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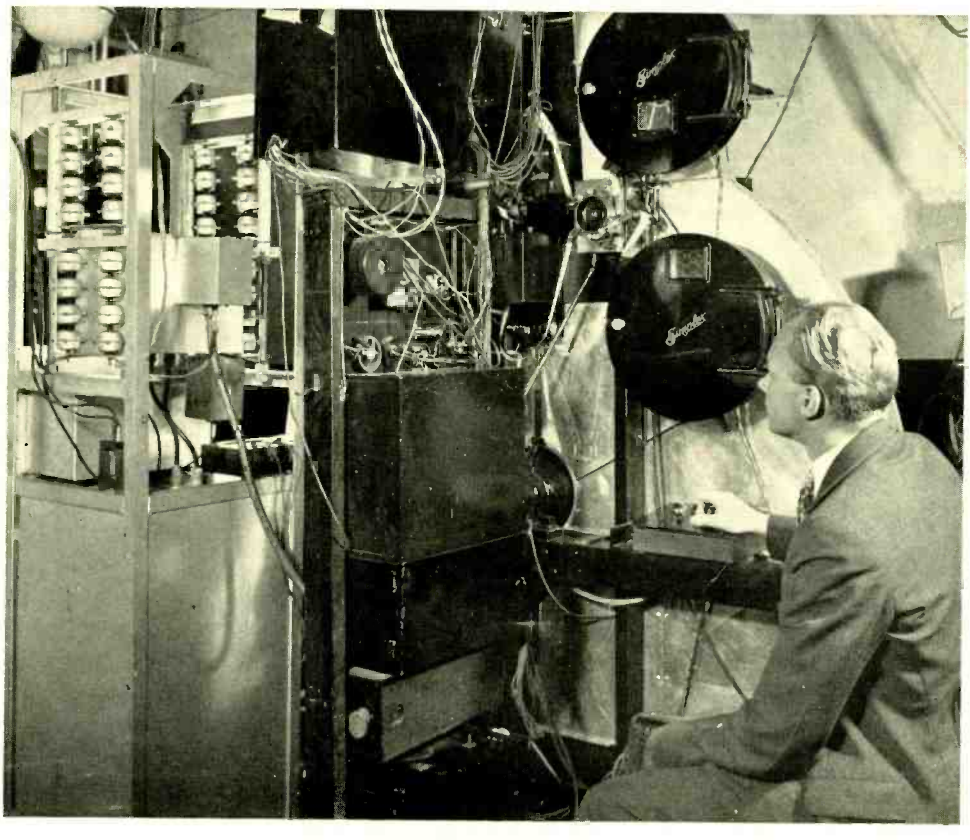
C. J. Davisson, research physicist of Bell Telephone Laboratories, winner with G. P. Thompson of the Nobel Prize in Physics.

Coaxial Cable System Transmits Motion Pictures

IN Philadelphia on November 9 executives of Bell System companies witnessed an experimental showing of motion pictures transmitted over the coaxial cable from New York City. In the Bell Telephone Laboratories in New York a sound-picture film was run through a transmitter and its two records—sound and scene—were converted into electric currents and transmitted to Philadelphia. There the picture was reproduced on a glass screen large enough for a group of ten people to see easily, while the accompanying sound came from a loud speaker. The sound picture described, by voice and animated diagrams, the coaxial cable system; and explained the operation of the picture transmitter and receiver. To study the possibilities of the coaxial system for transmitting a com-



Sending a motion picture from Bell Telephone Laboratories, New York, to Philadelphia over the coaxial cable plex current of a general type required in a television program, a motion picture was used. Its film moves uniformly past a picture gate where lenses in a large rotating disc sweep across it a light beam three-thousandths of an inch square. The beam scans the picture in 240 lines and at the rate of twenty-four frames a second. The resulting current contains frequencies between zero and about eight hundred kilocycles.

For transmission to Philadelphia this signal current is raised by modulation about one hundred kilocycles higher in the frequency range to avoid the portion of the range where transmission would be unsatisfactory and amplification difficult. The signal current is raised in frequency by double modulation and precise filtering; and a single sideband is obtained for transmission. Compensation is introduced for the different velocities of transmission of different frequency components in the band.

In transmission over the cable the lowest frequencies fall behind the highest, taking about twenty millionths of a second longer in travel. In that time the cathode beam can move forty times its width. The effect is the same as if the finer the picture details the more out of synchronism were scanning disc and cathode beam. Delay equalizers were therefore developed to keep together all the components of the current to a precision corresponding to the motion of the beam for half its width, that is, a dead-heat finish between all the frequencies to within a quarter of a millionth of a second.

At the receiving terminal, in a cathode-ray tube, the current is supplied to a set of plates so arranged that the current corresponding to the brightest spot on the film centers the electron stream on an aperture one two-hundredth of an inch square. For less bright points the beam does not center on the aperture and fewer electrons pass. The stream then passes two more pairs of plates; one of which sweeps it back and forth two hundred and forty times; and the other up and down once each twenty-fourth of a second.

The demonstration of course was not the first transmission of television image currents for long distances over wires. The first such demonstration was made by the Bell System in 1927 when television image currents were transmitted from Washington to Bell Telephone Laboratories in New York and there reproduced. In that demonstration transmission was over specially conditioned telephone circuits of ordinary construction. The characteristics of such circuits were sufficiently good for the poor grade of television picture then attainable by the equipment for scanning and reproducing (50 lines, corresponding to a band of about 22,500 cycles).

Following the demonstration Dr. Jewett made the statement that "the experimental 1,000,000-cycle repeaters on a portion of the cable are to be replaced by experimental 2,000,000-cycle repeaters, as the next orderly step in the development of equipment which will give a coaxial cable system capable of accommodating the maximum number of telephone channels which it is economical to handle on such a cable or the widest band of frequencies which the best television scanning and reproducing apparatus may require."

New Cathode-Ray Tubes

By M. S. GLASS
Vacuum Tube Development

IN telephone and radio work, a great deal of interest centers about the analysis of electrical phenomena of very short duration. This analysis requires a device which is free from inertia and able to respond to rapid fluctuations in circuit conditions. Some years ago there was developed in the Laboratories a low-voltage cathode-ray oscillograph which proved valuable for circuit analysis up to moderately high frequencies. This tube required a low pressure of inert gas to focus the electron stream. The use of "gas focusing" imposed a serious limit on the range of frequencies covered. The increasing use of higher frequencies in electrical communication has made it necessary to widen the range of frequencies which can be analyzed by this means. A new series of cathode-ray tubes (coded 325 and 326) with high vacuum and electrostatic focusing has been developed in the Laboratories to meet these requirements. The applications of these tubes include frequency and modulation measurements and wave-shape studies over a frequency band extending well up into the megacycles. They have been found especially suitable for the observation and recording of transients of short duration which require high fluorescent intensity together with good definition.

The construction of the tubes, which is the same throughout the series, is illustrated in Figure 1. A stream of electrons from an indirectly heated cathode is directed toward the fluorescent screen by a positive potential on the focusing electrode. A modulating electrode is located between the cathode and the focusing electrode and operated at a negative potential to control the magnitude of the electron stream. A collimating tube included in the focusing electrode collects the electrons which deviate too far from the axis of the tube. Emerging from this collimating tube the electrons enter the focusing field which is set up by the potential difference between the focusing electrode and the accelerating electrode. When the ratio between these two voltages is set at a definite value, the stream of electrons is brought to a sharp focus at a point on the fluorescent screen. The high positive potential on the accelerating electrode imparts kinetic energy to the electrons which is dissipated at the screen surface partly as a brilliant spot of light.

The focusing effect of the electrostatic field on the electrons is illustrated with the aid of the equipotential lines shown in Figure 1. Each line is more positive than its neighbor nearer the cathode. The force exerted on the electrons by the field is always at right angles to these lines and pulls the electrons toward the more positive part of the field. The electron paths moving away from the cathode will tend to converge in region A, diverge in region B, converge again in region C, and diverge slightly in region D. Comparing region A with region B and region C with region D, it will be seen that in each case the converging effect takes place before the electrons have been much accelerated by the field through which they are passing, while the diverging effect comes after the electrons have been subjected to a large accelerating force. Since rapidly moving electrons are much less affected by fields than slow ones, the converging effect of the field is stronger in each case than the tendency to diverge, with the net result that the electrons are brought to a focus.

It is necessary to design the electrodes for region A so as to keep down the convergence of the electron paths in that region. If this convergence is too great the electrons will pass through a focal point between A and B and be divergent when they reach region B where their divergence will be increased still further by the action of the field. Under these conditions the electron stream would spread out and a large proportion of it would be intercepted by the collimator. This would result in a very low beam intensity. In the new tubes this tendency is minimized by using a thick modulator diaphragm and by placing the emitting surface of the cathode very close to the aperture in this diaphragm.

Two mutually perpendicular pairs of parallel plates are provided in each tube to control the position of the spot. When a field is established between either pair of plates, the spot is deflected toward the more positive one by an amount which is proportional to the voltage impressed. If an alternating potential is applied the spot moves back and forth on the

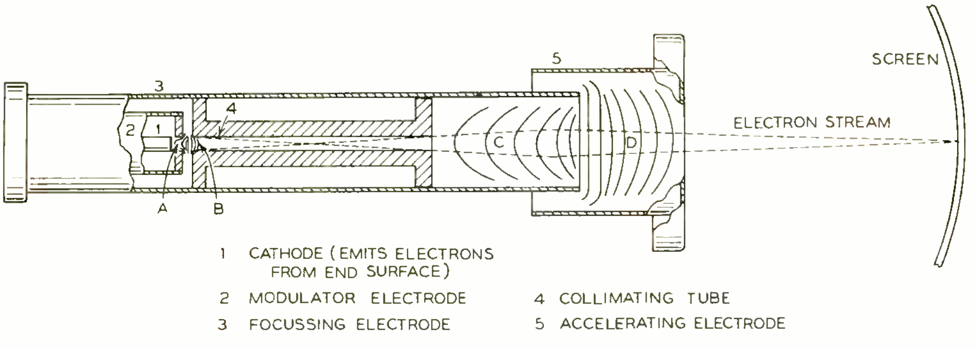


Fig. 1—A stream of electrons from a hot cathode, shown at the left end of the diagram, passes through a collimating tube and focusing field and then between two pairs of control plates which are not shown. It is brought to focus on the luminescent screen at the other end of the tube

screen in phase with the potential, and because of persistence of vision, gives the appearance of a line. If another alternating potential is applied to the perpendicular pair of plates, the spot traces out a curve which represents graphically the relation between the two alternating voltages. For this reason these tubes are commonly referred to as "cathode ray oscillographs," although they are not limited to oscillographic applications.

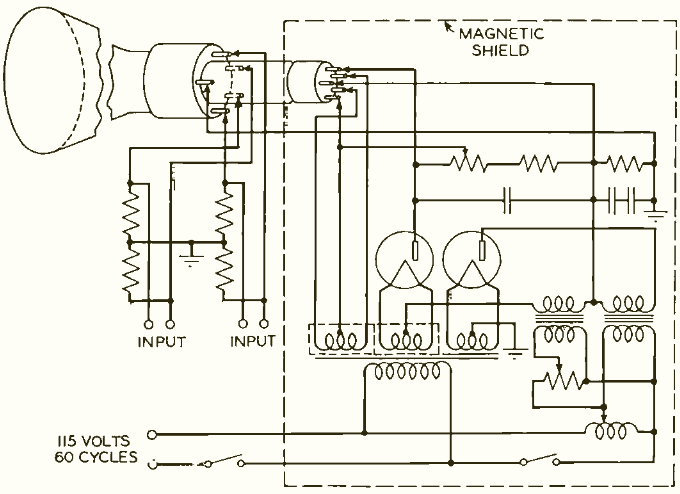


Fig. 2—Circuit diagram for the new cathode-ray tubes

Four separate leads connect the deflector plates of the tubes to external terminals. These leads make it possible to balance each pair of plates accurately with respect to the potential on the accelerating electrode so that the mid-point of the deflecting field is at that potential. This eliminates the defocusing of the spot and the distortion of the pattern which results if one plate of each pair is at or near the potential of the accelerating electrode while the other plates swing through wide variations of potential with respect to the accelerating electrode. In addition, the deflector plates are mounted in the tube in such a manner as to insure accuracy of alignment and perpendicularity of the axes of deflection.

The conducting coating on the interior walls of the bulb provides a return path for electrons which come from the screen and also serves as an electrical shield. A soft iron cylinder, if placed around the bulb, provides adequate shielding from the ordinary magnetic disturbances encountered.

