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LIFE TESTS OF DIAL APPARATUS
F. H. Hewitt

PROGRAM CIRCUITS ON OPEN WIRES
R. A. Leconte

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Philip C. Jones — *Associate Editor*

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In this Issue

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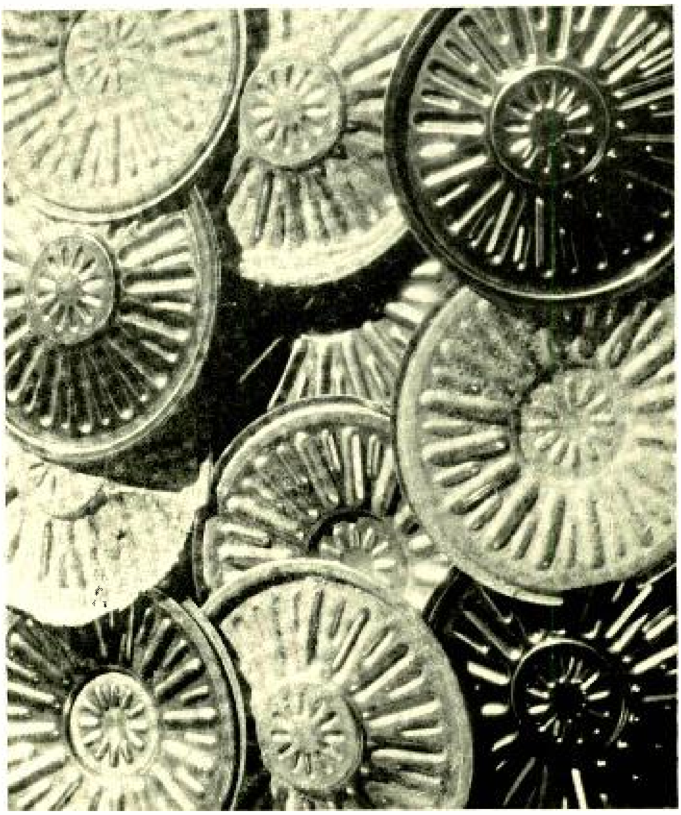

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Open-Wire Program Circuits

By R. A. LECONTE
Toll Development

CABLE circuits, because of their reliability and freedom from outside disturbances, are eminently suited for the extensive networks employed to carry the broadcast programs of the country. A cable program system*, with amplifiers and other auxiliary apparatus, capable of transmitting a band from 35 to 8000 cycles, has already been made available. There are wide stretches of country, however, which can be covered at the present time only by open-wire lines. Programs have been transmitted over such lines since the early days of broadcasting but the facilities originally employed were adaptations of existing message circuit apparatus, rearranged and supplemented to provide for a frequency band covering only the range from about 100 to 5000 cycles. These circuits gave creditable performance for moderate distances. Modifications were made later which somewhat improved these facilities, but although immediate relief was thus obtained, it seemed desirable to develop a new open-wire program system which would have general transmission characteristics comparable with those of the cable circuits.

The noise level on open-wire circuits is appreciably higher than on cables, and to maintain a satisfactory signal-to-noise ratio, therefore, a stronger signal must be transmitted. To provide for this, the new open-wire program amplifier, known as the 14-B, employs tubes of higher load carrying capacity than the cable amplifier, and arranges them in a push-pull circuit, as shown in Figure 1. High grade coils with permalloy cores having large in-

* Record, *January*, 1931, *p.* 233

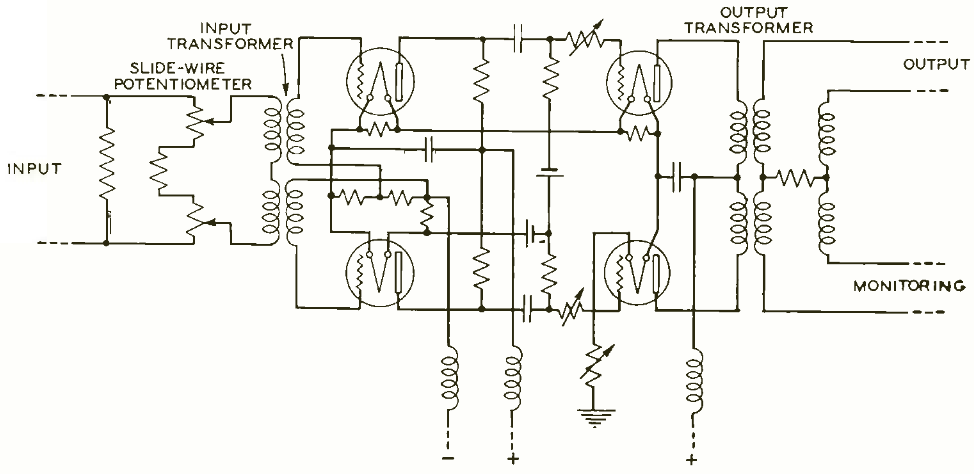


Fig. 1—*The* 14-*B amplifier uses tubes in a push-pull circuit and provides for monitoring through a dissymetrical hybrid coil*

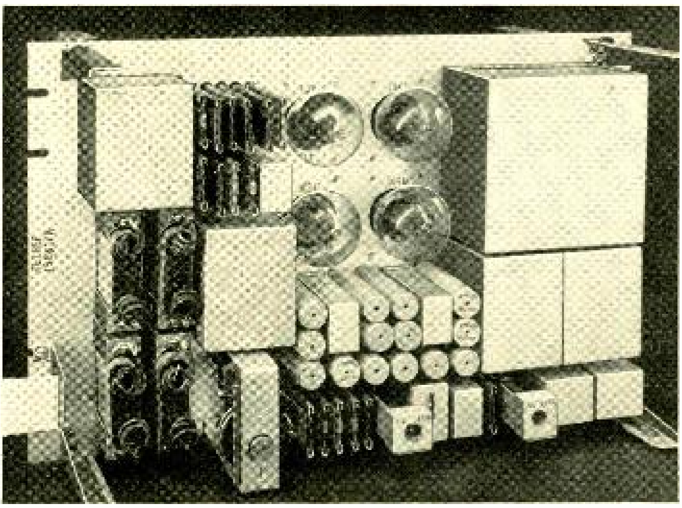


Fig. 2—The elements of the amplifier are mounted on one side of a steel plate, and overall covers, not shown, protect both the equipment on the front and the terminals on the rear

ductances, and resistance coupling between stages made it possible to obtain a small low-frequency delay. The employment of a push-pull circuit made it easier also to obtain a high-inductance output transformer, since the magnetizing effects of the two plate currents tend to cancel each other. As a result of these two features, the delay of the open-wire amplifier is only about six-tenths of a millisecond at fifty cycles. The gain of the amplifier, which is about 33 db, is constant within ± 0.1 db between 35 and 10,000 cycles.

A monitoring connection is provided through a dissymmetrical hybrid coil. This permits the signal to be transmitted from the output of the amplifier to both line and monitoring circuit, but because the number of turns on the line windings is large compared to that on the monitoring windings, the loss due to the monitoring circuit is only a few tenths of a decibel. Also, the voltage at the monitoring terminals when connected to a 600 ohm circuit is 30 db down from the voltage delivered to the line. The use of the hybrid coil arrangement has the advantage of preventing an accidental application of testing current, or short circuit at the monitoring terminals from appreciably affecting through transmission.

The amplifier equipment is mounted on one side of a steel panel, as shown in Figure 2, and all connections are on the back. Since it is essential that there be no interruptions of the program, both front and back of the panel are provided with metal covers which protect the tubes and wiring from mechanical hazards.

Since the transmission character-

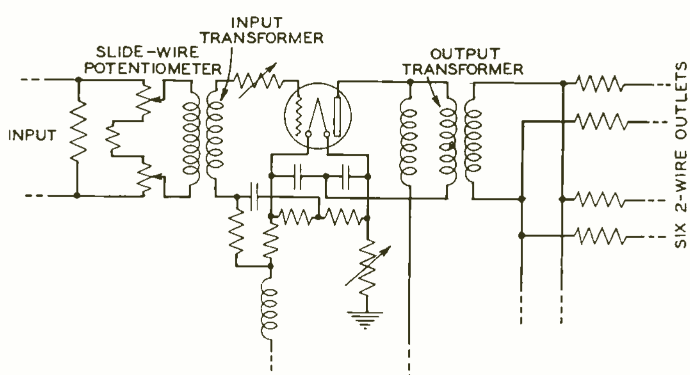


Fig. 3—The 11-F amplifier makes up for the loss occasioned by the insertion of a distributing network, which is required when several taps must be made

istics of the line are not the same for all frequencies, equalizing networks are always required, which in general are similar in function to those used with the cable circuits. These networks must be able to provide equalization for any of three gauges of wire and for a variety of repeater spacings, as well as for various weather conditions.

