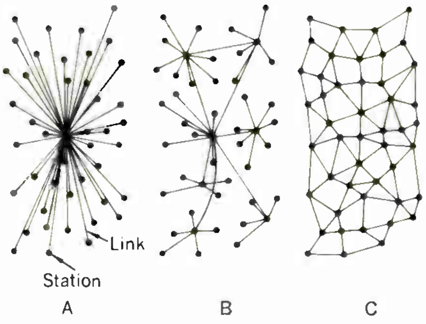
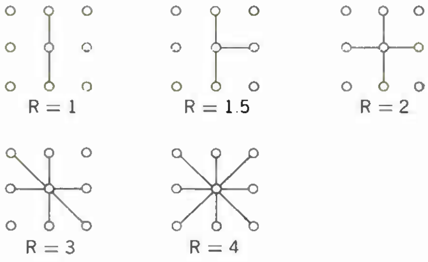


Fig. 2. Definition of redundancy level.



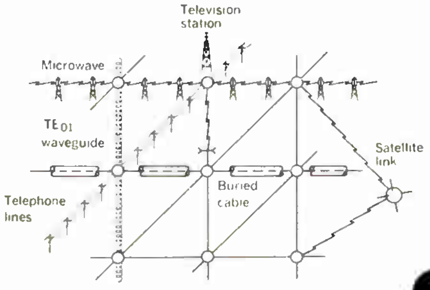


Fig. 3. All-digital network composed of mixture of links.

Fig. 3 demonstrates the basic notion: A wide mixture of different digital transmission links is combined to form a common resource divided among many potential users. (P. Baran, "On Distributed Communications Networks," *IEEE Trans. on Communications Systems*, March 1964.)

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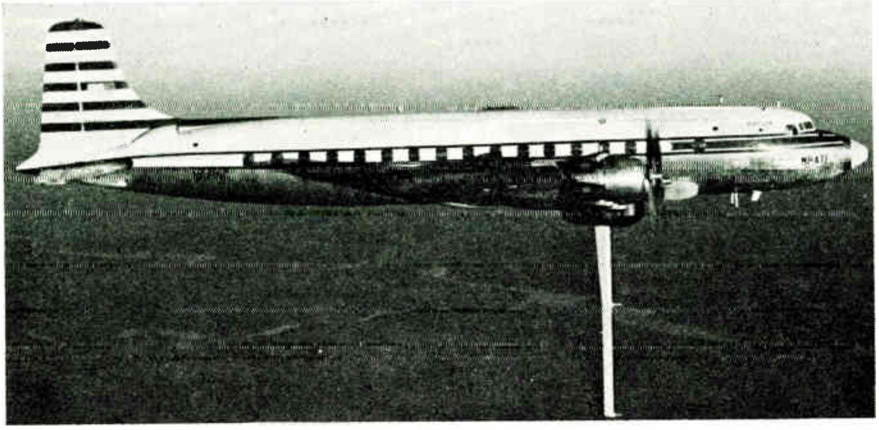
Year-round airborne educational television proves its reliability and its economic potential

For the third year, 5½ hours per day, 4 days per week from September to June, more than 1200 schools in the United States are receiving instruction of high quality from a television-equipped DC-6 aircraft. The broadcast comes from an altitude of 23 000 feet over Montpelier, Ind., to the six states participating—Illinois, Indiana, Kentucky, Michigan, Ohio, and Wisconsin. The program, financed primarily by The Ford Foundation Fund for the Advancement of Education and conducted by the Midwest Program on Airborne Television Instruction (MPATI), a nonprofit corporation formed for this purpose, first began operation in 1961.[1]

A detailed description of the equipment used by the aircraft has been previously published.[2] This note is a brief review of some of the theoretical concepts compared with the findings of three years' operating experience; some data on system reliability; and the system's current status and potentialities.

Fig. 1. Interior view of MPATI DC-6 Airborne Television station, showing most of the control and monitoring equipment including video tape recorders and the two 10-kW television transmitters.

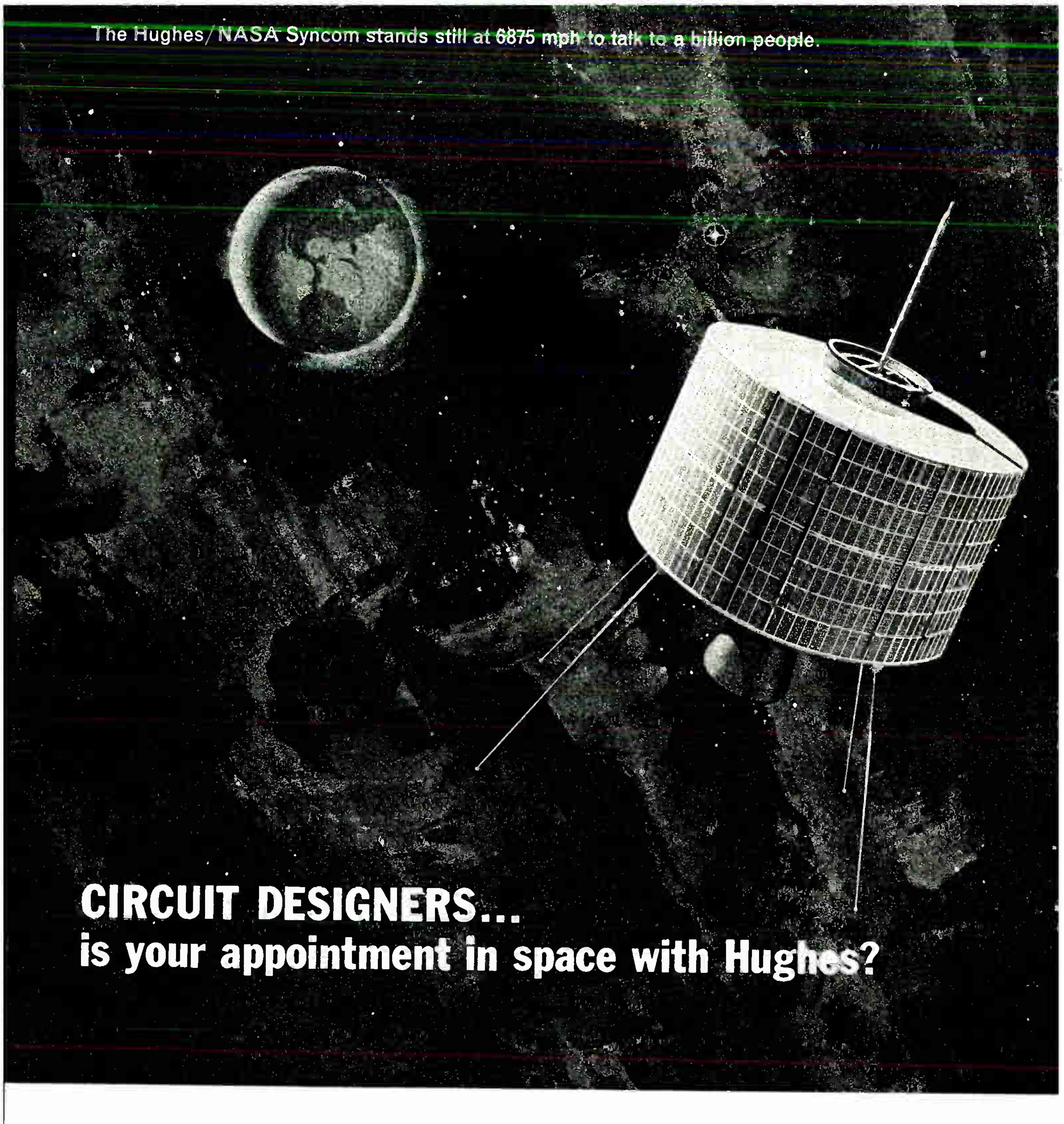
Fig. 2. MPATI DC-6 in flight, its gyroscopically stabilized antenna extended for broadcasting. The multislotted array provides a gain of 10 dB and radiates picture and sound for both transmitters.