The new tubes are made in two sizes which are interchangeable since focusing potentials and the deflecting potentials for full scale deflection of the spot are the same for all tubes of the series. The essential differences are in the size of the screens and the fluorescent material used in them. The maximum screen diameter of the 325 series is four and one-half inches while that of the 326 series is seven inches. Either size is available with any of three fluorescent screen materials. The 325A and 326A tubes are provided with green fluorescent screens of medium persistence and are suitable for visual observation or photography with green-sensitive film. The 325B and 326B tubes have screens of high fluorescent intensity on which an image may persist for several seconds after excitation has ceased. This fits them especially for the observation of non-recurrent or very low-frequency phenomena. The 325C and 326C tubes are provided with blue-fluorescent screens of highly actinic quality and are intended primarily for photographic

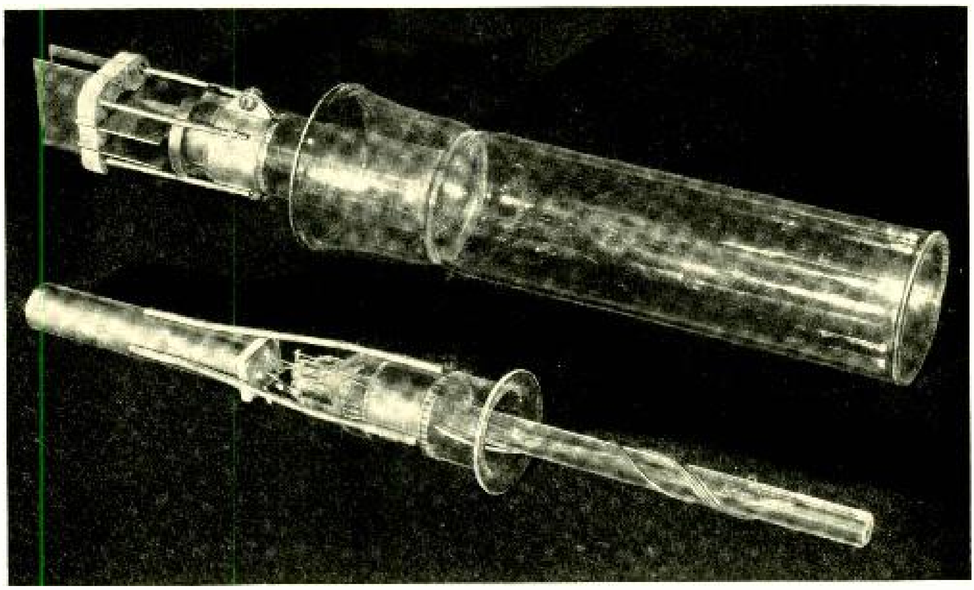
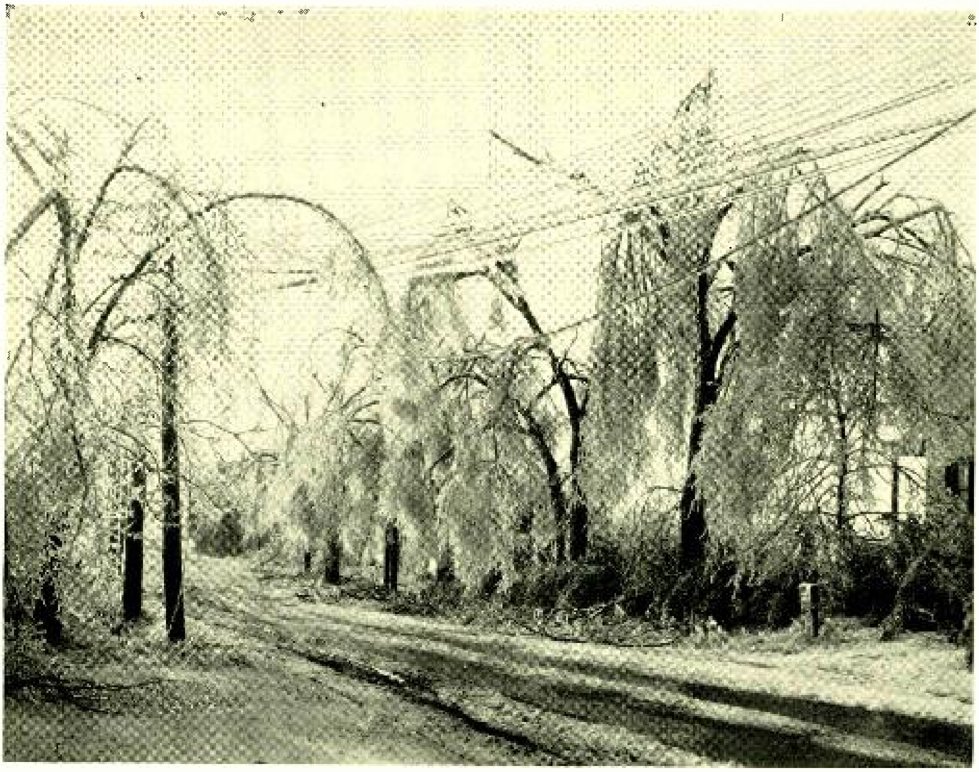


Fig. 3—The electron stream which impinges on the screen is developed by a gun which comprises an indirectly heated cathode to supply the electrons, a collimating tube and an electro-static field to accelerate the electrons and bring them to focus

recording with blue-sensitive film.

Each tube has two bases. There is a standard five-pin base attached in the conventional position at the end of the bulb which provides terminals for the cathode, cathode heater, modulating electrode and focusing electrode. The other is a special five-pin base attached along the neck of the bulb. This provides terminals for the accelerating electrode and the four deflector plates. It is accurately located with respect to the fluorescent screen and oriented with reference to the deflector plate system so that it may be used to fix the position of the tube in the mounting. There is a bayonet pin to lock the tube in position. The two bases make possible a large separation of the leads which operate at widely different potentials. This simplifies the insulation problem for the high voltages and enables the operator to shield completely that part of the tube circuit which operates far from ground potential. The use of two separate bases also permits wide spacing of leads in each base, which keeps capacities at a minimum.

To attain all the unique features embodied in these tubes it has been necessary to design a mechanical structure and a method of assembly radically different from those of any previous design. While no effort has been spared to maintain the degree of accuracy required in the assembly, it has nevertheless been so laid out as to lend itself to the use of conventional vacuum-tube machinery. Figure 3 shows partial assemblies which are later sealed together on a regular seal-in machine. A new technique which was developed for the production of the fluorescent screen has been found superior to the older methods, both in the speed of production and in the quality of screen. These various developments have made it possible to produce these highly specialized tubes without resorting to any specialized procedures.



Variation of Cable Loss With Temperature

By C. M. HEBBERT
Telephone Apparatus Development

IT IS a matter of everyday experience that changes in temperature affect the sizes of objects all around us. The Brooklyn Bridge is fitted with ingenious sliding devices in its floor to allow for the fifteen inches or more which it contracts from summer to winter. Rails on the railroad track have large gaps between them in winter but in summer fit snugly together. Pipe lines may even break due to excessive contraction during very cold weather. So it is with overhead telephone cables; they sag a bit more or shrink and draw away from the ground as the temperature varies according to seasons.

All such changes can be seen with the eye, but many other invisible changes take place at the same time. Inside the cable, which is almost continuously changing its size because of the temperature changes, there are many wires whose electrical "constants" are likewise dependent upon the temperature. It is well known that the resistance of a copper wire increases with increasing temperature although this effect is largely independent of any change in the physical dimension of the wire with temperature and is due to the physical properties of the copper. Actually the percentage change in resistance is many times greater than the percentage change in dimensions, the coefficient of linear expansion being only 0.000017 per degree Centigrade as compared with the d-c resistance coefficient of 0.00393 at 20° C. Both direct-current resistance and alternating-current resistance exhibit this increase with temperature, although the per cent change differs in the two cases.

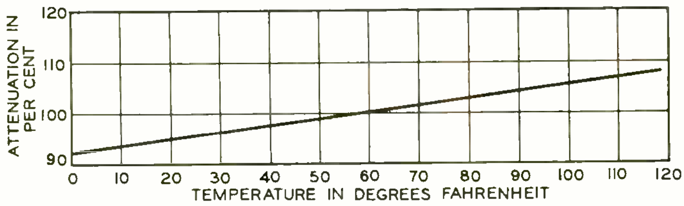


Fig. 2—Change of attenuation of nineteen-gauge cable pair with temperature at fifty kilocycles

If a pair of wires be considered, it will be found that the inductance, the capacitance between wires of the pair, and the leakage conductance also change with temperature. The inductance and capacitance depend upon both the distance between wires of the pair and upon their diameters. Heat, or lack of it, tends to change the distances and diameters, and causes a resultant change in the inductance and capacitance. At the same time internal pressure changes may be taking place which with other changes affect the characteristics of the paper between the wires. These changes show up in the capacitance differences as well as in the form of changes in the leakage between wires.

Measurements have been made on cables in the field and on a number of reels of cable in a temperature-controlled room at Bell Laboratories to determine just how large these changes due to temperature actually are. A few of the results for some 19-gauge pairs are shown by the curves of the accompanying illustrations. These show that increasing the temperature increases everything but the leakage conductance. At a frequency of fifty kilocycles the resistance increases by about twenty per cent as the temperature rises from zero to 120 degrees Fahrenheit. The conductance decreases by over sixty per cent. The changes of capacitance and inductance are smaller: capacitance increasing by only about 4.7 per cent and inductance by 1.2 per cent. The impedance of the cable also is affected by temperature variations but the effect is small. The magnitude of the characteristic impedance at

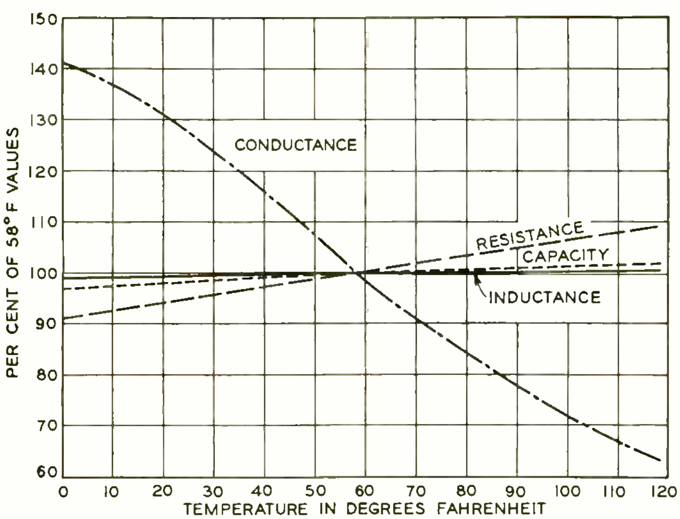


Fig. 1—Change of constants of nineteen-gauge cable pair with temperature at fifty kilocycles

fifty kilocycles decreases only about one per cent as the temperature increases from zero degrees Fahrenheit to 120 degrees Fahrenheit.

The attenuation, or transmission loss, of a cable pair depends upon the frequency and upon these so-called "constants," which the figures above show to be variable with temperature. The "constants" also are dependent to a greater or less extent on the frequency. It is not surprising, therefore, to find that the attenuation also varies with temperature, and the amount of the change differs for different frequencies. From the mathematical formula for attenuation, it can be shown that that quantity is only slightly affected by the large changes in conductance shown in Figure 1. Experimental confirmation of this is shown in Figure 2. It can also be shown that the attenuation change is caused largely by the change in the ratio of the series resistance to the series inductance. The similarity between the curve of resistance change in Figure 1 and the curve of attenuation change in Figure 2, coupled with the small change in inductance, illustrates this fact.

The actual loss in decibels per mile is shown for various frequencies and temperatures on Figure 3. Another way of expressing the variation between these curves is shown in Figure 4 where the changes in attenuation with temperature are given in decibels per degree per mile. At fifty kilocycles the loss of a mile of cable changes by about 0.0047 decibel for each degree Fahrenheit change in temperature.

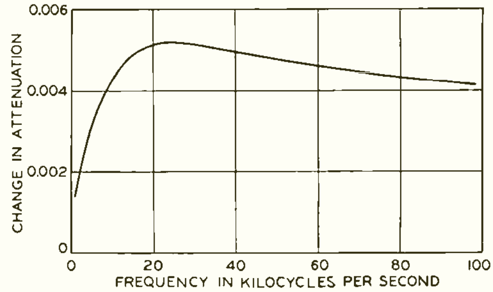


Fig. 4—Change in attenuation in db per degree F. per mile of a nineteen-gauge cable pair for various frequencies

This change in loss per mile for one degree change in temperature seems small, but even for cables only one hundred miles in length the change from summer to winter is about fifty db at twenty kilocycles. This assumes a one hundred-degree change in temperature which takes place over about a six months' period. Occasionally, however, there are drops of nearly fifty degrees within twenty-four hours' time. Such rapid temperature changes causing enormous variations in the loss of long cable circuits present a big problem in gain regulation and equalizer adjustment, since the overall char-

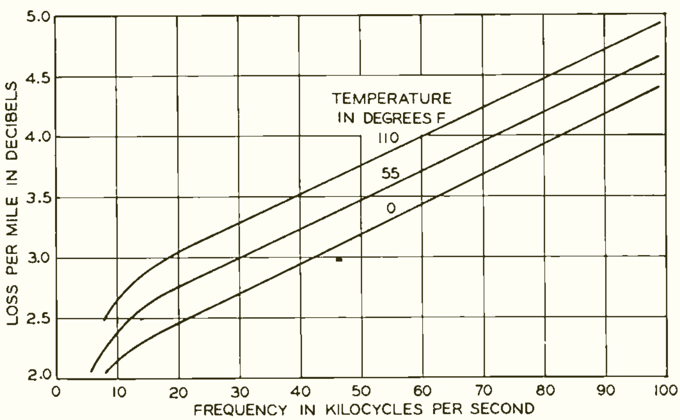
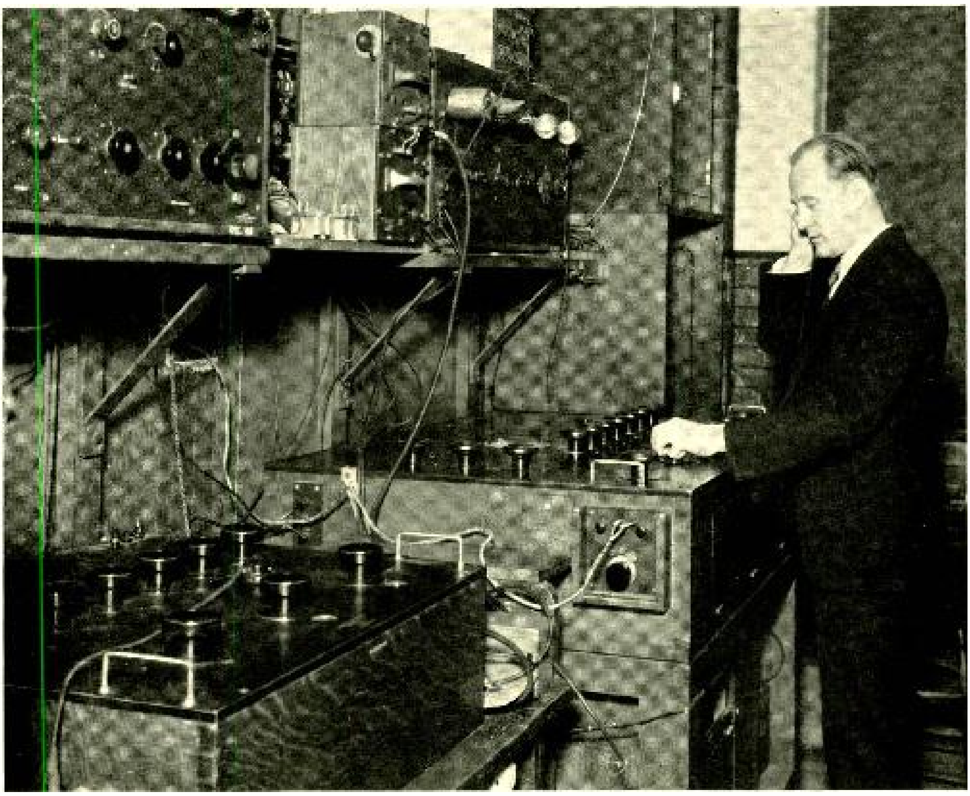


Fig. 3—Loss per mile of nineteen-gauge cable pair for various frequencies and temperatures

acteristics of a system must be kept reasonably constant at all times. It is because of this requirement that accurate knowledge of the effect of temperature changes on the cable loss is of such great importance.