At frequencies above 1000 cycles, the general shape of the attenuation curve is the same for all normal variations of these three factors, but differs in slope. This makes it possible to employ a single equalizer composed of four sections. By selecting one or a combination of the four sections, suitable equalization for any existing attenuation slope may be secured. The choice of sections is obtained by operating keys on the equalizer panel.

At frequencies below 1000 cycles, however, the shapes of the attenuation curves, although in general similar for various amplifier spacings and weather conditions, differ for the three gauges of wire. Three low frequency equalizers are therefore required. Each has several sections. A basic section provides the equalization over the complete frequency range for the repeater section of minimum length while the other sections are selected by keys to secure the proper slope for various amplifier spacings and weather conditions.

In contrast to cable facilities, open-wire circuits introduce practically no delay distortion, and since the associated amplifiers are designed for low delay distortion, delay correction is not needed where the line carries only the program circuit.

Usually the pair of wires carrying a broadcast program is also used for carrier telephone communication. The carrier frequencies on this pair are prevented from interfering with the program by suitable filters, and by

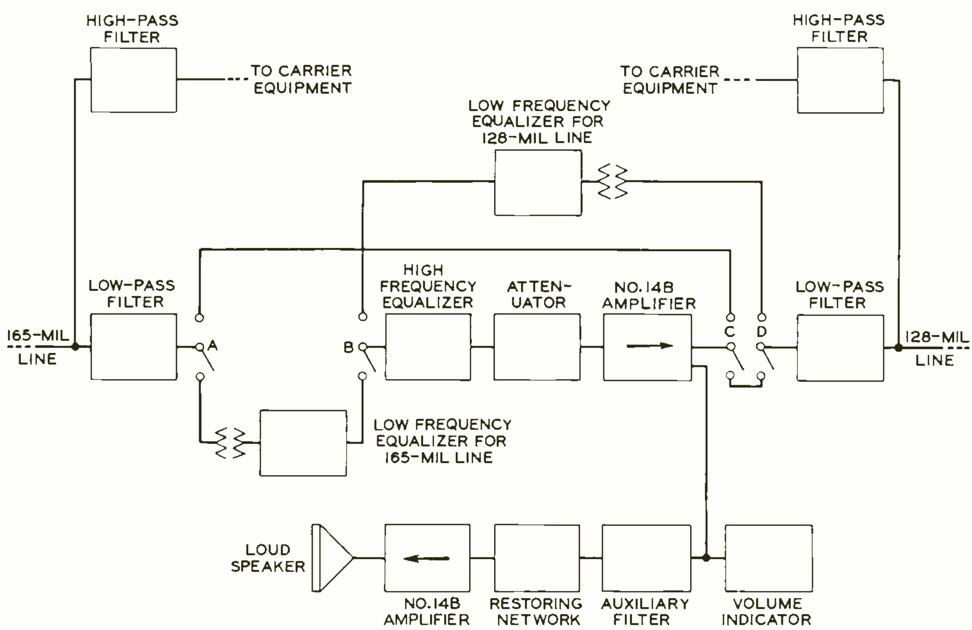


Fig. 4—By an arrangement of keys a single amplifier may be employed for transmitting in either direction

eliminating carrier channels which would occupy the same frequency band as the programs. Other pairs running along the same pole line, however, may also have carrier telephone circuits, and, since the lower carrier telephone channel may overlap the program channel in frequency, a certain amount of cross-induction from them is unavoidable. The cross-induction currents are ordinarily low in level compared to the full signal strength of the program and would not be noticeable. The various frequency components of the program, however, are not all at the same level: those of higher frequencies are generally much lower in level than those of the lower frequencies. Cross-induction is sufficiently below the level of the low-frequency components of the signal to have no noticeable effect, but this wide separation in level between cross-induction and signal may not hold for the higher frequencies in some cases.

To make the level separation satisfactory for the high as well as the low frequencies, arrangements have been provided so that predistorting networks may if desired be inserted in the program channel before amplification at the transmitting end of the line, which attenuate the lower frequencies sufficiently to bring them approximately to the level of the higher frequencies. The entire band of frequencies is then amplified to the transmitting level at which it passes over the line and through the various amplifiers. At this level the cross-induction effects are far enough below the signal to be negligible. At the receiving end of the line other networks, called restoring networks, are inserted in the program circuit, which produce a loss in the high frequency signals equivalent to that sustained by the low frequencies at the transmitting end. This network thus restores all parts of the transmitted signal to their correct relative levels, but since it attenuates the cross-induction as well as the signal, the cross-talk is as much below the signal now as it was before the attenuation, and is therefore of unobjectionable magnitude.

Program circuits differ from telephone circuits in that provision must be made to tap off connections at various points. A program originating in New York may be transmitted all the way to the Pacific Coast on a nation-wide hookup with taps at many intermediate points to branch networks or to local broadcast stations. At important key points the connections may be changed at frequent intervals and the program associated with various combinations of sections of networks and nearby stations. An arrangement for accomplishing this where the switching is complex has already been described in the RECORD.* At many points, however, the connections are of a semi-permanent nature, and the chief requirement is that the bridging of additional outlets should not affect the through transmission.

Such taps are obtained by a distributing network inserted in the circuit. The insertion of this network in the line, however, produces a loss, which is made up by a single-stage amplifier inserted in the line immediately ahead of the distributing network. The arrangement of amplifier and network, which form a single unit called the 11-F amplifier, is shown in Figure 3. One of the six outlets will be used for the through circuit and will be connected directly to the input of a 14-B amplifier, while the other five may be employed for connections to branch circuits or local stations.

*RECORD, *August*, 1932, *p.* 430

Although program circuits differ from telephone circuits in requiring transmission in only one direction, a reversal in the direction of transmission is often required. A circuit employed normally to transmit programs originating in New York, may frequently be used to transmit entertainments arising in San Francisco or some other western point. To make the fullest and most economical use of repeater facilities, therefore, it is necessary to be able to reverse the direction of their transmission in a minimum of time. This is accomplished by a simple key operation, which interchanges the connections between the lines entering an office and the input and output of the amplifier. The arrangement is shown in Figure 4, where the keys are represented by the switches A, B, C, and D. With the switches down, as in the illustration, the direction of transmission is from left to right, passing through a low-pass filter, switch A, a low-frequency equalizer suitable for the line on the left, switch B, the common high frequency equalizer, an attenuator, a 14-B amplifier, switches C and D, a low-pass filter, and on to the line to the right.

When transmission is to be reversed all switches are thrown to the up position. This removes from the circuit the low-frequency equalizer suited to the left-hand line and substitutes one suitable to the right-hand line, and carries the right-hand line around to the input side of the repeater circuit. With left to right transmission the program passes through the four switches in alphabetical order, A, B, C, and D, while with transmission from right to left, the order is D, B, C, A. When the lines on both sides of the repeater are of the same gauge only one low-frequency equalizer need be provided. Under these conditions the single low-frequency equalizer would be placed between B and the high-frequency equalizer, where it would be properly located in the circuit with the switches either up or down, and the two low-frequency equalizers shown in the illustration would be replaced by continuous conductors.

The new open-wire program transmission system provides transmission performances comparable to those of the B-22 cable program system. It constitutes an important step in the development of a nation-wide program network, and will permit a uniform high-grade transmission between any pick-up point and any group of broadcasting stations in the country.

Line Filters For Open-Wire Program Circuits

By A. W. CLEMENT
Telephone Apparatus Development

OPEN-WIRE circuits over which wide-band broadcast programs can be transmitted with greater naturalness and over greater distances than heretofore have recently been developed by the Bell System.* Whereas former open-wire program circuits have in general transmitted only up to 5000 cycles, the new circuits can transmit frequencies up to 8000 cycles. The new circuits are operated simultaneously with carrier telephone message circuits on the same wires, just as are the 5000 cycle circuits.