An interior view of the aircraft (Fig. 1) shows most of the broadcasting equipment. Two video tape recorders play back previously recorded lesson tapes; two 10-kW television transmitters operate upon television channels 72 and 76; and the necessary control and monitoring equipment allow the aircraft to broadcast two different lessons simultaneously. The exterior view (Fig. 2) shows the aircraft in flight, its gyroscopically stabilized antenna extended to the broadcasting position. The single multislotted array provides a gain of 10 dB and radiates both picture and sound for both transmitters.

Theoretical concept. In Fig. 3 the altitude-versus-range curve is the standard 4/3 earth-radius curve indicating the increase in radio horizon with antenna elevation. For a 23 000-foot altitude, a 214-mile horizon is indicated. The power-versus-range curve allows for normal transmitting and receiving antenna gains, a 10-dB receiver noise figure, a 30-dB signal-to-noise ratio, and a 10-dB fade factor. For a 214-mile range, 13-kW peak video power is indicated. The curve representing altitude versus cost per student-hour considers aircraft time on station at various altitudes. It is based upon the number of students within range of the MPATI aircraft; it includes aircraft and television operating and maintenance personnel, both ground-based and airborne, amortization of one primary and one stand-by aircraft and their television-broadcasting and support equipment, and all other associated costs. Students are assumed to be uniformly distributed in the area.

From the latter curve, it appears that the economical limit is not reached, although the curve is bending toward an asymptote. Actually, the equipment weight and the DC-6 payload capability



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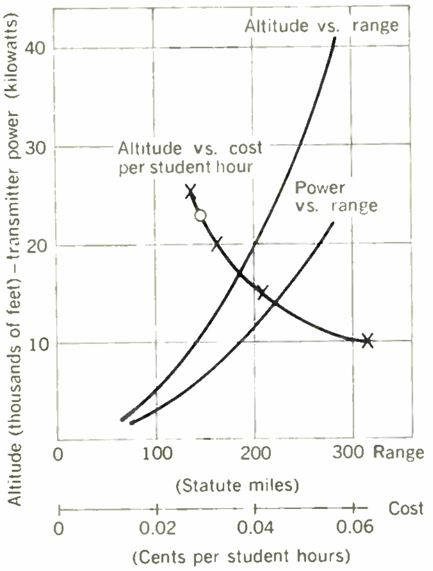


Fig. 3. Theoretical curves (range, power, and cost). The altitude-versus-range curve is the 4/3 earth-radius curve indicating increase in radio horizon with antenna elevation.

I. Overall system reliability

Operating Period	Program Hours Scheduled	Program Hours Lost	Per Cent Availability
1961 summer tests, May to Sept.	330	34.0	90.0
1961 to 1962 school year, Sept. 11 to May 24	1423	30.0	97.9
1962 to 1963 school year, Sept. 10 to May 23	1408	17.9	98.7
1963 to 1964 school year, Sept. 9 to May 28	1397	31.0	97.8

fix its maximum altitude at 23 000 feet. The cost curve for this altitude discloses 0.0295 cent per student per hour or about 44 cents per student per year for two-channel service, provided all schools within range participate. Comparing the actual parameters to these curves, first a power of 5-kW peak video is used because of primary power limitations of 70 kW in the present system. Theoretical coverage has been essentially achieved. At present more than 1200 schools are "officially" participating. They share the operating costs by paying one dollar per student per year. This does not cover present total costs, for MPATI's annual budget is about $3 million including teachers' salaries, preparation of lessons, and administrative costs. Remaining operating costs are still Foundation-supported. There must be participation by more schools in the area or higher rates before the operation can become self-sustaining.

Reliability. Before operation began, weather faults were anticipated by many as a possibly serious obstacle to reliable performance. As a matter of fact, a period of only 10 minutes of scheduled operating time was lost because of weather conditions in 2½ years. This record was achieved, in part, by the use of two aircraft. If the regular base at Lafayette is threatened, the aircraft can be dispersed in various directions before adverse weather closes in. A spectacular example of the system's performance in the face of bad weather occurred last spring. When, on a Tuesday, the number 1 aircraft lost cabin pressure because of icing conditions and had to reduce altitude, number 2 took off and continued the broadcast. Back on the ground, serious lightning damage to the tail of number 1 aircraft was discovered and it was flown to Atlanta, Ga., for repairs. Number 2 had to land in Nashville, Tenn., the same night because of bad weather, but the lesson tapes for the next day were on board. It was back on schedule on Wednesday, but had to land in Lexington, Ky.; in the meantime, at the end of the day, Lafayette Airport was still closed. A new supply of video tapes transported over icy roads allowed number 2 to meet the Thursday schedule on time.

These broadcasts have continued when most of the schools were closed because of weather. Last January, however, the spell was broken when, with the Midwest buried under 10-foot snow drifts and many schools closed, a broadcast day was finally missed. The aircraft were ready to go but a 40-mile-per-hour cross wind at the Lafayette Airport prevented take-off from the single available runway.

Overall system reliability, however, is good, as the record in Table I shows. It compares favorably with the 99.75 per cent average availability of 30-UHF ground broadcasting stations, as reported in the Television Allocation Study Organization study,[3] althoug ground stations operate in a more favorable environment and have had many years of operation in which to develop improved reliability.

A permanent service? When experience had confirmed the chosen operating parameters, and had dispelled skepticism regarding reliability, the Federal Communications Commission was asked to make the service permanent and to allow the transmission of six rather than two channels to fulfill additional