Measuring changes in cable impedance with changes in temperature

Transmission Line Structures as High-Frequency Networks

By W. P. MASON
Radio Research Department

As the radio art has progressed, the tendency has been to use higher and higher frequencies so as to secure a greater number of channels. The higher the frequency,

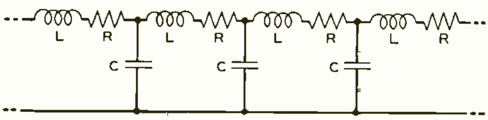


Fig. 1—Schematic representation of a transmission line

however, the more difficult it is to build such essential apparatus as filters and transformers because of the small values of inductances and capacitances required and the comparatively large effect of the interconnecting leads. Also the ratio of the reactance to the resistance of the coils, or their Q value, does not increase with frequency, and as a result the percentage selectivity of the filters, which is a function of Q, can be no greater at high frequencies than at low. This means that the frequency space required to permit the loss introduced by the filter to increase from the low value over the pass band to the high value outside the band increases with frequency, and thus efficient utilization of the frequency space becomes impossible. For use at these high frequencies it would be desirable to employ some arrangement in which the Q of the inductance elements increases with frequency.

It can be shown mathematically that a transmission line acts as an electrical network in which the resistance, inductance and capacitance are distributed in small increments along its length as shown in Figure 1. In such a line there is nothing equivalent to the interconnecting leads since both inductance and capacitance are continuously distributed so that the connecting leads reduce to zero length. Moreover, the resistance of such a line increases as the square root of the frequency, while the inductive reactance increases directly as the frequency with the result that the ratio of reactance to resistance, or the Q, also increases in proportion to the square root of the frequency. If sections of transmission lines could be connected together to form a filter, a number of advantages would be secured as compared to the ordinary coil and condenser filter.

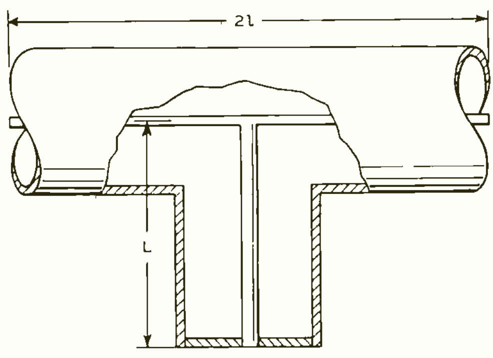


Fig. 2—A band-pass filter employing coaxial structures

As a matter of fact, sections of transmission lines can readily be connected together to form various types of filters. A section of line, with another section connected in shunt at the mid-point, for example, gives a band-pass filter providing the line is of such dimensions and construction that its inductance, capacitance, and resistance are of the proper values. For use at high frequencies, a satisfactory type of line is the coaxial structure, because it is a completely shielded transmission line, and the parameters are readily changed by varying the relative diameters of the inner and outer conductors. These advantages are also shared by a shielded-pair conductor consisting of two wires surrounded by a copper shield, and such an element is useful in balanced filter construction.

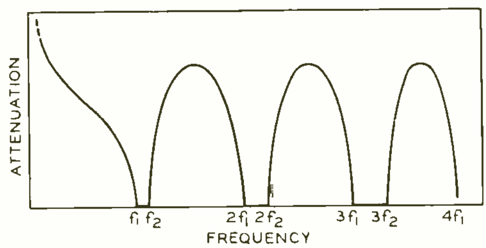


Fig. 3—Attenuation-frequency characteristic of the band-pass filter of Figure 2

One of the simplest and most useful types of transmission line filters, using the coaxial structure, is shown in Figure 2. It consists of a coaxial conductor of length $2l$ shunted in the middle by a short-circuited line of length L. If the line impedance of the side branch is half that of the main line, such an arrangement is a band-pass filter whose pass band lies between the frequencies f_1 and f_2, where f_1 is the frequency necessary to make $L+l$ a quarter wavelength, and f_2 is the frequency necessary to make l a quarter wavelength. Although transmission lines can be represented by the schematic of Figure 1, their action as filters differs somewhat from that of a conventional filter with lumped coils and condensers, since it is best represented as the transmission of waves. In this respect transmission line filters are similar to acoustic filters, as pointed out in a RECORD article (August, 1928, p. 392) which showed that the transmission-line filter is the electrical analogue of the acoustic filter.

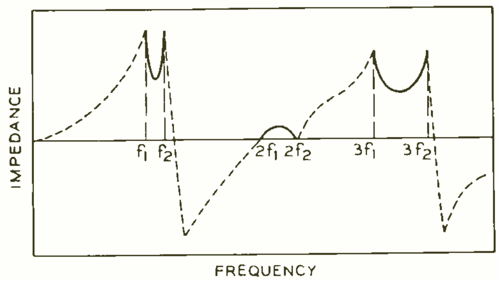


Fig. 4—Impedance characteristic of the transmission line filter

The selectivity of a filter of this type is obtained by virtue of wave interference between the direct and reflected waves in the structure. In this respect it is similar to devices in the optical field—such as the diffraction grating—which obtain a separation of waves of different frequency by wave interference. With an input voltage impressed on such a filter as is shown on Figure 2, the output current will initially be that transmitted directly through the main branch, but in the meantime an electromagnetic wave will have started down the side branch. After a short period, the current reflected from the side branch will be transmitted to the output. If the frequency of the impressed voltage is in the attenuating region of the filter, this reflected current will be out of phase with the directly transmitted current, and will result in wave interference or current cancellation, which will cause the filter to attenuate currents of this frequency. If the frequency of the impressed potential lies in the transmitting band of the filter, however, the reflected wave will be in phase with the directly transmitted wave, and the filter will transmit. The ordinary electrical filter with lumped constants can be looked on as a limiting case of the transmission-line filter in which all the coils are equivalent to very short lengths of line of very high impedance, and condensers as open circuited lines of very short lengths and very low impedances. The output current will be the sum of all the direct and reflected waves existing in the output and hence the selectivity of a coil and condenser filter can be regarded as being due to wave interference. In fact one method of calculating the transient behavior of a coil and condenser network is to calculate the direct and reflected waves occurring, assuming the elements are short sections of lines, and then to proceed to the limit by letting the line lengths approach zero.

The attenuation-frequency characteristic of the filter of Figure 2 will be as shown in Figure 3. There are a number of pass bands located at harmonic intervals; the lowest pass band will be bounded by the frequencies f_1 and f_2 already referred to, and the higher pass bands will be bounded by multiples of these frequencies. The characteristic impedance of the filter will be as shown in Figure 4. For the first band and all odd harmonic bands it will be very high, while for the even harmonic bands it will be very low. Using its first band, therefore, such a filter would be suitable for connecting high-impedance tubes as shown in Figure 5. The band width is easily regulated by changing the length of the side branch, and the impedance can be varied by changing the ratio of the diameters of the outer and inner conductors.

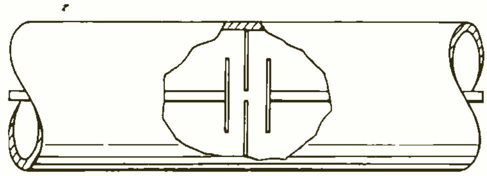


Fig. 6—A coaxial filter employing a lumped capacitance

Since the length of such filters depends on the frequencies of the pass band, it is obvious that they would become unwieldy at low frequencies. Even at thirty megacycles, for example, the length of the main conductor would be five meters. By the use of condensers, however, shorter lengths may be employed, and this use of lumped capacitances has the further advantage of spreading apart the multiple pass bands. At high frequencies this harmonic sequence of pass

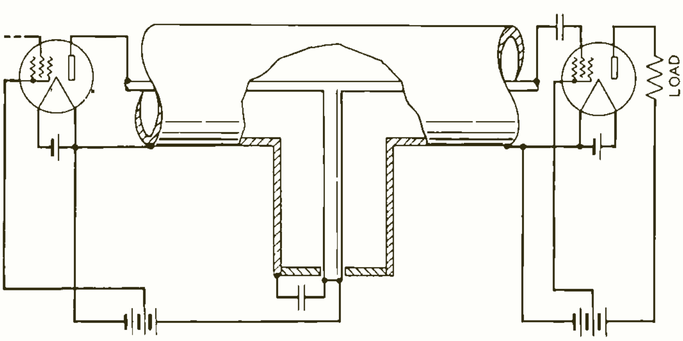


Fig. 5—One use of a band-pass filter such as is shown in Figure 4 is for connecting high impedance tubes

bands is not particularly objectionable, since the gain of vacuum tubes falls off rapidly at high frequencies. For lower frequencies, however, it is often desirable to have the secondary pass bands removed further from the main band.

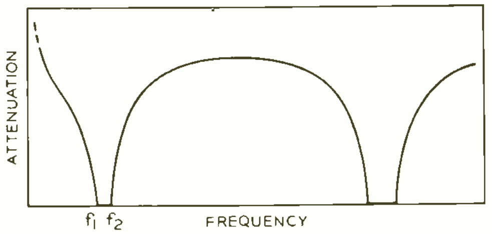


Fig. 7—Attenuation-frequency characteristic of the coaxial filter with lumped capacitance as shown in Figure 6

Such a filter is shown in Figure 6, where the lumped capacitance makes the branch circuit unnecessary. The attenuation frequency characteristic of such a filter will be as shown in Figure 7. If the series capacitance is small and the shunt capacitances large, this filter will have a very narrow pass band, and will be useful in separating radio channels which do not differ much in frequency. A measured characteristic for three sections of this type is shown in Figure 8, where it may be seen that a large insertion loss is attained outside the pass band. Such a filter has been used experimentally in connection with the radio link between Green Harbor and Provincetown to permit a transmitter and receiver to be connected to the same antenna. This filter is installed at the unattended radio station, where the coaxial conductors forming the filter run vertically up one of the poles above the platform.

Besides their use as filters, these structures may also be made to serve as transformers by combining the transmission lines and condensers in an unsymmetrical manner. One of the simplest types of this form of transformer consists of a quarter-wavelength conductor shunted at one end by a quarter-wavelength short-circuited line of different characteristic impedance. The ratio of the image impedances at the two ends remains constant at all frequencies, so that over its pass band the structure acts as a transformer to transform from one resistance at the input to another at the output.

Such transformers have many advantages at high frequencies due to their simplicity of construction, the large amount of power they can carry, and the small loss they have in their pass bands. By combining condensers dissymmetrically with transmission lines, a large number of types of transformers can be obtained which should be of considerable use in short-wave radio systems.

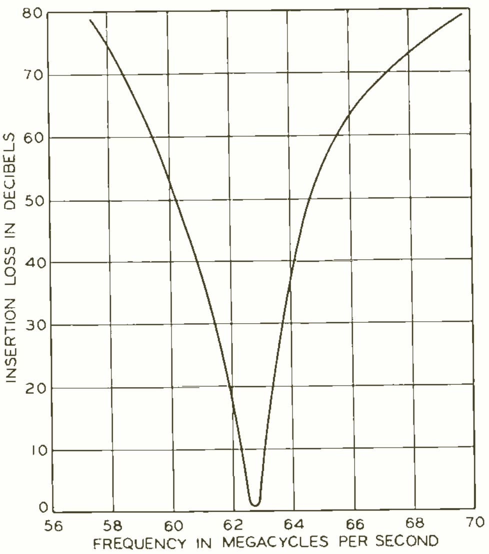
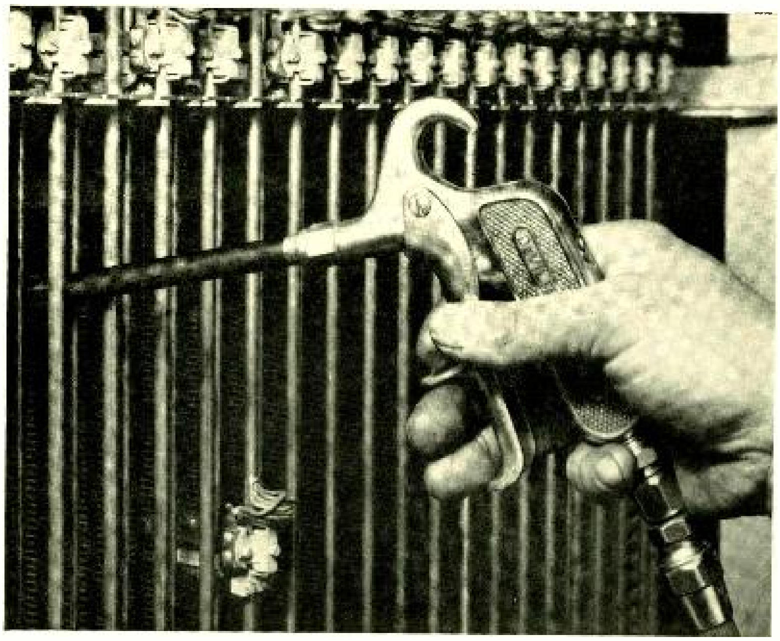


Fig. 8—Insertion loss characteristic of the lumped capacitance filter



Pressure Cleaning

By G. H. DOWNES
Local Central Office Facilities

THE problem of the most effective way of removing dust accumulations from telephone equipment has been one of increasing complexity of late years with the widespread introduction of dial central-office equipment. Contact failures of the open-contact variety, which are believed to result largely from floating air-borne dust, have been observed to contribute a major percentage of the trouble found in most central-office switching systems, and this percentage has tended to be greater in dial systems because of the larger proportion of contacting points and the many exposed contacting surfaces. Various means have been investigated for controlling the dust and lint in switchrooms both as a matter of day-to-day housekeeping and of periodic removal of long-term dust accumulations. As a result of extended investigations and field studies compressed-air cleaning has now been recommended as an aid to this work. It possesses one great advantage over other methods in that the compressed air jet reaches places otherwise inaccessible. The facilities standardized for this purpose consist of a compressor and an exhauster with their associated accessories.