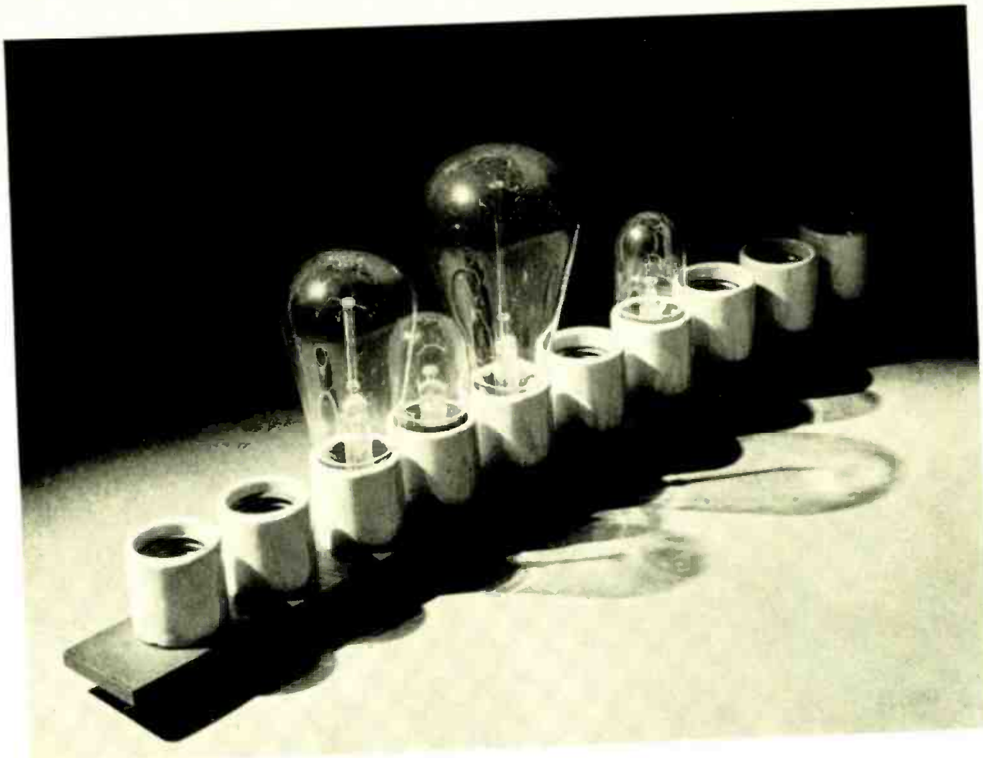
Wherever it is necessary to separate the carrier and program currents, filters are employed. At each side of repeater stations and at the line side of terminals, for example, a high-pass and a low-pass filter, called line filters, are connected in parallel; the high-pass filter readily passes the carrier currents but suppresses the program currents, while the low-pass filter passes the program and suppresses the carrier currents. These low-pass filters are thus a part of the program circuit, and must meet the severe requirements for this class of service.

The primary purpose of these low pass line filters is to attenuate highly all frequencies above the program band while readily passing all those within it. They must be so designed, however, that in performing this primary function, they introduce no objectionable distortion in the program circuits themselves. In general, when currents of a wide band of frequencies pass over any circuit not specially equalized for such a band, they suffer distortion. This distortion is principally of two forms: amplitude distortion, occurring when the loss is not the same at all frequencies in the band, and delay distortion, occurring when the currents of various frequencies require different intervals to build up and die out. The distortion due to a single filter would ordinarily be inappreciable but since very long program circuits may have as many as fifty filters as well as much other apparatus, the overall distortion, if not corrected, would be readily perceptible.

Amplitude distortion in low-pass filters and lines usually decreases the strength of the higher frequency currents more than the lower, and thus has the effect of somewhat narrowing the transmitted band. When present in small amounts, its effects are not readily noticeable except to a practiced ear, and its correction is relatively easy of accomplishment.

The result of delay distortion is distinctly different and in general is both more noticeable and more difficult to correct. Its effect on a transmitted signal is to prolong the interval of time required for the signal to build up to its full amplitude, and what is generally more noticeable, to prolong the time required for it to die down. In a low-pass filter, this prolongation is most marked at the higher frequencies. The effect is illustrated in Figure 1, which shows oscillograms of pulses of

*Record, p 162 *this issue*.



Resistance Lamps

By N. INSLEY
Telephone Apparatus Development

FOR more than 30 years incandescent lamps have been used for resistance purposes in power and ringing current supply circuits. At first, such lamps were of the regular carbon filament type used for illumination. Later, about 17 years ago, when the rugged forms of tungsten lamps had come into common commercial use for lighting, this type began to be used for resistance purposes until at the present time extremely few of the carbon type resistance lamps are employed in the telephone plant.

Up to about five years ago the tungsten resistance lamps were the standard types and sizes used for illumination purposes but were purchased under specifications having requirements for electrical characteristics which insured the necessary uniformity but which could be met by lamps selected from the supplier's regular commercial output. These are the lamps that have been listed as the No. 6 and No. 7 types.

As is well known, carbon has a negative temperature resistance coefficient; that is, when the temperature of the carbon filament is increased, such as would be the case when a current is passed through it, the resistance of the filament decreases. On the other hand, the temperature resistance coefficient of tungsten is positive and much greater in numerical value than that of carbon. As an illustration, the resistance of a tungsten lamp at the temperature at which it is operated when used for lighting is 10 to 12 times the resistance of the lamp when cold. Therefore, when there is a variation in the voltage on a circuit containing a tungsten resistance lamp the variation in current will be considerably less than that of the voltage. In many cases where the current under trouble conditions would be sufficient to damage apparatus in the circuit, the use of a tungsten lamp in series will increase the resistance sufficiently to restrict the current to a safe value. This characteristic makes the tungsten lamp very valuable as a regulating and protecting device and in many places makes it much more desirable than an ordinary resistance.

While the tungsten illuminating lamps had very desirable electrical characteristics for use in telephone circuits, from an equipment standpoint there were decided objections to them on account of their size. They were of the order of 2⅝″ in diameter and 5¼″ in overall length and generally required special mountings. Accordingly, there was an urgent demand for smaller resistance lamps which led to the development of a new series of lamps with a tubular bulb 1¼″ in diameter and with an overall length of less than 3″. The contrast in size between the two types is shown in the photograph at the head of this article. The new series of lamps which is known as the No. 8 type may be mounted on 1¾″ centers on regular relay mounting plates in relay bays where they project less than 3½″ from the mounting plate. It was necessary to mount the older types of resistance lamps on special slate mounting panels which usually had to be placed at the top of the bays to be out of the way. The new lamps on the relay mounting plates may be placed in the bays wherever convenient and in addition to allowing savings in mounting space have decided advantages from the standpoint of lowering of wiring costs and of reducing breakage.

Tungsten resistance lamps of the earlier series were all of the vacuum type but their characteristics have not satisfied many of the recent circuit needs in that the rate of change of resistance with change of current in the working range was too low. To meet these special circuit requirements, several types of so-called gas-filled lamps were made available in addition to the vacuum types. These lamps are filled with inert gases at pressure less than atmospheric.

Figure 1 shows the comparative characteristics of vacuum types and

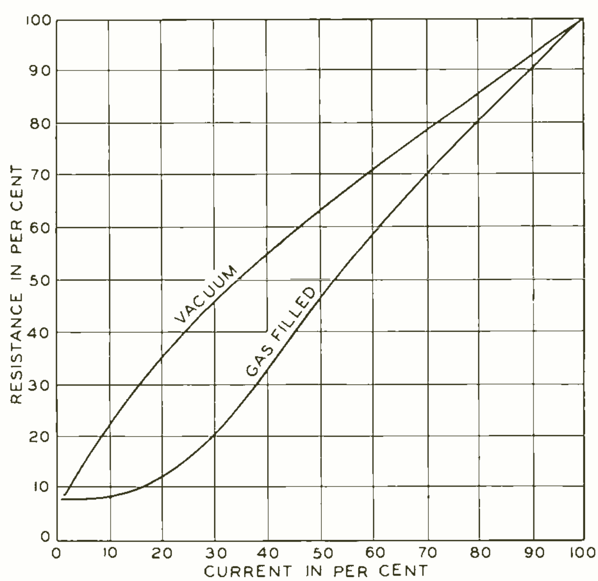


Fig. 1—Resistance-current characteristic of vacuum and gas filled lamps

gas-filled tungsten lamps. The 100% point on this graph corresponds to the rated voltage of the lamps for lighting purposes. The ratio of the resistance at 100% current to that at zero current is the same for both lamps. However, it may be seen that the gas-filled lamps maintain their low resistance until there is a considerable increase in current while in the case of the vacuum lamp only a small increase in current is needed to cause an appreciable increase in the resistance.