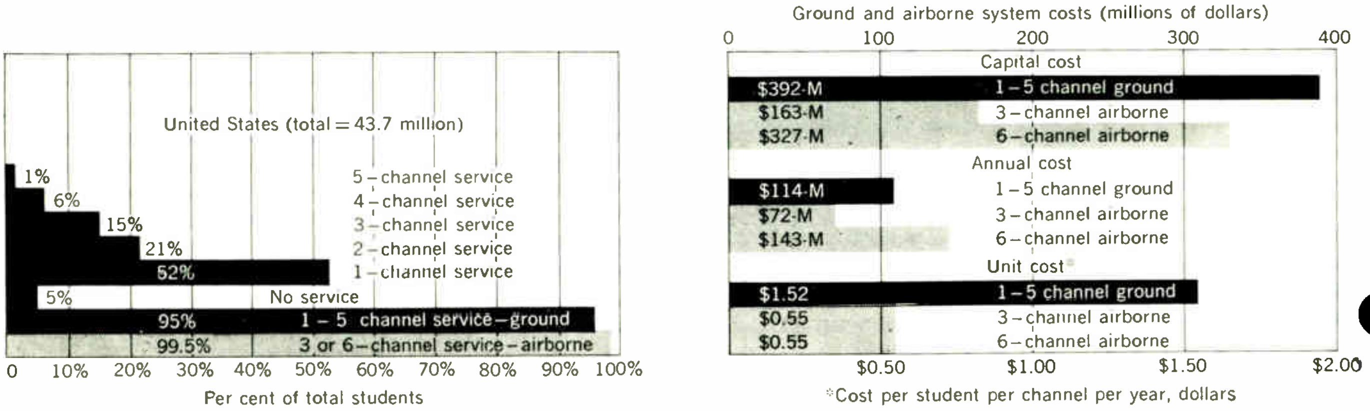
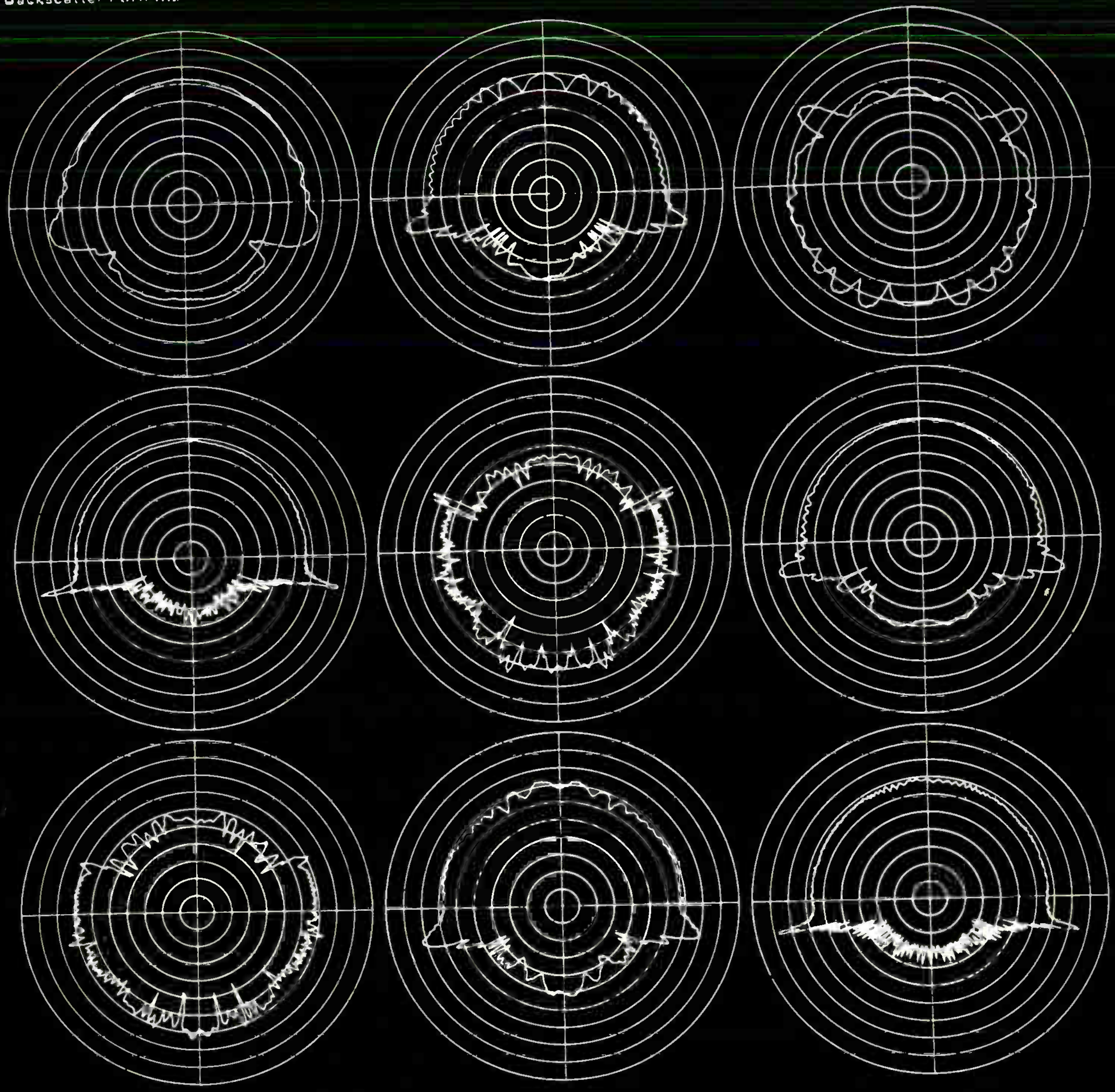


Fig. 4 (left). Ground station versus airborne station coverage. It is assumed that all students from kindergarten through college within range of the station participate in the overall system. (Right) Ground versus airborne costs, including all distribution costs but not cost of teachers' salaries, lesson production studios, or classroom receivers.



Backscatter Patterns

educations needs.[4] A Westinghouse study,[5] filed in the FCC hearing, discloses airborne distribution the most economical of all means of distribution. A National Bureau of Standards study,[6] shows that airborne distribution makes more efficient use of the available spectrum. The Westinghouse study compares a nation-wide airborne distribution network to a 931-station ground distribution system proposed in a Department of Health, Education, and Welfare study.[7]

It was hoped at first that a six-channel airborne system in operation by 1965 would be possible, but because of hearing delays the hope has dimmed. However, when all comments and responses to comments are filed and studied, the FCC must resolve the issue of whether airborne educational television is in the public interest.

The advantages of ground station distribution are:

- Piecemeal implementation
- Local control of programming
- Economic coverage of populous areas

Its disadvantages are:

- Insufficient frequency spectrum
- High cost of rural coverage

The advantages of airborne station distribution are:

- Most economical operation of all systems
- Inherent coverage of rural areas
- Conservation of frequency spectrum

Its disadvantages are:

- Necessity of coordination between states
- Requirement of large *initial* capital investment

Distribution study. The Westinghouse study proposes a 33-station airborne television system to cover the nation, and compares student coverage of the 931 ground station systems with the 33-station airborne systems, with the results shown in Fig. 4, left. For the comparison it is assumed that all students (college, secondary, elementary, and kindergarten) within range of the stations participate in television instruction.

The cost comparison (Fig. 4, right) is on the same basis for both systems and includes all distribution costs but not the cost of teachers' salaries, studios for lesson production, or classroom receivers.

The Westinghouse study shows the capital cost of a three-channel nation-wide airborne system to be 42 per cent of that of the 931-station ground system; the total annual operating cost of the airborne system to be 63 per cent that of the ground system; and the annual cost per student per channel on a nation-wide basis to be 55 cents, or 36 per cent that of the ground system.

Other uses for airborne systems. Once classroom instruction becomes nation-wide, many other uses of the system are possible—one, obviously, in adult education or in broadcasting cultural programs to the home during nonschool hours. MPATI has considered courses in agriculture for farmers.

The national network would be less vulnerable to atomic attack than ground-based installations, and could serve to keep the populace informed of the national situation. Aircraft from other bases could be quickly moved to replace equipment in a damaged area. Such aircraft properly equipped could help to reestablish damaged parts of the national telephone and telegraph network.

The system might perform a great service to the nation in providing weather information. In fact, the Weather Bureau has approached MPATI with the idea of equipping the aircraft with weather instruments.

Finally, the cost per student is low with the airborne system used for educational purposes only, but it could be drastically reduced further in a multipurpose system that would serve the national and local interests and in which the costs could be shared among the various users.

Frank G. Mullins
Westinghouse Electric Corp.
Baltimore, Md.

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Molecular electronic infrared tracking system is made up of relatively few components

An infrared tracking system that uses molecular electronic components has been demonstrated. Extensive use of molecular electronic techniques made it possible for the system to be built with 543 components, which number is the electronic equivalent of 6300 conventional components. Included are 135 specially developed molecular electronic devices and 408 standard components. The system performs well. High reliability is claimed for it, and power requirements are low.

A mosaic of 100 individual infrared detection cells enables the tracking system to detect targets within a four-degree field of view, automatically acquiring targets and track without mechanical scanning. Each detector has its own channel amplifier.