The compressor unit, Figure 1, is a vertical type two-cylinder compressor driven by a one-horsepower motor. Motors are available for either 110-volt, sixty-cycle a-c, or 115-volt d-c operation, and may be operated directly from the regular frame appliance outlets without special fusing. A twenty-five-foot cord and a starting switch are included. The compressor, which weighs approximately 225 pounds, and its component parts are mounted on a framework supported by four rubber-tired wheels, two of which are of the swivel type. The dimensions have been kept to a height of thirty inches, a length of forty-two inches, and a width of eighteen and one-half inches, which permits the compressor to be used in standard aisle spaces. Many of the features of this compressor have been designed specifically to facilitate its use for pressure cleaning. The discharge line is provided with twenty-five feet of quarter-inch inside-diameter air hose which terminates in a duster type air gun, shown in the illustration at the head of this article. The pressure of the air discharge from the compressor apparatus is adjustable to values between twenty and seventy pounds per square inch through a one-sixteenth-inch nozzle orifice.

Two separators are provided in the air-discharge line of the compressor in order to remove any oil or moisture which might otherwise be present in the air discharge. The compressor is unusual in that no air storage tank is provided. An adjustable automatic tripping mechanism operates to hold open the intake valves to prevent pressure build-up beyond a predetermined limit. A safety valve is provided which will operate at a pressure of ninety-five pounds per square inch should the automatic tripping mechanism fail to function. Each compressor is equipped with all the tools and gauges necessary for

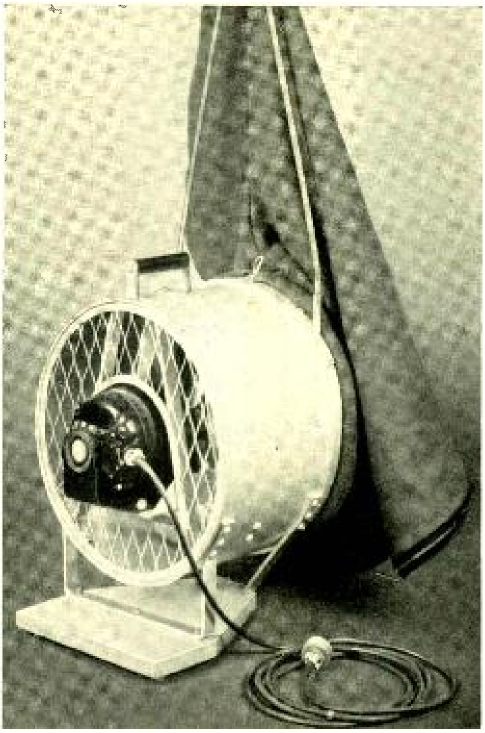


Fig. 2—Two of these exhauster sets are employed in cleaning a panel frame

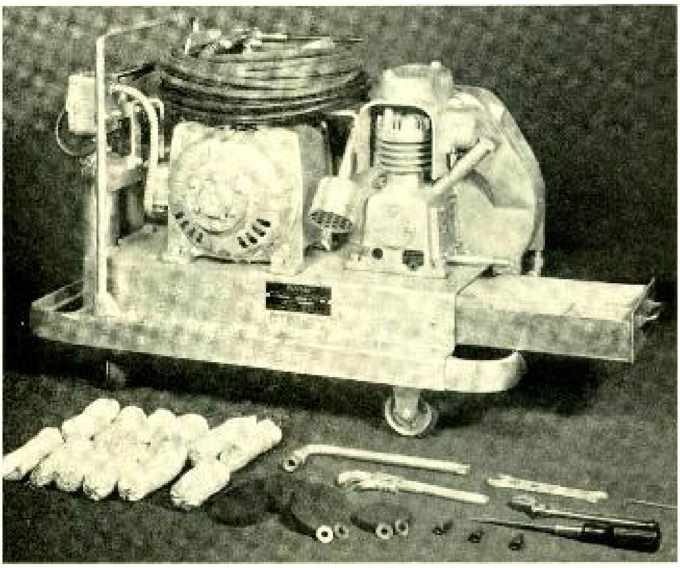


Fig. 1—Compressor for cleaning dial equipment

proper operation and maintenance.

The exhauster set, shown in Figure 2, which has been developed especially for this purpose, consists of a quarter-horsepower motor-driven six-blade fan arranged to draw air from an enclosed space and discharge it through an air filter into the switchroom. The motor is resiliently mounted, has enclosed bearings as a protection against dust, and is available for either a-c or d-c operation as is the compressor. A twenty-foot rubber-covered cord with a molded plug is provided, and the starting switch is integral with the motor housing. The dimensions are held to a width of 17⅝ inches and a length of 15½ inches so that it may be placed in equipment aisles of minimum width, and its weight of fifty pounds makes it readily portable. The filter bag is made from woven wool-felt, and is an effective air cleaner even for finely divided dust or soot. The air delivery with a clean filter is above 1500 cubic feet per minute.

When a unit of equipment such as a panel frame is being pressure cleaned, it is necessary to surround the frame with a curtain so that the dust raised in the cleaning operation may be confined. Various materials have been tried for this purpose, one of the most widely used being twill jean cotton cloth. A fireproofing solution has been recommended for the treatment of this material when so desired. The suggested method of hanging the curtains is to attach a supporting sash cord or rope and pulleys to the frame superstructure, after which the curtains are hung on this cord by hooks. The top of the curtain is attached as closely as possible to the underside of the overhead cable racks to minimize the possibility of dirt getting outside the enclosure. Such a curtain is erected on each side of the equipment unit to be cleaned and a rolling ladder is enclosed on each side. An excess of material is provided at the curtain ends so as to extend the enclosure completely around the frame to be cleaned. Binder clips are used as necessary to make the enclosure as tight as practicable. A tailored opening is provided near the floor line of one end of each curtain into which an exhauster set is inserted.

The compressor is placed in operation adjacent to but outside the curtained enclosure. The exhauster sets

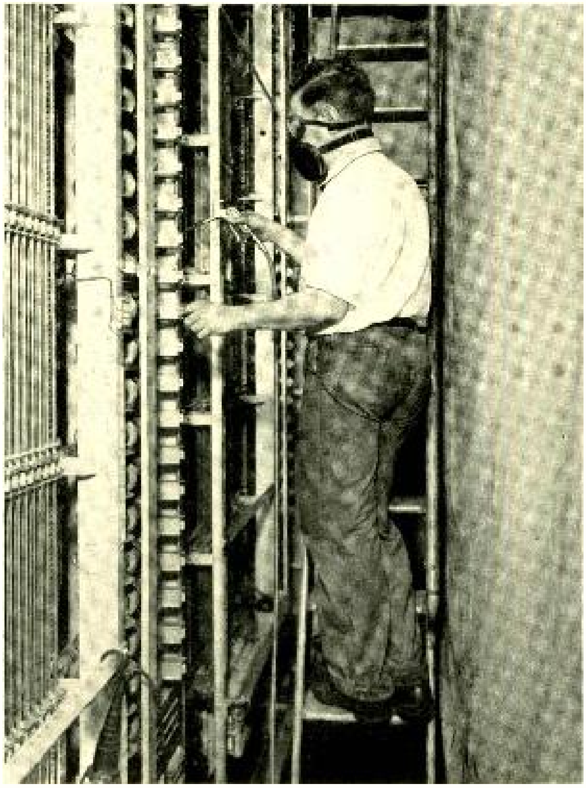


Fig. 3—A rolling ladder facilitates the cleaning of all parts of the frame

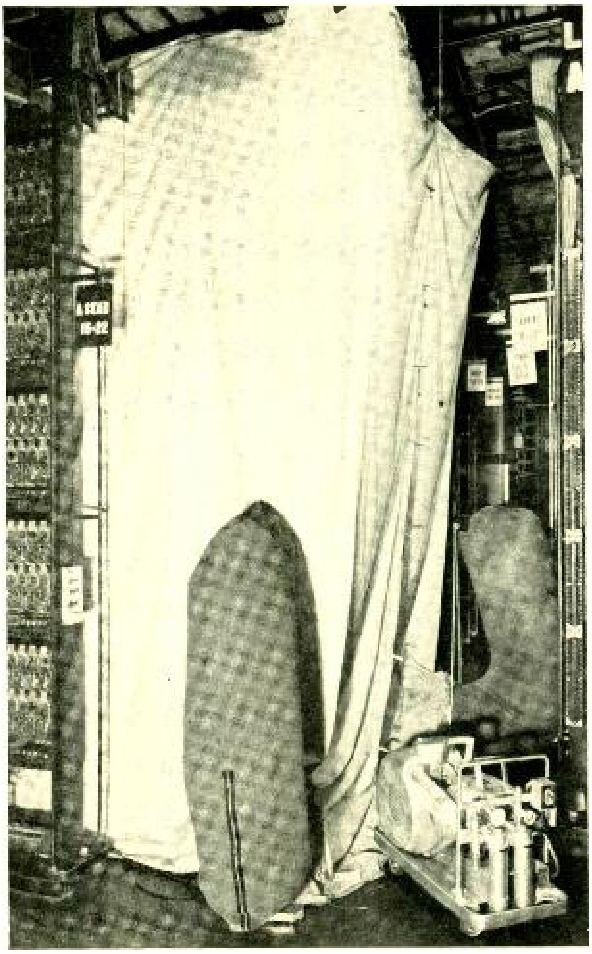


Fig. 4—For the cleaning operation a curtain is hung around the frame and two exhausters and the compressor are set outside

are started, thus producing a marked down-draft toward them within the enclosure which serves to drive the dust raised by the compressed air jet into the filter bags where it is collected and held until the bags may be cleaned in some suitable location. The arrangements for this pressure cleaning are shown in Figures 3 and 4.

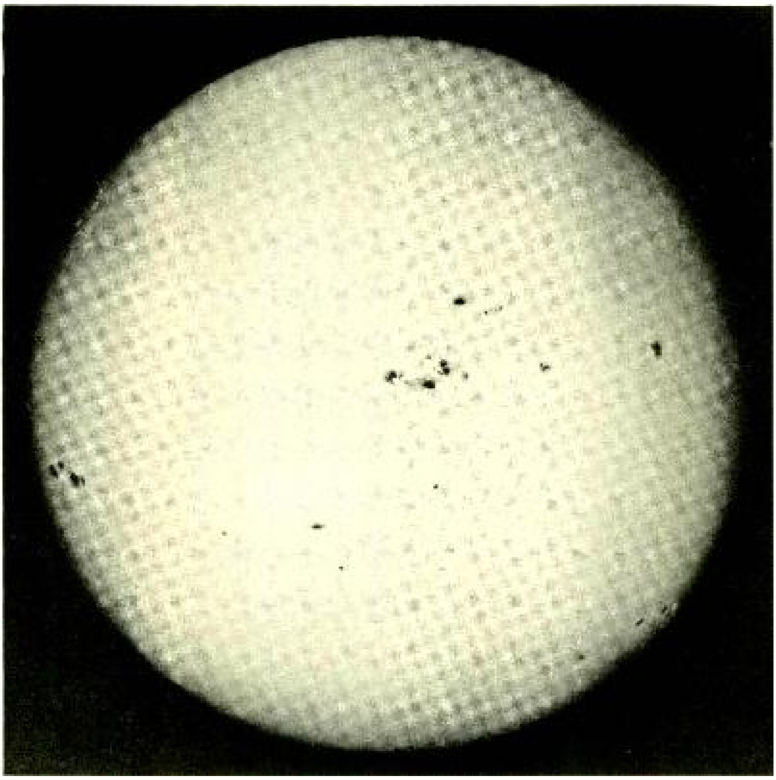
The cleaner dons goggles and a filter respirator, and the cleaning proceeds. A period of light traffic is selected and—with a panel selector frame for example—all the circuits on one side of the frame are usually made busy, and the relay covers associated with the relays of these circuits are then removed. If excess oil is present on parts of the selector frame, particularly the drive equipment, it is removed with a cleaning cloth to prevent the oil from being sprayed by the compressed air. The cleaning of the frame is preferably started at the point furthest removed from the exhauster sets and continued in an orderly manner toward the sets so as to collect the greatest possible amount of dust. If the wiring forms for the apparatus bay are furthest removed, these are cleaned first. Then the relays and sequence switches associated with this wiring would be cleaned, and finally the elevator apparatus and multiple banks on the same side of the frame, working in each bay from the top and progressing downward. An exception to this procedure is that the clutches are cleaned before any other apparatus since they are usually particularly dirty.

When cleaning wiring forms, the compressed-air duster nozzle is directed downward over the wiring so that the air stream will not be pointed directly at relay mounting plate openings. When cleaning commutators the duster nozzle is held at an angle of about thirty degrees with the commutator surface, at the same time making a downward stroke on one side of the commutator and an upward stroke on the opposite side. The sequence switches may be cleaned with the rotors revolving. For multiple banks the duster is held at an angle of about sixty degrees with the front of the bank and pointing toward the end of the frame at which the exhauster sets are located. The nozzle is held as closely as possible to the bank, and the duster gun moved slowly up and down over the bank terminals. With sensitive relays or mica-covered resistances, care is taken not to place the duster nozzle too close to the apparatus.

After the wiring and apparatus on both sides have been cleaned with the 1/16-inch nozzle and about sixty pounds pressure, a final dusting operation is performed on the framework, ladders, and the inside of the curtains using the 3/32-inch nozzle. The exhauster sets are permitted to run for a few minutes after the cleaning is completed to clear out any dust remaining suspended in the air. The relay covers are then replaced, the curtain enclosure dismantled, and the frame circuits restored to service after being routine tested. Experience has indicated that on subsequent cleanings where less dust is present, it should not be necessary to remove relay covers or revolve the sequence switches except possibly on alternate cleaning cycles.

With the exercise of reasonable care, pressure cleaning can be performed with no hazard to adjustable apparatus. Contact performance subsequent to cleaning with this method is decidedly improved as gauged by the usual maintenance indices. At times, depending on initial dust conditions, there has been some transient increase in troubles, particularly at relay contacts where covers have been removed. This condition, however, soon becomes stabilized at a lower rate of failure than obtained prior to the cleaning. The recommended interval between successive pressure cleaning operations is a rather extended one, and varies with dirt conditions in the particular locality involved.

Studies have indicated that pressure cleaning compares reasonably well with the vacuum cleaning methods generally in use from the viewpoint of man-hours expended. In one office studied, the average cleaning time per frame using compressed air was about 4.7 man-hours while vacuum cleaning required about 4.0 man-hours. This slight difference in time, however, is justified by improved performance of the equipment and by a better appearance of the central office.



Wide-World Photo.