To illustrate the advantage of the gas-filled type it may be assumed that the normal current in the circuit in which the lamp is used corresponds to the 20% point on the current coordinate. The corresponding resistances of the vacuum lamp is therefore 35% and the gas-filled lamp only 12% of the resistance of the lamp at rated voltage.

For a more definite example it may be assumed that a certain circuit may be exposed to 125 volts under trouble conditions and that the lamp will be required to offer 100 ohms resistance under these conditions in order to limit the current to a safe value. Of course when the circuit is subjected to only normal voltage it is desirable to have the lamp resistance as low as possible. From the curves it may be seen that for these conditions a gas-filled lamp will give the same protection as a vacuum lamp at the high voltage while offering only one third the resistance under normal conditions. On the other hand, if a certain lamp resistance is allowable under normal conditions, the gas-filled lamp will offer up to three times as much protective resistance under excess voltage conditions as the vacuum lamp while having no greater resistance under normal conditions. Because of these characteristics the gas-filled resistance lamp has proved to be of great value in recent circuit development work.

A Continuously Adjustable Band Pass Filter

By G. H. LOVELL
Telephone Apparatus Development

TO select certain groups of high frequency currents and discriminate against others, it has been customary to employ tuned circuits on account of their simplicity and ease of construction. In some applications, however, tuned circuits have pronounced short-comings. Their transmission is decidedly non-uniform, on account of the sharp peak at the resonant frequency. For any given combination of coils and condensers, the peak is much sharper at the low-frequency end of the tuning range than at the high-frequency end, so that the width of the passed band varies with the frequency setting. These drawbacks were very evident in preliminary consideration of a selective network which was required in connection with a new high-frequency generator. Happily recent advances in the filter art made it possible to design a filter-type network which satisfactorily met all the requirements.

The generator, which was to be used in the study of quartz crystals, was to deliver currents of precisely-known frequency anywhere in the range from 400 to 1200 kilocycles. Since the range required to investigate a single crystal is only a few hundred cycles, it was desirable to sweep over this range by turning a single control knob. How this was accomplished has already been described in the RECORD.* The filter which is the subject of the present article was for use in the output circuit of the generator. The location of the band with respect to frequency was to be readily adjustable to any place in the 400-1200 kilocycle range, and it was not to require resetting during the sweep over a frequency range of 3000 cycles.

Design of this filter presented most of the difficulties inherent in any high frequency filter, such as those of controlling the effects of stray and distributed inductances and capacitances, and in addition other difficulties due to the requirement of readily adjustable band location. Any one of a number of different types of band-pass filter sections might have been used for the purpose if it were practicable to vary all of the elements, both coils and condensers, in the filter. The variation of so many elements, how-

*RECORD, *December*, 1932, *p.* 100 and *p.* 102

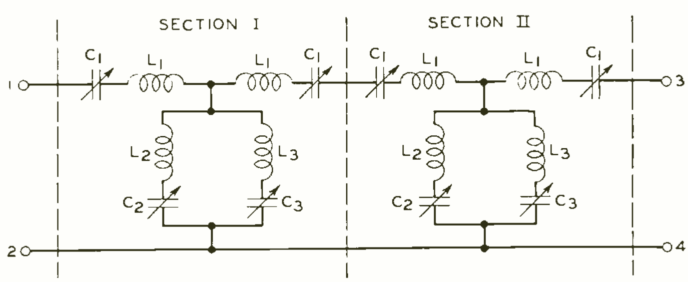


Fig. 1—This structure was chosen for the adjustable band pass filter. From an electrical standpoint the two adjacent capacitances C_1 could be combined in a single condenser, but the needed range in capacitance can be more readily obtained by two condensers

ever, would have required a large number of controls in order to shift the pass band of the filter from one position to another.

The first problem, then, was to determine a type of filter section which could contain few adjustable elements and at the same time meet the transmission requirements. These were: that the filter transmit the same band width in cycles at any setting; that it provide the same amount of discrimination at any setting against frequencies outside the band; that it have small distortion within the band; and that the impedance of the filter remain approximately constant at various settings, so as not to introduce

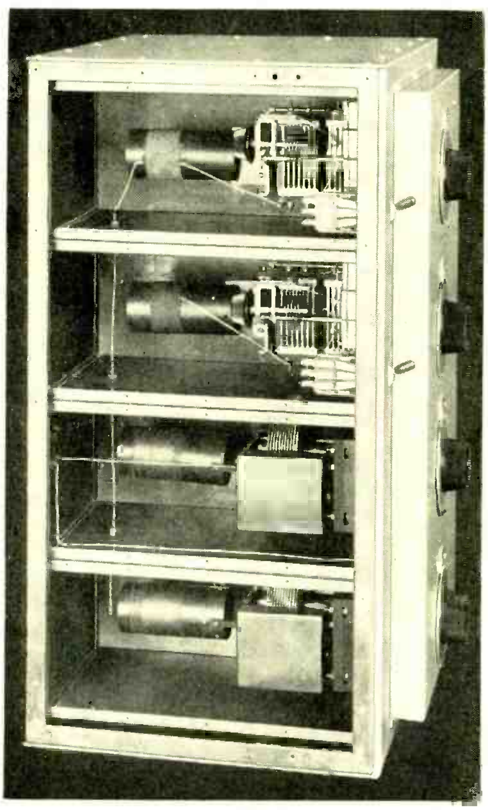


Fig. 2—A side view of the filter, with covers removed, shows one of the two sections. Each combination of associated coil and condenser is mounted in a separate compartment

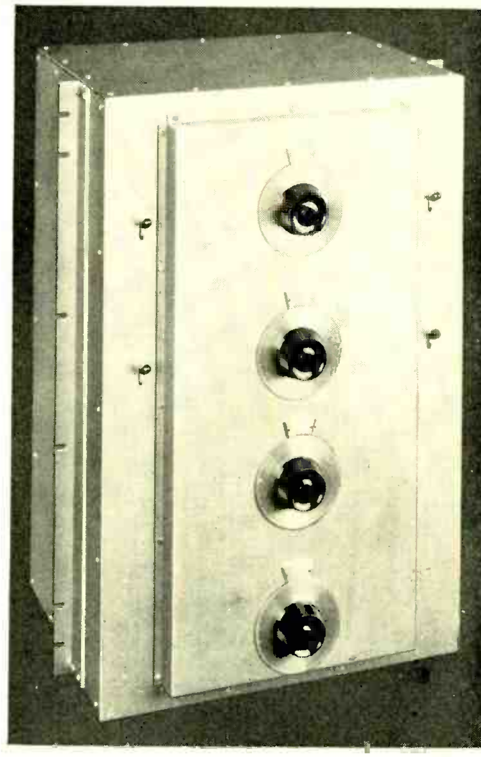


Fig. 3—The two upper knobs control the shunt condensers; and the two lower knobs, the series condensers

reflection losses* at some frequencies.

With all these requirements in mind, the characteristics of a number of available types of filter sections were studied. As a result of this study a filter section was found which seemed to meet the requirements best. In this section the band of the filter might be shifted up or down by adjusting the coils only, or the condensers only. Further consideration showed that if adjustable coils were used they must have a large range of inductance adjustment. Such coils have a small ratio of reactance to resistance as the inductance becomes smaller at the upper end of the frequency range. This would cause a much larger attenuation loss at the

*Record, *July*, 1932, *p.* 374

h frequencies than at the lower. n t e other hand adjustable condensers may be constructed which have negligible loss, and which consequently may be varied over the wide range without affecting the filter loss.