The completed engineering model measures 18 inches in diameter, is 30 inches long, and weighs 95 pounds. Most of the weight is in the standard optics used in the unit. Special optics would reduce the size and weight in an operational system to 13 inches in diameter, 24 inches in length, and about 30 pounds in weight. The electronics section would occupy less volume than a half carton of cigarettes.

Part of the new system, and essential to its operation, are the 100 high-performance molecular preamplifiers which amplify each of the cell detector signals. Each amplifier is the size of a postage stamp and consists of two silicon wafers mounted in a package ⅜ by ¾ by 1/32 inch in size. The amplifier has a voltage gain of 45 000, stabilized within 10 per cent from $-40°C$ to $+80°C$. It has a total input power requirement of one to environment pollution, urbanization, management of national resources, and the current status of engineers and scientists. The Convention *Proceedings* contains transcripts of 33 papers.

The annual Lillian Moller Gilbreth Scholarship, awarded by the SWE to an outstanding woman student of engineering, was presented to Valerie R. Peterson, University of Wisconsin.

From a questionnaire circulated within the past few years, a profile of the average woman engineer emerges: she is about 36 years old. She is equally likely to be married or single. If married, she has three children. She is employed by industry and earns a median salary of about $10 000 per year. A college graduate, she has a bachelor's degree in engineering or one of the physical sciences, and either has an advanced degree or has taken specialized training, related to her work, at the graduate level. She is a member of one or more of the technical societies. She is unlikely to be a licensed professional engineer.

Throughout the Conference the role of women engineers was depicted as one that involved meeting the massive problem of raising living standards in a world of increasing population—"to utilize the resources of nature, and of human nature for the benefit of mankind."

Miss Cavanagh in her address to the delegates said in part: ". . . industry wants more women engineers and scientists in the high-demand fields to fill its deficits, thus stabilizing supply and demand, so it can gain a more even distribution for its engineering and development costs; education wants more women students so it can meet industrial and governmental demands for the most highly qualified graduates, and so it can maintain and expand its plant in the face of stable male enrollments; and government wants more women so it can both develop a strategic manpower reserve in critical categories and stabilize the costs of its engineering requirements. These are not necessarily harmonious objectives, and thus we must all look deep into our own motives before we can hope to achieve the essential balance in human values which is one of the major objectives of this Conference."

Cosmic energy theory may revise concept of universe

Two physicists have apparently unlocked the mystery of the most enor-

mous source of energy in the universe in their mathematical description of an immense cloud of gas that unleashes more power than 10^{27} hydrogen bombs per second. Nine such "quasi-stellar objects" have been discovered by radio astronomers in the past 13 months, and since then much of the scientific world has been curious about their nature and significance in astrophysics.

According to the latest hypothesis, described in a paper delivered to the American Physical Society, the objects are neither colliding galaxies nor chains of exploding stars. The first physically consistent explanation reveals that each of the objects is a vast collection of hot, electrically charged gas or plasma that may already have collapsed like a giant balloon because of its tremendous mass.

By celestial standards, the mathematical model of the objects is relatively cool—averaging far below the 300 000-degree temperatures of "hot" stars.

The quasi-stellar objects thus far discovered are calculated to be between 2 and 10 billion light years distant. Yet the radiation is so strong that until March 1963, one of the objects had been considered to be a faint star in our own Milky Way galaxy. The system is at least a few light years in diameter, and its density is about 1000 times greater than our own galaxy. In plasma physics theory, these factors make it a superpowerful, gaseous "midget" by celestial standards, in which the vibration of hot, charged particles propagates radio waves.

Scientists have conjectured that the tremendous intensity of these radio waves results from gravitational collapse. In this process an object becomes top-heavy, and, during the course of its normal contraction, it suddenly reaches a critical size where the centripetal force causes the entire system to collapse cataclysmically.

The missing link in earlier calculations is a power source called "Debye free energy." This energy is usually so small that it has been considered seriously only in atomic reactions, or in calculations of liquid electrolytes. On the scale of the mysterious objects in space—that are nearly as massive as an entire galaxy—the Debye free energy becomes an imposing factor, and may be sufficient, in itself, to account for the power of the radio emission.

It is suggested that the new discovery can be checked experimentally by training radio telescopes on the distant objects at certain other frequencies. Assuming that each of the quasi-stellar sources has a mass about 100 million times greater than that of the sun, the signals received can be interpreted in part as corresponding to vibrations of the electrons within the plasma. Therefore, there should be another type of signal at about 1 Mc/s, corresponding to proton oscillation. A fainter radio wave below 1 Mc/s frequency, coming from helium ions, is anticipated

Dr. Louis Gold, and Dr. John W. Moffat, of the Martin Company Research Institute for Advanced Studies are responsible for the startling new theory.

Nondestructive readout memory developed

An electrically alterable, nondestructive readout memory, called the Piggyback Twistor, is being developed for applications in a number of telephone switching systems. It operates in microseconds, and has a storage capacity of more than 200 000 bits.

The device uses two magnetic materials—one for information storage and the other to sense the stored information. Both magnetic materials are thin, narrow tapes that are spirally wrapped around a fine copper conductor. The tapes are wrapped "piggyback fashion," one on top of the other.

The memory device has 4096 words, each storing 54 bits of information. Each of the 4096 words consists of a copper strap that is wrapped around a flat cable in which 54 twister wire pairs are contained. A bit is stored at the intersection of each word strap and twister pair, and there are more than 200 000 such intersections in the memory.

The information stored in the memory can be read out repeatedly with current charges, without changing the memory contents.

Experimental Piggyback Twistor memories have been built in modular sizes up to 300 000 bits, with read-cycle times of about $5\ \mu s$. The twister wire is made and handled in long lengths to facilitate modular assembly.

To write information into the memory, current is pulsed into a word strap, and currents are pulsed simultaneously down all twister wires. The magnetic field derived from both the word current and the twister wire current magnetizes the storage tape in the vicinity of the particular word strap. The polarity of the current on the twister wire determines whether a binary "one" or a binary "zero" is stored at a given bit in the memory. About 20 μs are required to write one word, and as there are 4096 words the memory can be "loaded" in less than one tenth of a second.

The readout is the same as the write-in—as far as the word strap is concerned—but the current amplitudes are lower. The current flowing through a selected word strap is sufficient to switch the sensing tape. Once this tape is switched, a voltage is induced into the copper wire, and this voltage is read out at the terminals of the memory.

The polarity of the readout voltage is determined by the state of magnetization written into the storage tape. The new memory device is a development of the Bell Telephone Laboratories.

