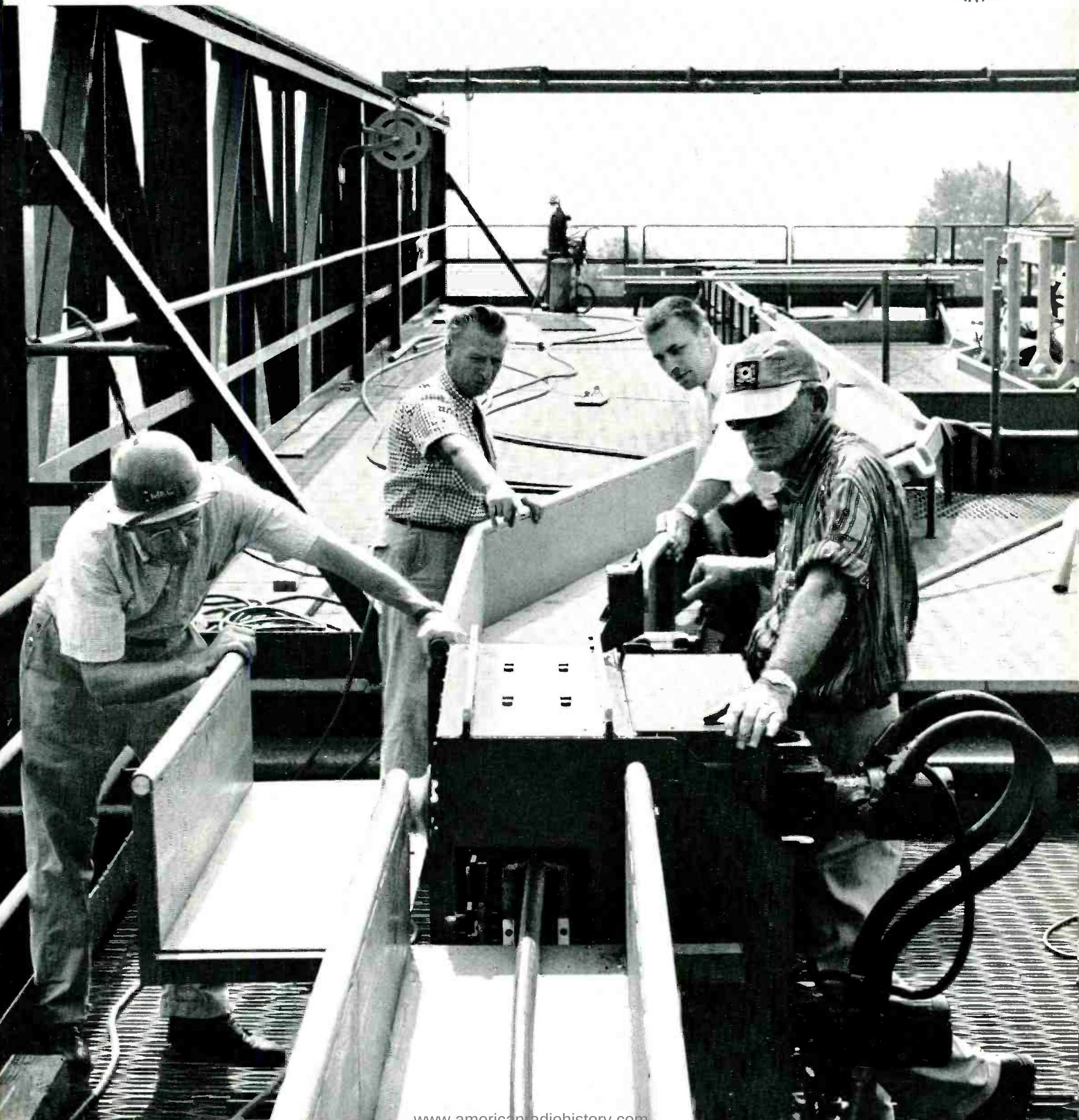
October 1959

Bell Laboratories RECORD

Communicating with Large-Scale Computers
Variable-Capacitance Amplifier
Flying-Spot Store for Electronic Switching
No. 4 CAMA and the "Bylink" Circuit
An RF Power Transistor



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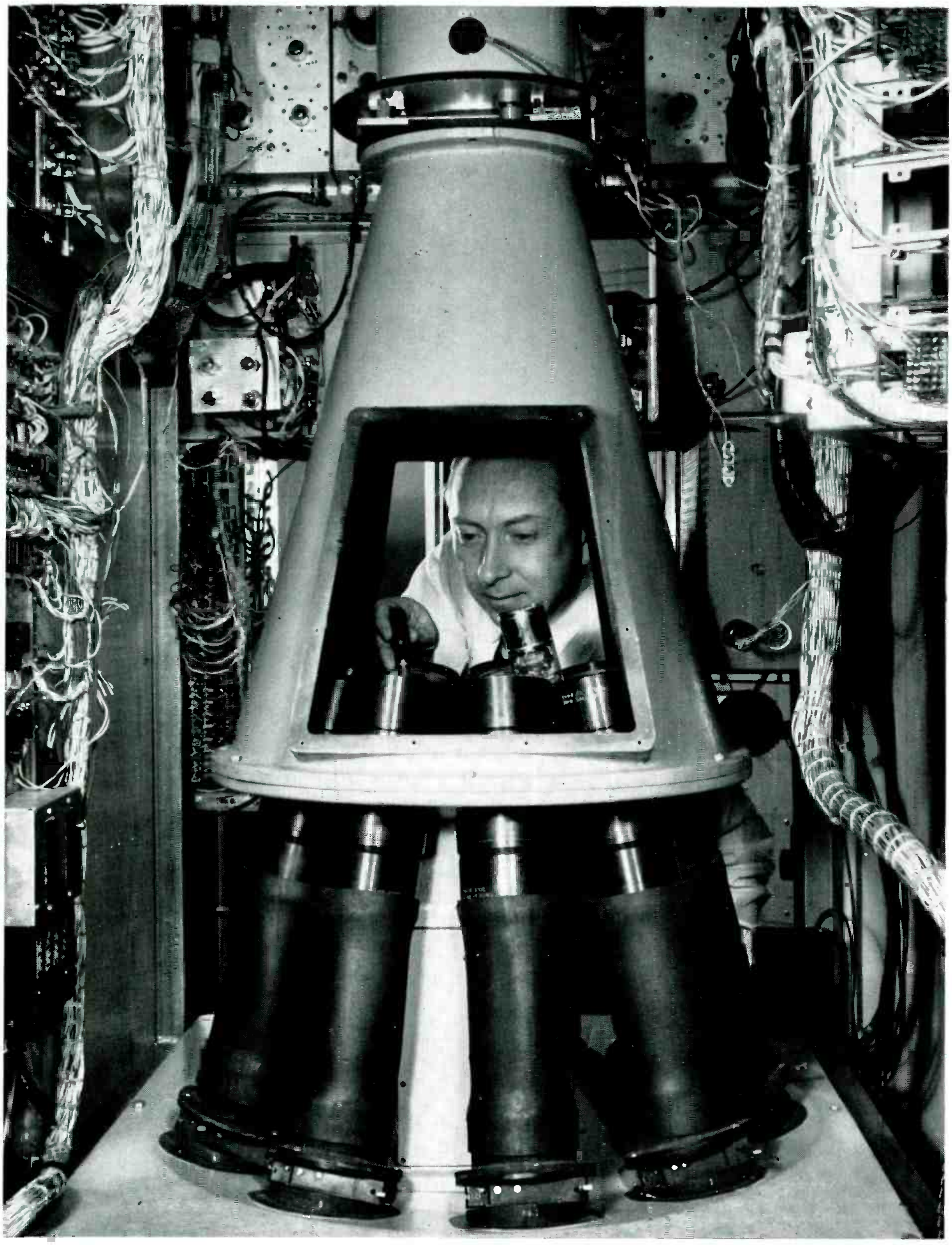
Cover

On "deck" of cableship model erected at Chester, New Jersey, M. E. Campbell, T. C. Barlow, K. R. Bierma and C. H. Chase watch transporter retrieve cable from "overboard" (see p. 399).



J. J. Madden makes adjustments on the laboratory model of an early flying-spot store. With cover plates removed, some of the lenses which form nine channels can be seen. Cathode-ray tube is at top.

Telephone switching requires ready access to large amounts of control and translation information. To store this information in the electronic switching system, Bell Laboratories has developed the "flying-spot store"— a digital information-storage system based on electro-optical principles.

C. W. Hoover, Jr.

An Experimental Flying-Spot Store For Electronic Switching

A number of new electronic storage devices and memory systems have evolved over the past ten years. These electronic memory systems generally have the special attributes of small size and high speed. On the basis of the progress made recently on such systems, it appeared likely that electronic memory elements suitable for use in telephone switching could be developed. This was one of the important factors which led to the development of an experimental electronic switching system (ESS) at the Laboratories (RECORD, *October*, 1958).

In general, switching systems require two kinds of memory to control the operations required in establishing and taking down telephone connections. First, they must have a small, *temporary* memory for storing momentarily useful information like the number of the called telephone. In the experimental ESS, an electronic device called a "barrier-grid store" (RECORD, *June*, 1956) furnishes this temporary memory. The switching system must also have a large *semi-permanent* memory for storing its basic operational routine and number-translation information.

For electronic switching, the engineering studies that preceded its development indicated that an electro-optical system, now known as a "flying-spot store," would be a suitable device to perform certain semi-permanent memory functions. This article will be concerned with some of the fundamental concepts underlying the design of the flying-spot store for an early experimental model of the ESS.

The system plans for initial development called for using this memory system primarily for storing translation information. For instance, it would translate the directory numbers that customers use into "equipment" numbers, an arbitrary designation used by the switching machinery to speed and simplify the handling of calls. In most electromechanical systems, this translation is semi-permanently "wired-in."

As the development of ESS progressed, however, a basic change was made in the central control, and this decision seriously affected the basic design of the flying-spot store. Specifically, the central control was changed to a "stored" program system from a wired-program-type central control. The data required for this program, which in effect controls the entire operating procedure of the system, were to be stored permanently in the flying-spot memory.

Thus, the flying-spot memory system now stores two kinds of information: (1) the permanent program for the central control, and (2) the less permanent translation information. Storage of the central-control program in the flying-spot memory put an additional, and at the time, stringent premium on both speed of operation (accessibility) and capacity.

These, then, are the general functions and requirements of the flying-spot store in the experimental ESS. A logical place to start the story of its design is with a fundamental understanding of a basic, single-channel photographic storage system.

The essential features of such a system are shown in the diagram on this page. Information, coded in the form of very small opaque and transparent areas, is stored on developed photographic film. A transparent area may be thought of as a binary "1" and an opaque area as a binary "0." Thus, each area represents a single binary "bit" of information. Data coded in this way are read from the film by a light beam generated by a movable spot on the screen of the cathode-ray tube. The light beam from the spot on the screen is focused in the film plane by the objective lens. Light in this focused beam, passing through the film plane, is converted into an electron current in the photo-cathode of the photo-multiplier tube. This current is amplified and appears as output current from the photomultiplier.

When the light beam is blocked by an opaque area on the film, no current flows in the output circuit of the tube — a binary "0." Light passing through a transparent area on the film plane results in an output current — a binary "1." The position of the focused beam of light on the film plane depends on the position to which the spot is moved on the cathode-ray tube screen. In turn, the desired position of the spot is controlled by the voltages applied to the deflection plates of the cathode-ray tube. In other words, the film plane stores the information in proper binary form; and the photomultiplier converts the light signals representing 1's and 0's to electrical signals and transmits the information to the system in a form it can use.

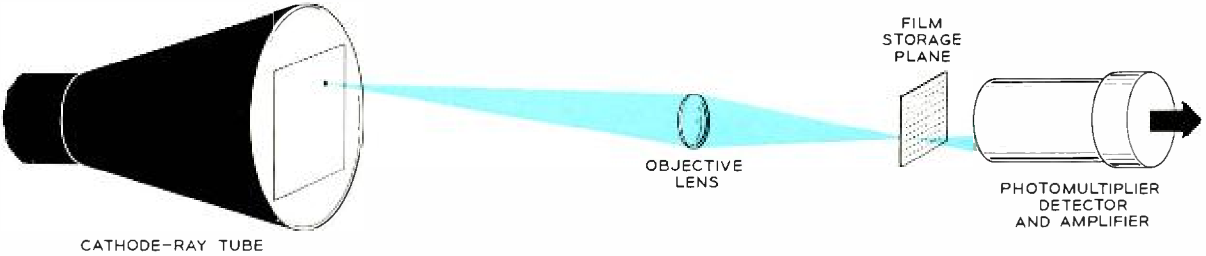
In a simple, single-channel storage system of this kind, the capacity of the memory depends on two factors: (1) the size of a spot on the cathode-ray tube screen that represents an individual bit of stored information, and (2) the size of the working area of the cathode-ray tube screen. For example, if the effective spot diameter is 0.020 inches on a cathode-ray tube with a working area 5 by 5 inches, each row and column of the array may contain 250 non-overlapping spots (5/0.020), and can therefore store 250 bits. Total storage capacity of such a single-channel system would be 250^2, or 62,500 bits.

Drawbacks of Single Channel System

This is a relatively large number and would seem to be a considerable amount of stored information. However, a small telephone switching system may require from 500,000 to one million bits for translation information alone.

To store this much information in a single-channel system would require an array of from 700-by-700 to 1,000-by-1,000 spots on the screen of the tube. No cathode-ray tube meeting this resolution requirement was immediately available. Two other important requirements for the design of a high-capacity, single-channel memory also indicated that such a system was not feasible.

The first of these requirements was beam positioning. Briefly, this was a problem of tolerances.

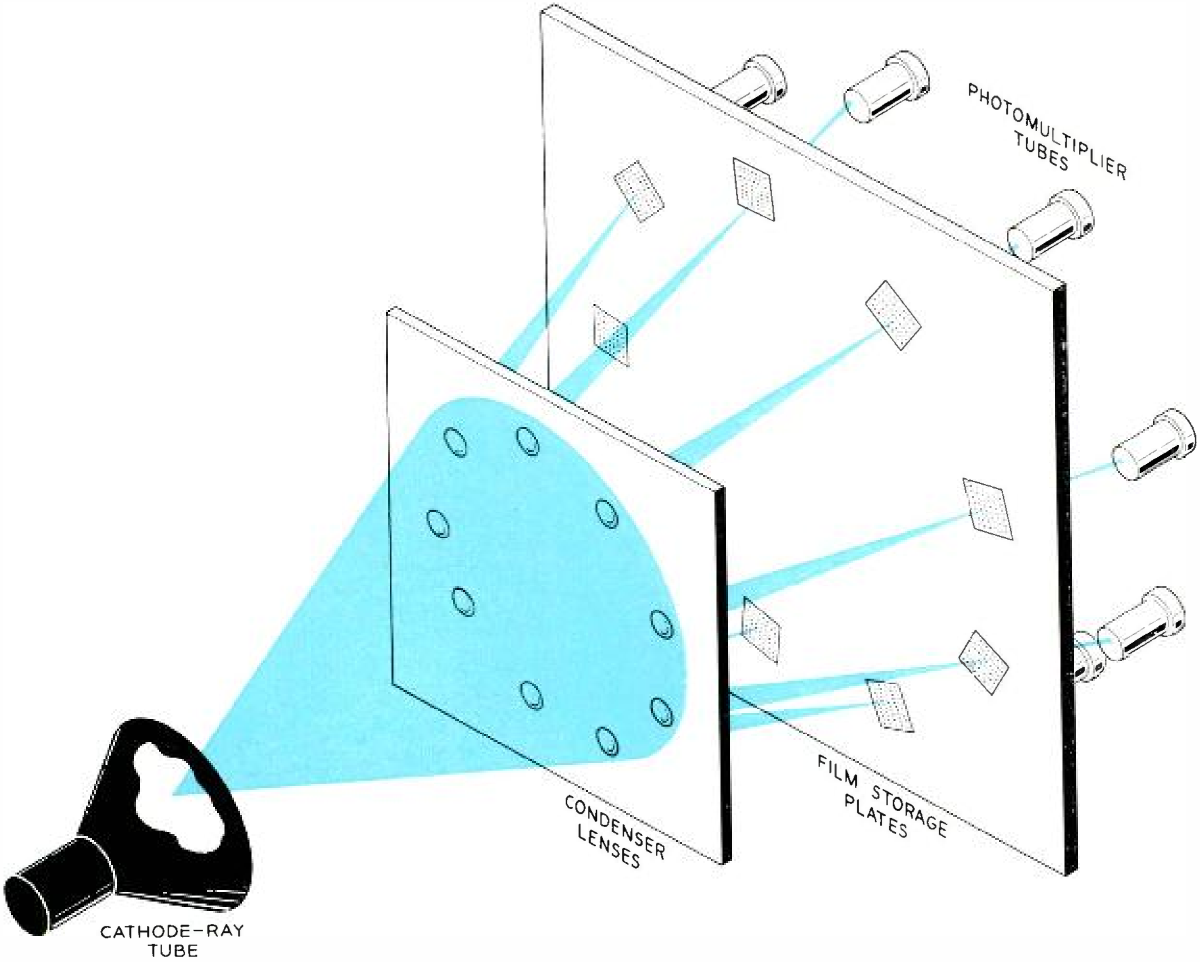


The basic single-channel storage system. Spot for reading out stored information can appear at any position in the spot array, which is the square area sketched on the face of the cathode-ray tube.