Forecasting Sunspots and Radio Transmission Conditions

By A. L. DURKEE
Transmission Development

THAT there is a close relationship between the best frequencies for long-distance radio communication over short-wave circuits and the average number of spots on the sun has been recognized for some time. The frequencies which give the best transmission are considerably higher during periods of great sunspot activity than at times when sunspots are few. This has been attributed to increased ionization in the higher layers of the atmosphere when sunspots are numerous, with the result that the shorter radio waves are more effectively returned to the earth. In years of high solar activity severe disturbances of the earth's magnetic field occur frequently. These disturbances, known as magnetic storms, are nearly always accompanied by disturbances of short-wave transmission.

Solar activity is now approaching another peak in its well-known eleven-year cycle of change, and in view of its influence on radio communication, its probable magnitude is of particular interest at the present time. Attempts have been made to predict the magnitudes of the peaks on the

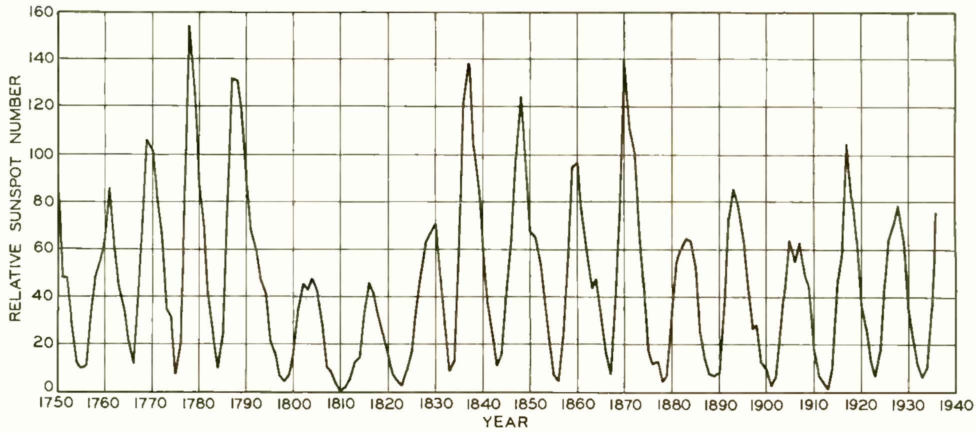


Fig. 1—Variations in sunspot activity since 1750

assumption that there are systematic, long-period variations superimposed on the eleven-year cycle, but the determination of these long-period effects is quite uncertain with the limited amount of data now available. Dependable sunspot observations go back less than two hundred years, which in terms of eleven-year cycles represents a comparatively short range of experience.

Astronomers express sunspot activity in terms of an index which is determined by the grouping as well as the actual number of sunspots present, and is called the relative sunspot number. The values of this number for each year since 1750 are shown in Figure 1. A new method of analyzing these data proposed by the author indicates the possibility of making short-range forecasts of the probable magnitude of succeeding peaks of the curve on the basis of the activity at the preceding minima. This analysis shows that the magnitude of each peak apparently is related to the average sunspot number at the preceding minimum and the rate at which the sunspot numbers begin to increase immediately after the minimum. High minima and high rates of increase tend to be followed by high maxima.

To show this relationship each maximum sunspot number was plotted against the square root of the product of the preceding minimum sunspot number and the rate of change of activity at that minimum (Figure 2). This particular function was selected by trial, and three-year averages of the relative sunspot numbers were used in determining the maxima and

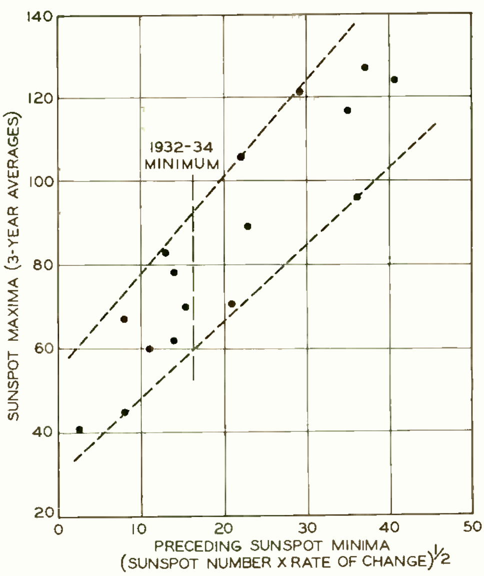


Fig. 2—Relation between sunspot maxima and preceding minima

minima. The results show a correlation which is indicated by the points all falling within the band between the two straight lines. The abscissa corresponding to the mininum of 1932-1934 is 16.2; hence it appears from Figure 2 that the three-year average sunspot number for the coming peak may fall somewhere in the region between 60 and 90.

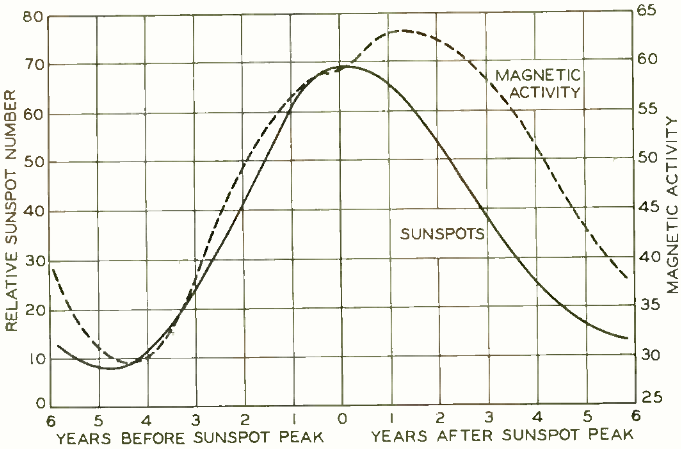


Fig. 4—Average sunspot and magnetic activity cycles

The years of highest sunspot numbers are not always those of greatest terrestrial magnetic disturbance, although both effects follow an approximate eleven-year cycle. There is a tendency, more pronounced in some cycles than in others, for magnetic activity to lag behind sunspot activity and the effect has been particularly noticeable in the last three cycles. This is illustrated in Figure 4, where the three sunspot* and magnetic-activity cycles since 1900 have been superimposed and smoothed by averaging. These results show that the peaks of magnetic activity came later than the sunspot peaks, and that a given sunspot number was associated with substantially higher magnetic activity in years following than in years preceding the sunspot peak.

*Magnetic activity is represented by numbers which are proportional to the average change from day to day of the mean horizontal intensity of the earth's magnetic field.

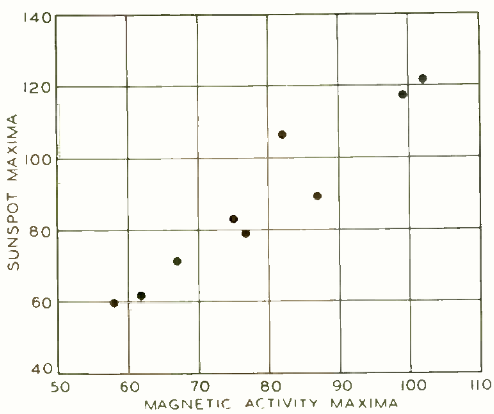
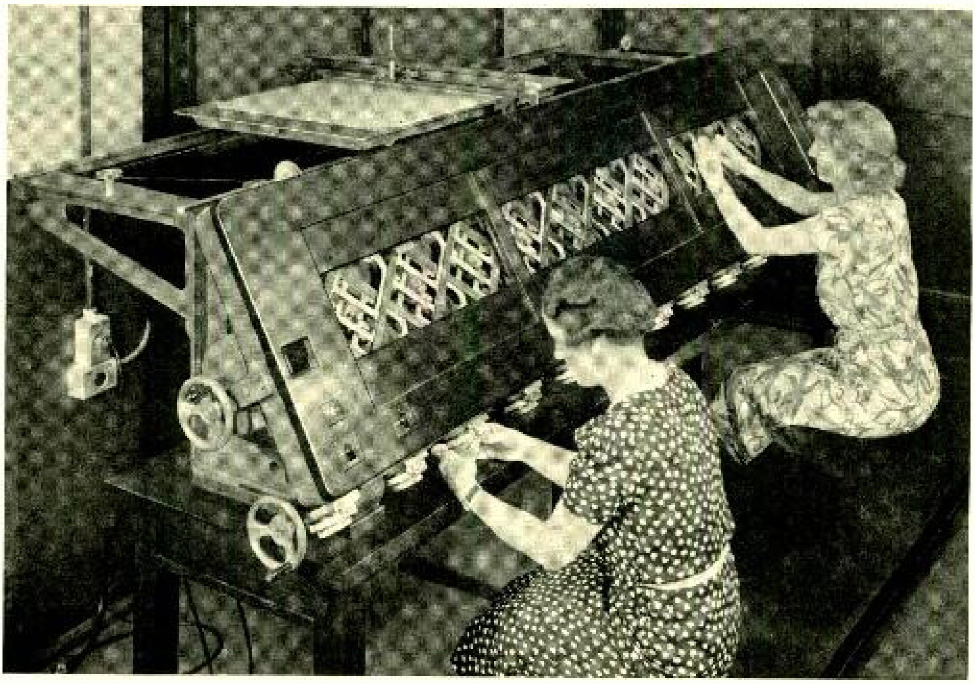


Fig. 3—Relation between sunspot maxima and magnetic activity maxima

Data on which to base forecasts of magnetic activity are more limited than those for sunspots, although consistent observations on day-to-day variations in the earth's magnetic field go back about one hundred years. In Figure 3, three-year averages taken at the peaks over this period are plotted against the corresponding, although not always coincident, average sunspot peaks. The points fall roughly along a straight line, which naturally would indicate that these factors are correlative.

These results, together with the results shown in Figure 4, suggest that a moderate peak of sunspot activity in any cycle probably will be accompanied by an equally moderate peak of magnetic activity and that the year of greatest magnetic disturbance will occur possibly a year or two after the year of highest sunspot number.



The Isograph—A Mechanical Root-Finder

By R. L. DIETZOLD
Mathematical Research Department

TO determine theoretically the behavior of an electrical network, or conversely to derive the constants of a network whose behavior is prescribed, it is necessary to know its natural or resonant frequencies. Part of the mathematical work is the solution of a polynomial equation. The degree of the polynomial, which is the highest power of the variable that occurs in it, may be high, however; and the higher the degree, the harder it is to find the roots of the equation. An eighth-degree polynomial that arose in design work some time ago required four days for its solution. Only the more important problems can justify this amount of time, and as a result it has been necessary to employ less satisfactory methods, in which the behavior of small sections of the network are analyzed separately. A study was therefore undertaken to develop an easier technique of root extraction. Although methods having marked advantages were discovered, the problem remained formidable until the isograph was invented by T. C. Fry, and constructed in these Laboratories. This isograph is shown in use in the illustration at the head of this article.

With the help of this device the roots of polynomials may be located quickly and easily, irrespective of whether they are real or complex. Neither does the presence of multiple roots complicate the process in any way. If, as sometimes happens, only one root or pair of roots is of interest, these may be extracted without regard to the others. Since the process is one of successive and independent approximation, an error made at any point is automatically corrected by the next step. The machine will handle polynomials in which the highest power is not greater than ten, which is adequate for the design problems met at the present time, and its precision is at least as good as that of a ten-inch slide rule. This also is satisfactory, since simple methods have been developed for improving the precision of the roots to any desired extent once their values are known approximately.

To explain the principle on which the machine operates, it will be necessary to talk in terms of complex numbers, since when resistances are present in the network, as in all practical cases, the roots are themselves generally complex. Suppose, then, that $w = a_0 + a_1 z + a_2 z^2 + \cdots + a_n z^n$ is the polynomial. Any particular value

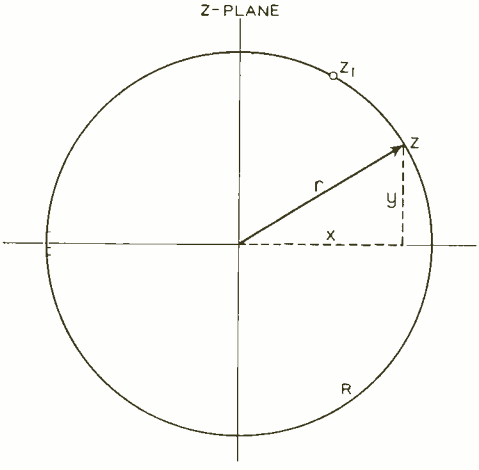


Fig. 1—The independent variable, z, of the polynomial is in general a complex number, and may be represented as above

of z, say $x+iy$, can be represented in the usual way by plotting the point whose coördinates are x and y, as has been done in Figure 1. If this

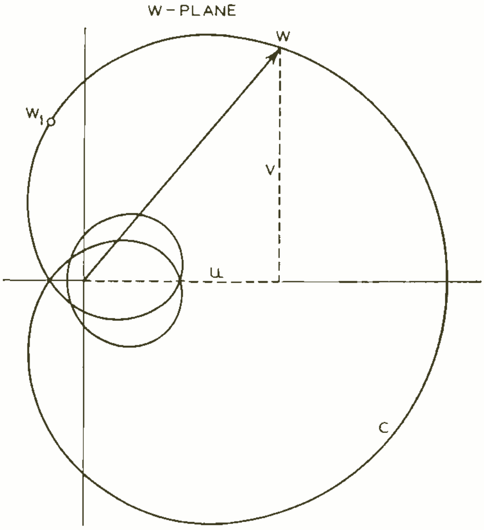


Fig. 2—For each value of z there is a corresponding value, w, for the polynomial, which is also a complex number

value of z were substituted in the polynomial it would give some particular value of w, say $u+iv$, and this can be represented by the point whose coördinates are u and v. To avoid confusion, however, it is better to plot w on a separate chart as in Figure 2. Thus to every point z in Figure 1 there corresponds a point w in Figure 2, so that as z moves to a new value z_1, w moves to a new value w_1. Further, if z follows a closed path R in Figure 1, returning to its initial value, w will follow some closed path C in Figure 2, returning to its initial value.

Now it is shown in the theory of functions of a complex variable that if there lies within the curve R no value of z for which $w = 0$, then the graph of the polynomial C does not inclose the point zero; otherwise, the number of times that C encircles the origin is just equal to the number of roots contained in R. The way in which Figure 2 has been drawn, for example, would indicate that there are three roots of the polynomial within R.