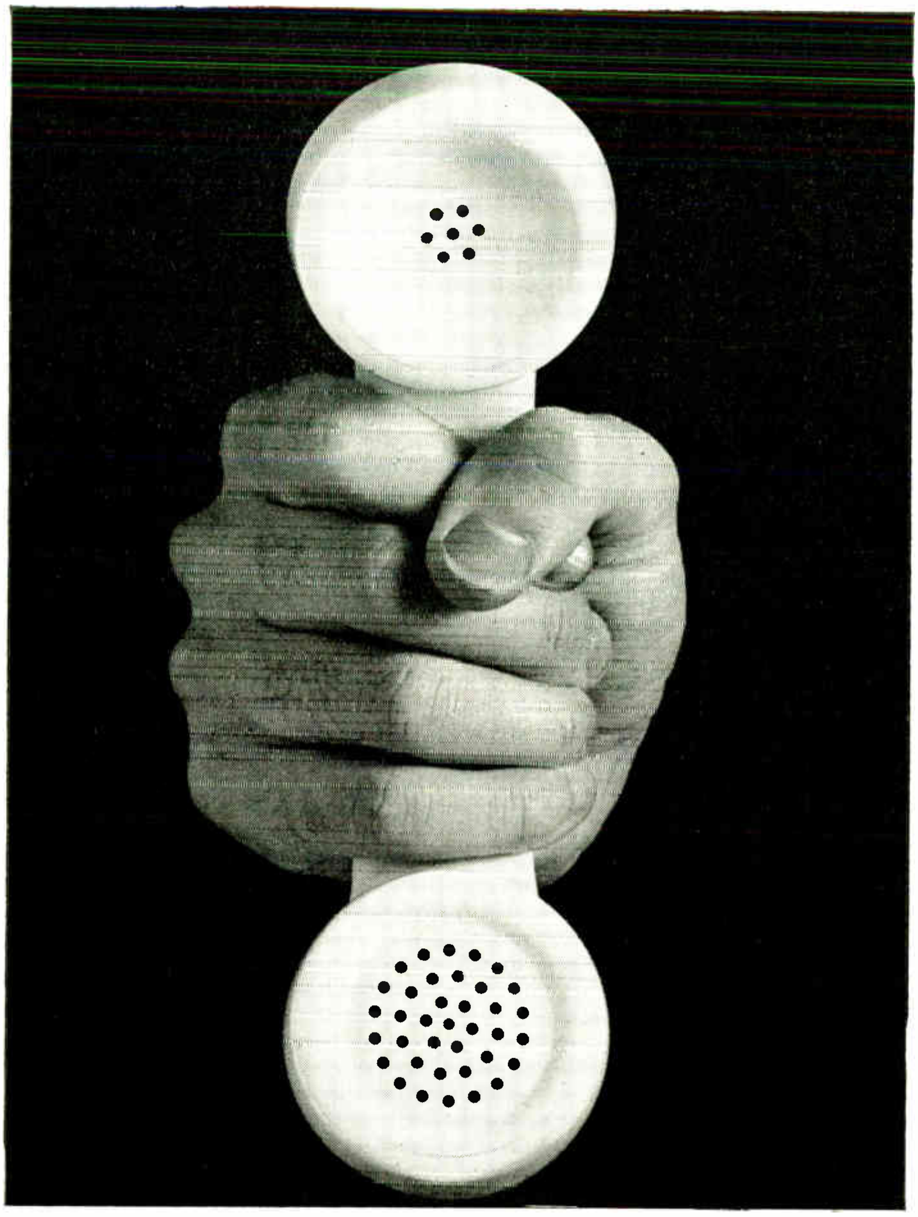
National Academy of Engineering proposed

Plans have been drafted, by a National Academy of Sciences committee of 25 of the nation's leading engineers, for the formation of a National Academy of Engineering. The committee will seek a Congressional charter for the proposed academy.

The National Academy of Sciences' meeting on April 28 was the culmination of a series of discussions that began in 1960, when the Engineers Joint Council, in cooperation with the Engineering Foundation and the Engineers' Council for Professional Development, and with representatives from the National Academy of Sciences and the National Research Council, appointed a committee to make an intensive study of the need and feasibility of an engineering academy. This and subsequent studies indicated that such an academy would be desirable and practical. Furthermore, because of the clear interrelationship between science and engineering, it was decided that the proposed National Academy of Engineering should be closely affiliated with the National Academy of Sciences.

The National Academy of Engineering would be a private, nonprofit organization dedicated to the furtherance of engineering, and it would serve the nation in connection with problems in engineering and technology. The preliminary objectives of the Academy are as follows:

1. To formulate programs for effective utilization of national resources.
2. To explore means for promoting cooperation in engineering in the U.S. and abroad to secure concentration of



effort on significant engineering problems.

3. To encourage the interaction of engineering with the physical, medical, and social sciences in support of more effective application of technology.

4. To sponsor such engineering research that may be beneficial to the national interest.

5. To offer its data and services to the Government.

6. To advise the Government, whenever called upon, on national policy matters pertinent to engineering.

The National Academy of Engineering committee includes the following IEEE members: H. W. Bode, Vice President, Bell Telephone Laboratories, Inc.; Walker L. Cisler, President, Detroit Edison Co.; Elmer W. Engstrom, President, Radio Corporation of America; William L. Everitt, Dean, College of Engineering, University of Illinois; J. Herbert Hollomon, Jr., Assistant Secretary of Commerce for Science and Technology; Clarence H. Linder, Former Vice President, General Electric Co.; W. H. Pickering, Director, Jet Propulsion Laboratory, California Institute of Technology; J. A. Stratton, President, MIT; C. G. Suits, Vice President and Director of Research, General Electric Co.; F. E. Terman, Provost and Vice President, Stanford University; Eric A. Walker, President, The Pennsylvania State University; and Ernst Weber, President, Polytechnic Institute of Brooklyn.

Bureau of Standards changes radio broadcasts

Several changes in the schedules and contents of National Bureau of Standards (NBS) radio broadcasts of time and frequency standards have been made recently.

At zero hours (12:00 midnight) Universal Time (UT) on April 1, 1964, the transmitting clock controlling NBS stations WWV, WWVH, and WWVB was retarded 100 milliseconds. The last such adjustment, necessitated by changes in the speed of the earth's rotation, was made on November 1, 1963. U.S. Navy stations NBA, NPG, NPM, NPN, and NSS were also clock-retarded at the same time.

On April 1, stations WWVB and WWVL began broadcasting continuously from 1630 (4:30 p.m.) UT on Wednesdays to 2230 (10:30 p.m.) UT on Fridays. On Saturday, Sunday, and Monday these stations broadcast from 1630 to 2230 UT. The stations alternate operation on successive Tuesdays.

WWV now broadcasts the frequency offset—M150—in Morse code immediately following the on-the-hour voice announcement, and broadcasts propagation forecasts in Morse code every five minutes following code time announcements. The M150 symbol indicates that the signal, as broadcast, is offset from the U.S. Frequency Standard by -150 parts in 10^{10}.

A new schedule of geophysical alerts on WWV and WWVH was initiated on April 1. The following signals are broadcast in Morse code (seven words per minute) on WWV during the first half of the 19th minute, and on WWVH during the first half of the 49th minute past each hour:

GEO-MMMMM, magnetic storm
GEO-NNNNN, magnetic quiet
GEO-CCCCC, cosmic-ray event
GEO-SSSSS, solar activity
GEO-QQQQQ, solar quiet
GEO-WWWWW, stratospheric warning
GEO-EEEEE, no geoalert issued

By agreement with the Naval Observatory, WWV and WWVH started broadcasting on May 1, 1964, daily corrections to the regular time signals to enable users to obtain a very accurate value of UT-2. During the last half of the 19th minute of each hour on WWV, and the last half of the 49th minute of each hour on WWVH, Morse code signals are broadcast as follows: UT-2, space, AD or SU, space, three digits.

UT-2 is obtained by adding or subtracting (as indicated) the number of milliseconds indicated by the last three digits to the time as broadcast. The symbols are revised on a daily basis, with the new value appearing for the first time during the hour after midnight UT, and continuing for the following 24-hour period.

Device detects impact of salt grain from 1-cm height

An ultrasensitive electronic device developed by NASA's Ames Research Center can detect the impact made by a single grain of table salt dropped on a surface from the height of one centimeter—a distance equivalent to the diameter of an aspirin tablet. The instrument is also capable of detecting an impact 1000 times less than the impact generated by the falling grain of salt.