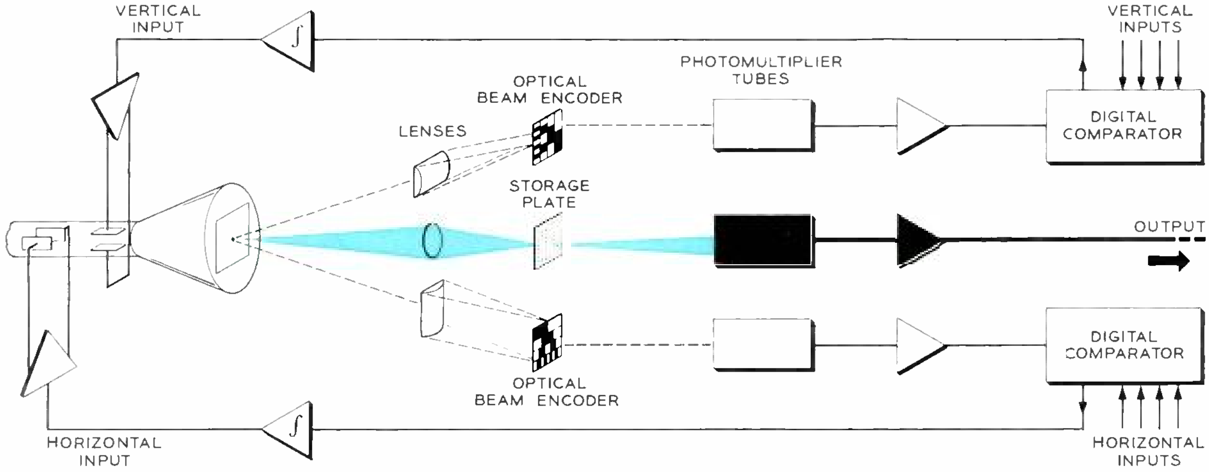
The heart of the problem lies in the fact that the reading beam from the cathode-ray tube must be very accurately positioned at or very near the center of the storage spot. If the beam strays even slightly from this position, ambiguous information may be read out. The design goal in this respect was to position the reading beam in the center of the spot to be read within one-tenth (plus or minus) of the spot diameter. To achieve this accuracy at each spot in a 1,000-by-1,000 array, the beam-positioning system would have to be accurate to 0.01 per cent.

In somewhat more tangible terms, accuracy of this order meant that the accelerating voltage for the electron beam would have to be regulated to 0.01 per cent, since deflection factor is linearly proportional to this voltage. In fact, the accelerating-voltage tolerance would have to be still smaller, since it would be necessary to accommodate some departures from perfection in all of the other elements of the beam-positioning system. Thus, the high-capacity, single-channel system imposed tolerance requirements on the components and operation of the system that would be very difficult to obtain and to maintain.

The second factor which forced a radical modification of the originally proposed single-channel system was the requirement for high-speed operation. In the ESS application, this requirement had two facets. As with most digital systems, stored information from the flying-spot memory is used in the form of "words" of several bits each — typically, 19 to 25 bits. But in a single-channel system, data can be read out only one bit at a time. Also, when the program information for the central control was added to the data already stored in the flying-spot store, the frequency of reference to this memory was increased by a factor of several hundred. An additional premium on speed is imposed on the central con-



Arrangement of lenses, storage-plates and photodetectors in the multi-channel system. The light, or absence of light, from an area on each storage plate produces one bit of a multi-bit order word.



A very simplified sketch of the servo system for beam-positioning. Heavy lines show an information channel similar to one in first sketch. The elements of the servo system are above and below.

trol during the "busy hour," because it must keep up with traffic in all instances.

The solution of these two problems — beam-positioning accuracy and speed of operation — resulted in the present form of the flying-spot store. The problem of accuracy in beam positioning was solved by the development of a beam-positioning system based on the feedback principle. The problem of operating speed, and the collateral problems of high capacity and resolution requirements for the cathode-ray tube and the optical system, were solved by the introduction of a number of parallel optical channels that are read out simultaneously. This arrangement also ultimately reduced the requirements on beam-positioning accuracy, since the required total capacity could be achieved with fewer spots on the screen of the cathode-ray tube.

The parallel-channel optical arrangement determined to some extent the type of feedback system developed for beam positioning, so it is logical to discuss the multi-channel concept first. The parallel-channel arrangement used to increase storage capacity is shown on the previous page. As the sketch shows, this early system has nine optical channels, arranged around the surface of a cone projected from the center of the cathode-ray tube. The objective lens in each channel focuses on its associated film plane an image of the bright spot on the screen of the cathode-ray tube. Each channel has a photomultiplier tube for read-out, so that a single beam-positioning operation in the cathode-ray tube results in the readout of nine bits in parallel, rather than only one as in the single-channel system.

In the experimental electronic switching system in which this version of the flying-spot store (Model I) was used, most words were made up of 18 bits. Two beam-positioning operations, then, were required to read out an entire word, as opposed to 18 in a single-channel system.

This is of course a great increase in speed as well as in storage capacity. Actually, the capacity of the multiple-channel system is the product of the number of channels by the number of bits stored in each channel. The number of bits per channel is restricted only by the number of spots in the spot-array on the face of the tube.

How Capacity Was Increased

Increasing the storage capacity by adding channels, therefore, does not require more stringent resolution requirements for the cathode-ray tube or the optical system. Also, the requirements on the accuracy of the beam-positioning system for the cathode-ray tube can be reduced in proportion to any reduction in the number of spots in each row of the array.

Historically, the multiple-channel concept was devised to ease the requirements on cathode-ray tube resolution and to increase storage capacity prior to adoption of the stored-program mode of operation. The increased requirements on both speed and capacity imposed by the stored-program concept then made it imperative that the parallel-channel arrangement be adopted and improved.

At the start of the development of the flying-spot store, measurements were made of (1) the total flux (light) available from a spot on the face of the cathode-ray tube of the size determined by the per-channel capacity, and (2) of the flux required by signal-to-noise and sampling time considerations at the photocathode of the photomultiplier. These measurements showed that each lens was required to pick up only a very small fraction of the light from the spot to provide a sufficiently high level of flux at the photocathode, even in the case where the maximum light level was required. Maximum light would be required for the minimum sampling time — 0.1 microsecond.

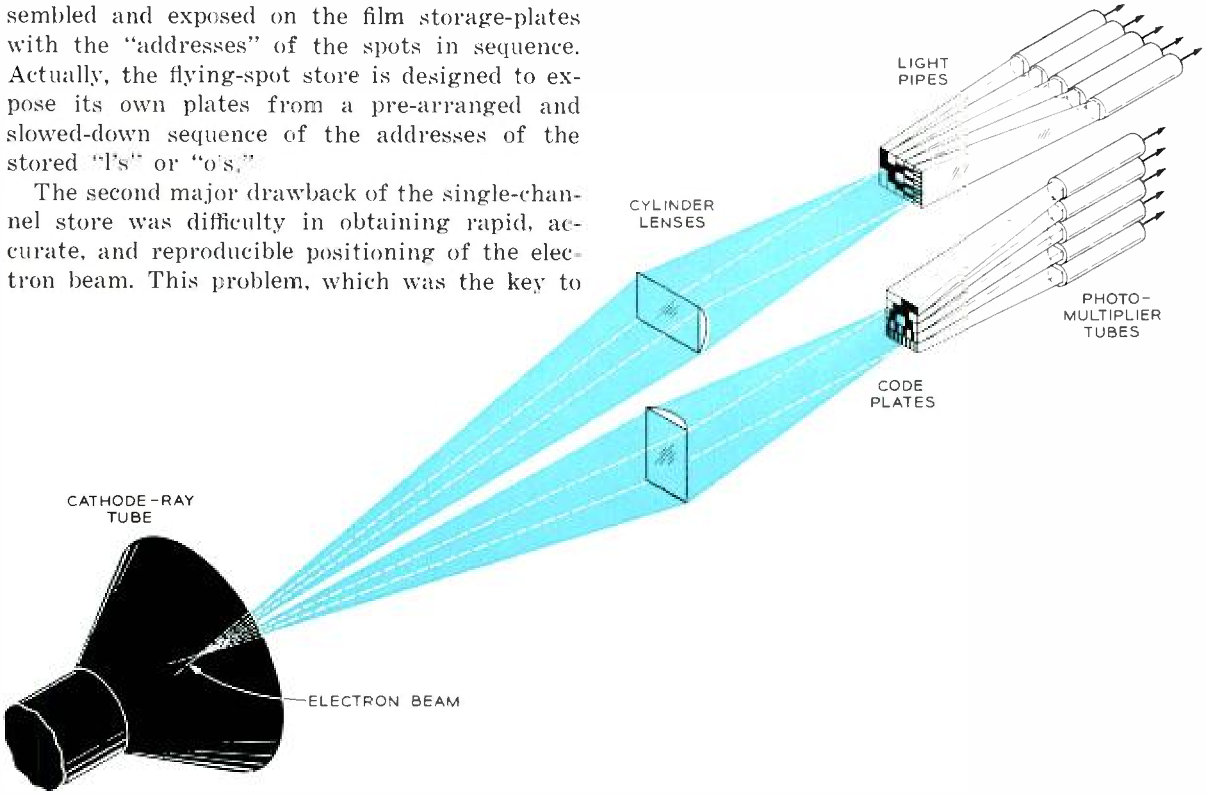
Translated into optical requirements, this means that lenses of high *f* number, or low light-gathering power, operated at a magnification of less than unity, will suffice as objective lenses. This basic condition makes the multi-channel system very attractive, since it permits great flexibility in such factors as number of channels and other system arrangements.

In the multiple-channel system, one or more bits of each word (either program or translation) are stored on each of the nine photographic plates. Later versions of the flying-spot store have arrays of up to 50 storage plates. Although Model I has two bits of each word located adjacently on each plate, it is usually possible to make the number of channels equal the number of bits in a word so that a single beam-positioning operation reads out the entire word in parallel. For this reason, the information to be written into the store is assembled and exposed on the film storage-plates with the "addresses" of the spots in sequence. Actually, the flying-spot store is designed to expose its own plates from a pre-arranged and slowed-down sequence of the addresses of the stored "1's" or "0's."

The second major drawback of the single-channel store was difficulty in obtaining rapid, accurate, and reproducible positioning of the electron beam. This problem, which was the key to the feasibility of a flying-spot memory system, was overcome by designing a beam-positioning system which uses the feedback principle. This feedback, or "beam servo," system provides extreme accuracy in beam positioning and long-term positional stability. The feedback system performs these two important functions by locking an image of the beam to a pair of reference edges at each position in the spot array. To do this, beam position is sensed optically and the actual, or existing, position of the beam and the required position are compared. An "error" signal is generated by this comparison. The error signal is then used to drive the beam of the cathode-ray tube to the desired position.

The feedback arrangement used in the flying-spot store is shown in very simplified form in the diagram on the opposite page. A basic memory channel is shown in heavy lines and the feedback arrangement is shown in lighter lines. In this system, two important elements have been added to generate the necessary error signal.

The first of these is an optical beam encoder which provides information on the beam position at all times. The optical beam encoder consists of two identical sections, one of which provides the X axis (horizontal) beam position and the other



Details of the beam-positioning encoding system. Cylinder lenses form a line image rather than an image of the spot. This line image then moves across the code plate, indicating the spot position.

other furnishes Y axis (vertical) beam position. They operate independently and the basic mode of operation can be understood by considering either.

As shown in the sketch on the previous page, the cylinder lens in the Y axis, or vertical-position section of the encoder, forms a horizontal line image of the spot on the cathode-ray tube screen in the plane of the code plate. Now consider what happens with motion of the spot. As the spot moves horizontally, the line image moves left to right on the code plate at constant height, and the areas of the code plate illuminated by this image are therefore unchanged, provided the line image is long enough to cover all the columns in all horizontal positions used.

As the spot moves vertically, the line image is scanned vertically along the code plate. Vertical beam position is obtained by observing the pattern of light signals transmitted through the columns of the code plate. Thus, the signal from the first column on the left indicates whether the beam is in the upper half (light transmitted) or lower half (no light transmitted) of the screen. The signal in the second column then tells whether the beam is in the upper or lower half of the side of the screen indicated by the left-hand column. That is, the second column locates the spot in a horizontal quarter section of the screen. In a similar manner, the other, smaller columns add information until the beam position is defined to the desired accuracy. Thus, six columns give 2^6, or 64, discrete beam positions, and seven can define 128 positions.

A lucite light pipe behind each column of the position code plate conducts light signals passing through the column to a photomultiplier which converts these light signals to electrical signals. The light pipes are used because of the convenience they afford in optical and mechanical arrangements. The horizontal beam-position encoder is rotated 90° around a horizontal axis relative to the vertical beam-position encoder.

The second important element added to the basic system to generate the error signal is the digital comparator. Again, two identical units are used and operate independently. The Y axis comparator compares the existing beam position obtained from the vertical section of the optical beam encoder with the required vertical position presented at the input and generates a signal of proper polarity and amplitude to drive the beam to the address positions required.

Briefly, the over-all feedback system works like this. Beam-positioning signals, both horizontal and vertical, are sent to the deflection plates of the cathode-ray tube through the comparators and the integrating and deflection amplifiers. As the beam moves toward the required position, the encoders generate present-position signals that go to the comparators. Here, the required-position and actual-position signals are compared and the resulting error signal is then used to move the spot to the required position. In actual operation, this sequence takes a fraction of a microsecond to reach an adjacent spot and up to 20 microseconds to reach any remote point in the array. Physically, the optical beam encoder system is located in the center of the cone formed by the nine output channels. The entire flying-spot memory system is arranged vertically in a single equipment cabinet, as shown in the photograph on page 366.

In addition to greatly increased accuracy in beam positioning, the servo system makes the flying-spot store quite impervious to the effects of vibration and extraneous electrical noise. This is because the encoders and the storage plates are located in the same plane, and the feedback loop between them can compensate for relative movement between cathode-ray tube and storage plane.

Use in Very Early System

A flying-spot memory system that embodies these basic principles was tested operationally in an experimental switching system for some time, and has demonstrated that it has the speed of operation required in a full-sized central office. The laboratory model of the switching system served only a few lines so only 35,721 bits of stored data (an array of 63 by 63 spots) were required. Many specific design problems, not discussed in detail here, were important to the over-all development of the Model I storage system and to the formulation of fundamental design concepts.

In its present state of development, the flying-spot store appears to be an excellent system for storing large quantities of data semi-permanently. It also shows promise of having a wide variety of designs applicable to many different memory situations.

Because only a fraction of the total equipment is used for each information channel, the flying-spot store is essentially a large-capacity device. Only a few additional components and a very small increase in power are required to add extra channels, since most of the equipment is associated with the beam-positioning operation. This very economical memory system appears to have both the speed and the capacity needed for the stored program and for storing the directory-to-equipment-number translations in future electronic systems for telephone switching.

The versatile semiconductor diode has recently found exciting new uses as an amplifier. Because of its low-noise properties, it should soon be extensively applied in the communications industry.

E. D. Reed

The Variable-Capacitance Parametric Amplifier

Low-noise amplification at microwave frequencies has for many years been the undisputed prerogative of vacuum-tube amplifiers. This prerogative has not been seriously challenged by the transistor, although great strides have been made in extending its operations to ever higher frequencies. Within the last two years, however, we have witnessed solid-state art entering the field of microwave low-noise amplification and becoming firmly entrenched in it. Of the three solid-state entries — the maser (RECORD, *July*, 1958), the variable-capacitance amplifier and the variable-inductance amplifier — the first two have already yielded results which make their early application in practical systems an exciting reality.

The present intensive technical activity and widespread interest in this new field are readily understandable, since lowered noise in amplification leads to important improvements and economies in communication systems. The smaller the noise contribution of the amplifier, the smaller will be the degradation of signal-to-noise ratio as both signal and noise pass through the amplifier. Thus, weaker incoming signals can be amplified and receiver sensitivity is increased. Increased sensitivity, in turn, can be used to advantage in many ways. It can result in a longer distance between repeaters, for example, or an increased total route distance of a radio-relay system. Increased sensitivity is vital to the success of various satellite communication schemes now being considered. It is also of great benefit to the radio astronomer. In the military field, increased receiver sensitivity leads to improved radar performance. In cases where transmitting power has been pushed to the limit of present technology, an increase in receiver sensitivity is the only means available for further extending the range of radar systems.

In the race for lower and lower noise, we presently find the maser far in the lead, since the noise associated with its basic amplifying mechanism is negligibly small. Many applications, however, do not require and cannot benefit from this ultimate in noise performance. For these applications, the variable-capacitance "parametric" amplifier offers the advantage of simplicity. Its noise performance lies somewhere between that of vacuum tubes and masers yet, in contrast to masers, neither refrigeration nor a magnetic field are required. If we are willing to introduce a moderate amount of refrigeration, that is, refrigeration to liquid nitrogen temperature, further improvements in noise performance can be obtained.

This paper will deal primarily with the variable-capacitance amplifier. Of the various types of parametric amplifiers presently under investigation, this amplifier, using the variable-capacitance effect in semiconductor diodes, has clearly emerged as the most attractive. Because it gave rise to such promising noise performance within only a short time of its conception at Bell Laboratories, it immediately aroused widespread interest and attention. *Electronic News* of November 10, 1958, for instance, listed some three dozen laboratories in this country engaged in various phases of work on variable-capacitance amplifiers. This effort will undoubtedly result in important system applications in the near future.