The contour R is arbitrary, and might have been drawn in many ways. The choice of a circle of radius r and center at the origin, as shown in Figure 1, however, is simple and convenient. For this choice, the number of times C loops around the origin gives at once the number of roots of absolute value less than r. Also, if $z=x+iy$ be written in the form $r(\cos\theta+i\sin\theta)$, only the parameter θ varies as z describes R, and the polynomial becomes

$$w=a_0+\sum_{1}^{n} a_k r^k \cos k\theta+i\sum_{1}^{n} a_k r^k \sin k\theta,$$

where the symbol Σ indicates the summation of a number of terms in which k assumes successive integral values. From this expression the real and imaginary parts of w can be found for each value of θ. If only the terms which depend upon θ are plotted, they will evidently give a contour C which loops around the point $w=-a_0$ once for each root of w in R.

A root of the polynomial might then be found as follows: the constant term, reversed in sign, is first marked on the w-plane. Next radii r_1, r_2, etc., are assigned successively to z, and the corresponding contours C_1, C_2, in the w-plane are computed and graphed. Suppose that C_1 loops the critical point n_1 times, and C_2 loops the point n_1+1 times. Then are n_1 roots of absolute value smaller than r_1 and one root of absolute value intermediate between r_1 and r_2. If r_3 is taken between r_1 and r_2, the absolute value of the root is located between r_3 and r_2 or between r_3 and r_1, depending on whether C_3 encircles the critical point n_1 or (n_1+1) times. By continuing in this way, one may locate the absolute value of the root within limits as narrow as desired by successive approximations. If such a value is assigned to r that the root lies on R, then C will pass through the point $-a_0$. Hence if C passes through the critical point as nearly as can be told from the graph, the root is located to within the precision of the plot. The magnitude of the root is r, and the angle of the root is the value of θ for which the point on C coincides with $-a_0$.

In Figure 3 is shown a set of curves taken from the solution of an eighth-degree equation having four pairs of conjugate complex roots. A value of 0.5 for r gives a curve entirely to the right of the point $-a_0$, and thus indi-

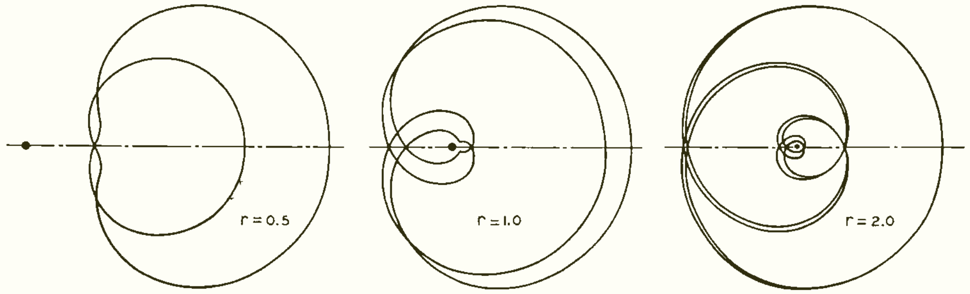


Fig. 3—By assuming three values for r, 0.5, 1.0 *and* 2.0, *and plotting the curve, it is found that two pairs of roots lie between* 0.5 *and* 1.0 *and two pairs between* 1.0 *and* 2.0

that there are no roots smaller than 0.5. A value of 1.0 for r gives a graph that loops $-a_0$ four times. From this curve it is known, therefore, that there are two pairs of roots smaller than 1.0 and thus that there must be two larger. By taking a value of 2.0 for r, it is seen that there are four pairs of roots smaller than 2, and thus it is shown that of the eight roots of the equation, two pairs are between 1 and 2 in value and two pairs are between 0.5 and 1.0 in value. The more precise determination of a root is indicated in Figure 4. A value of 0.65 for r shows no roots smaller, and a value of 0.69 shows one pair smaller. There is thus one pair of roots between 0.65 and 0.69 in value, and by assuming a value of 0.671—determined approximately by interpolation—a pair of roots is located at that value.

Although the theorem upon which this procedure is based had long been known, and its use as a means of locating complex roots of polynomials had even been suggested,* the labor of computing enough values of w to define each contour c was so great as to render the scheme almost fantastic. What the isograph does is to perform these computations and draw the curves c mechanically, thus eliminating the drudgery associated with the method.

The mechanism which accomplishes the curve tracing is an elaboration of the harmonic synthesizer built many years ago by Professor D. C. Miller of Case School of Applied Science. From the expression

$$w - a_0 = \sum_1^n a_k r^k \cos k\theta + i \sum_1^n a_k r^k \sin k\theta,$$

it is seen that for an assigned value of r, the real part of w is a summation of harmonic cosine terms with the coefficients $a_k r^k$, while the imaginary part is a summation of sine terms with identical coefficients. Then if cranks, one for each term, are so geared to a common shaft that as the first turns through one revolution, the second turns through two, the third through three, and so on, the displacements of a point on the k^{th} crank from two perpendicular directions are proportional to $\cos k\theta$ and $\sin k\theta$ respectively. Further, if the cranks are of adjustable length, the constant of proportionality may be made $a_k r^k$. To

*By A. J. Kempner, The University of Colorado Studies, v. 16, 1928. Professor Kempner's work was first learned of when he published a second paper in the Bulletin of the American Mathematical Society (December, 1935) while the isograph was under construction. It would appear that the possibility of drawing the C-curves mechanically had not occurred to him.

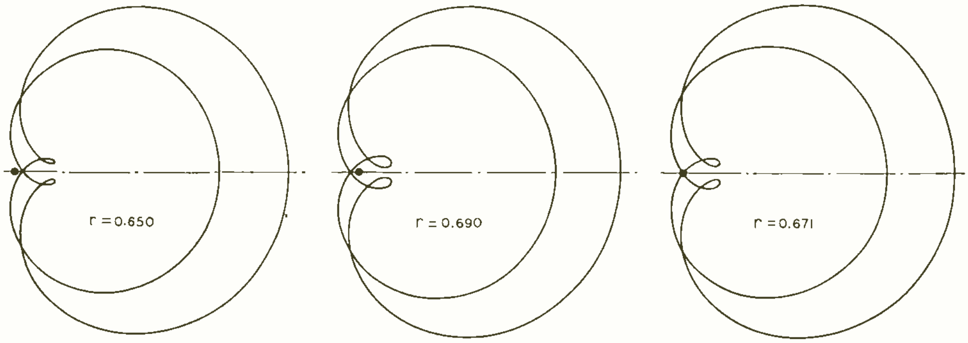


Fig. 4—By assuming values for r of 0.65, 0.69 *and* 0.671, *it is found that there is one pair of roots at* 0.671

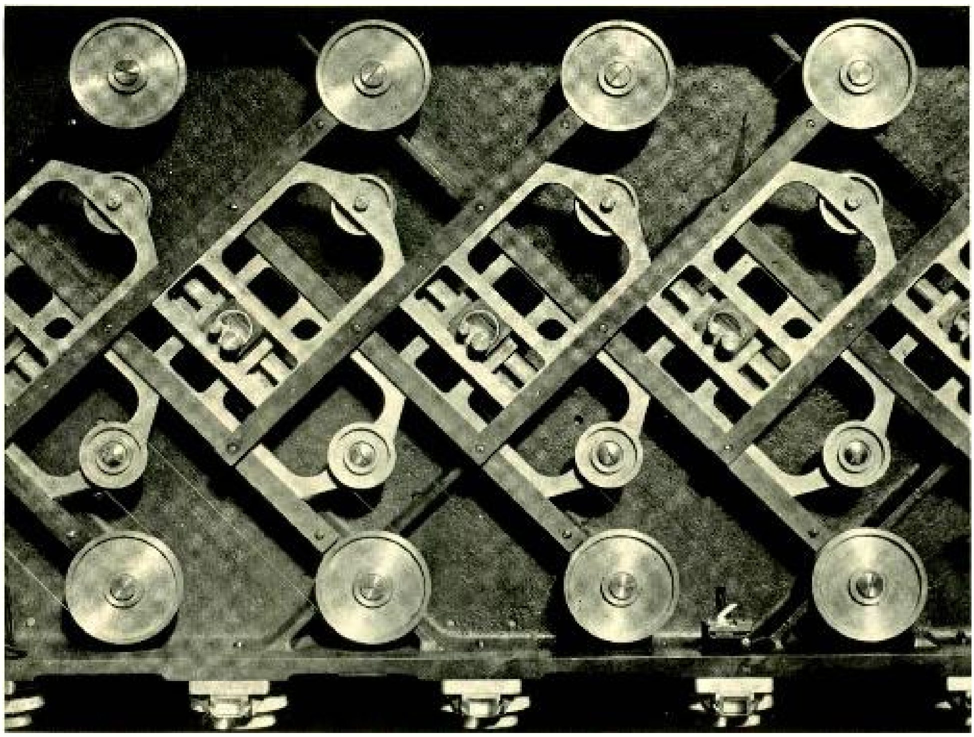
determine the real and imaginary part of w it remains only to sum up the displacements from the two directions for all the cranks. How this is accomplished is described in a companion paper starting on the next page.

Even though the c-curves are drawn mechanically for each absolute value assigned to z, if it were not for an additional feature of the machine, considerable computation would still be required in a solution. Before the cranks can be set, the crank-lengths $a_k r^k$ must all be computed, and the calculation of these products for each value of r employed would be sufficiently tedious of itself. The isograph has, therefore, been equipped with an auxiliary device, a cylindrical slide rule, for computing the crank settings mechanically.

The slide rule consists of a set of cylindrical drums, each carrying a ten-inch logarithmic scale, and driven through friction clutches by a gear system identical with that which drives the cranks. Thus the displacements of successive scales as the shaft rotates are in the ratios 1, 2, 3, etc. If the value unity is set initially to the hair line on each scale by means of the friction clutch, and the shaft then rotated until the value r appears under the hair line of the first scale, the readings on the other scales will be r^2, r^3, etc. To obtain the products $a_1 r$, $a_2 r^2$, it is only necessary to set the scales initially to a_1, a_2, a_3, etc., instead of unity. The slide rules are located each below the corresponding crank for convenience in setting up the instrument. The relative positions of slide rules and cranks may be seen in the illustration on the next page which shows a small section of the isograph with the cover removed.

During two months of operation, the isograph has provided a convenient and rapid means of root extraction. The advantages of the mechanical solution are the more conspicuous the higher the degree of the polynomial and the greater the proportion of complex roots. It was found that the equation of the eighth degree with no real roots, whose solution by previously existing methods required four days, can now be solved in one day with the help of the isograph. A more significant advantage, however, is that the mechanical solution requires no special skill and produces no fatigue in the operator, so that costly errors are avoided.

The machine lends itself also to certain incidental applications. It may be used to improve to any desired precision roots already located approximately, and it is frequently useful in evaluating polynomials for complex values of the variable. For known networks of lumped elements whose behavior can be expressed as the quotient of polynomials of not greater than the tenth degree, the isograph is also found very convenient for computing performance. If such networks form a regenerative system, such as feedback amplifiers, contours may be drawn with the isograph which loop the singing point in unstable cases in quite the same way as the Nyquist diagram. The addition of a simple attachment to drive the table at a uniform rate would fit the machine for service as an ordinary harmonic synthesizer, and open other fields of usefulness.



The Mechanism of the Isograph

By R. O. MERCNER
Research Design Engineer

THE real roots of a polynomial may be determined graphically by substituting values of the variable into the various terms and plotting the corresponding values of the polynomial. The roots are then the values of the variable at which the curve drawn through the plotted points crosses the horizontal axis. When the roots of the polynomial are complex, however, having both a real and an imaginary component, this simple graphical solution cannot be employed. In such a case a graphical solution is possible, but curves of a different sort must be drawn, and the method is far too laborious for ordinary use without some mechanical plotting device. The isograph, recently built in these Laboratories, removes most of the exacting work from this plotting process, and makes practicable the solution of complex polynomials of as high as the tenth degree.

The complex variable z of such a polynomial may be expressed as $r(\cos\theta + i\sin\theta)$ where r represents its magnitude and θ the angle that r makes with the axis of reference. When its variable is written in this form, a polynomial of the tenth degree would be written as

$$w = a_0 + a_1 r\cos\theta + a_2 r^2 \cos 2\theta \ldots\ldots\ a_{10} r^{10} \cos 10\,\theta + i\,(a_1 r \sin\theta + a_2 r^2 \sin 2\theta + \ldots\ldots a_{10} r^{10} \sin 10\,\theta)$$

For any value of r a curve can be

plotted giving the value of w — or of $(w - a_0)$ if the constant term is transferred to the other side of the equation—as the value of θ is varied continuously from 0 to 360 degrees. How plots of this type are used to determine the roots of the equation is described in an accompanying article found on page 130.

Since the independent variable in plotting the curves is an angle, what is required for the isograph is a rotating unit that provides two linear motions—one proportional to the sine and the other to the cosine of the angle. There would have to be ten of these units to provide for the ten terms of the equation, and while the first unit moves through an angle θ, the second unit must move through an angle 2θ, the third unit through an angle 3θ, and so on. Then by providing a means of summing the sine and cosine motions separately, and allowing these motions to control two perpendicular motions of a pencil and drawing board, a closed curve will be described as θ increases from 0 to 360 degrees.