The device—called a momentum

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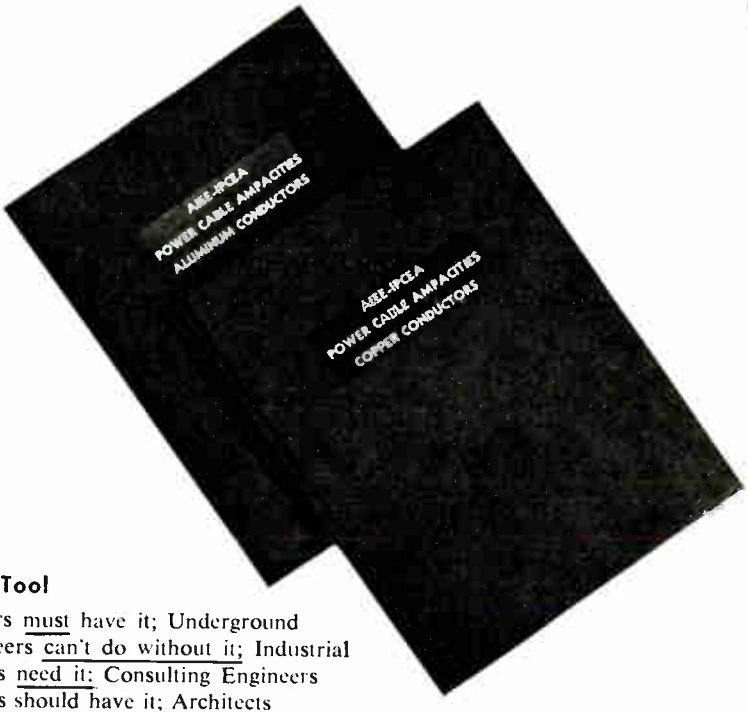

Errata sheets, correcting several minor errors, are available without charge to earlier purchasers of these publications, from the Secretary, Insulated Power Cable Engineers Association, 283 Valley Road, Montclair, N.J. Errata sheets are included with shipment of new orders.

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(CONTENTS — PRINTED MATTER)
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Correspondence

Philosophy and Science. Dr. Bronwell's premises are quite unrealistic in his article "Is Philosophy Off Limits?" (May issue, page 110.) Modern philosophy appears to be in the same onanistic circle with the other academic circles he criticizes. Philosophy is busy analyzing the (deep) meaning of its words, in a way very analogous to the way science is busy analyzing the meaning of its measurements. Each thus feels itself to be fundamentally limited by the state of the art of measurements. It is by no means self-evident, or even truly provable, that refinement of tools cannot lead to new worlds of knowledge and accomplishment. It can only be said that almost everyone interested in the arts and sciences spends most of his time this way, at least partly for the reason that he hasn't an idea for something better to do, and such activity has social approval and earns one a living.

The academic philosopher has, further, almost nothing to say in the language of the scientist or engineer. This is not to say he shouldn't or couldn't write in that language, but scientists and engineers are investigating their own problems in appropriate language, a language different from that of the formal philosopher.

The role of technological prophecy and direction pointing has been taken over by science fiction writers, who of course are often scientists, engineers, and philosophers of the less academic persuasion. They have already predicted the next era of technological achievement, and because they are extrapolating present science and semiscience they are almost inevitably correct on most counts. The journals of this type of "philosophy" are science fiction journals (with the possible exception of *Science*), not technical journals. Where would a modern Spengler find publication today?

In case anyone has not been reading the current technological philosophy journals, the next era of human progress, assuming it is not catastrophically terminated, will include advances in "psionic and telepathic" techniques, utilization of "antigravity" and "time travel" equipment, miniaturization of "atomic energy" supplies, and control of "social problems" by various new mass psychological and communication techniques. Note that none of the terms within the quotation mark pairs can be acceptably defined, and therefore all are outside the purview of formal philosophy. Note also that those of the technically trained who believe any or all of these prophecies to have much merit are the "cranks," just as Goddard and Wright were cranks, and just as even today Spengler is generally regarded as one.

The more important practical aspects of the problem Bronwell raises, I feel, are not emphasized. He notes the importance of creative and individualistic personalities in the history of human ideas. Today the forces tending to prevent such individuals from achieving productive maturity are even more intense than they were in the past. These "forces" are *not* malevolent ideologies. There are, first and foremost, stupid pedantic individuals who decide whether people should be admitted to universities and jobs, or who teach and supervise, who believe there is some correlation between academic performance (degrees and grades), or past achievement in industry (income and title), and creative talent. Second, there is far more (and usually unconscious) imparting to the young by parents and teachers of the insecurity of life in our society and the importance of gaining specialized training in one of those (mysterious) fields for which there is a clear economic future. Further, with the population rise, the standard of living increase, the greater mechanization of menial work, the increased centralization of population, the rise in average level of education, has come an intensification of the acquisition drive, the drive to achieve ownership of things, and while there is nothing immoral or even acultural about this drive, it leaves less time and energy than did even the 12-hour workday for noneconomic dreaming and scheming; now more nonwork time tends to be spent passively "enjoying" things.

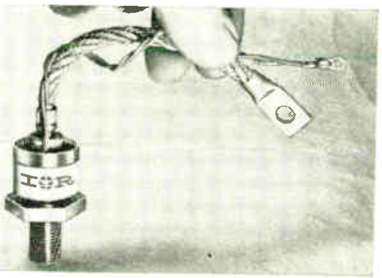
Dr. Bronwell: how does *your* admissions department go about selecting for admission to the University of Connecticut those applicants (from out of state, particularly) who have mediocre or poor academic records and eccentric personalities including psychiatric problems, but who need educating so their individualism can result in isolated contributions to human progress?

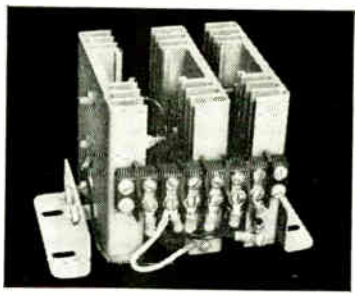
G. F. Quittner
Cleveland Heights, Ohio

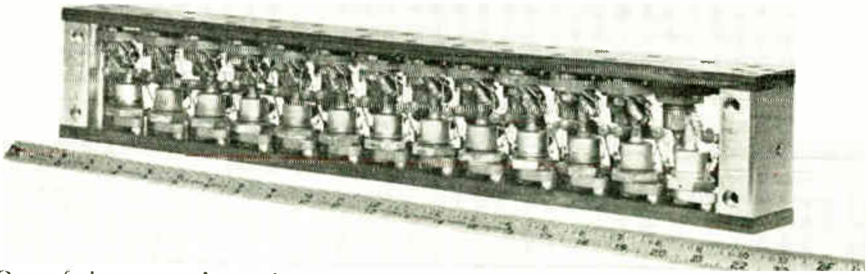
Is Philosophy off Limits? (Dr. Bronwell replies). Mr. Quittner has broadened the scope of discussion in well-recognized directions. He has mentioned some of the sociocultural inhibitors of the development of creative individualistic personalities. With most of his comments I cannot take issue. He has apparently misinterpreted my use of the term "philosophy." It was my intention, and I believe that it is rather explicitly stated in the article, that it is the scientists and engineers who are to do the philosophizing in their own realms, not the philosophers. Nothing but confusion could emanate from philosophers indulging in technological prophecy. The use of the word "philosophy" was intentional because, as Webster defines it, philosophy is the "love of wisdom," or the "science that investigates the facts and principles of reality . . . ," and these definitions rather aptly express the goal.