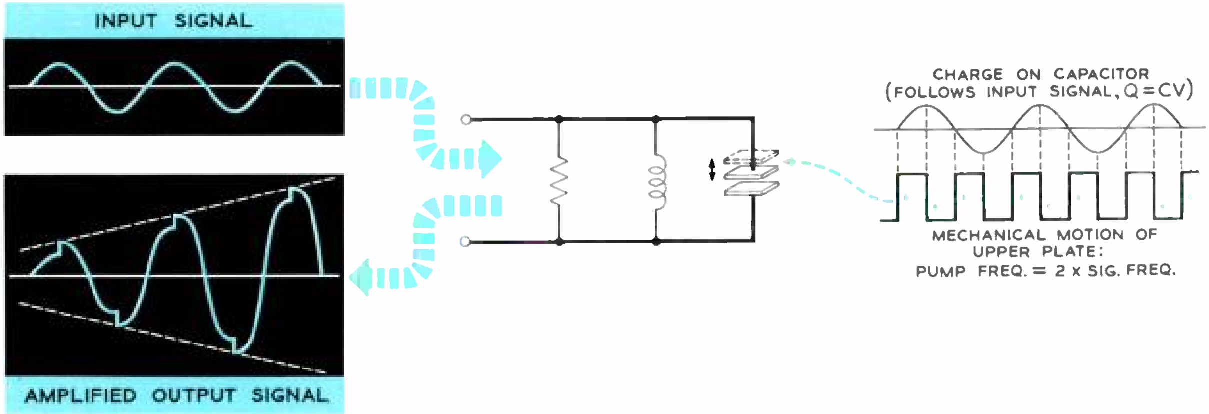
Parametric amplification using ferrites as variable-inductance elements has been demonstrated too, but noise figures have not been reported as yet. Work is also in progress on vacuum-tube parametric amplifiers. Using the variable reactance generated by a modulated electron beam, R. Adler of Zenith has been successful in obtaining low-noise amplification in the UHF band.

There are two basic types of variable-capacitance amplifiers: the negative-resistance amplifier and the up-conversion amplifier. Both types were first demonstrated at Bell Laboratories, by M. E. Hines and A. Uhlir respectively (RECORD, *October*, 1957). Uhlir, with Signal Corps support, also developed semiconductor junction diodes optimized for operation as low-loss, variable-capacitance elements. The two types of amplifiers have in common the use of a variable-capacitance diode as the active element and a high frequency ("pump") signal as the principal energy source. They differ, though, in their mode of operation, in the applicable frequency range, and in several other respects to be explained later.

Negative-Resistance Parametric Amplifier

Let us first examine the physical principles involved in the operation of the negative-resistance amplifier. Suppose we have at our disposal a simple resonant circuit (*See drawing on this page*). This circuit is unconventional only in that one of the plates of the capacitor is movable. It is clear that a small sinusoidal signal voltage of frequency *s* (*top left in drawing*), applied to the terminals of this circuit, would cause the charge on the capacitor to vary sinusoidally also. The reason is that the charge on the capacitor equals the capacitance times voltage ($Q = CV$). Next, imagine that the upper capacitor plate is pulled upward a small amount whenever the charge is at a maximum, regardless of polarity. This maximum, of course, occurs twice every cycle. The plate is returned to its original position whenever the charge is zero — again twice every cycle.

In other words, we are performing, with the upper capacitor plate, a square-wave "pumping" motion at twice the frequency of the applied signal. The phase relationship has been so chosen that the capacitance is always decreased during that part of the cycle which finds the charge



Mechanical analogy to variable-capacitance amplification: top plate of capacitor is "pumped" up and down at twice the signal frequency; capacitance is decreased when voltage increases.

relatively constant. But for constant charge, the Q = CV relation states that the voltage across the capacitor is inversely proportional to the capacitance. Hence, whenever we decrease the capacitance, we increase the voltage and obtain gain. This "pumping-up" of the signal voltage is shown as an amplified output signal at the bottom left in the drawing.

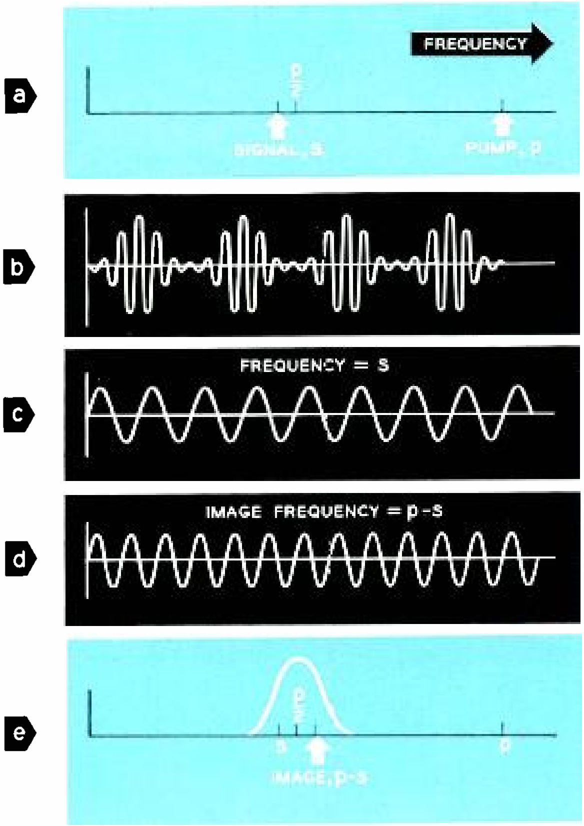
Another way to look at this amplification process is to note that we always have to do work *on* the circuit whenever we separate the plates in the charged condition, since we have to overcome the attractive force between the opposite charges on the capacitor plates. No work is expended, however, in restoring the original plate-separation, since this occurs whenever the charge on the capacitor plates, and hence the attraction between them, is zero. The energy transferred from the external pump *(not shown in sketch)* to the circuit provides the signal gain and internal amplifier losses.

Why do we call this type of gain "negative-resistance" gain? Because, like a resistor, this type of parametric amplifier is a two-terminal or single-port device. In the case of the familiar *positive* resistance, the power reflected is always less than the incident power. Conversely, we speak of a *negative* resistance if the reflected power exceeds the incident.

A well-known example of this kind of amplification is a child pumping-up the excursions of a swing. Twice during each complete cycle—that is, at both extremes of the swing — the child will raise his center of gravity and lower it during both downward phases of the swing. Another example is the well known "button-on-a-loop."

Let us now turn to a practical high-frequency amplifier. Here, of course, our capacitance is varied electronically and the capacitance itself is not a parallel-plate capacitor, but rather a special kind of semiconductor diode — one in which the terminal capacitance varies with the applied voltage. We shall describe this diode later. Depending on the operating frequency, the environment of this diode may either be coaxial or stripline circuitry or, in the microwave range, a waveguide cavity.

Another important difference between the idealized analogue treated earlier and a practical situation pertains to the pump and signal frequencies. We saw that for maximum energy transfer from pump to circuit, the signal frequency must precisely equal half the pump frequency and must bear a definite and fixed phase relation to the pump. This frequency and phase relation is very difficult, if not impossible, to maintain, since the incoming signal ordinarily varies in both frequency and phase in a way which is beyond the control of the receiver. If, however, we are willing to settle for something less than maximum energy transfer, such exact control is not required. In part (a) of the above drawing the frequency of an incoming signal is marked *s* and the frequency of the pump is marked *p*. As shown, *s* is somewhat less than half the pump frequency, *p/2*. As a result of this frequency difference, the signal and pump will no longer interact favorably all the time, but rather will drift periodically into and out of the condition for favorable interaction. Hence, the amplified signal emerging from the amplifier will be modulated as shown in part (b). Separated into its component sinewaves, this modulated signal is the sum of two uniform signals, (c) and (d) — one at the signal frequency, *s*, and the other at the frequency *p-s*. In (e) we have repeated the frequency scale but have added the new fre-



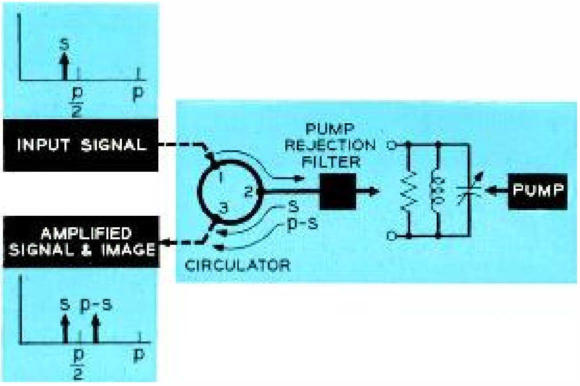
A signal that is displaced from half the pump frequency (a) results in a modulated output (b), composed of components (c) and (d). The image frequency is symmetrical around p/2 (e).

quency, *p-s*. We note that *p-s* is as far above *p/2* as *s* is below. Because of this symmetry, *p-s* is called the "image" of the signal.

The generation of this third frequency is a very important characteristic of the negative-resistance amplifier: by introducing a signal which differs in frequency from half the pump frequency, we get back not only an amplified signal at the signal frequency but an equally strong signal at *p-s*. Two important facts to bear in mind with this image signal — or as some call it, the "idler" — are these: First the image signal is an inevitable by-product of this type of amplification. Suppressing it would also suppress the desired amplification of the signal. Second, the closer the signal is to half the pump, the closer the image will be to the signal, and the more difficult it will eventually become to separate signal and image by filtering. Consequently, the amplifier must have enough bandwidth to encompass both the signal and its image.

In contrast to conventional amplifiers, this type of variable-capacitance amplifier must have twice the bandwidth occupied by the signal. It therefore accepts and amplifies twice the normal input noise. All the more surprising that, in spite of this handicap, the over-all noise performance of the variable-capacitance amplifier is still better in some cases than the best we can do with vacuum tubes. This is primarily due to the small amount of noise contributed by the semiconductor diode.

The reader may justly wonder at this point how the various signals we have encountered so far — namely the input signal, the amplified output signal, the image and the pump—are unscrambled and put to use. One neat method makes use of another solid-state element, the ferrite circulator (RECORD, *August*, 1957), illustrated in the drawing on this page. The signal to be amplified is introduced at terminal 1, and by the circulator action is guided to terminal 2. Here, it enters the parametric amplifier, is amplified and re-emerges at terminal 2, together with its image. Again, by the circulator action, these two signals are guided to terminal 3, which thereby becomes the effective output terminal. Prior to detection, the two signals are separated in a suitable filter network. The pump signal is confined to the variable-capacitance diode and is prevented from leaking into the output by means of a sharp pump-rejection filter placed between the parametric amplifier and terminal 2 of the circulator.



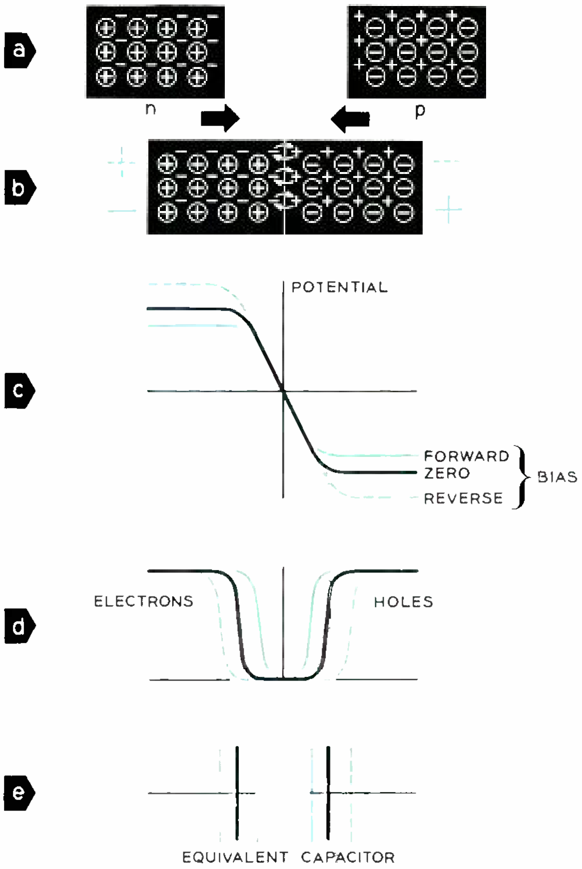
Three-terminal circulator: signal is introduced at 1 and enters amplifier through 2; the amplified signal, together with its image, returns through terminal 2, and the output appears at terminal 3.

Variable-Capacitance Effect in Semiconductor Diodes

Until now we have assumed, without explanation, the existence of an electronically variable capacitance. Since this really is the heart of the parametric amplifier, an explanation will next be given of the variable — capacitance effect in semiconductor diodes (RECORD, *May*, 1955). At the top of the drawing on page 377 we see two sections of semiconductor material. In the n-type section on the left, the circled plus signs represent fixed positive charges due to donor impurities, and the minus signs represent mobile negative charge-carriers or electrons. In the p-type section, the circled minus signs represent fixed negative charges due to acceptor impurities, and the plus signs represent mobile positive charge-carriers or holes. By themselves both slabs are electrically neutral—that is, in the n-type material the fixed positive charges are neutralized by precisely the same number of electrons, and similarly in the p-type material the fixed negative charges are exactly neutralized by the same number of holes.

Let us now go through the fictitious process of forming a p-n junction by bringing the two slabs into contact, as in part (b) of the drawing, and observe in slow motion the events leading to the establishment of equilibrium.

With the p and n section in contact, electrons will diffuse from a region of high to one of low electron density — that is, from left to right. Similarly, holes will diffuse across the junction from right to left. As this diffusion proceeds, the loss of electrons will render the previously neutral n-type section increasingly positive.



At a p-n junction, the region swept free of charge carriers can be varied by changing bias voltage. This action is electrically equivalent to changing the spacing between the plates of a capacitor.

Also, the diffusion of holes from the right to left will render the p-type section increasingly negative. The resulting potential difference between the two halves will set up an electric field at the interface, as shown by the black curve in part (c). This field is so directed as to oppose and finally bring to a halt the diffusion of electrons and holes across the junction. In addition, the field will sweep clear of electrons and holes a narrow region about the interface, thus giving rise to the equilibrium distribution of electrons and holes shown by the black curve of (d). The central layer — also called the *depletion layer* because it is devoid of mobile charge carriers — may be thought of as a nonconducting or dielectric region. Since it is bounded on both sides by regions containing mobile charge-carriers — that is, conducting regions — we may compare the diode to a parallel-plate capacitor with a plate separation equal to the width of the depletion layer.

Suppose next that the junction is given a slight reverse bias — a bias so directed as to increase the potential difference between left and right — the dashed tan curve in (c). The positive potential applied to the n-side will then urge the electron distribution toward the left, and the negative potential applied to the p-side will urge the hole distribution to the right. This will cause a widening of the depletion layer and a decrease in terminal capacitance. Similarly, a forward bias (solid blue curve) will urge the electron and hole distributions toward each other, the depletion layer will shrink, and the capacitance will increase. Thus we have here a capacitor, the terminal capacitance of which will vary with the applied voltage.

It is very important to note that this variation in capacitance results from a very minute motion of electron and hole distributions, and that an actual flow of these charge carriers across the junction is not involved. These are the principal reasons why both the high-frequency and low-noise performance of the variable — capacitance diode are superior to that of the transistor. In fact, the motion of charge carrier distributions under the influence of the applied voltage is so minute — only a few millionths of an inch — that transit-time effects are completely negligible. These, of course, constitute basic limitations in the high-frequency response of transistors and many other electron devices. What does limit the high-frequency performance of the diode is an inevitable fixed capacitance, which appears in shunt with the useful variable capacitance. This fixed capacitance depends on the contact area of the diode, the width of the depletion layer, the type of encapsulation, and the applied bias. Together with the series resistance of the diode, it determines the upper frequency limit for amplification. At present, this limit lies in the 30-60 kmc range for silicon p-n junction diodes of good quality.

The series resistance of the diode, the value of which depends primarily on the composition and geometry of the bulk of the semiconductor material, is the principal source of internal noise in the parametric amplifier. Recent experiments at the laboratories by Uenohara have shown that this noise can be considerably reduced by refrigeration of the diode to liquid nitrogen temperature.

An experimental amplifier combining these ideas and principles was built by M. Uenohara

M. Uenohara inspecting diode waveguide apparatus used in work on parametic amplication.

of the Laboratories (RECORD, *July*, 1958). As illustrated in the drawing on page 379, it uses a variable-capacitance diode in a simple waveguide cavity. For this amplifier, Uenohara specifies a useful signal band (thickened portion of response curve) 4 mc wide with a midband gain of 20 db. For the reasons given earlier, this signal band is well separated from half the pump frequency.

How about its noise performance or sensitivity? Because of the presence of the image band, there is no one number which fully describes the noise behavior of this amplifier. Rather, we must know whether the signal is coherent, as in communications, or noise, as in radio astronomy. Also we must have information on the source temperature. For instance, when a coherent signal originating from a room-temperature source is introduced in the signal band only, Uenohara's amplifier will exhibit sensitivity equal to that of traveling-wave tube having a 5 db noise figure. However, when this same amplifier receives signals from the *cold* sky, such as from satellites, it will exhibit noise performance equal to a traveling-wave tube having a noise figure of 3.7 db. In still another case, when the signal itself is noise, as in radio astronomy, the same amplifier will have the sensitivity of a 2 db traveling-wave tube. Here, the "signal" may be introduced in both the signal and the image band, so that the effective bandwidth is now equal to the signal band, and not twice this band as in single-sideband reception.