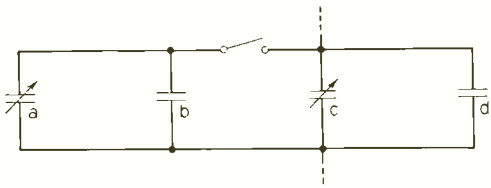


Fig. 4—C_2 and C_3 of Figure 1 are composed of fixed and variable condensers in parallel. c *is the tuning condenser.* b *and* d *are used to place the total capacitance within the desired range.* a *is adjusted when the filter is built so as to make the capacitance of* a+b *the same in the two sections of the filter.*

For this reason the filter sections were made with fixed coils and adjustable condensers.

The filter consists of two such sections, shown schematically in Figure 1. The functions of the elements in determining the action of the filter may become evident, in a rough fashion, when it is remembered that the impedance of a path through an inductance and a capacitance, connected in series, is a minimum for the frequency at which these two elements are in resonance. Accordingly, frequencies close to that for which C_1 and L_1 are resonant will be readily transmitted through the filter from terminals 1 and 2 to terminals 3 and 4. At frequencies close to the resonant frequency of either C_2 and L_2 or C_3 and L_3, however, the filter tends to provide a short circuit through one or the other of the shunt paths provided by the combinations of these elements.

In this filter the values of the elements are so proportioned that the resonant frequency of the series path is midway between the resonant frequencies of the two shunt paths. Thus the filter becomes a band-pass structure, and has peaks of attenuation symmetrically located above and below the pass-band. While the cut-off frequencies are dependent on all the elements in the section, the mid-band frequency, which is half way between the two cut-off frequencies is determined by the resonance of L_1 and C_1; and the two peaks of attenuation are determined, one by the resonance of L_2 and C_2 and the other by the resonance of L_3 and C_3.

Mechanically, the framework of the filter is a box-shaped brass cage, fronted by a panel and covered on the remaining sides with aluminum sheets. On the inner surface of the panel the condensers are mounted, and to the

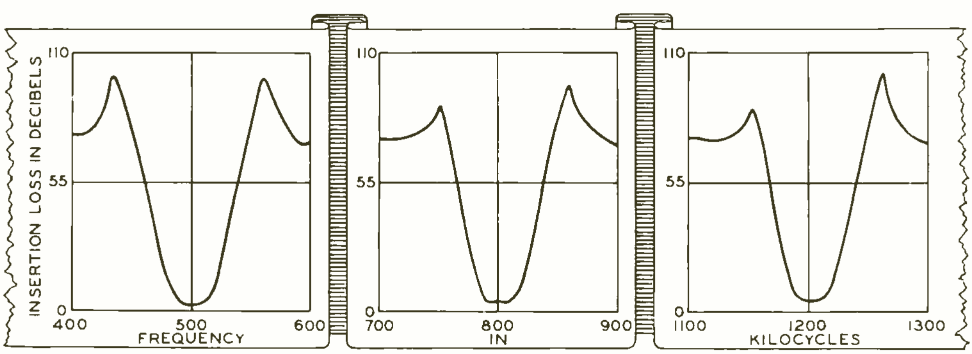


Fig. 5—A constant band width of 3000 cycles is secured throughout the range from 400 to 1200 kilocycles

backs of the condensers their associated inductance coils are affixed. Each tuned circuit is individually shielded by a copper can and the stators of the adjustable condensers are closely surrounded by shields to reduce the effects of stray capacities. The removal of the panel makes all the parts accessible.

The wiring of the filter is simple. Since the coils are mounted on the condensers, and wired as a unit, virtually the only wiring to be done after assembly is connecting two vertical wires to join the outer terminals of the coils. One of these vertical leads can be seen in Figure 2. The ground connections are made by the shunt condensers which are in contact with the panel.

By locating close to each other the corresponding arms of the two sections of the filter, it is easy to gear together the condensers having identical functions. This cuts the number of independent controls in half. Of the four control knobs (Figure 3), the upper two are used for setting the shunt condensers, and the lower two for setting the series condensers. By the use of adjustable condensers in which the plates are so shaped that the resonant frequency, rather than the capacitance, is proportional to the angle through which the control dial is turned, the pass band of the filter can be set with equal accuracy throughout its range. Verniers, added to the condenser dials, increase the precision of the setting.

The shunt capacitances are composed of four condensers in parallel (Figure 4). By the use of keys located on either side of the panel, a portion of the total capacitance can be disconnected from the circuit. This arrangement is a simple means of increasing the range and the precision of adjustment of the condensers and is more economical than larger variable condensers. In this filter, for example, when the keys are thrown to the "in" position, the filter covers a frequency range from 400 to 535 kilocycles; and when they are thrown to the "out" position, it covers the range from 535 to 1200 kilocycles.

By the use of the verniers, the dials can be read to one-tenth of the smallest scale division, and the filter can be set to within $\pm$ 500 cycles, which is only about .06 per cent of the mid-band frequency when the filter is operating in the middle of its range. A calibration chart gives each setting in terms of the mid-band frequency. Using this chart, the pass band of the filter can be placed anywhere in the range which the filter covers. Such insertion-loss characteristics as those shown in Figure 5 for certain settings of the control dials are representative.

This style of filter is not restricted to the high-frequency range of the filter described. In addition to this filter, which has a range from 400 to 1200 kilocycles per second and a band width of 3000 cycles, a filter has been built, similar in appearance and construction, with a range from 22 to 52 kilocycles and a band width of 500 cycles.

Testing the Life of Dial Apparatus By Machines

By F. H. HEWITT
Telephone Apparatus Development

ONE of the important steps in the development of a new piece of dial apparatus is a life test to assure that the apparatus will function satisfactorily in the field for a long enough time to make its use economical. Often such a test discloses defects in design which might not otherwise be detected for a long time, during which thousands of pieces of apparatus would have been manufactured and placed in service.

Where it has been decided that a particular design is to be given a life test, there are a number of factors which the laboratory engineers must consider in deciding upon the method of test. The most ideal testing condition is that in which the apparatus is operated in conjunction with the equipment with which it is to be associated in the field, and at the same speed as in commercial use. It is seldom practicable to do this, however, for the amount and size of associated equipment, and the length of the expected life, make such tests unduly expensive and time consuming. Usually it is found more economical to design a testing machine in which the equipment is made to perform its expected number of operations in as short a time as possible without introducing abnormal conditions that

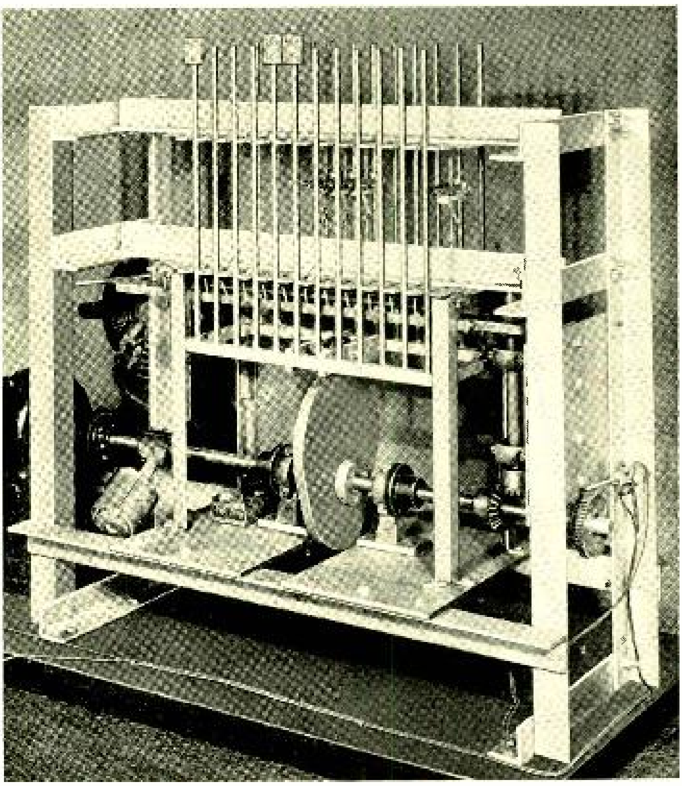


Fig. 1—This machine tests the durability of non-snagging trip fingers for panel selector frames. Three of these fingers, and one of the standard fingers, appear beneath the four multiple brushes