However, I find myself asking questions about Mr. Quittner's comments. Mr. Quittner relegates technological prophecy to the realms of science fiction and indeed, points to the quite phenomenal success of this medium in predicting astounding discoveries that have materialized. Now, here is the crux of the problem: If technological prophecy has been successful in science fiction, why shouldn't it be given a legitimate place in our professional societies? There are plenty of chaise-lounge creativists around who can conceptualize plausible ideas. But experience has shown that it is the wide chasm between conceptualization and the reduction to reality that is the hardest to bridge. Bridging this chasm has often required a lifetime of dedicated scientific inquiry. Learning how it can be effectively bridged is the most difficult part of the process—a process that goes far beyond the superficialities of science fiction.

Today, our talented youth are blinded to the future. If we are to lift more of our youth out of the morass of research trivia and set their feet firmly on pathways that might lead to great discovery, we must find ways of giving them far more substantial visions of the future than those of science fiction. As long as the professional societies







have no adequately established mechanism for developing philosophical perspective, youth will largely remain in a state of academic myopia.

Again, let me point out that Robert Goddard's ideas of rocket travel in interplanetary space were completely ignored during his lifetime by all the major scientific and engineering professional societies because he was working beyond the fringe. The professional societies had no way of dealing in philosophical futures, and they have none now.

This is the problem we face today, but it is becoming more acute. The perimeters of professional society operation are expanding and multiplying. But we have no established means of looking beyond today's perimeters. Can we truthfully say that this is expecting too much of Homo sapiens, that he must crawl before he walks? Surely there are those in our scientific–technological society who have clear-sighted visions of the future and who also have the solid substance of scientific–technological pioneering, so that their prophecy goes far beyond mere superficiality. But, like Goddard, they find no professionally recognized forum where they can espouse their ideas. It is not uncommon that the truly significant ideas first emerge from outside the professional societies altogether, then in due course they become "legitimatized" by the profession.

The supreme contribution of any professional society is to get a firm grip on philosophical futures—to bring a Robert Goddard into a forum of highest priority and prestige and let him reveal to the society membership the full dimensions of his visions of the future, not just the scientific aspects of rocket propulsion, or of gyroscopic stabilization, or of liquid and solid propellants, but the largest philosophical consequences in opening up whole new fields of astrosciences, planetary sciences, and cosmology sciences. Visionary? Certainly, but Goddard was fully equipped to do this. And so are many pioneering research scientists and engineers today who find themselves gagged because the professional societies have no forum for this kind of philosophical interplay.

The greatest void in our professional societies is found in this exploring of new ideas in their largest philosophical dimensions; looking beyond present-day perimeters; and taking hold of embryo ideas that might have profound ultimate consequences and bringing these out into the open forum for philosophical exploration by the ablest scientific and technological minds of our times.

The void is reflected back into our universities to create philosophical cemeteries. Such philosophical discussion would carry ideas far beyond the mere superficialities of science fiction; it would quickly separate the wheat from the chaff; and it would give a fresh air of validity to scientific prophecy that would excite the spirit of adventure in youth.

Philosophical futures can be dealt with successfully only if they are programmed and managed by scientists of large vision and experience. They cannot be successfully achieved within present organizational structures. While a certain amount can be accomplished by alert professional society committees that are looking ahead, still experience has clearly shown that many of the greatest conceptions will fall far outside of the present perimeters of society operation, as was clearly evidenced by Goddard's rocket ideas, or nuclear power, or computers, or solid-state physics in their earliest stages.

Clearly, philosophical prophecy is unique in its character. It has dimensions much larger than any committee, or even of the whole professional society, and it can succeed only if it is organized as a distinctly separate, top-level function in the society. Furthermore, it must be programmed and managed by the leading pioneering scientist–engineers in the nation. They can readily identify people with ideas who may be beyond the fringe, or in the subterranean depths, but who should be brought out into the open and given a forum of highest priority. Only in this way can we get a truly meaningful vision of the future and make rapid progress toward its fulfillment; only in this way can we captivate the imaginations of youth with great challenges instead of myopic trivia.

Arthur B. Bronwell
The University of Connecticut
Storrs, Conn.

Failure by the pound. Parkinson's law[1] states that "Work expands so as to fill the time available for its completion." An extension of this law that especially applies to military systems is that the "required" functions expand so as to fill the allowable weight or allowable space.

The high-performance modern aircraft missiles, spacecraft, and submarines are examples of weight and/or space-limited systems and, therefore, of function-limited systems. In the evolution of such space- or weight-limited systems, microminiaturization techniques permit an increase in the number and complexity of the required functions.

In assessing the reliability of such systems and the associated miniaturization technology, it must therefore be concluded that the proper criterion to use is not the mean-time-between-failure of the various components but rather the mean-time-between-failure per pound or mean-time-between-failure per cubic foot.

Eugene W. Baer
U.S. Naval Underwater Ordnance Station
Newport, R.I.

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1. Parkinson, C. Northcote, *Parkinson's Law*, Boston: Houghton Mifflin Co., 1959.

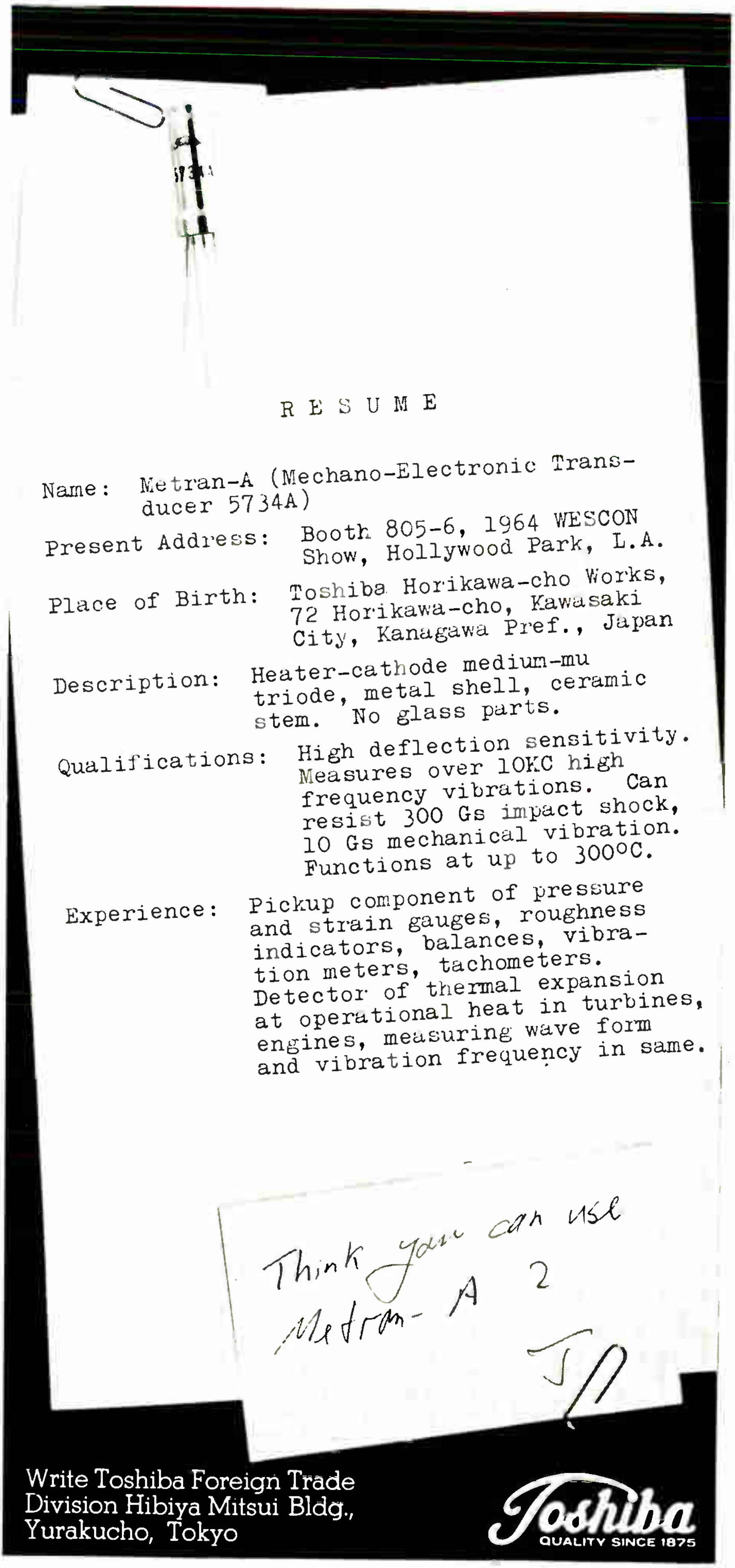
The professional engineer and scientific theory. The ideas expressed in the Griffin-Warren letter (February issue) comparing the role of the engineer to that of the scientist are all too true. I have noticed that some of the engineering colleges are primarily training men for design and research. These are not the only fields of engineering and there is still much need for men who understand the basic principles to resolve engineering problems in the "field." I have at times resented the implication that *only* the research and design men are of the highest intellect.