By placing the diode in a resonant cavity, it is apparent that we can extract the highest gain per diode, but we are at the same time paying the penalty of a restricted bandwidth. This restriction can be eliminated by mounting the diode in a nonresonant environment. Gain per diode is thereby sacrificed, but over-all gain can be recovered by using large numbers of diodes in suitable arrays. These diodes then become part of a transmission line and interact with traveling signal and pump waves. R. Engelbrecht of the Laboratories has built such an "iterated" amplifier using 16 pairs of diodes in a modified coaxial line. This amplifier has a bandwidth of 200 mc at an operating frequency of 600 mc.

The Up-Conversion Amplifier

The second major type of parametric amplifier is the so-called "up-converter." It differs from the negative-resistance amplifier in these respects:

(1) The frequency involved here, in addition to the signal frequency, s, and the pump frequency, p, is the upper sideband, $p+s$. In contrast, the negative-resistance amplifier uses only the lower sideband, $p-s$.

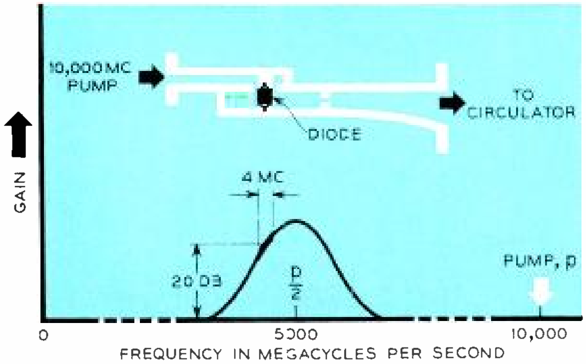
(2) In a well-known theorem, J. M. Manley and H. E. Rowe of the Laboratories have shown that gain in the up-converter is proportional to the frequency ratio $(p+s)/s$. Hence, to achieve reasonable gain, the pump frequency must be many times greater than the signal frequency, whereas a ratio of only two was required for the negative-resistance amplifier. This requirement for a large ratio of pump to signal frequency has restricted experimental up-converter work to signal frequencies in the UHF band.

(3) In the up-converter, the signal frequency is inevitably shifted in the amplification process, while in the negative-resistance amplifier the amplified signal may be used either at the original frequency or at the lower sideband frequency.

(4) The up-converter is a true two-port amplifier having unconditional stability, whereas the negative-resistance amplifier, being a single-port amplifier, requires a circulator for stable operation.

With up-converters, over-all system noise figures of less than 2 db have been achieved in the UHF band. Such amplifiers have been built at the Laboratories by Uhlir and at Airborne Instruments Laboratories.

The Manley-Rowe Theorem, incidentally, suggests still another type of parametric amplifier. It is a hybrid between the negative-resistance and the up-conversion types. In common with the former, it uses the lower sideband, $p - s$. In contrast to the negative-resistance amplifier, however, and in common with the up-converter, the pump frequency is chosen many times higher than s. The lower sideband signal at $(p - s)$ — now also much higher in frequency than the input signal — is the useful amplified output. This operation has the advantage of higher gain and better stability than the negative-resistance amplifier. UHF amplifiers of this type have been built at the Laboratories by H. Seidel and G. F. Herrmann and also by Workers at Federal Telecommunication Laboratories. The application of these low-noise amplifiers in scatter propagation systems should offer attractive economies.



Top: the structure of M. Uenohara's 5,000 mc variable-capacitance parametric amplifier. Response curve shows that the operating region, which is slightly off the center frequency of 5,000 mc, gives a 4 mc bandwidth with a gain of 20 db.

This review of variable-capacitance amplifiers has been restricted to a description of broad principles and a small number of representative experiments. The intense industry-wide attention these amplifiers have received testifies to their great potential. It is only a matter of time before they will be extensively introduced into the communications industry.

Ground Broken for New Building at Holmdel

Ground was broken at Holmdel, N. J., in August for the new Bell Laboratories building. Initial occupancy for about 1,500 employees will start late in 1961, although the plan provides for ultimate expansion to about 4,500 persons. The Western Electric Company will construct the building, expected to cost about $20,000,000, and will hold title to the Holmdel property, as it does to some other facilities used by the Bell Laboratories staff.

Noted architect Eero Saarinen has produced a new design in consultation with Western Electric Company and Bell Laboratories engineers. It is aimed at meeting the needs of modern electronics technology while providing improvements in comfort and in convenience of use by the occupants.

The design uses four identical sections, separated by courts, yet integrated into one rectangular building under a common roof and enclosed in a metal and glass facade. The low weight of the curtain wall achieves savings in the structural design and foundations and in its mobility at the time of any necessary additions to the initial development.

The over-all construction costs will be considerably less than reproducing conventional laboratory facilities to accommodate an equal number of employees. The compact design will also produce real savings in operation and maintenance costs.

Inside the building, laboratory and office facilities may be created and rearranged with flexibility since the interior "walls" will be movable partitions. The partitions can be arranged on six-foot module lines to allow up to 5,000 square feet of clear-span area without columns. Laboratory service facilities, including electrical, water, gas and exhaust systems, can be brought to any area of whatever size with comparative ease from service cores spaced about 45 feet apart throughout the building.

The interior offices and Laboratories face aisles perpendicular to the routing of major foot traffic around the walls of each section of the building. The result will be a minimum of traffic within work areas, yet with easy access to other offices and floors.

Adequate parking facilities are located immediately at each end of the building, and elliptical one-way traffic circles which girdle the building and parking areas will lead to four access roads.


Photograph taken in computation center at the Murray Hill, N. J., location of Bell Laboratories showing input-output arrangements of the IBM 704 computer. From the right: high-speed output printer with data sheet, card reader, and lighter colored tape units extending into the background.

Modern, large-scale digital computers must be programmed in a complex and esoteric machine language. In recent years, however mathematicians have simplified programming by developing methods for readily translating the everyday mathematics of science and engineering into computer language.

J. M. Manley

COMMUNICATING WITH LARGE-SCALE COMPUTERS

The computation speed and storage capacity of modern digital computers have increased considerably in the past few years. This increased speed and storage have made possible the solution of problems that are so long and tedious that they could not be tackled otherwise. Equally important, these changes have also made possible much simpler methods of using large-scale computers.

With these simplified methods, engineers and scientists can now outline their problems in a language very similar to the mathematics with which they are familiar, and let the computer translate this into a language it understands. This article will describe, from an engineer's viewpoint, these improved methods for using computers. It will not be concerned with the intricate inner workings of the machines themselves. The discussion will also point up the fact that an engineer or scientist need not be a computer expert and his problems need not be long and involved for him to take advantage, even occasionally, of the tremendous capacity for work of the modern computer.

In solving an engineering problem, computers use the same mathematical operations on the same numbers that the engineer uses. The important advantages of the computer are much greater speed and reliability, particularly in doing a sequence of calculations over and over. These are natural properties of any well-designed machine.

Hand vs. Machine Calculation

The large-scale computer, in addition to doing arithmetic, controls the arithmetic operations and stores numbers. So it is considerably more than a higher speed, larger capacity desk calculator. Computers are actually more like the combination of an engineer, his paper and pencil, and the desk calculator. They take over many of the tasks the engineer previously performed himself, either mentally or by using paper and pencil. To achieve its over-all speed, the computer performs its own control operations, and does these just as quickly as it does arithmetic operations.

Before we examine how computers do engineering problems, it might be well to describe briefly how the calculations would be done with paper and pencil and slide rule or desk calculator, and then relate this to the way a computer would do the same problem. Suppose, for example, you want to calculate the resistance of a parallel tuned circuit, the coil of which has series resistance R. You would first reduce your problem to this mathematical form:

$$Z_r = \frac{R}{R^2 C^2 \omega^2 + (\omega^2 LC\text{-}1)^2} .$$

To organize your calculations, you might lay out rows and columns on a data sheet as shown in the sketch at the top of page 384. Then you would multiply C by ω_1, ω_2, ω_3, and so on, and copy the results in the appropriate spots in the ωC column. Each of these intermediate results would then be multiplied by R and put into the RCω column. Next, you would square each of the RCω values and copy it into its appropriate rectangle. Thus, you would gradually fill in all of the rectangles, one at a time, until the final column of answers, Z_r, was complete.

In doing this same calculation, a computer would of course have to be directed. First, after being instructed to multiply C by ω, it must be told to store the result, just as you copied the product Cω into the proper square of the data paper. Second, it must be instructed to go on to the next calculation, the next storage operation, and so on, until all the operations have been carried out and it has calculated a value for Z_r. Third, the machine must be instructed to go back to the beginning and go through the whole calculation again for the next value of ω.

Note that the order of operation the computer uses has been changed. This change gives the machine a standard sequence of operations which may be repeated for each value of ω. Practically, it would not be worthwhile to use a large computer for such a simple problem unless a very large number of points, or values of ω, were

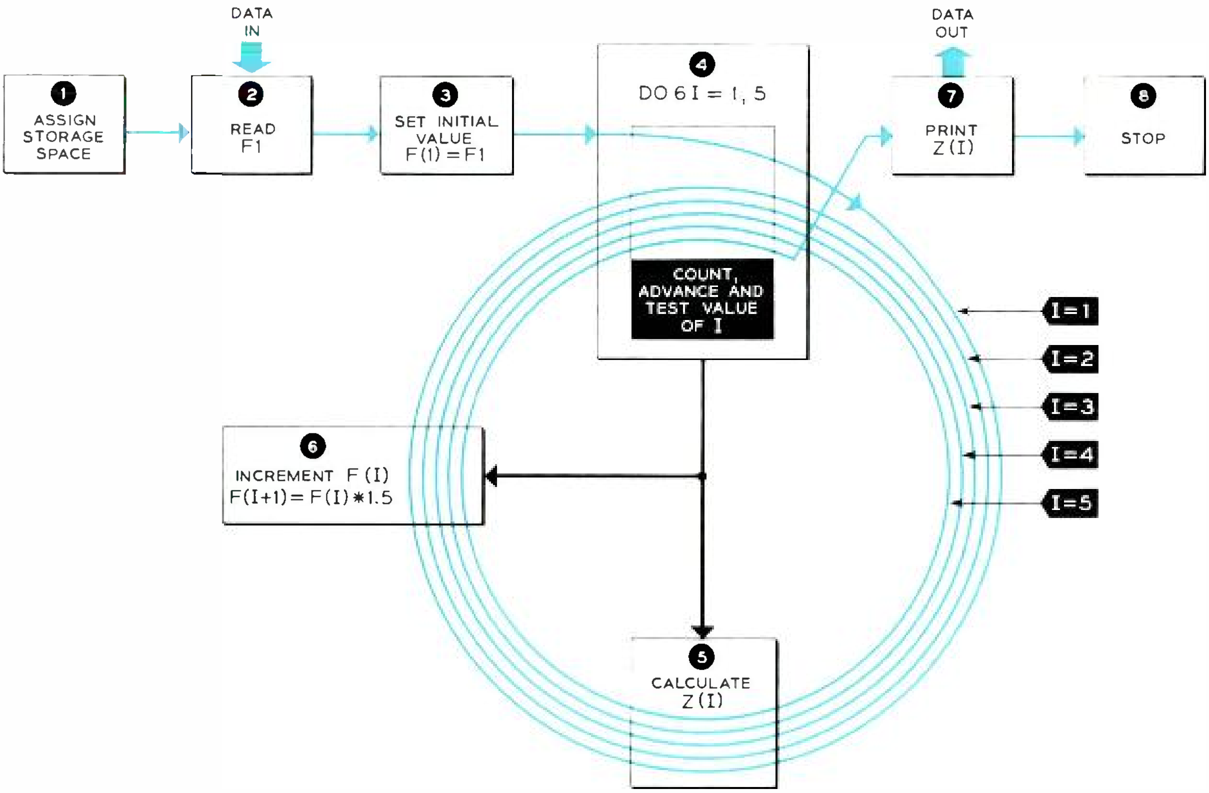


Diagram of a program for doing a repetitive calculation with each value of frequency F (I) increased by a factor of 1.5. Information goes through computer from left to right, and each numbered block is a program instruction. Step 4, which says "do the statements which follow, up to and including statement 6 for all values of I from 1 through 5," is the key instruction since it monitors the repetitive calculation. The heavy line in the middle of spiral carries various values of I.

needed. The example was chosen because the operations required in both types of calculation could be more easily described and compared.

Because computers must be carefully directed, a list of *all* the necessary instructions for controlling the machine must be written out explicitly, in proper sequence and ahead of time. Some of these instructions you may have kept in your head before. This list is called a "program" and is stored in the computer, along with the other necessary data, at the beginning of a calculation. Actual computation begins immediately after all of the data are put into the machine, and it follows the stored program to its end.

Some of the program statements instruct the machine to perform arithmetic operations and store the result. Other instructions tell it what operation to do next. Normally, each instruction is executed as soon as the preceding one has been completed.

A particular group of numerical operations which occurs several times in a calculation need be written only once and may be stored and referred to whenever desired. This is like a small program within the main program and is called a "sub-routine." Libraries of these may be built up and used just like tables of integrals.

The instructions of a computer program must be written so that they will be interpreted correctly by the machine. But what language does one use in communicating with a computer? Numbers are the basic language units in any calculator, and in a large-scale digital computer they may be interpreted in any one of three ways. A number may represent (1) a constant or a value of a variable in the problem, (2) a program instruction, or (3) the location, or "address," of either of these in the storage unit.

Operationally, the basic functions of a digital computer are adding digits and shifting them from one digit position to another. If we communicate with the computer at this level, our vocabulary is very simple, but the program must be very lengthy and repetitious.

In a simpler form of computer — a desk calculator — digits are added when the ADD button is pressed. Also, two numbers already stored in the machine may be multiplied or divided if one of two other buttons is pressed. Internal mechanisms of the calculator translate the triggering of these buttons into a whole sequence of additions and digit shifts that will accomplish the desired arithmetic operation. This built-in translation, in effect, adds the two more complex words "multiplication" and "division" to the machine's vocabulary. To use these words, it is not necessary to perform an equivalent set of detailed operations, or even to know just what they are.

Similarly, in communication with large-scale computers, the machine's vocabulary of many complex "words," or operations, means that programs can be shorter, easier to write, and more like our customary description of mathematical procedures. This new language may also be thought of as writing a super-program of subroutines. Translation processes for basic words such as "multiply," "divide," and "store" may be built into the machine. But the more complex words or expressions must be translated during the calculation of a particular problem. The meaning of each symbol and word in these languages is very precise, so they resemble the language of mathematics more than the language of human speech with its important property of redundancy.

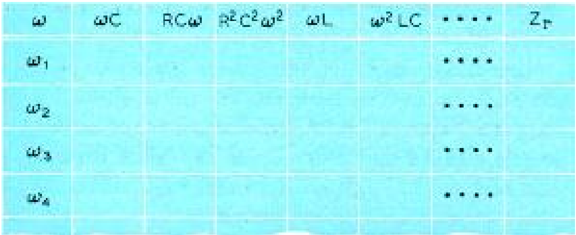
New Translation Techniques

Mathematicians at Bell Laboratories and elsewhere have spent considerable time developing the necessary translation techniques for these more complex languages. It is these highly developed techniques that have made it possible for engineers and physicists to take advantage of high-speed computers without becoming computer experts and without spending a long time in assembling programs. The price of these advantages is the job of translation from mathematical to computer language. But this translation process becomes more feasible as the speed and storage capacity of computers increase.

To give some idea of how these translation systems work, we will consider briefly two of these new languages — FORTRAN (from FORmula TRANslation), used with the IBM 704 Computer, currently in use at the Murray Hill, N. J., location of Bell Laboratories, and the General-Purpose Interpretive System for the IBM 650, also located at Murray Hill. The latter translation system was developed by the Mathematical Research Department. Since these systems apply to specific computers, it will be necessary to outline first the kinds of numbers and the storage units used in these machines.

Most of the work inside a digital computer is carried out with binary units, because the simplest kind of electronic element, from many viewpoints, is an on-off switch. The fundamental units of machine language then, are the binary digits 1 and 0.

By using the new translation techniques, however, one way write programs with the familiar decimal numbers. Internally, each of these numbers, or words, is represented by 35 binary digits



ω	ωC	$RC\omega$	$R^2C^2\omega^2$	ωL	$\omega^2 LC$	• • • •	Z_r
ω_1						• • • •	
ω_2						• • • •	
ω_3						• • • •	
ω_4						• • • •	

A sheet of data paper as it might be set up to organize the calculations involved in computing the resistance (Z_r) of a parallel tuned circuit. The dots in the horizontal rows show that some values have been omitted for convenience in illustration.

and a sign digit in the 704, or by 70 binary digits in the bi-quinary system used in the 650. The extra binary digits in the 650 are used for checking and error reduction. In the machine's adding circuits, which are combinations of the basic binary units, it is natural that the binary point be kept in one place. In other words, the machines represent numbers by a "fixed-binary-point notation."

In engineering and physics, however, very small numbers are just as important as very large ones, so a provision has been made for translating numbers into "floating-decimal-point notation." In both machines this is done externally by having two of the ten available decimal digits represent the exponent of 10.

In the interpretive system for the 650 computer, for example, the number ± 2.4789341 x 10^5 is written as ± 2478934155. Here, 50 has been added to the exponent to handle both positive and negative exponents. In FORTRAN, several forms of floating-decimal-point translations are possible. The "normalized" form for the same number is ± 0.24789341E+06. Translating these forms is an important part of the new languages, since floating-point decimal numbers in the input must be translated to binary numbers in the machine, and the process reversed in the output. Varying amounts of this translation process for number forms are built into modern machines. For example, we may feed decimal numbers to the 650 and floating-point decimals to the 704.