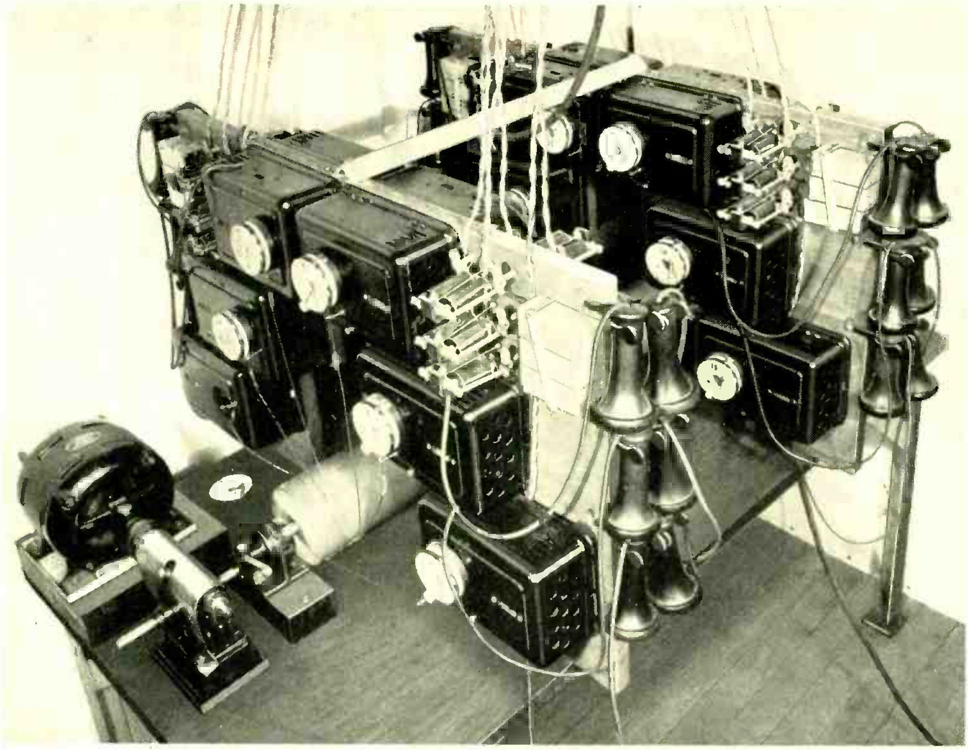


Fig. 2—The effect of radio suppression units on the life of dial contacts is tested in a machine which operates the dials repeatedly

accelerate the wear far beyond actual operating conditions. Often these machines can be made to relieve the testing engineer of much work by automatically checking and recording the performance of the apparatus under test.

A case in point is the machine shown in Figure 1, for testing the durability of non-snagging trip fingers on the vertical trip rods of panel selector frames. By accommodating twenty-four fingers, this machine took the place of an entire selector frame, simulating the set of operations in which the fingers trip the multiple brushes. When a finger failed to trip the brush the testing machine was designed to stop automatically.

In actual operation an elevator rod carrying a multiple brush is driven upward and is stopped at the tripping position. A vertical rod, associated with the elevator rod and carrying the tripping finger, is then rotated until the finger engages the trip lever of the brush. When the elevator and brush are again started upward, the finger operates the lever and trips the brush. The test simulating these conditions was made to determine whether the slight flexure, which the rotation of the tripping rod gives the newly designed finger, would break the finger after repeated operations.

In the testing machine, sections of elevator rods bearing brushes were carried in a frame which was driven up and down by a cam so shaped that there was a short pause in the upward motion. During this pause the trip rods were rotated by a cam driven through bevel gears by the main cam shaft. Since the two "sleeve" springs of each brush used in the test touched each other when the brush was tripped the failure of any finger to trip its brush was made to stop the machine automatically by wiring the twenty-four pairs of sleeve springs in series through a relay controlling the driving motor. To keep the motor going during the part of the cycle before the brushes are supposed to be tripped, a separate pair of contacts was paralleled around the sleeve spring contacts. This pair was kept closed by a cam on the main cam shaft while the brushes were untripped, and was opened after tripping should have occurred.

Apparatus operated manually in the field is also tested mechanically in the laboratory whenever possible. An example is found in the machine (Figure 2) for testing the effect of radio suppression units on the life of dial contacts. Here manual operation of the test was out of the question because it was necessary to test twenty-four dials and their associated circuits.

The circuit associated with the dials under test simulated the worst electrical condition for contact wear, a party line, by incorporating both the dial and subset of the calling party and the ringer and condenser of the second party. Fifty feet of drop wire, representing the house wiring, carried the circuit to a network simulating a short cable loop. The circuit terminated in a pulsing relay as in a central office.

Mounted on the finger wheel of each

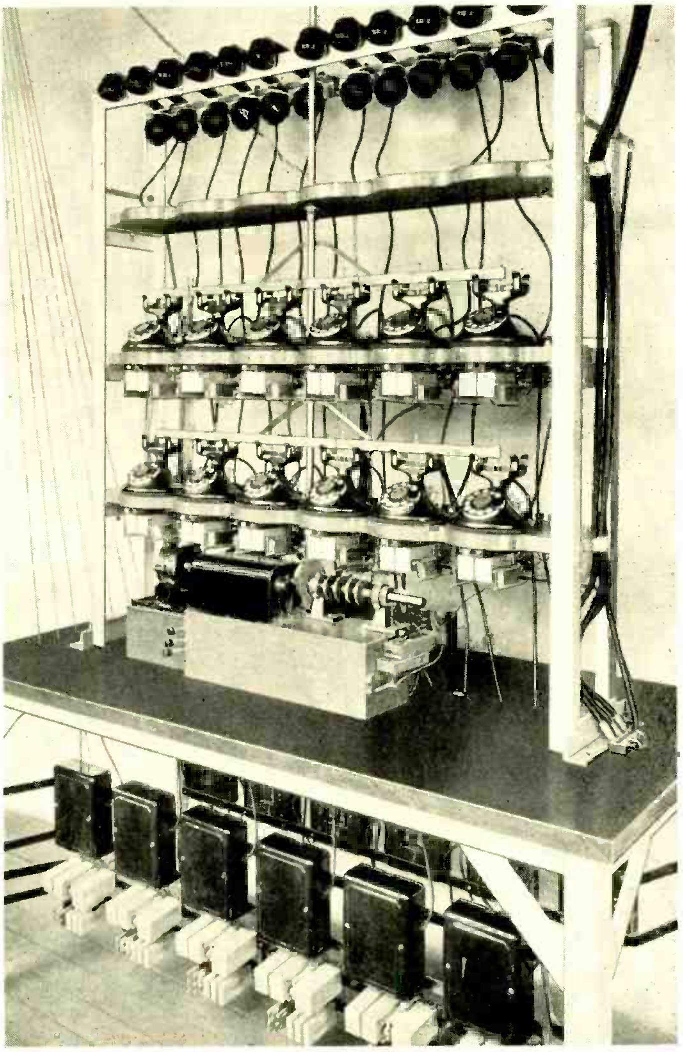


Fig. 3—The study of contact trouble in subscribers' handset mountings was facilitated by a machine which operates the switchhook contacts under proper circuit conditions, and stops itself when the resistance of the contacts exceeds a predetermined value

dial was a light wooden wheel bearing a cork to act as a subscriber's finger. Wound around the wheel was a cord whose other end was wound around a drum. A motor intermittently drove the drum, turning the dials until the zero hole had reached the finger stop, when a heavy coil spring quickly reverted the drum to normal. This motion unwound the cords from the drum so rapidly that the dials returned to normal with practically no drag on them. This machine operated rapidly enough to give the dial contacts a satisfactory life test in several weeks.

Another mechanical test of manually operated apparatus was that of the contacts in subscribers' handset mountings. Capable of testing eighteen handsets at a time, entirely automatically, the machine (Figure 3) switched from one circuit condition for the break of the switchhook contacts to another for the make of the contacts, and stopped operating when the resistance of any pair of contacts became objectionably high, lighting a lamp indicating the contacts in trouble. The machine was used to test twelve handsets, associated with circuits of which half simulated a manual system and half a PBX system.