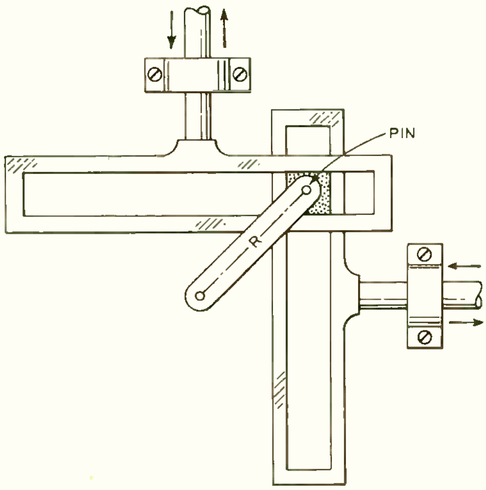


Fig. 1—A "pin and slot" mechanism is employed to derive two linear motions from a rotation

To secure motions proportional to the sine and cosine of the angle of rotation, the isograph utilizes the "pin and slot" mechanism illustrated in Figure 1. Here an arm rotating about a fixed point carries a pin arranged to slide, by means of a rectangular block, in rectangular slots cut in two slide-bars, each of which is free to move back and forth in one direction only—the two motions being at right angles to each other. These motions are equal to the length R times the sine and cosine of the angle of rotation. This is obvious from the definition of a sine and cosine as shown graphically in Figure 2. Here sin θ is equal to A/R and cos θ to B/R, so that the distance A is always equal to R sin θ, and the distance B, to R cos θ. By making the length of the arms adjustable, so that they may be set equal to the constants $(a_k r^k)$ of the equation, the displacement of the sine and cosine arms of Figure 1 are always proportional to one pair of terms. The ten units provided are geared to a com-

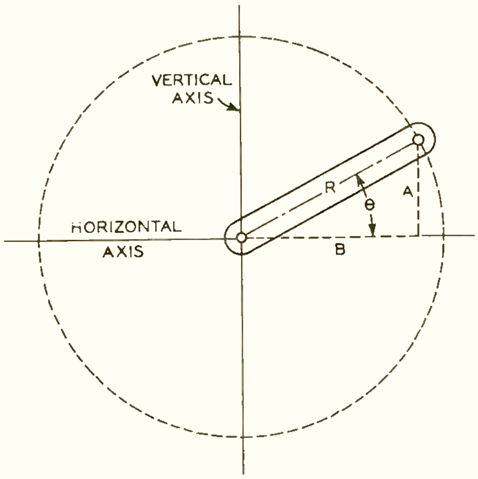


Fig. 2—As the bar rotates, the motion of one slide bar is always equal to B and that of the other to A—equal respectively to r cos θ and r sin θ

mon driving motor, but the gearing is designed so that when the arm of the first unit moves through an angle θ, that of the second unit will move through an angle 2θ, that of the third through 3θ, and so on.

To provide for summing up all the sine terms and all the cosine terms, the ends of all the slide-bars carry pulleys so that a single wire may be carried around all the sine pulleys and another around all the cosine pulleys as indicated in Figure 3. Stationary pulleys are mounted between the moveable ones so as to keep the direction of pull on the wires in line with the motion of the slide-bars. These wires control the relative motions of a pencil and drawing board to plot a curve as the angle is varied from zero to three hundred and sixty degrees.

To attain the desired results, precision of the highest order had to be maintained in building all the essential parts of the isograph. The machine was built in the Laboratories' shop so as to utilize the skill of the expert mechanical technicians. The main foundation of the machine is a cast-iron bed plate eight feet long and two feet wide made in the form of a box with shallow sides and ends about three inches high. No machining was performed on the casting for several months so as to allow sufficient aging time, and thus hold the warping to a minimum. On the back of this casting are mounted the driving motors, shafting, and worm gears that drive the ten rotating units, which are mounted on the front of the casting.

The construction of the rotating

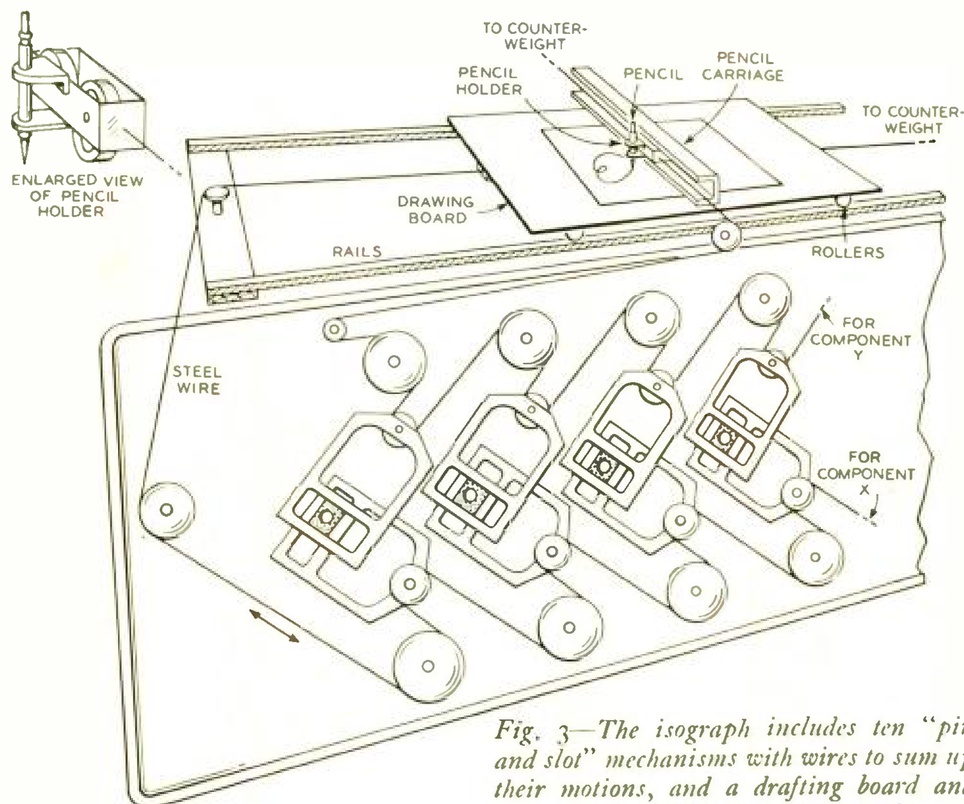


Fig. 3—The isograph includes ten "pin and slot" mechanisms with wires to sum up their motions, and a drafting board and stylus which the wires control

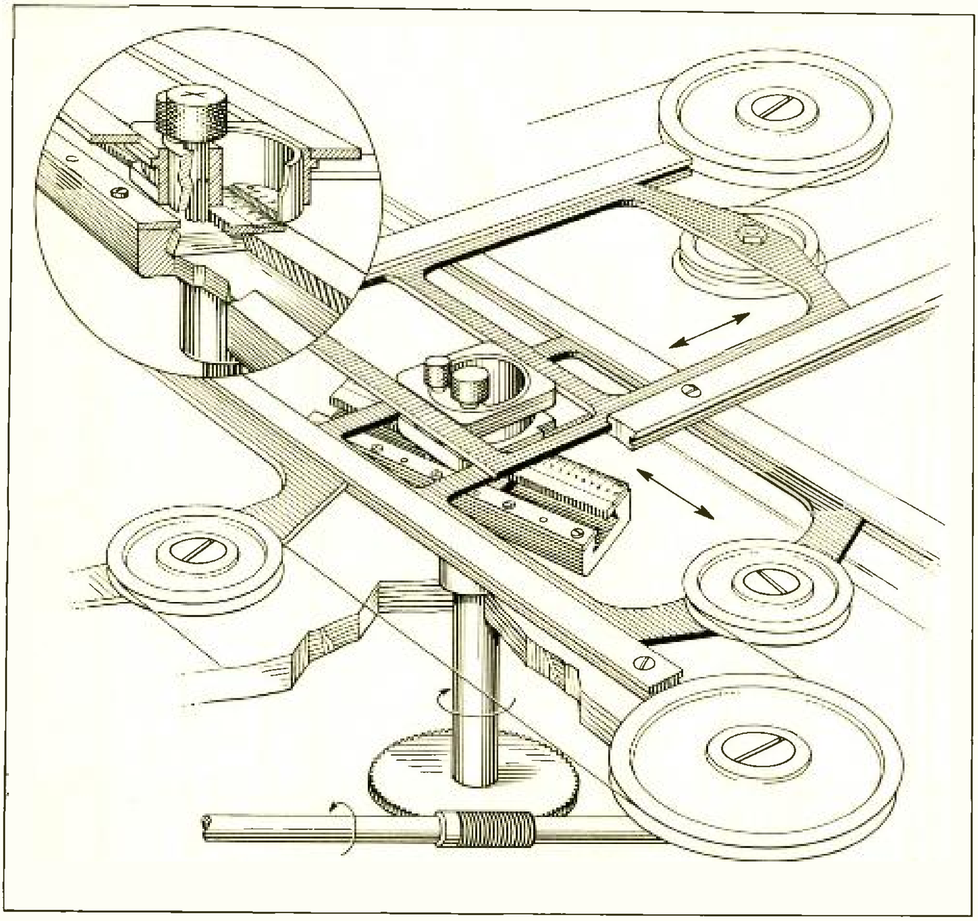


Fig. 4—Diagrammatic detail of a single pair of slide bars with their driving element

elements is shown in Figure 4. The drive shaft passes through the bed plate and is fastened to the center of a steel bar that acts as the arm of Figure 1. This bar is grooved to receive the pin of the "pin and slot" mechanism. In order that the pin may be adjusted for different crank lengths, corresponding to the coefficients $A_k'R_k$ of the various terms in the equation, a rack is cut along one edge of the groove so that a pinion attached to the pin may move it along the bar. After adjustment the pin is secured in place by a set-screw.

The top of the bar carries a carefully graduated scale to which the center of the pin must be set accurately. The scale is made visible at the center of the pin by constructing the latter as a hollow cylinder. A vernier scale within the cylinder enables the effective arm length to be adjusted very exactly to the desired value on either side of the center—one side for positive coefficients and the other for negative. The total range of adjustment is three inches.

The hollow pin turns in a rectangular bronze block which fits the slots of two slide bars, one for the sine motion and one for the cosine motion. The slide bars are identical steel plates running in bronze ways set accurately at right angles to each other. At the end opposite to the slot each plate carries a pulley around which is passed the wire that sums up the sine or cosine motions of the ten elements. One end of each wire is fixed. The other end of the cosine wire is led by pulleys to the drawing board, which consists of a thin aluminum sheet mounted on ball-bearing rollers so that it is free to move back and forth in only one direction. A counter-weight fastened to the other edge of the board keeps the wire under constant tension. The free end of the sine wire is led by pulleys to a counter-weighted pencil carriage, which is mounted with ball bearings in a fixed guide crossing the drawing board at right angles to its direction of motion. Thus the board is displaced back and forth in proportion to the sum of the cosine terms, and the pencil is displaced back and forth in a perpendicular direction in proportion to the sum of the sine terms; and this combined motion gives the desired curve.

The drive arrangement at the rear of the bed plate is shown in Figure 5. Two driving motors and drive shafts are employed. The one to the right and above drives the ten operating elements described above. The worm wheels on the ten units are all of the same size, but the worms have leads running from a single to ten, and thus give the ten speeds required. The other motor and shaft, like the first in speed and gear ratios, drives the ten slide rules mounted along the bottom of the isograph, and is used to determine the proper setting of the arms as described in the accompanying article. Each drive is equipped with an electro-magnetic clutch so that the machine may be quickly stopped or

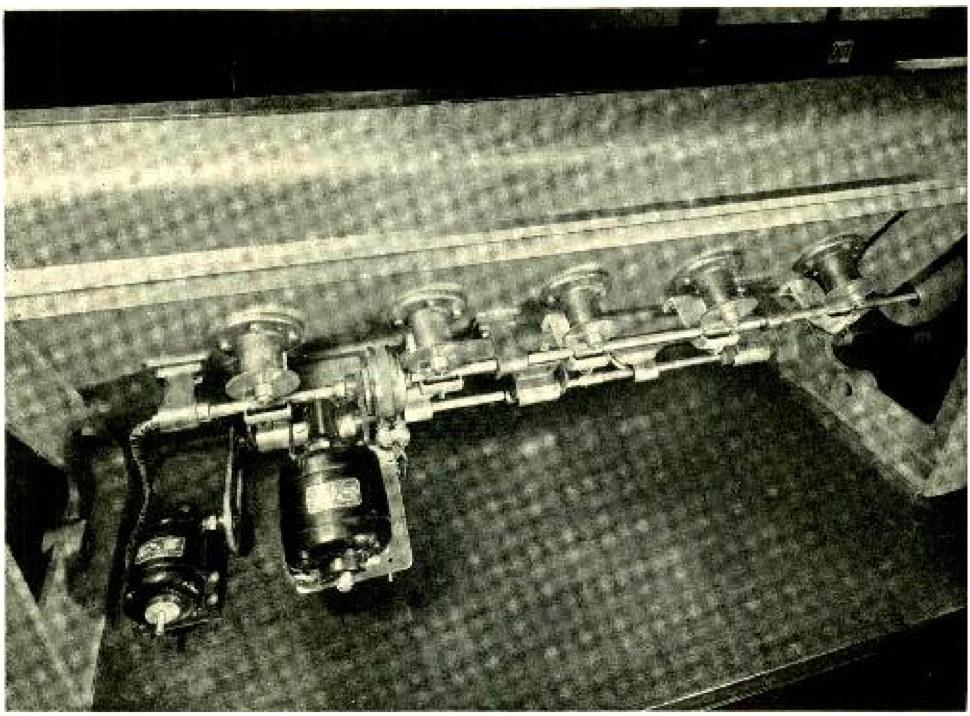


Fig. 5—The motor drive for the isograph is mounted on the back of the bed plate

started, allowing the motors to remain running. Hand wheels at the left end of the bed plate permit the isograph to be hand operated if it is so desired.

Although the mechanisms involved are not complicated, the construction of a satisfactory isograph is long and difficult because of the extreme precision with which all parts must be made and assembled. Loose motion or "back lash" must be reduced to almost indetectable amounts. After being cut, the gears were fitted to the bearings with an accuracy of 0.0001 of an inch for play and concentricity. The slide bars are lapped and fitted individually to their bronze guides to secure a minimum friction and no play. The guides are then screwed to the base plate, and then pinned in place after the final adjustment. All the pulleys have ball bearings, and are accurately adjusted for alignment. The scale by which the arm length is set is graduated to 0.025 of an inch and may be read with the vernier to 0.001 of an inch. With a little skill, however, it is possible to read to one-quarter of this amount.

A removable cover is provided for the isograph which has clear glass sliding windows over each element so that the arm lengths may be set. Safety switches are provided at each window so that, when any one is opened, the machine will stop. The main bed plate is fastened to heavy angle brackets, which allow the isograph to be set on a specially constructed table at an angle convenient for operating. These brackets are evident in Figure 5 and the position of the isograph with respect to the table is also shown in the same illustration. A bench in front of the isograph permits the operators to move readily from position to position as they set the slide rules or the arms of the elements.

Conductance in Telephone Cables

By F. B. LIVINGSTON
Outside Plant Development

IN the early days of the telephone, cables were used only for comparatively short distances and mostly for exchange-area service. The most important characteristics of such cables from the standpoint of transmission were conductor resistance and capacitance. Direct-current insulation resistance was also of importance, but mainly as a means for determining the dryness of cable insulation, and hence as a check on the integrity of the lead sheath after the cable was installed.