For the storage of temporary results during calculations, the 650 uses a magnetic drum. The 704 computer uses square arrays of tiny coils with toroidal magnetic cores. Sometimes it also uses a rotating drum. There are 2000 locations for storing words of ten decimal digits in the 650, and there may be as many as 32,768 in the 704.

Each storage location is identified by a single serial number — its "address" — instead of by its position in an array, as in the paper and pencil case. Also, the machine's storage is more efficient, because any storage location can be used over and over again for temporary results.

In the general-purpose system, program instructions are expressed in a code of ten decimal digits. Each instruction specifies three things: the numerical operation; location in storage of the two numbers to be operated on; and the location where the result is to be stored. For example, the instruction + 1 402 405 510 means add (indicated by +1) the number in storage location 402 to the number in location 405, and put the sum in location 510. The actual numbers stored on the drum at these addresses are of course in binary form.

The vocabulary of the general-purpose system includes more operation words than just add, multiply and divide. Instruction code + 0 300 402 512, for example, means take the square root of the number in location 402 and put the result in location 512. Other instructions program the computation of exponentials, logarithms, sines, cosines, arctangents and a few others. The machine actually computes the values of these functions at the desired point in the program from suitable formulas. Storing such functions as tables in the machine would require tremendous space, and even then necessitate interpolation.

Program Translation

In addition to the instructions for various numerical operations, the computer requires special "control" instructions. Some examples of these special instructions, along with their codes, are shown in the accompanying table. In the interpretive system, each instruction is translated into the proper series of machine-language instructions, and is executed before the next instruction is interpreted.

By contrast, the FORTRAN statements of a problem are all translated into a nearly optimum program of machine-language instructions for the 704 computer before it does any calculating. This process is called "compiling" and is performed by the 704 using the rules of translation as the program of instructions, and the list of FORTRAN statements as data. The translated program that results is then available for immediate calculation of the original problem. Translated programs are also punched into cards, which may be stored for reference or used in a subsequent recalculation with no further machine translation. When a problem is repeated for different parameter values or range of variables, it is not necessary to rewrite the program in any machine calculation. One need only change the values of the input data.

FORTRAN also has a considerably richer vocabulary than the interpretive system. For example, storage locations are designated by symbols like A1, X, Y, and BETA that suggest the stored variable. Mathematical operations are also designated by symbols: + for addition, * for multiplication, / for division, and EXPF(X) for e^x, to name a few. Several of these operations may be combined as a formula and written in a single statement such as

Y = (BETA + A1*X)/(ALPHA + B2*X).

This means "Calculate the expression on the right for the value of X under present consideration, and store the result at location Y." FORTRAN also has a notation for subscripted variables: C(I), for example, is the Ith element of the sequence $C_1, C_2 \dots C_I \dots C_n$.

Input and output operations are written as READ and PRINT, followed by a list of the variables to be entered or copied out. As in the interpretive system, control operations are available in FORTRAN, but we have the advantages of a more extensive set and more descriptive designations. The symbols for some of these operations, along with their meanings, are also shown in the table below.

The IF statement shown in the table *(seventh row)* is an example of a "branching operation." Here, after reaching a certain point in the program, the calculation may proceed in any one of three ways, depending on whether an intermediate result found at this point is negative, zero, or positive. Without this ability, the machine would have to be stopped after deriving the intermediate result, and wait while the operator decided what should be done next.

In both of these systems for communicating with computers, the information is conveyed to the machine on a stack of business-machine cards with numbers punched in them. The 704 can also use a reel of magnetic tape. Outputs are either punched on cards or recorded on tape, and a printed sheet of the desired answers can be obtained from either. Some of these input and output media are shown in the photograph on page 380 Since reading magnetic tapes is much faster than reading punched cards, tape is usually used with the 704 to match its higher computing speed.

The general procedure for putting information into the computer goes something like this. Program steps are worked out on paper and then punched on business-machine cards on a standard key-punch machine. The information on the cards is automatically transferred to magnetic tape on a machine that is not part of the computer. This tape is the actual input to the 704 computer and contains all of the information the computer needs to solve a problem — data, instructions and control operations.

Answers are recorded on magnetic tape, and are then printed out on data sheets. These sheets are also printed on an external machine, and the results of the calculations can be printed in a variety of easily interpreted formats, with column

Examples of Control Statements and Their Meaning

CODE	MEANING
General-Purpose Interpretive System	
+ 7 000 600 604	Read five numbers from data cards and store them in locations 600 to 604.
+ 7 400 520 529	Punch into output cards the ten answers in locations 520 to 529.
+ 0 000 000 000	Stop calculating.
+ 8 000 000 010	Return to the starting point designated 10.
+ 8 700 455 005	If the number in location 455 $\leq$ 0, return to the branching point designated 5; otherwise go to the next instruction.
FORTRAN System	
GO TO n_1	Instead of doing the next statement in sequence do statement n_1 and then those following it.
IF (A-B) n_1,n_2,n_3	Go next to statement n_1 if $A < B$, to n_2 if $A = B$, to n_3 if $A > B$.
DO n_2 I = 1,N	Do all the following statements up to and including statement n_2, N times, using I = 1 the first time, I = 2 the second, etc.

and row headings typed in if desired. In some cases, these data sheets are reproduced just as they come from the printer and incorporated into reports and memoranda.

As mentioned earlier, one of the great advantages of the modern computer is its extreme reliability (and speed) in performing repetitive calculations. In the simple problem considered earlier, for example, there are two general ways in which the calculation can be repeated for different values of frequency.

In the first way, the initial value of the frequency (F_1) is read into the machine as a constant. After the impedance (Z_r) has been computed at this frequency and the answer stored or punched out, an instruction in the program tells the machine to multiply the initial value of frequency by a certain factor, say 1.5. This is followed by an instruction that tells the computer to go back to the starting point, where the calculation for Z_r is started again at the new frequency. In this way, the impedance is calculated at a set of frequencies that increase logarithmically. The illustration on page 368 is a diagram showing how such a repetitive program works.

The author at the "in-process" printer of the 704 computer. This printer is used mainly to print instructions and intermediate results to guide the operator while a program is being run. In the background, G. H. Mealy is working at the switch panel of the main control center of the computer.

The frequency can also be increased by adding a certain increment to itself each time. Each time the frequency is increased, an instruction compares it with the highest frequency desired. When the limit is exceeded, an instruction tells the machine to stop calculations. In the FORTRAN language, the DO statement (*see table on page 385 and illustration on page 382* makes this repetitive process very easy to program.

In the second way of repeating the same calculation, *values* of frequency at which we want to know the resistance are read into the machine as data. This method is particularly useful when one or all of the elements in the tuned circuit vary with frequency in a complicated way and only measured values are available. The values of the circuit elements at one frequency and the value of this frequency are then punched into a data-input card or cards. Into a second card or group of cards, we punch the values at the next frequency and a second frequency. This way, as many data cards or groups of cards are punched as there are frequency points to compute.

The Actual Calculation

After the machine has read in the program and the constants used for all frequencies, it reads the data for the first point and performs the calculation at this frequency. Then it reads the data for the second frequency and computes again, following the program as before. This goes on until the last set of data has been computed, and the machine then stops.

Large-scale computers do such calculations very rapidly. It is very difficult to measure the relative speed of the processes we have described. But roughly, a problem which would take about two days to complete using a slide rule and paper and pencil might be done in about five minutes on the IBM 650, or in about five seconds on the 704 — these times do not include the time for programming or for compiling (in the 704).

Because of their great advantages in speed and reliability, computers are being used more and more for the solution of engineering problems. More and more, these important laboratory tools are freeing engineers, mathematicians, and research scientists from some of the tedious but necessary calculations of the past, permitting them to devote more time to creative science and engineering — the special province of man.

In the future, many telephone customers will be able to dial directly into the nationwide toll network through 4A or 4M Centralized Automatic Message Accounting (CAMA) facilities. With this equipment, a circuit arrangement called the "bylink" connects certain vital circuit segments in less than fifty thousandths of a second.

A. S. Middleton

No. 4 CAMA AND THE "BYLINK" CIRCUIT

Automatic Message Accounting is one of the major postwar developments in the Bell System. By automatically recording the details needed for billing long-distance calls, it has become an important factor in supplying fast, efficient telephone service. A subsequent development — Centralized Automatic Message Accounting or CAMA — extends this type of service by centralizing the equipment so that one system can serve many central offices.

In recent years, therefore, Bell Laboratories has devoted considerable effort to broadening the applicability of CAMA. The latest development in this field is the use of CAMA to enable type 4A or 4M toll offices to function with step-by-step local offices. That is, with this new development, a customer whose local office uses step-by-step switching equipment may dial directly into the nationwide long-distance network. He dials without interruption and does not need to wait for a second dial tone.

At the type 4A or 4M office, such a call is connected in a fraction of a second to an incoming register — a circuit that stores the called number. Another circuit — the register link — makes this connection, and its great speed of operation is the new factor that makes uninterrupted dialing possible.

The customer first dials a directing code, usually 112, and then dials the number he is calling. The complete number might then be something like 112-MA3-1234. Or, including a long-distance area code, it might be 112-412-MA3-1234. In the local step-by-step office, the 112 causes a trunk to be selected to the toll office, and as soon as this trunk is seized, a signal is sent to the toll office. This signal alerts the toll office to connect equipment to receive the called number, and the connection must of course be rapidly established before the customer dials the next digit after 112. The time available after the 112 depends partly on how fast the customer dials, but for design purposes it must be considered to be about 50 thousandths of a second. The actual time is somewhat longer and includes a period required for the local office to select the trunk.

During this brief period, the register-link circuit in the toll office must connect the trunk to an available register — a function which is performed with a "bylink" arrangement. The bylink is a path through the contacts of two fast-operating relays: one associated with the calling trunk and one with the selected register. The term "bylink" was adopted because, in effect, this circuit by-passes the link that is later set up through the contacts of a crossbar switch. Dialing can be received by the incoming register as soon as this bylink is closed. The first block schematic shows the bylink for the pulsing path.

Because the crossbar switch of the register link takes somewhat longer to operate, the connection through it is established while the dialing via the bylink is going on. Once the link is set up on the crossbar switch, however, the bylink is released.

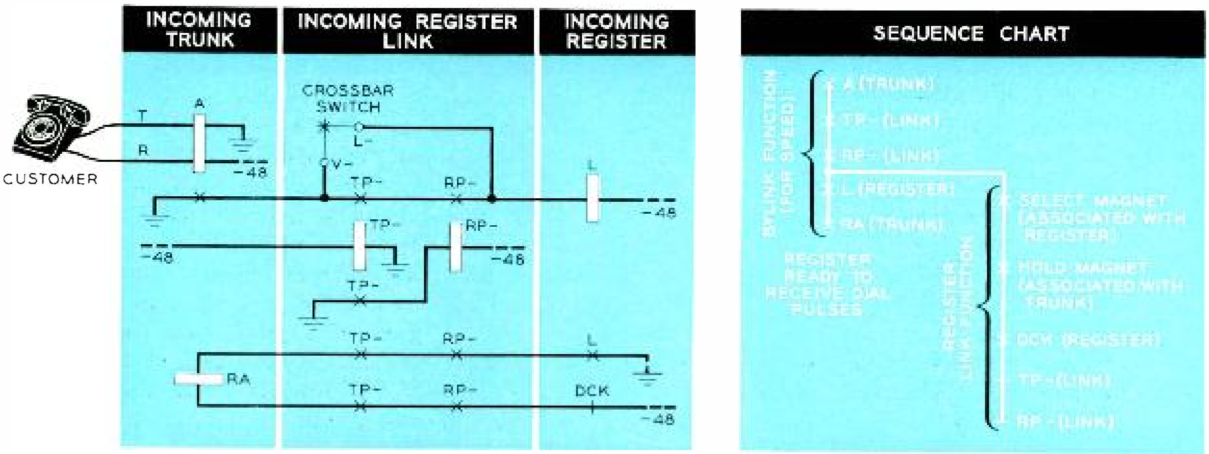
Bylink operation had been previously used in the No. 5 crossbar system and in the crossbar tandem systems. The register link circuit in these systems serves 200 trunks with a group of ten 3-digit registers which are arranged in a full access multiple — that is, every register appears on every crossbar switch of the link circuit. But the register of the No. 4-type toll CAMA systems was designed to receive ten digits and to outpulse those digits. This makes the register holding time considerably longer than that of the local systems' registers. The calls per trunk offered in the busy hour, and the holding time of a register, determine the number of trunks a group of registers can handle efficiently.

For No. 4-type toll CAMA, traffic studies revealed that only about forty trunks could be served in some cases if the registers were connected to the register link in the full access arrangement of ten registers used previously. Since the design of the No. 4-type toll CAMA office calls for one or two transverter groups with a theoretical ultimate of eighteen hundred trunks, four hundred and fifty registers (forty-five groups of ten each) would be required if all trunks were provided. This is relatively inefficient and uneconomical.

A more efficient arrangement for the toll register-link circuit is obtained through the use of a partial access "slipped" multiple of twenty registers. Slipping means that if, for example, registers 0-9 are placed on the first crossbar switch, then registers 3-12 are placed on the second, etc., thereby approaching a random selection pattern. The efficiency of this arrangement enables one hundred and forty trunks to be served by a group of twenty registers. Thus, for the eighteen hundred trunk CAMA office, only two hundred and sixty registers would be required: thirteen groups of twenty each. This is a saving of one hundred and ninety registers and affords a satisfactory trunk-to-register ratio.

Design Features

The design of the register link frame was determined by the number of trunks to be served. Since one hundred and forty trunks may be connected, seven 20-vertical crossbar switches are required: one trunk connected to each vertical. The twenty registers connect to the horizontals (seventy) of the crossbar switches and are arranged so that some appear on three switches and others on four switches. Three hundred control relays are required: one relay per trunk served for trunk preference, and two relays per register



The bylink path of customer-dialed pulses. Link connection through crossbar switch is achieved while the dialing via bylink is going on; bylink is released when link is set up on crossbar switch.

per switch appearance for preference and busy control. These switches and relays comprise a single-bay frame with all apparatus always equipped and wired. The equipment design also combined the link frame and one bay of ten registers as a shop-wired assembly unit; the second bay of ten registers is shipped as a separate unit, and is connected to the other two bays by local cable at the job location. This equipment design achieved manufacturing and installation savings, and also facilitated design of the circuit arrangement required for installing less than twenty registers.

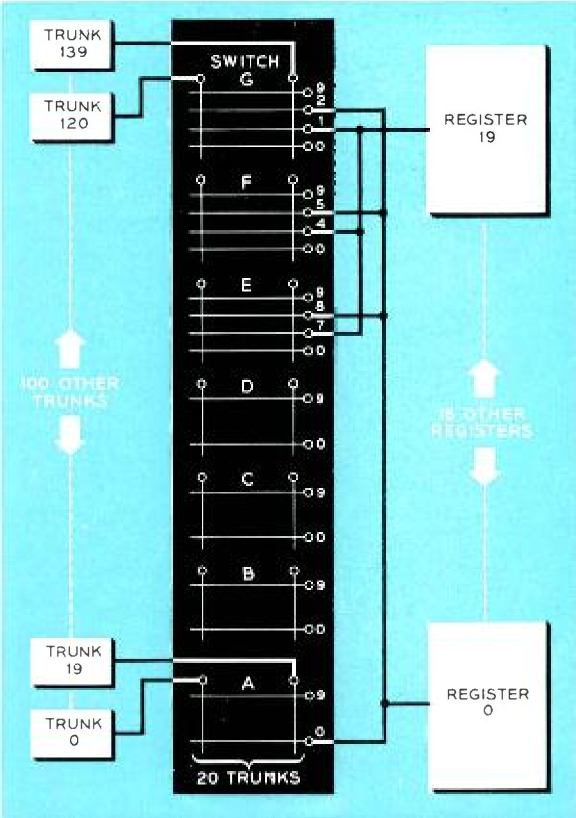
The circuit shown in the second block schematic is arranged to provide either the full group or twenty registers or one half of the group (for small jobs). When only ten registers are needed to serve forty trunks or fewer, the registers numbered 0-9 appear in their positions on the switches and are also arranged to appear in place of (and serve calls for) the unequipped registers 10-19. Since one local cable connects the three bays of a register and link frame, omitting or adding ten registers is a simple process. No special cross connection facilities or temporary cables are required. The local cable arms for the omitted registers are simply connected to the terminal strip of the registers that are equipped for the necessary connection.

An additional feature of the design of the register-link circuit uses the trouble recorder to facilitate maintenance. As soon as a register is selected, it starts a timing cycle about 0.2 second long. If the register-link circuit has not completed its function before this time has elapsed, the register disconnects the trunk from the register link. At the same time, the register and register-link circuits store information in a register-link alarm circuit for subsequent transmission to the trouble-recorder circuit. Under any trouble condition, the register-link circuit must be released promptly since it is a common-control circuit serving one hundred and forty trunks. To take a trouble record directly from the register-link circuit would necessitate holding the link for an additional second or two; hence the need for temporary storage of information in the register-link alarm circuit.

Handling Information

This register-link alarm circuit is a fast device using dry-reed relays to receive and store the following information: the number of the link frame involved, the designation of the switch on the frame, and the register number. These data must be recorded during the release time (about 0.3 second) of the register following a time-out. Having registered the information, the link alarm circuit can then bid for the trouble recorder, where the information will be perforated on a trouble record card if the recorder is idle. A major alarm sounds for this condition and demands immediate maintenance action because of the possible service reaction to the customers.