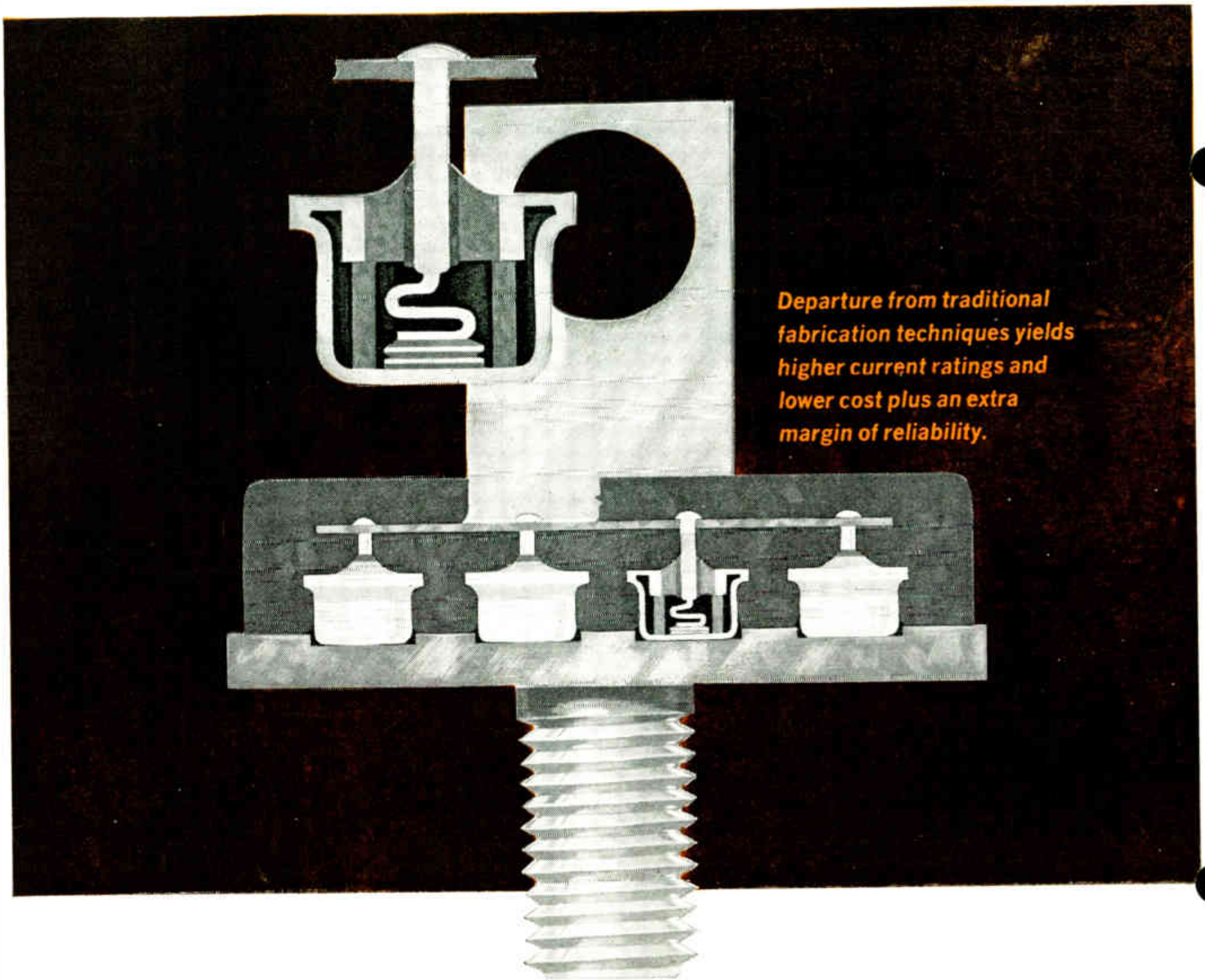
On the other hand, I applaud any effort directed at raising the standards of the profession as a whole, and I must admit that too many of the so-called practical engineers turned loose in industry have been found wanting on basic theory and its application.

Here in Mexico we have men with a B.S. degree in mechanical electrical engineering, but there is a tendency to separate the two branches as in the States. For the design and research engineers the separation is probably better, but for many power engineers in industry having the combined degree is a good thing.

There is still a great need for good practical professional engineers who can apply scientific theory in the field. Some of the specialists can't see the "forest because of all the trees."

Bruce W. Bryan
Cananea, Sonora
Mexico





Departure from traditional fabrication techniques yields higher current ratings and lower cost plus an extra margin of reliability.

Motorola's New Rectifier Design Breaks High-Current Barriers

For years, high-current rectifier manufacturers have been searching for a universal rectifier cell which would be adaptable for use in numerous configurations and capable of filling virtually any rectification application. Motorola has perfected such a universal cell and is using it in a new high-current rectifier design. These new high-current silicon rectifiers will:

1. **Increase the current-handling capability of a single device from its present maximum limit of approximately 400 amperes to 1000 or more amperes and increase surge capacities up to six times that of present devices;**
2. **Appreciably cut the present cost of such devices;**
3. **Provide an extra margin of equipment reliability due to reserve capacity and built-in redundance; and**
4. **Increase equipment design flexibility.**

How the Breakthrough Was Accomplished

There are two basic methods of making high-current rectifiers. One method uses large single rectifier junctions to carry the required current (as the current requirements are increased these single junctions must become larger and larger); the second method is to parallel a number of lower current rectifiers.

There are a number of problems associated with large single-junction rectifiers. Large-area rectifier junctions cannot be made without some imperfections, and the larger the area (higher current capability) the greater the number of imperfections.

When current is passed through such a device, the current is not necessarily distributed equally over the entire area. Some areas will assume more than their normal share of current, and these high-current areas may ultimately result in high heat density areas ("hot spots") which can cause thermal fatigue and deterioration. During abnormally high current surges, such thermally stressed or deteriorated areas can assume excessive current and destroy the entire rectifier.

Instead of using a large-junction rectifier, Motorola employs a number of perfect (for all practical pu poses) small-junction, medium-current units connecte in parallel to provide practically any desired total current rating. Breaking up the large rectifier junction into