In operation, a motor drove a horizontal shaft, bearing a cam which pushed a vertical rod. Horizontal arms from the rod bore adjustable pins which operated the handset plungers opening and closing the switchhook contacts. Four other cams on the horizontal shaft did the switching. Just before the switchhooks made contact, a path was closed from the tip and ring of each set through a loop to a line relay or tripping relay. After the contacts were made, these circuits were removed and the resistances of the contacts were tested. Any resistance exceeding about three ohms lighted an associated lamp and stopped the machine with the contacts still closed. If the contact resistance was satisfactory, a path was made from tip and ring through the loop to a talking circuit, and the contacts were then opened. Check circuits gave alarms if the make and break conditions were not being provided in proper sequence, and if an apparent contact failure was really a failure of some part of the testing circuit. The entire cycle of operations described occupied only three seconds.

These examples illustrate some of the many problems encountered in the design of life testing machines. The extent to which a rate of operation can be accelerated without distorting its effect, and the extent to which certain field conditions can be simplified or neglected, the testing engineer must decide in the light of his past experience with similar tests and his knowledge of the physical limitations of the apparatus in question. The design of a testing machine thus often becomes one of the most interesting parts of the laboratory engineer's work.

A Self-Contained Bridge for Measuring Both Inductive and Capacitive Impedances

By H. T. WILHELM
Telephone Apparatus Development

PREVIOUS designs of impedance bridges* have followed two trends. The one has been to build a self-contained unit for measuring either inductive or capacitive impedances. This form has the advantage of high precision and of convenience of operation. The other tendency has been to use a separate balance unit** which may be employed with external standards of capacitance, inductance, and resistance. This arrangement permits maximum flexibility since any type of impedance can be measured by merely changing the standard. Recently, however, a bridge has been developed which combines the advantages of the self-contained unit with the convenience of being able to measure both inductive and capacitive impedances with a single bridge. This great advantage in convenience and ease of manipulation has been obtained without appreciable sacrifice of precision by providing three types of bridge circuits that may be secured by a simple rearrangement of a small number of elements. The type of circuit most convenient for the impedance being measured is obtained by the operation of a few keys.

In addition to the usual two ratio arms, the bridge incorporates only standards of resistance and capacitance, a fixed resistor, and two fixed capacitances. These may be grouped to form a comparison bridge, Figure 1, for the measurement of capacitive impedances, an Owen bridge, Figure 2, for the measurement of inductive impedances where the ratio of inductance to resistance is large, and a resonance bridge, Figure 3, for measuring inductive impedances where the ratio of inductance to resistance is small. Of the two circuits for measuring inductive impedances,

*RECORD, *December*, 1929, *p.* 167
**RECORD, *January*, 1932, *p.* 173

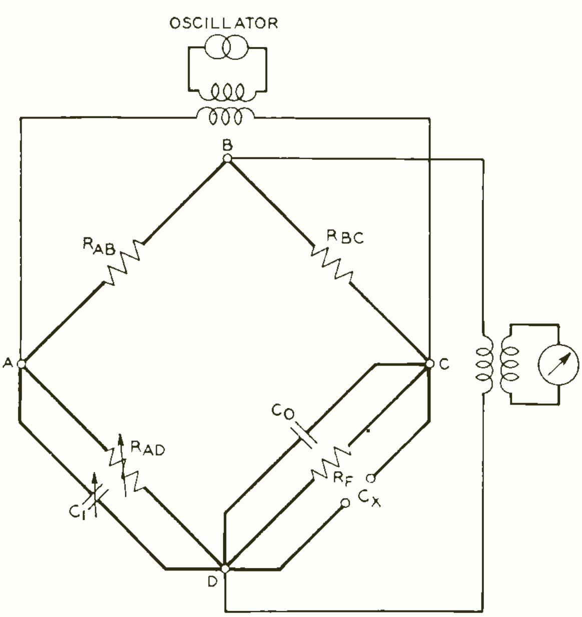


Fig. 1—A comparison bridge circuit is employed for measuring capacitive impedance

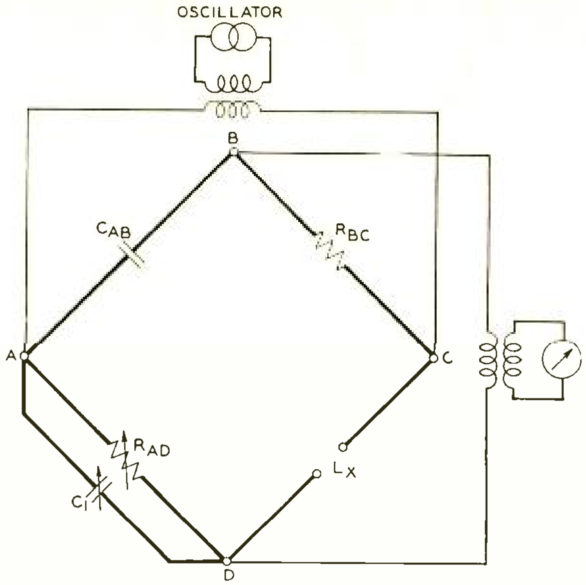


Fig. 2—An Owen bridge circuit is employed for measuring inductive impedance of high Q

complete bridge of Figure 4.

This simple and compact arrangement was possible largely because each of the three optional bridge circuits is of the parallel type. An impedance is a complex quantity which has the effect, when an alternating potential is impressed across it, of limiting the current that flows to a definite value and of shifting the phase of the current with repect to that of the voltage across it. To completely specify the value of an impedance, therefore, there must be given not only a total impedance in ohms, but an angle of phase shift. Since the impedances usually measured, however, are generally to be used in circuits with other impedances, and it may be necessary to calculate the total impedance of the circuit, it is more convenient to evaluate an impedance not by its mag-

the Owen bridge is preferable since it is direct reading for inductance, and the balance is independent of frequency. However, the resistance range is limited practically by the range of the condenser standard, making it necessary to use the resonance bridge circuit to supplement the Owen bridge. It will be noticed that in all three circuits the ratio arm R_{BC}, and the resistance standard R_{AD}, are unchanged in position; the capacitance standard C_1 and the fixed capacitance C_0 may be either in the arm AD or in the arm DC; while the ratio arm resistor R_{AB}, the fixed resistor R_F, and the fixed capacitance C_{AB}, although unchanged in position, may be cut into or out of the circuit as desired. These changes in circuit arrangement are accomplished by the manipulation of a few keys as may be seen in the schematic of the

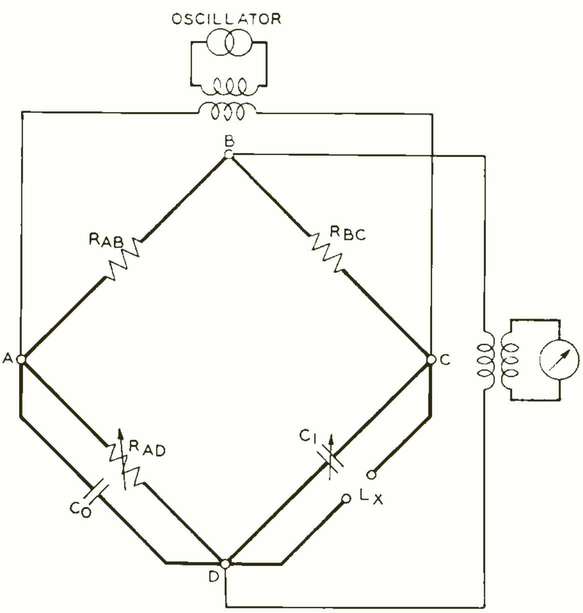


Fig. 3—A resonance bridge circuit is used for measuring inductive impedance of low Q

nitude and phase shift but by giving the values of the pure reactance and resistance which connected together would have the same impedance and produce the same phase shift. Such equivalent circuits may be built up by connecting pure resistances and reactances either in parallel or in series, but the values of the components of each in the two cases are different, of course. This is illustrated in Figure 5.