With both the switch designation and the register number available on the trouble card, the identity of the bylink relays involved is readily determined, since the designation of the bylink relays refers to both the register number and the switch on which the register appears. Location and prompt clearing of trouble prevents serious interruption of the fast and efficient service that the register-link circuit is designed to give.



Block schematic of trunk and register arrangement showing registers 0 *and* 19 *connected. Circuit is arranged to provide either the full group of 20 registers or half of the group (small jobs).*

The diffusion process and the intrinsic-barrier structure promise transistors that will operate at higher voltages and frequencies. As a step in fulfilling this promise, Laboratories engineers have developed a transistor that operates at ten mc with a power output of five watts.

J. E. Iwersen and J. T. Nelson

AN RF POWER TRANSISTOR

Electromagnetic waves of radio frequency — the vast band of frequencies that can be propagated through space — have become a major pathway for modern communication. This is true not just in the communication media we usually associate with radio, such as commercial broadcasting, television and long-distance telephony. Radio is also the basis of such important military communications as radar, satellite and missile tracking, and missile guidance.

In the design of such systems, transistors do not have the position of prominence that they have achieved in present audio or low-frequency systems. But transistor engineers are now beginning to change this situation. Actually, ever since the invention of the junction transistor (RECORD, *August*, 1951), the general tendency in transistor development has been to increase frequency response while maintaining or improving the capacity to handle power.

More recently, the advent of the diffused-base transistor (RECORD, *December*, 1956) has made possible great increases in the frequency range of power transistors. Sufficient increases in frequency response would put the operating range of power transistors in the vicinity of 10 megacycles, and would allow their use as the output stage in radio transmitters.

With these promising possibilities, transistor development engineers at Bell Laboratories undertook the development of an experimental high-power, high-frequency transistor. The program was generally directed toward the design of a 5-watt, 10-megacycle transistor for a military application.

The development of a 5-watt, 10-mc transistor was not the sole objective, however. The program was broadly directed toward the design of a device with very good high-frequency gain and efficiency. This more general attack on increasing frequency response would, hopefully, provide a basis for the development of power transistors for still higher frequencies. This higher range of frequencies — 70 to 100 mc — would of course be of even greater interest.

In line with this plan, the designers took advantage of two fundamental concepts in modern transistor design — solid-state diffusion, mentioned earlier, and the intrinsic-barrier structure (RECORD, *March*, 1958). They also used silicon as the basic material. Silicon is desirable in a power device because of its low intrinsic carrier density at a given temperature. This characteristic of silicon permits operation at a higher temperature, and makes possible the use of a smaller structure for a given power dissipation. Also, the thermal conductivity of silicon is higher than that of germanium, so heat is dissipated more readily.

Solid-state diffusion makes it possible to fabricate the very thin base and barrier regions necessary to high-frequency operation. The advantages of the second design feature — the intrinsic-barrier structure — have been described in detail in the article just referenced. Briefly, this structure yields a device with a collector of low capacitance and high breakdown voltage, in conjunction with collector and base regions of low resistivity.

The general transistor characteristics that these design concepts make possible can be mathematically related to the specific electrical objectives by so-called "optimization" equations. For our purposes, however, we will consider only briefly how the available transistor parameters can be adjusted to meet the electrical objectives.

For the first electrical objective — an output of 5 watts when operated as a Class A amplifier — the product of maximum peak operating voltage times maximum peak operating current must be at least some fixed value. In this case, it is 40 watts. The first factor, maximum voltage, is directly related to the width of the barrier region of the collector. Maximum current for a given area of the transistor's emitter is limited by the number of impurities in the barrier region, so this factor may be adjusted by varying either the number of impurities or the area. That is, the power requirement demands that the product of barrier width times total area and density of impurities in the barrier be some constant.

The second design objective — operation at 10 mc — calls for a large bandwidth and high power gain. If we consider the transistor as a common-emitter current amplifier, high power gain will be achieved with high current gain, low input impedance and high output impedance. And for adequate bandwidth, these characteristics must not degrade too rapidly with frequency. The predominant factor influencing the current gain is "transit time," or the time it takes for a charge to pass through the base region. This in turn means that the base region must be kept as thin as possible.

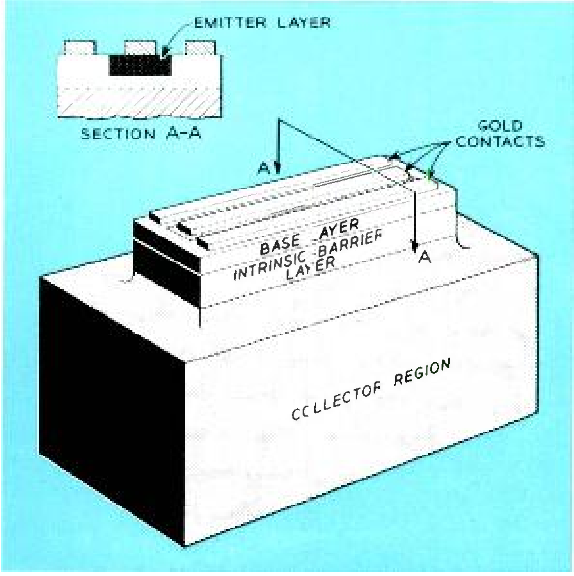
Input impedance, another factor in high power gain, equals approximately the base resistance of the transistor. This parameter can be lowered by a high density of impurities in the base region, plus a thick base and a long, narrow emitter. To keep the output impedance high, the collector capacitance should be low, which means, in turn, that the barrier region should be thick and the area small.

The two conflicting requirements on base thickness that the frequency objective imposes are somewhat resolvable. A closer examination shows that the current gain depends on the inverse of the square of the base thickness, while the base resistance is only dependent on the first power of the base thickness.

The final electrical objective — the efficiency of the transistor — will be highest when the ratio

Structure and Dimension	**Value and Units**
Emitter Width	0.008 inch
Emitter Length	0.060 inch
Base Thickness	0.00006 inch
Base Impurity Density	10^{17} atoms/cm (avg.)
Barrier Impurity Density	5×10^{14} atoms/cm
Barrier Thickness	0.0004 inch

Structure of the RF power transistor. The long, rectangular shape of this device differs considerably from the more usual square or circular forms. Vertical dimensions are greatly expanded to define more clearly the various areas. The associated table gives the actual size of the various areas and structures shown on the sketch, right.



of maximum to minimum operating voltages can be kept as high as possible. The power objective has already established certain requirements for maximum voltage, so the job that remains is to see that the minimum voltage is kept low. This calls for lowering the impurity density in the barrier and for keeping the barrier as narrow as possible.

A summary of the electrical objectives and their relationship to physical parameters is shown in the table on this page. An arrow pointing upward indicates a positive relation between the objective and the parameter; an arrow pointing downward indicates a negative, or inverse relationship. The double arrow indicates a square-law dependence. One objective — power — has a "free," or independent, parameter, emitter length. And since power is not to be maximized but only set at the 5-watt level, emitter length permits the power level to be set without reference to the other five parameters. These other five parameters, therefore, are available for optimizing the gain-bandwidth and efficiency objectives.

The (gain) x (bandwidth)^2 and efficiency columns show that only one parameter, barrier thickness, is involved in both of these factors. This means that four of the other five parameters can be pushed to the limit of fabricability, while barrier thickness can be used to exchange gain for efficiency.

There are of course many second-order interactions between parameters and objectives. About these it is sufficient to say that they are unimportant or are optimized in the same way as those listed in the table. The importance of these second-order interactions has been determined only for the frequency range obtainable with present fabrication limits, however.

From these design considerations evolved a transistor with a long narrow emitter, a thin, heavily doped base, a lightly doped barrier region, and a barrier width selected as a compromise between high frequency gain and collector efficiency. This description does not mention the doping of the emitter and collector regions. High doping — the addition of many impurities — is necessary in the emitter for high alpha and in the collector to insure low series resistance. These conditions must be met, although they are not specifically mentioned in the design requirements.

How Physical Parameters Affect Electrical Objectives

	Electrical Objectives		
Physical Parameters	**Power**	**(Gain) X (Bandwidth)^2**	**Efficiency**
Emitter Length	↑		
Emitter Width	↑	↓↓	
Base Thickness		↓	
Base Doping		↑	
Barrier Doping	↑		↓
Barrier Thickness	↑	↑	↓

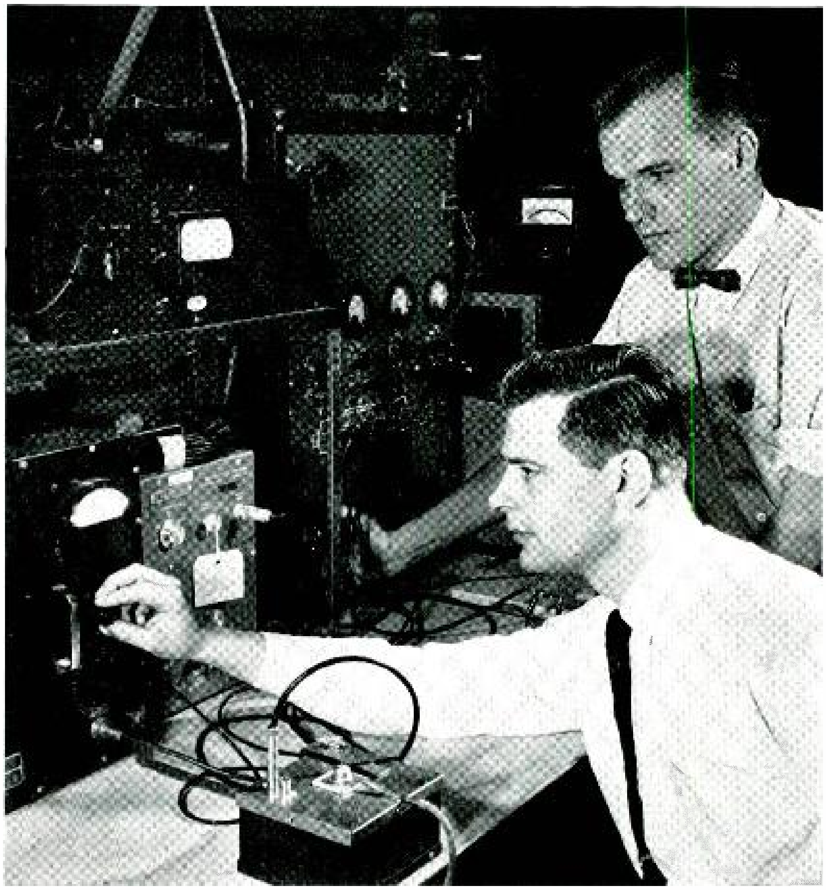
After the design requirements outlined above were established, the principal concern was the development of techniques for controlling the impurity and dimensional requirements necessary to build a transistor which met or surpassed the 5-watt, 10-mc criteria. The final physical structure and the dimensions and doping levels achieved for the completed transistor are shown in the sketch and accompanying table on page 391.

A device of this kind could not have been made without the excellent control of doping and layer thickness offered by solid-state diffusion. Since the junctions lie very close to the upper surface of the wafer, the silicon just below the surface must be free of mechanical damage. If this were not the case, rates of diffusion would be altered by the damage, and the depths of the junction would in turn reflect the damage and be irregular. Before uniform layers could be obtained, special polishing techniques had to be developed to give surfaces that were substantially free of scratches and damage. Actually, the depths of permissible defects had to be less than a small fraction of the already very thin layers. These precision polishing techniques were developed at the Laboratories by F. Keywell.

In addition to high-quality surfaces, the polishing also had to yield wafers of closely controlled thickness, because the intrinsic-barrier layer is the parent material left between the base-layer diffusion and the collector diffusion. The thickness of the intrinsic barrier, therefore, is determined by the original thickness of the wafer. Practically, the barrier width shown on the illustration represents a compromise that had to be made to develop the transistor with the polishing techniques available.

The ratio of emitter length to emitter width also represents a compromise between the very high ratio that was desired and what could be accomplished in practice. This compromise was brought about by two factors. The first was the degree to which the designers were able to control the surface geometry of the emitter. The second and more difficult factor was the problem of aligning a metallic contact that would distrib-

J. E. Iwersen, foreground, and J. T. Nelson, checking some of the characteristics of the experimental five-watt, ten-mc transistor. Transistor is mounted in special jig, left.



ute the current on the emitter and base contacts very near the edge of the emitter. In operation, this emitter carries peak currents of 0.4 ampere, so that very thick contacts are required to distribute the current uniformly over its full length.

The assembled transistor is mounted in the standard Western Electric "header" used for germanium power transistors. This container is adequate for use at 10 mc.

Electrical performance tests of various types have indicated that this experimental transistor meets, more than adequately, the requirement of delivering 5 watts of power at 10 mc. The peak operating voltage (common emitter) is over 100 volts, and the maximum current is over 400 milliamperes with a collector voltage of less than 10 volts at 400 milliamperes. This collector-voltage requirement permits the transistor to operate at a bias of 200 milliamperes and 60 volts, with current swings of from 0 to 400 milliamperes and voltage swings of from 10 to 110 volts for an output of 5 watts (Class A).

The current gain (common emitter) is about 8 to 12 at 10 mc, indicating the point of unity gain as 80 to 120 mc. The input impedance is 10 to 20 ohms, and the output impedance is 200 to 450 ohms. These numbers are not independent and lead to (power gain) x (bandwidth)^2 values of from 2 to 5 x 10^{16}. In terms of decibels, this is a power gain of 23 to 27 db at 10 mc, or a power gain of 3 to 7 db at 100 mc. These performance figures can be obtained from calculations based on the physical parameters of the transistor, or they can be measured. Agreement between calculated and measured values has been within the measurement error.

Power oscillator circuits have been designed to check the performance of the device. At 10 mc, over 5 watts has been obtained with an efficiency in excess of 50 per cent. At 110 mc, the transistor has put out 1.2 watts with an efficiency of 17 per cent. No real attempt was made to design an optimum circuit that would maximize the performance at the higher frequencies.

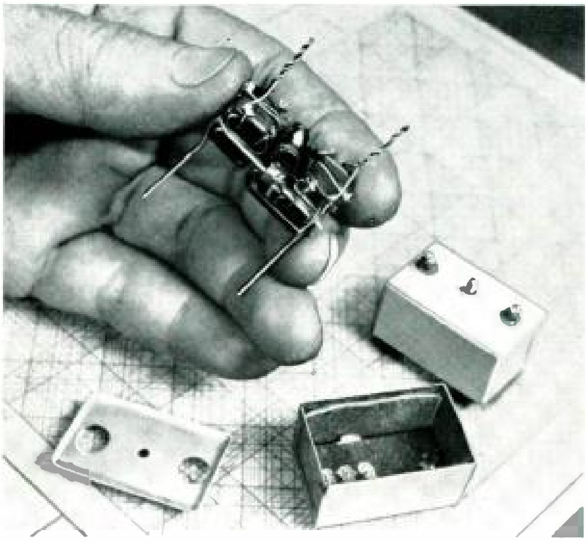
This experimental transistor may be the first of a new group of junction devices that can be used in the lower radio frequencies. The development has also shown that as fabrication techniques improve, it will be possible to design power transistors of even higher frequency response.

New, tiny personalized electronic devices demand small components. A miniature crystal filter measuring $\frac{7}{8}$ inch by 1-1/2 inches by $\frac{3}{4}$ inch in height has been designed for a pocket-radio receiver used in modern radio paging services

Miniature Crystal Filters

With the development of personal radio signaling service, walkie-talkies, mobile radio and similar short range, high-frequency communication systems, a need has arisen for the design of smaller and smaller devices for use in both transmitting and receiving equipment. One device which has recently undergone considerable development in this respect is the intermediate-frequency crystal filter used in the receiving circuits. This filter must pass a modulation band of approximately 15 kc in the radio-frequency range of 10 to 20 mc and must rapidly attenuate frequencies outside this specified band.

For the development of a miniature crystal filter of this type it is necessary that the crystal units be ground and adjusted to very precise frequency tolerances and that they remain stable in frequency with changes in temperature, shock and vibration. The crystal units must also be free from spurious resonant frequencies which may be located close to that of the fundamental resonance. These objectives have been met in the latest design of a crystal unit by supporting the crystal plate on flexible spring wires and by assembling the unit in a small metal container which is hermetically sealed and filled with dry air. The spurious frequencies are moved away from the fundamental frequency by proper contouring of the crystal plate and by assuring the correct ratio of plated-to-unplated area on the crystal-plate surfaces.



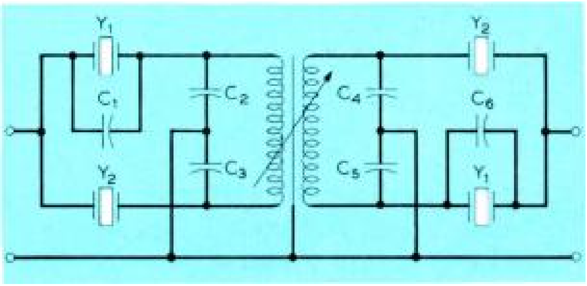
View of the complete filter assembly and its metal container. It is made up of four crystal units, six capacitors and one transformer; the latter is tuned by adjusting a small threaded-core slug.