With the advent of loading, about 1900, much longer cable circuits became possible, and with the higher characteristic impedance of these loaded lines another property of the cable circuit became important. This property called conductance or leakance is equal for a given frequency, to the dielectric power loss divided by the square of the voltage. For direct current, conductance is the reciprocal of the insulation resistance, but when measured with alternating current of voice frequencies much higher values of conductance are found representing power losses of more complex nature than simple flow of current through the insulation.

The importance of conductance in loaded circuits is illustrated by the 450-mile Boston-Washington cable completed about 1914, for which the transmission loss caused by conductance might have been as much as twenty per cent of the total, if the regular core drying had not been supplemented by a special drying* accomplished by forcing hot dried air through the heated lead covered cable. This drying process was later rendered uneconomical by the trend toward the use of much finer gauge conductors in voice-frequency toll cable circuits caused by the development of repeaters and other transmission apparatus.

All cable characteristics vary somewhat with temperature and frequency, and early work looking toward the improvement of cable, included studies of the effects of both temperature and frequency on cable characteristics over the voice range. It was found that while capacitance, resistance, and inductance change but little with changing frequency within the voice-frequency range, the conductance increases greatly with increasing frequency.

With the introduction of special pairs in cables for high-quality program transmission and the prelimi-

*Record, *June*, 1935, *p.* 312.

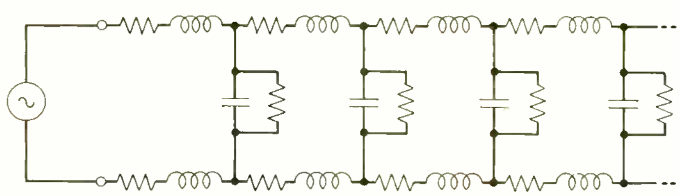


Fig. 1—Series-parallel arrangement of impedances and admittances similar to that of a cable pair except for the greater smoothness of the latter

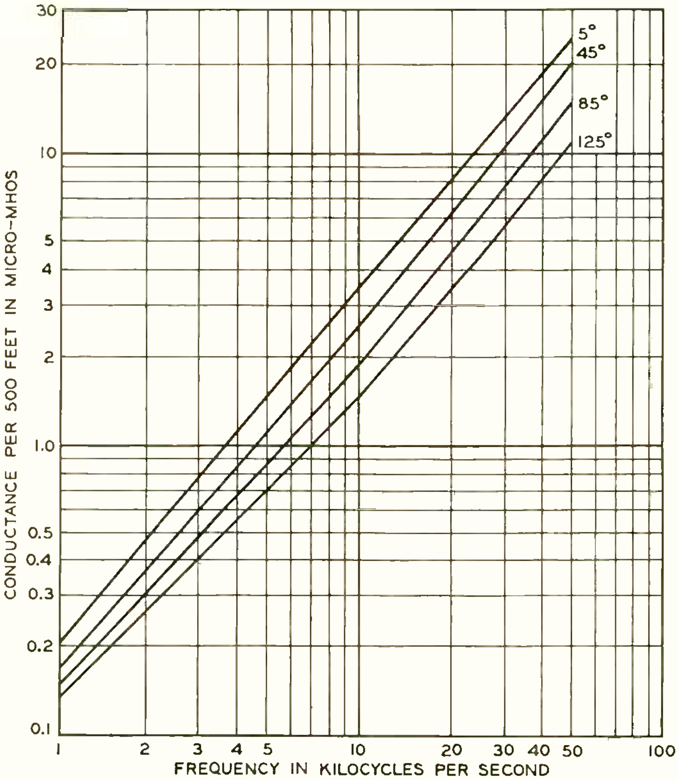


Fig. 2—Average relationship for paper-insulated toll cable between frequency and conductance for four temperatures

nary consideration which was being given to the use of carrier systems in long-distance cables, the need became apparent for better data on the effect of temperature change on the cable conductance. Such data as were then available indicated that there were wide differences in the rates at which conductance changed with temperature for different cables and even for different pairs in the same cable. Although the contribution of the conductance losses to the total attenuation loss may be comparatively small, the contribution of conductance to the variation in loss with respect to temperature change was known to be rather large and difficult to predict from the data then available. It was decided that a more extended series of tests should be undertaken to measure the variations of the primary constants of commercial cables with frequency, over the usual range of temperature to which the cable may be exposed. Several reels of cable were selected, which represented as nearly as possible the manufacturing variables affecting the cable characteristics, such as the range of dryness usually encountered in commercially dried cable, seasonal variations, and variations in the insulating paper. The capacitance, conductor resistance, and inductance were measured at the same time as the conductance, because they were needed for correcting the conductance readings as noted below, and it seemed desirable to accumulate more data on the variations of these characteristics with temperature and frequency.

The reels of cable were tested in a temperature-controlled room at frequencies ranging up to fifty kilocycles. The conductance and capacitance were measured on the shielded bridge originally devised by George A. Campbell* and subsequently refined by the Laboratories. The capacitance, conductance, inductance, and resistance of a cable circuit are distributed along the entire length of the cable in a series-shunt arrangement as indicated by the diagram in Figure 1. In an arrangement of this kind the cur-

**Electrical World and Engineer, April 2, 1904.*

rent and voltage at any point along the circuit are affected by losses in the other parts. The circuit constants at different points, therefore, have different reactions to the near end. A measurement at one end of a long line of this kind with the far end open does not therefore in general give the true total admittance of the line. In a similar way a measurement at one end of a long line closed at the far end does not give the true total series impedance. It would, of course, be desirable to confine the tests to cable lengths short enough to make this sort of error negligible, but this would involve the possibility of serious errors due to end effects and to inaccuracy of measurement, besides tending to make the sample less representative.

Calculations of the true values from the bridge readings can be made but may become very laborious, as will be seen from an approximate formula for calculating true conductance, G, from the measured values of conductance g, capacitance c, resistance r, and inductance l. This formula,

$$G = g - \tfrac{1}{3}\,\omega^2 c^2 r + \tfrac{2}{3}\,\omega^4 c^3 l\, r - \tfrac{2}{3}\,\omega^2 c g^l \ldots$$

in which ω stands for 2π times the frequency, is part of an infinite series, and is useful, therefore, only for such lengths and frequencies as will make the series converge rapidly. The error due to the omission of terms beyond those shown above is less than one per cent for a 500-foot length of ordinary toll cable at frequencies of 50,000 cycles or less. The difference between the values of conductance measured by the bridge and the true values for such a length are indicated by Table I.

Numerous readings were taken over a range of frequency and temperature, and from them the true values of conductance were calculated. The average results are plotted in Figures 2 and 3. The variation of conductance with frequency was found to follow approximately the formula $G = af^n$, where a and n depend on such conditions as the type of cable, the amount and distribution of insulating material around the conductor, the dryness of the insulation, and the temperature of the

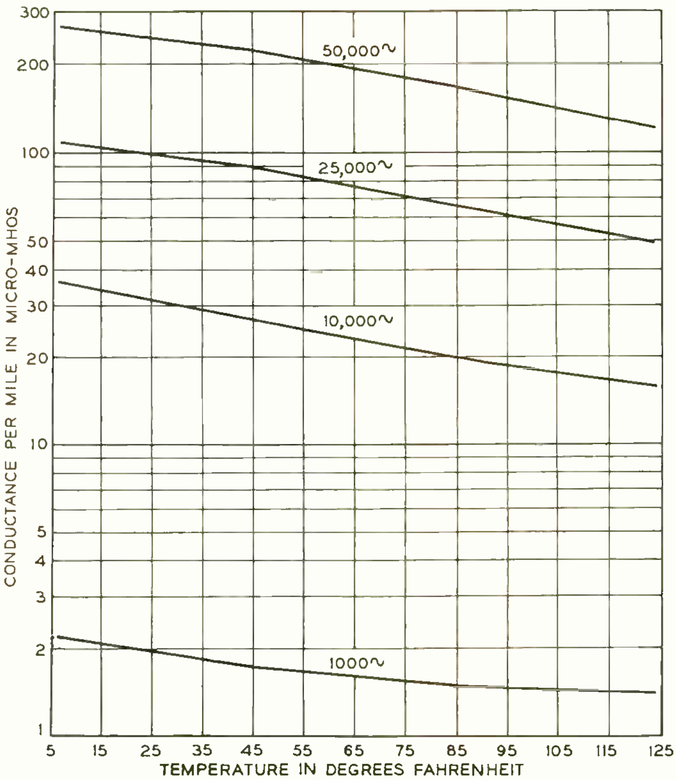


Fig. 3—Average relationships for paper-insulated toll cable between conductance and temperature at various frequencies

Table I—Measured values and true values of conductance in micromhos for a 500-foot length of ordinary 19-*gauge toll cable*

Frequency	*Measured "g"*	*True G*
1,000 cycles	.110	.110
10,000 cycles	2.06	2.00
25,000 cycles	10.70	6.95
50,000 cycles	36.0	19.0

cable. For the usual type of 19-gauge voice-frequency toll cable and for frequencies from ten to fifty kilocycles the value of n was found to be about 1.3—that is, the conductance increased as about the 1.3 power of the frequency. More recent tests on similar cables for a range of frequencies up to several million cycles showed about the same rate of increase to hold for these higher frequencies.

While it is known that this relation does not apply universally for all insulations and for all frequencies, some recent measurements on other types of cable circuits employing a number of different structural forms and a number of insulating materials other than paper showed that for these also the conductance increased with frequency up to several million cycles per second approximately according to such an empirical formula—the values of a and n depending again on the type of structure and the nature, amount, and distribution of the insulating material and its condition.

The data obtained in these studies of the effects of temperature and frequency changes on the cable conductance and other constants have been of considerable value in the design of temperature compensating equipment for program circuits and other long cable circuits and in the design of equalizing networks for cable-carrier telephone systems.

R. O. Mercner

M. S. Glass

Contributors to this Issue

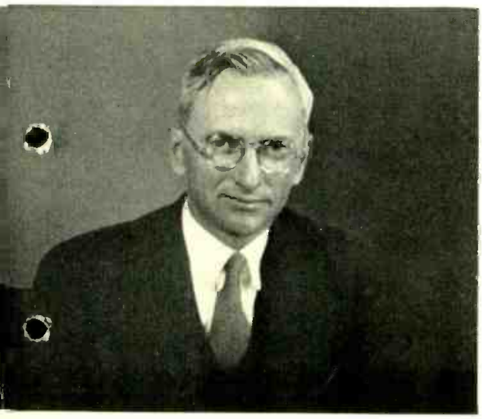
R. O. Mercner entered the Bell System as a draftsman with the New York Telephone Company in 1915. About eight months later, he joined the Engineering Department of the Western Electric Company where, with the Apparatus and Research drafting departments, he engaged in the designing of apparatus. In 1919 he entered the design group as a design engineer, and there participated in the design of vacuum-tube and radio equipment. He now has charge of the Research Design and Drafting Department.

Mr. Mercner attained his technical training in night courses at Temple University and Franklin Institute, both in Philadelphia, and Pratt Institute and Brooklyn Polytechnic Institute, both in Brooklyn.

G. H. Downes graduated from the Sheffield Scientific School of Yale University in 1920. He then spent one year as a time study engineer with the Winchester Repeating Arms Company. In 1921 he joined the Department of Development and Research of the A. T. and T. Co. and became a member of the Technical Staff of the Laboratories in 1934. He has been associated for the most part with the development of apparatus employed in manual, panel, and step-by-step systems. He has also had a part in many field studies involving such things as the source and effect of dust and dirt.

M. S. Glass received the B.S. degree from William Penn College in 1923. He devoted the two following years to teaching and the summers to study at the University of Colorado. In 1926 he received the M.S. degree from the University of Chicago and then entered the vacuum tube department of the Laboratories where he has since been engaged in development of special vacuum tubes.

A. L. Durkee received the degree of B.S. in Engineering from Harvard University in 1930 and joined the Department of Development and Research of the American Telephone and Telegraph Company in July of that year. There, and as a member of the Transmission Development Department, his work has been largely on radio-transmission problems associated with the development of trans-



G. H. Downes

A. L. Durkee

F. B. Livingston

C. M. Hebbert

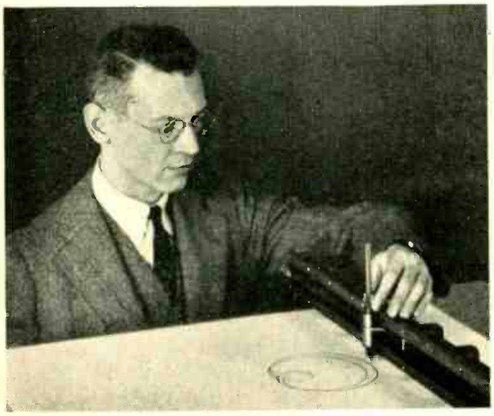
oceanic radiotelephone circuits. The study of sunspots was undertaken in connection with an estimate of transmission disturbance conditions which radio circuits may experience in the next few years.

F. B. Livingston received the B.S. degree in Electrical Engineering from the Kansas State College in 1912 and joined the Western Electric Company the same year. In 1913 he joined the lead covered cable development group, where he has taken an active part in most of the important developments since that time. Mr. Livingston has been associated with the group that provides a point of contact with the A. T. and T. Company for the other groups of the Laboratories' cable development and design engineers located at Hawthorne, Kearny and Point Breeze. This group also conducts special cable studies at the Chester Field Laboratory in New Jersey.

R. L. Dietzold received the S.B. degree in Electrical Engineering from M.I.T. in 1925, and the Ph.B. degree in Physics from Yale in 1927. After one year at Oxford University, he was appointed to an instructorship in mathematics at the Polytechnic Institute in Brooklyn, which he held two years. Since 1930 he has been a member of the mathematical research group at the Laboratories.

After graduating from Otterbein College, C. M. Hebbert was an Assistant in Mathematics at Ohio State University and the University of Illinois, receiving a Ph.D. degree at Illinois in 1917. After war service in the Aviation Ground School and a year as Instructor in Mathematics at Illinois, he joined the Department of Development and Research at the American Telephone and Telegraph Company in 1920 and worked on problems in wave propagation and inductive interference. Transferring to the Laboratories in 1929, he has been engaged chiefly on network theory and filter design and on studies basic to his present article.

W. P. Mason received a B.S. degree in Electrical Engineering from the University of Kansas in 1921 and immediately joined the Technical Staff of the Laboratories. While here he took post-graduate work at Columbia University and received an M.A. degree in 1924 and a Ph.D. degree in 1928. The first four years of his work with the Company were spent in investigations of carrier transmission systems. Since then he has been occupied in the development of wave transmission networks, both electrical and mechanical.



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