To attenuate signal frequencies located only 30 kc away from mid-band by 60 db or more, it is necessary to use a filter containing at least two sections, connected in tandem; this is done with a transformer bridge-type of circuit. The circuit is equivalent to a two section lattice-type structure, but has the advantage of using only two crystal units per section instead of four. However, it does require the use of a coupling transformer between crystal sections, and to keep unbalance and ground currents from flowing from one section to the other, it is essential at these high frequencies that an electrostatic shield be placed between the two windings on this transformer. In addition to these requirements, the new transformer must be capable of being tuned to obtain maximum transmission through the pass band of the filter itself.

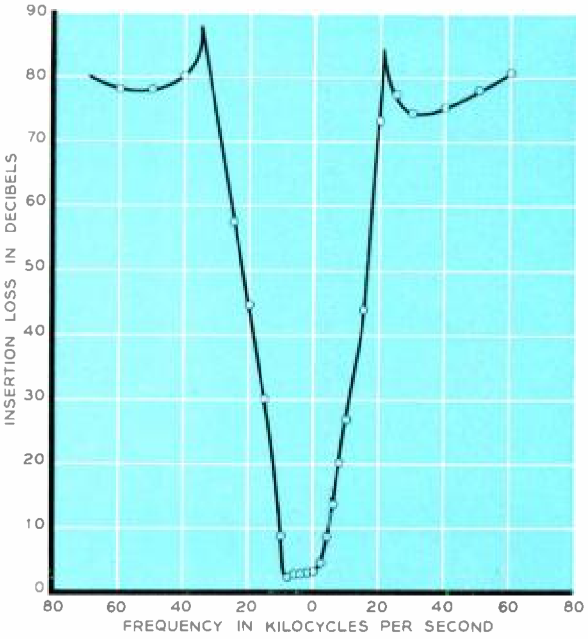
Final Filter Assembly

The design of such a transformer presented many difficulties but was finally resolved as follows: A spiral of Formex copper wire is wound on a standard 10 by 32-screw; this winding is covered by one layer of transparent cellophane tape, one layer of 0.001-inch tinned copper, and a second layer of transparent cellophane tape; the secondary winding is applied and finally the screw is removed. This results in a shielded 1:1 ratio transformer with the turns of the primary winding so spaced as to permit tuning by means of a threaded-core slug. The direct capacitance between windings with the shield grounded is less than 0.5 μμf. The capacitors used in the assembly of the filter are miniature silvered mica capacitors with a voltage rating of 75 volts or less.

The complete filter assembly and its metal container are shown in the photo on the opposite page. It consists of a total of four crystal units, six capacitors and one transformer interconnected as shown in the accompanying circuit schematic. Capacitors C_1 and C_6 are used to control the location of the attenuation peak above the transmission band, while capacitors C_2, C_3, C_4 and C_5 serve a double purpose; first, to provide partial tuning for the 1:1 ratio transformer so as to give maximum output at the midband frequency; and second, to control the location of the peaks of attenuation below the transmission band. Fine tuning of the 1:1 transformer is accomplished by adjusting a threaded-core slug.



Circuit schematic of the miniature intermediate-frequency crystal filter. The capacitors C_1 and C_6 are used to control the location of the attenuation peak above the specified transmission band.



This graph illustrates the insertion loss characteristic of a filter made for 20.4 mc. Insertion loss over transmission band is less than 5 db; attenuation is over 70 db plus or minus 30 kc.

A preliminary design for radio paging to operate at 20.4 mc is shown on the graph. Insertion loss of this filter over the transmission band is less than 5 db, and the attenuation is over 70 db at plus or minus 30 kc from the mid-band frequency. The filter measures ⅞ inch by 1-1/3 inches by ¾ inch in height not including the studs or terminals, and it has a volume of about 0.9 cubic inch. This particular filter was constructed for use in one of the preliminary circuit designs for a pocket-carried radio receiver that could be used in a radio-paging system.

C. T. GRANT
Transmission Systems
Development III

NEWS

Satellite Communication Station Being Built at Holmdel Location For Use in Transmission Tests

The Laboratories is constructing an experimental ground station for sending and receiving telephone messages by way of man-made satellites at the Holmdel location. This station could point the way to a network of terminals for sending telephone calls and live television programs to distant parts of the world. These stations would "bounce" radio signals off dozens of sky-mirror satellites.

The station will include control buildings and two large antennas for communication experiments with objects in outer space. One of the uses of the installation will be to take part in communication projects sponsored by the National Aeronautics and Space Administration. One of the projects at Holmdel will test the quality of radio signals transmitted between stations on opposite sides of the United States by reflections from a satellite.

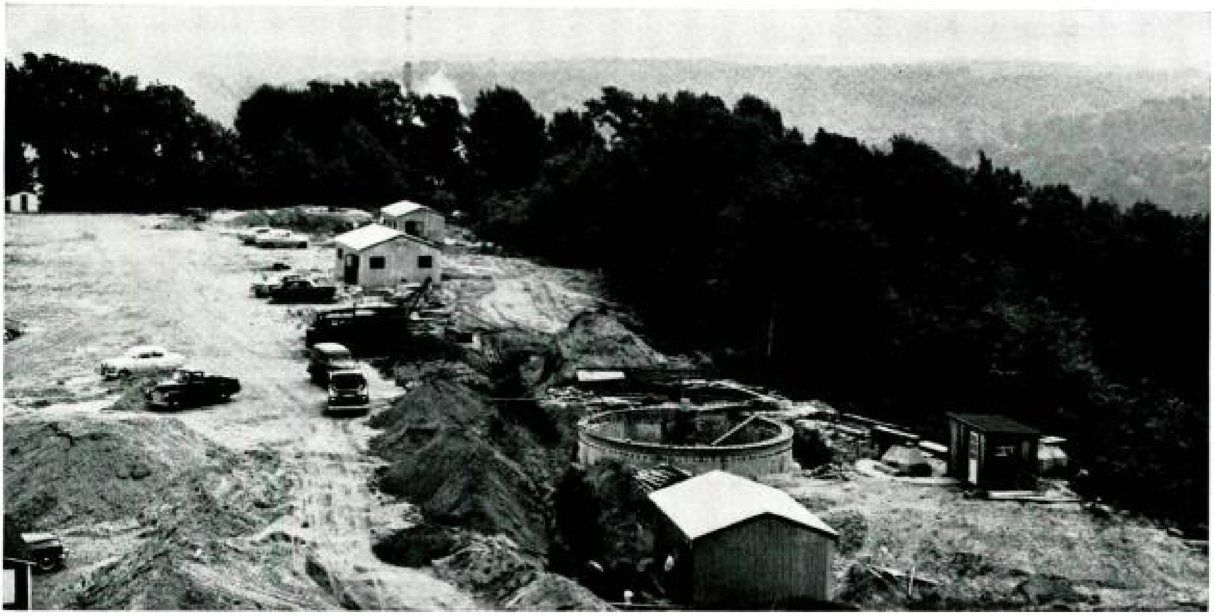
Although single telephone channels will be used in the experiment, the objective is to determine whether television's "broadband signals" (the equivalent of about 900 telephone channels) could also be transmitted.

The microwave radio signals to be used in the experiment will be analyzed to obtain information about transmission effects. The data also will be studied to discover the reflection characteristics of satellites in orbit.

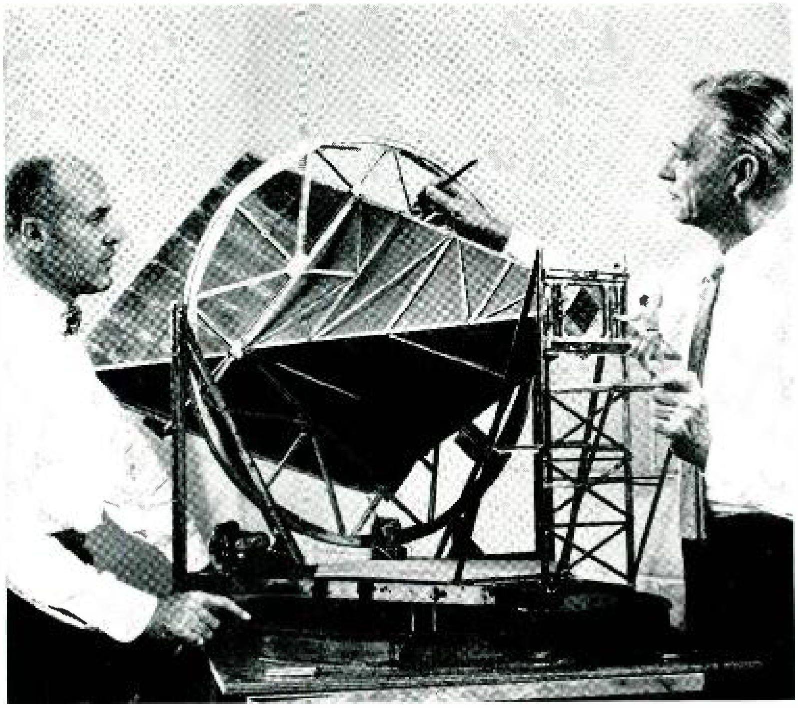
First Tests With Moon

The satellite experiments will probably be preceded by test transmissions of signals using the moon as the reflector. The signals will be received and transmitted between the NASA's Jet Propulsion Laboratory at Goldstone, California, and the Holmdel location of the Laboratories, some 2300 miles away.

Heart of the project will be the antennas and the transmission techniques. A dish shaped antenna, commercially available, will transmit signals, and a horn-shaped antenna will receive them. The latter antenna was



Satellite communication station under construction at the Holmdel location of the Laboratories. Circular concrete structure in the foreground will be the base for the horn antenna. Concrete base in background will be for the conventional dish-shaped antenna used for the transmitter.



W. C. Jakes, left, and A. B. Crawford examine a model of the giant horn antenna to be used at the Holmdel ground station for experimental communication via man-made satellites. The horn antenna will be about 50 feet long and the aperature will measure about 20 feet by 20 feet. Small figure of man gives some idea of actual size.

designed by Laboratories engineers and is a large version, adapted for tracking, of the horn-reflector antenna. This was originated some years ago for radio-relay use and is being introduced into the Bell System.

The horn-reflector design permits the antenna to receive radio energy from essentially one direction, and less than one-millionth as much from other directions. The result is greater concentration on the wanted signal and less pickup of "noise" from other directions, especially the radiation from the ground, than for conventional antennas.

The horn's highly sensitive detector is a MASER (short for "microwave amplification by stimulated emission of radiation") (RECORD, *March*, 1957). Inside the device, ruby crystals will amplify signals from the satellite. The crystals will be contained in a liquid helium "refrigerator," at a temperature approaching absolute zero — about —460 degrees F.

One of the initial and crucial problems in the experiment will be tracking the speeding satellite precisely, and for this purpose the Laboratories will provide special equipment. Data predicting the "passes" of the satellite will arrive in coded form and the new equipment will rapidly convert the information into a form suitable for controlling the antennas.

The first proposal for a system of satellite communications was offered in 1945 by A. C. Clarke, engineer and author. In 1955, J. R. Pierce, Director of Research — Communications Principles, proposed a system of passive satellite relays upon which the present experiment is based. Since then, Laboratories engineers have developed many of the devices required for the tests.

New Copper Paste For Printing Circuits on Ceramic

A new method for producing printed wiring directly on ceramic bases without the use of adhesives has recently been developed by A. W. Treptow and Miss Lucille Finneran of the Metallurgical Research Department. The new process, uses standard silk-screen printing techniques to form the pattern, in conjunction with a copper-bearing paste. After printing the desired pattern on a ceramic base, a technician "fires" the piece in a two-step process, to get a clean, durable pattern with excellent electrical characteristics.

In present methods of production of printed wiring, a sheet of copper foil is usually bonded to a plastic base with an adhesive. The desired pattern is then produced by one of several methods usually involving the removal of undesired material. Thus the bond of the copper to the base depends on the strength of the adhesive.

With the new process, a technician prepares a paste from a finely ground mixture of copper oxide and a special powdered glass blended with a standard vehicle for silk-screen printing. He then can print the paste by standard screen-printing and bond it to the ceramic by firing. The printed pattern is first fired in air at 750 degrees C to burn out the vehicle, and then fired at 850 degrees C in a controlled atmosphere.

Printed wiring cards prepared this way can be dip-soldered without failure of the bond, and without the use of corrosive fluxes.

The new process is suitable for automatic production techniques, and should prove competitive in cost with other printed-wiring methods. There are other potential uses for the new copper paste in addition to printed circuits. For example, with suitable modification of the vehicle, the copper can be applied with a brush or a spray gun. When fired, these coatings form a good base for metal-to-ceramic bonds using lead-tin solders.

I. M. Ross, left, and L. A. D'Asaro examine with oscilloscope characteristics of the stepping transistor element in special circuit.

New Stepping Transistor Developed by Bell Laboratories

A p-n-p-n semiconductor element that can serve as the basic building block of a silicon stepping transistor was described at the Western Electric Show and Convention held in August in San Francisco. As reported by L. A. D'Asaro, of the Transistor Development Department, this element has potential application to digital computers, pushbutton dialing, and telephone switching.

The four-terminal device acts as an on-off switch controlled by pulses. By merely interconnecting several devices, designers can make various logic circuits perform various functions.

A more complex device, fabricated from a single piece of silicon, can also perform these logic functions. As a prototype arrangement, Laboratories engineers have made a stepping transistor with four stages, or elements. This device performs the *function* of a complex circuit. Hence it is referred to as a "functional device." The concept of a functional semiconductor device is a promising approach to microminiaturization.

The stepping transistor itself is the result of work originated in 1954 by I. M. Ross of the Transistor Development Department. His object was to build a semiconductor device that would function similar to a gas stepping-tube. Thus it was to be a digital counter capable of carrying out at high speeds many of the same functions usually performed by complex circuitry or else performed at low speeds by chains of mechanical stepping switches and relays.

For its operation, the gas stepping tube uses the bistable voltage-current characteristic of a gas discharge. One-way transfer of voltage between its electrodes —one anode and several cathodes —is obtained by the nonsymmetrical geometry of the cathode's construction.

The stepping transistor uses a p-n-p-n transistor as the bistable element. The design of the structure results in a bistable voltage-current characteristic between a single common electrode and a set of multiple electrodes. Again, nonsymmetrical geometry obtains a one-way transfer of voltage.

Unlike the gas stepping tube, however, the stepping transistor does not basically require close proximity between stages. This is why elements of the stepping transistor, comprising single four-terminal stages, can be separately encapsulated and connected externally.

Stepping transistors have been operated at speeds up to one million pulses per second. This speed is 100 times greater than that of the gas stepping tube. With improved designs, Laboratories engineers expect the stepping transistor will operate even faster.

Laboratories to Develop UNICOM Network

The United States Army Signal Corps has awarded to the Western Electric Company a new research and development study contract for a universal integrated communication system, known as UNICOM. The development will be carried out under the direction of Bell Laboratories with International Telephone and Telegraph Corporation and Radio Corporation of America as associates.

The UNICOM concept calls for a circuit and message switching network designed for efficient handling of bulk messages as well as high priority traffic. The Military Communications Engineering Department, under the direction of C. A. Armstrong, will be responsible for the project.

Ship Model Built at Chester To Test Cable-Laying Art

A "cable ship" is in the final stages of construction at the Chester location of Bell Laboratories. The structure, firmly anchored to a hilltop, is a mockup of the cable tanks and working decks of an actual cable-laying vessel. The model, named the "*Fantastic*," will help Laboratories engineers carry out the most extensive modernization of cable-ship equipment and techniques since the first telegraph cables were laid a century ago. The changes are needed to handle improved underwater telephone cable systems now being planned.

The mockup, 50-feet high and 200-feet long, will enable engineers to simulate deck layouts and cable-handling operations of future and existing cable ships. During cable-laying experiments, a winch pulls the cable out of the cable tank, down the hill on which the ship stands, and around a sheave, simulating the cable being pulled into the sea by gravity.

The present underwater cable system includes electronic repeaters, or amplifiers, spaced about 38 nautical miles apart. They are flexible and are handled just like the cable when laid in the sea. To transmit greater traffic in a proposed new cable system, however, the Bell System now plans to use rigid, metal-encased repeaters, three feet long and one foot in diameter.

Yet these rigid repeaters must be paid out with the cable—preferably through the cable engine and over a number of different surfaces. Moreover, payout should be continuous, reliable, and at reasonably high speed (*see cover*). To achieve this, a technical revolution in shipboard machinery and techniques is being brought about.

Construction of a life-size mockup was found to be more practicable and economical than chartering a cable ship for the long periods necessary. Moreover, many of the needed experiments could not be readily performed nor adequately observed aboard a real ship at sea. Thus the skeletonized *Fantastic* enables engineers to watch their experiments and to obtain motion-picture records for detailed study.

The structure is the only one of its kind in the world. It stands several hundred yards from the underground "dry-land ocean" (RECORD, *February*, 1959), another unique Bell Laboratories facility, announced last year.

Two levels of the new "cable ship" show, on deck, engineers placing model of cable repeater in "highway" ready for launching, while below others work out methods of stowing coiled cable in "tank".

Nike-Zeus Test Sites To be Constructed

The Department of the Army has announced that contracts have been awarded to construct facilities at three sites for the testing of the Nike-Zeus anti-missile system. The contracts are for facilities on Kwajalein and Johnston Islands in the Pacific and at Point Mugu, California.

Nike-Zeus, designed to become the nation's first weapon to intercept intercontinental ballistic missiles, is the third in the Nike missile family built for the Army by the Western Electric Company. Its forerunners, Nike-Ajax and Nike-Hercules, were built for defense against attacking aircraft and air-breathing missiles.

Construction at these sites will make possible a test program leading to the future demonstration of capabilities of the Army's Nike-Zeus system over an ocean area that provides room for more extensive firings than possible in the United States.

Work on Kwajalein, a two by one-half mile island, concerns at this time establishment of some elements of a Nike-Zeus firing battery. The Johnston Island project calls primarily for adding some 24 acres to the tiny island by a dredged fill. Johnston Island, a mile long and one-half mile wide, will be a site from which simulated ICBM's will be launched by the Army to verify the missile-killer capabilities of Nike-Zeus. At the U.S. Naval Missile Test Center at Point Mugu, work includes mainly construction of missile launchers and a missile radar building.

Western Electric will install and maintain the Kwajalein Nike-Zeus facilities and will also be directly involved in the test firings. Bell Laboratories and Douglas Aircraft Company will also play important roles in this phase of the operation. Prime contractor for the Nike-Zeus project is Western Electric, with over-all technical supervision assigned to Bell Laboratories.

The Nike-Zeus research and development effort is directed from the Whippany location of the Laboratories, with some 40 subcontracting companies contributing to the program. These include Douglas Aircraft Company which is responsible for the missile hardware and launching equipment.

W. W. Mines Named Editor of RECORD

Effective with this issue, W. W. Mines, formerly Associate Editor of the Record, assumes the responsibility of Editor. He succeeds G. E. Schindler, Jr., who has accepted the position of Public Information Supervisor in the Public Relations Department of the A. T. & T. Company.

Mr. Mines graduated from the University of Maryland in 1949. For several years he edited technical manuals at the Sperry Gyroscope Company, and later became Assistant Editor of the *Sperry Engineering Review.*

Prior to joining the staff of the Record in 1956, Mr. Mines was Assistant Editor of the Sylvania *Technologist.*

Western Electric to Build Network for Tracking Mercury Satellite

The National Aeronautics and Space Administration has awarded a letter contract to the Western Electric Company to direct an industrial team to develop a world-wide network of tracking and ground instrumentation stations. The network is to be used in Project Mercury — the United States effort to put a man in orbital flight and return him safely.

Bell Laboratories will undertake the responsibility for systems engineering, design of displays and controls at command centers, and development of simulation devices and will also perform general engineering consulting. Other team members are International Business Machines Corporation which will be responsible for computer programming and data processing; Bendix Aviation, which will develop the radars, telemeter receivers and equipment for remote sites; and Burns and Roe, Inc., which will be responsible for construction and logistics at the sites. Western Electric, as the prime contractor, will be responsible in addition for contract management for over-all logistics and training and ground communications.

The tracking network—expected to be completed in 1960—will be made up of existing components whenever possible and will be made as portable as is feasible. The equipment must be capable of monitoring the onboard equipment of the capsule, including the life support system, the physiological reactions of the Astronaut, or pilot, and the command control equipment. It must also be capable of maintaining communications with the capsule during its flight around the earth. The equipment may be re-deployed for later phases of Mercury and for other future projects.

The network will include both radar-tracking and telemetry installations located in Africa, the South Pacific, Central America, Cape Canaveral, Florida, Hawaii, Southern California, and on islands and ships in the Atlantic and Pacific oceans.

Contents of September 1959 Bell System Technical Journal

The September 1959 Bell System Technical Journal contains the following articles:

Studies in Tropospheric Propagation Beyond the Horizon, by A. B. Crawford, D. C. Hogg and W. H. Kummer.

Group Testing To Eliminate Efficiently All Defectives in a Binomial Sample, by M. Sobel and P. A. Groll.

A Network for Combining Radio Systems at 4, 6 and 11 kmc, by E. T. Harkless.

Synthesis of Active RC Networks, by B. K. Kinariwala.

Mode Conversion at the Junction of Helix Waveguide and Copper Pipe, by J. W. Lechleider.

TALKS

Following is a list of speakers, titles, and places of presentation for recent talks presented by members of Bell Laboratories.

Brattain, W. H., *Solid-State Circuit Elements,* Walla Walla Area A.I.E.E. Subsection, Walla Walla, Washington.

Brattain, W. H., *Nature of Bell Telephone Laboratories,* Walla Walla Rotary Club, Walla Walla, Washington.

Brown, W. L., *Annealing of Radiation Induced Defects in Germanium,* RCA Laboratories, Princeton, N. J.

Budlong, A. H., *Electronic Switching,* Hotel Suburban, Summit, N. J.

Geller, S., see Wernick, J. H.

Gillette, D., see Ling, D. P.

Herbst, R. R., *Automatic Mechanical Design of Modular Type Apparatus,* Duke University, Durham, N. C.

Lewis, W. D., *Creativity in an Industrial Organization,* Harvard University, Cambridge, Mass.

Ling, D. P., and Gillette, D., *Lectures on Guidance Systems Engineering,* Second Institute for Missile and Rocket Technology, U. of Connecticut, Storrs, Conn.

Lowry, W. K., *Automatic Equipment for Information Handling,* Internationale Arbeitstagung, Automatische, Dakumentation in der Praxis, Frankfort/Main.

Mallery, P., *Flux-Steering Magnetic Devices for Logic,* Sixth Annual Symposium on Computers and Data Processing, Denver Research Institute, Estes Park, Colo.

Roberts, A. W., *Logical Design of a Transistor Resistor Logic Subtracter,* Sixth Annual Symposium on Computers and Data Processing, Denver Research Institute, Estes Park, Colo.

Ruppel, A. E., *The Dew Line Story,* Kiwanis Club, East Rockaway, N. Y.

Sanders, J. H., *Optical Masers,* Atomic Energy of Canada, Ltd., Chalk River, Ontario, Canada.

Slichter, W. P., *Nuclear Resonance Studies of Motion and Configuration in Glassy Polymers,* Conference on Molecular Organization of High Polymers in the Solid State, New York Academy of Sciences, N.Y.C.

Slichter, W. P., *The Use of Nuclear Magnetic Resonance in Studying Polymers,* M.I.T., Cambridge, Mass.

Slichter, W. P., *Hindered Motion in Solid Polymers,* Gordon Research Conference on Magnetic Resonance, New Hampton, N. H.

Sturzenbecker, C., *Magnetic Devices,* Research and Development Class of the 9941 Air Reserve Squadron, Winston-Salem, N. C.

Wasserman, E., *Theory of Optical Activity of Bimesityl Derivatives,* International Molecular Quantum Mechanics Conference, Boulder, Colo.

Wernick, J. H., and Geller, S., *Semiconducting Ternary Compounds for Possible Thermoelectric Applications,* Gordon Conference on Inorganic Chemistry, New Hampton, N. H.

Winslow, F. H., *Trends in Polyethylene Research,* 21st Summer Conference of the New England Association of Chemistry Teachers, U. of Connecticut, Storrs, Conn.

PAPERS

Following is a list of authors, titles, and places of publication of recent papers published by members of the Laboratories.

Abel, J. L., see Chynoweth, A. G.

Abrahams, S. C., see Prince, E.

Anderson, P. W., *Spectral Diffusion, Phonons, and Paramagnetic Spin-Lattice Relaxation,* Phys. Rev., 114, pp. 1002-1005, May 15, 1959.

Bodle, D. W., and Hays, J. B., *Electrical Protection for Transistorized Equipment,* Elec. Engg., 78, pp. 812-817, Aug., 1959.

Bommel, H. E., and Dransfeld, K., *Excitation of Hypersonic Waves by Ferromagnetic Resonance,* Phys. Rev. Letters, 3, pp. 83-84, July 15, 1959.

Brady, G. W., *A Study of Amorphous SiO,* J. Phys, Chem., 63, pp. 1119-1120, July, 1959.

Burbank, R. D., see Heidenreich, R. D.

Chynoweth, A. G., and Abel, J. L., *Polarization Reversal by Sideways Expansion of Domains in Ferroelectric Triglycine Sulfate,* J. Appl. Phys., 30, pp. 1073-1080, July, 1959.

Dransfeld, K., see Bommel, H. E.

Flood, W. F., *A Simple Way of Measuring the Power of High Intensity Light Beams,* Rev. Sci. Instr., 30, pp. 487-488, June, 1959.

Hays, J. B., see Bodle, D. W.

Helmke, G. E., see Pondy, P. R.

Javan, A., *Possibility of Production of Negative Temperature in Gas Discharges,* Phys. Rev. Letters, 2, pp. 87-89, July 15, 1959.

Krusemeyer, H. J., *Surface Potential, Field Effect Mobility and Surface Conductivity of*

ZnO crystals, Phys. Rev., 114, pp. 655-664, May 1, 1959.

Miller, R. L., *Nature of the Vocal Cord Wave*, J. Acous. Soc. Am., 31, pp. 667, June, 1959.

Pondy, P. R., and Helmke, G. E., *Measuring and Controlling Dust*, Symposium, Proc. on Cleaning of Electronic Device Components and Materials, A.S.T.M. S.T.P. 246, pp. 1-11, March, 1959.

Pondy, P. R., *A High Temperature Ceramic Metal Seal Made with Low Vapor Pressure Materials*, Proc. Fourth Nat'l Conference on Tube Techniques, p. 29, July, 1959.

Prince, E., and Abrahams, S. C., *Single Crystal Automatic Neutron Diffractometer*, Rev. Sci. Instr., 30, pp. 581-585, July, 1959.

Ralston, A., *A Family of Quadrature Formulas which Achieve High Accuracy in Composite Rules*, J. of the Assoc. for Computing Machinery, 6, pp. 384-394, July, 1959.

Sanders, J. H., *Optical Maser Design*, Phys. Rev. Letters, 3, pp. 86-87, July 15, 1959.

Schimpf, L. G., *Carrier Transmission for Closed Circuit Television*, Electronics, 32, No. 24, pp. 66-68, June 12, 1959.

Stone, H. A., Jr., *The Field Effect Tetrode*, I.R.E. Nat'l Convention Record, 7-Part 3, pp. 3-8, 1959.

Turner, D. R., *Junction Delineation on Silicon in Electrochemical Displacement Plating Solutions*, J. Electrochem. Soc., 106, pp. 701-705, Aug., 1959.

Turner, D. R., *Electroplating Metal Contacts on Germanium and Silicon*, J. Electrochem. Soc., 106, pp. 786-790, Sept., 1959.

Varnerin, L. J., *Stored Charge Method of Transistor Base Transit Analysis*, Proc. I.R.E., 47, pp. 523-527, April, 1959.

PATENTS

Following is a list of the inventors, titles and patent numbers of patents recently issued to members of the Laboratories.

Atalla, M. M., Scheibner, E. J. and Tannenbaum, E. — *Fabrication of Semiconductor Devices Having Stable Surface Characteristics* — 2,899,344.

Busch, K. J. — *Magnetic Radar Pulse Duration — Clipper and Damper* — 2,898,482.

Dreyfuss, H. and Pferd, W., — *Design for a Coin Telephone Set* — D-185,799.

Dubuar, A. S. — *Dial Telephone System Arranged for Machine Announcement on Intercepted Calls* — 2,899,503.

Goodall, W. M. and Rowe, H. E. — *Broad-Band Amplifier Employing Parallel-Series Coupling Network* — 2,899,508.

Hoesterey, D. C. — *Piezoelectric Field Effect Semiconductor Device* — 2,898,477.

Houghton, E. W. — *Wave-Guide Termination* — 2,901,711.

Hussey, L. W. — *Transistor Test Set* — 2,899,642.

Johannesen, J. D., Myers, P. B. and Schwenker, J. E. — *Switching Circuit* — 2,899,570.

Kircher, R. J. — *Diode Circuits* — 2,899,569.

Kompfner, R. — *Apparatus Utilizing Slalom Focusing* — 2,899,597.

Lovecky, A. J. — *Wire Unwrapping and Rewrapping Tool* — 2,898,952.

Lynch, R. T. — *Method of Manufacturing Sintered Cathode* — 2,899,299.

Matthias, B. T. — *Ferroelectric Devices* — 2,901,679.

McCarthy, J. A. — *Electron Discharge Device* — 2,899,577.

Miloche, H. A. — *Switching System Network* — 2,901,547.

Moll, J. L. — *Transistor Test Set* —2,900,582.

Mueller, R. L. and Stieritz, W. G. — *Gaseous Discharge Device* — 2,899,588.

Myers, P. B. see Johannesen, J. D.

Myers, P. B. — *Switching Circuit* — 2,899,571.

Ohl, R. S. — *Method of Treating Silicon Surfaces* — 2,900,702.

Peek, R. L., Jr.—*Circuit Controlling Device* — 2,898,422.

Pferd, W., see Dreyfuss, H.

Read, W. T., Jr. — *High Frequency Negative Resistance Device* — 2,899,646.

Read, W. T., Jr. — *High Frequency Negative Resistance Device* — 2,899,652.

Rogers, S. C. — *Sampling Circuit* — 2,900,507.

Rowe, H. E., see Goodall, W. M.

Scheibner, E. J., see Atalla, M. M.

Schwenker, J. E., see Johannesen, J. D.

Slonczewski, T. — *Oscillator Automatic Tuning Circuit* — 2,899,643.

Stieritz, W. G., see Mueller, R. L.

Sullivan, Michael V. — *Burst Separator for Color Television* — 2,901,532.

Tannenbaum, E., see Atalla, M. M.

Teal, G. K. — *Method of Making Electrical Resistors*—2,901,381.

Theuerer, H. C.—*Method of Preparing Silicon* — 2,901,325.

Tryon, J. G. — *Binary Adder-Subtracter* — 2,899,133.

Younker, E. L. — *Binary Half Adder* — 2,901,602.

Charles W. Hoover, Jr.

Charles W. Hoover, Jr., a native of Akron, Ohio, received a B.E. degree in Mechanical Engineering in 1946 from Yale University and a B.S. degree in Electronics Engineering from M.I.T. in 1947. Following graduation from M.I.T., he spent three years as an electronics and technical officer in the U. S. Navy, where he taught a course in airborne early warning radar and operated a group of A.E.W. aircraft in the fleet. In 1950, he returned to Yale, where he received the M.S. degree in 1951, and the Ph.D. degree in 1954 both in physics. At Yale, Mr. Hoover developed and constructed a proton linear accelerator and contributed to the development of the heavy-particle linear accelerator now in operation there. He also worked on the development of high-speed counting circuitry, the neutron velocity spectrometer, and did research on the secondary-electron, resonance-discharge mechanism of breakdown at high frequency. In 1954, Mr. Hoover joined Bell Laboratories and began work on the flying-spot store memory system—the subject of his article in this issue. In this work he was particularly concerned with physical design, development of the beam-positioning system, and methods of measurement for the devices used in the system. At the present time, he is a Military Research Engineer in the Military Research Department. He is a member of Tau Beta Pi, Sigma Xi, and The American Physical Society.

E. D. Reed, author of "The Variable-Capacitance Parametric Amplifier," received his B.Sc. (E.E.) from the University of London and his M.S. and Ph.D. (E.E.) from Columbia University. Following two years of military service and a year of graduate work at Columbia he joined Bell Laboratories in 1947. Here, he was engaged in the development of microwave and millimeter wave tubes, and more recently with parametric amplifiers. He is presently associated with exploratory development of maser amplifiers and microwave ferrite devices.

E. D. Reed

J. M. Manley was born in Farmington, Missouri, and received the B.S. in E.E. degree in 1930 from the University of Missouri. He joined the Transmission Research Department of the Laboratories in the same year and has been associated with it since that time. For a number of years, his work was analysis of and experiments on magnetic modulator circuits, including carrier-frequency generators, subharmonic generators, and high-power pulse generators for radar during World War II. Following this, he worked on the trials of pulse code modulation in 1947 and new multiplex methods. In 1956, he joined a group doing research on transmission lines. He is a Senior Member of I.R.E. and a member of the A.I.E.E., Sigma Xi and Tau Beta Pi. Mr. Manley is the author of the article "Communicating With Large-Scale Computers" in this issue.

J. M. Manley

A. S. Middleton was born and raised in New York City. He joined the Laboratories in 1945 as an assembler and wireman. In 1948 he became a technical assistant and worked with a group which prepared educational information on the No. 4-type toll switching systems. During this period he participated in the 4A training school conducted by the Laboratories for Operating

A. S. Middleton

AUTHORS (CONTINUED)

J. T. Nelson

Company personnel. In 1952 he joined the 4A Circuit Design Group where, as an associate member of the technical staff, he worked on a number of circuits—particularly link circuits and trunk-test circuits. Mr. Middleton is the author of "No. 4 CAMA and the 'Bylink' Circuit" in this issue, and has recently become a member of the No. 5 Crossbar Marker Group at the new Columbus, Ohio, Laboratory unit.

J. T. Nelson, co-author of the article "An RF Power Transistor" in this issue, was born in Portland, Oregon. He received the B.A. degree in physics from Reed College in 1950, and the M.A. and Ph.D. degrees from the University of Oregon in 1952 and 1955. He then joined Bell Laboratories and engaged in the development of high-frequency, silicon power transistors. Recently, Mr. Nelson has been working on the development of diffused-base germanium transistors for use in an experimental broadband submarine cable.

J. E. Iwersen was born in Staten Island, New York and received the B.S. degree from Wagner College in 1949, the M.A. in 1951 and the Ph.D. in 1955 from the Johns Hopkins University, all in chemistry. He then joined the Laboratories where he has worked principally on the advanced development of radio-frequency power transistors. Mr. Iwersen is a member of the A.C.S. and I.R.E. He is co-author of the article "An RF Power Transistor" in this issue.

J. E. Iwersen