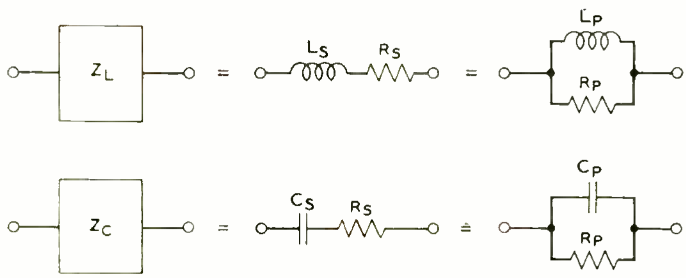


Fig. 5—Any impedance may be represented by either of two equivalent circuits—one with pure reactances and resistances in series, and one with them in parallel

In dealing with capacitive impedances, the parallel type of equivalent circuit is most convenient because capacitive impedances are usually connected in parallel, since the total capacitance is easily obtained from the parallel values of the individual capacitances. For measuring capacitive impedances, therefore, the comparison bridge circuit of Figure 1 is employed, and the equivalent parallel values of capacitance and resistance are obtained directly from the two standards in the arm AD. With this arrangement the fixed resistor R_F is employed to bring the resistance component within the range of the standard, and the fixed capacitor C_0 is used to balance the residual capacitances of the capacitance standard and of the fixed resistor.

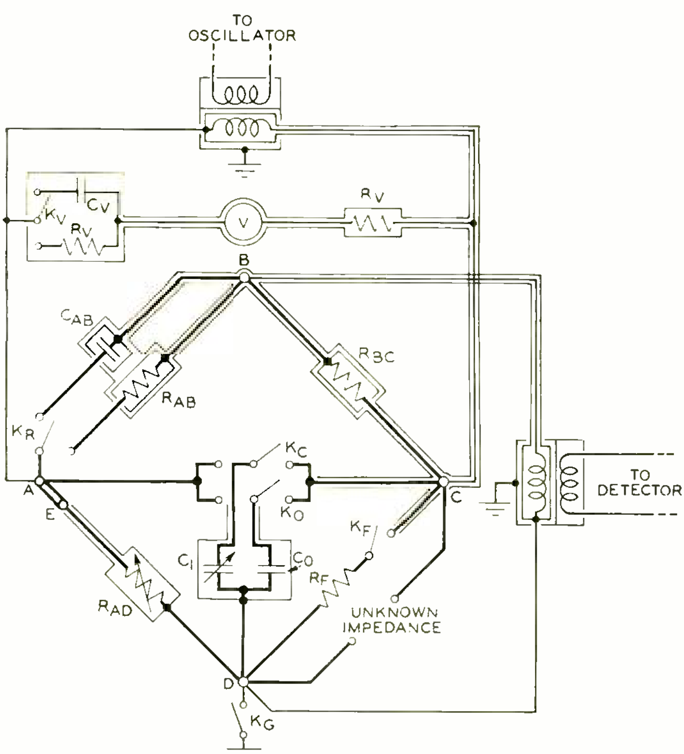


Fig. 4—A few keys provide for the necessary changes in circuit as shown in this schematic of the complete bridge

Inductive impedances, on the other hand, are usually connected in series, and as a result the most convenient equivalent values of inductance and resistance would be the series values. To measure equivalent series values of inductances either would require the bridge to incorporate inductance standards, which are large and thus not desirable in a self-contained unit, or would greatly complicate the shielding and switching arrangements. The new bridge has been designed therefore to measure the parallel values of the equivalent circuits in all cases.

When the series values of inductance and resistance are required, they may readily be computed from the two transformation formulae, namely

$$R_s = R_p\left(\frac{1}{1+Q^2}\right)$$

$$L_s = L_p\left[1-\left(\frac{1}{1+Q^2}\right)\right]$$

where $Q = \frac{R_p}{2\pi f L_p}$

and where the subscripts $_s$ and $_p$ indicate series and parallel respectively. It will be noticed that the computations involve the use of Q, which is the tangent of the angle of phase shift. In order to simplify computations, tables have been made giving values of $\frac{1}{1+Q^2}$ for values of Q from .001 to 100.

The bridge incorporates a voltmeter, indicated in Figure 4, arranged to read the voltage across the impedance being measured, which is always convenient and is essential for some purposes. The bridge is arranged for making measurements on impedances which have one terminal grounded or which are balanced to ground. Complete shielding is incorporated as is indicated in the illustration. This bridge is useful for investigating the impedance of various transmission circuits, such as subscriber loops, as well as for measuring the impedances of individual pieces of telephone apparatus. The convenience of a multi-purpose bridge should make it a desirable form for laboratories which require a single bridge for a wide range of measurements.

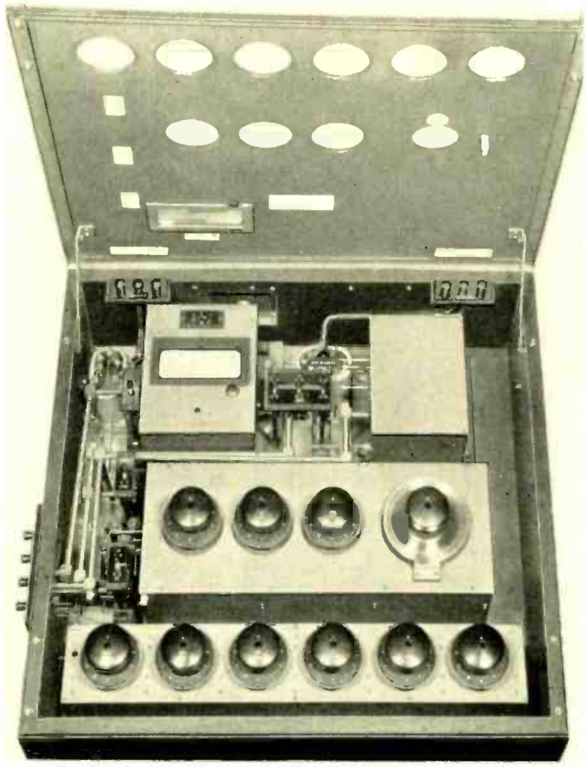


Fig. 6—Interior of the multi-purpose bridge

A Mathematical Theory Of Rational Inference

By THORNTON C. FRY
Research Mathematician

CONCLUSIONS are drawn from experiments but experiments are never "conclusive"; there is always the chance that the inferences from them are wrong. No matter how many times the same result is arrived at there still remains a certain amount of ignorance on the part of those who observe or draw conclusions. To the mathematician in his concern with rational inference the importance of his ignorance as to an event is measured by what he calls "probability". When he tosses a coin and essays to predict heads or tails, his ignorance of what the event will be is expressed by saying that there is no reason to expect heads rather than tails; the probabilities of the two cases are equal, each is a one in two chance, a probability of ½.

If he knew that the coin was a freak with heads on both sides there would be certainty instead of ignorance; the probability of heads up on the next toss would be one in one or unity, and the probability of tails coming up would be zero.

Suppose, however, that the mathematician is handed a coin, heads up, and is to determine by the experiment of repeated tosses whether it is a normal coin or a freak with two heads. Suppose in addition that on the first toss it comes heads up; on the next the same, and also on the third. What rational inference can he draw? What is the likelihood that both sides of the coin are stamped with heads? and what is the likelihood that they bear different stamping?

Now, in this matter of testing hypotheses by experiment "likelihood" has a technical meaning. One of our hypotheses about the present experiment is that the coin has its normal single head. The "likelihood" of that assumption is numerically equal to the probability that a normal coin would turn up heads in three successive throws. This is a one in eight chance; the likelihood is ⅛. Our other hypothesis is that the coin is a two-headed freak. In that case heads is always a one in one chance; the probability is unity and so is the "likelihood" of that hypothesis on the basis of the experimental evidence of the three throws.

On that basis it is eight times as likely that the coin is a freak as that it is a good one. The evidence points strongly to the conclusion of a defective coin; but despite these odds most of us would be very skeptical. How many times would the same experimental result have to be obtained before we would change our minds? But let the answer to that question wait and consider first why we are unwilling to adopt the presumptive conclusion.

It does not fit with our common

This is a brief resume of an address recently read by the author before a group of engineering societies. The complete address will appear in Scripta Mathematica.

sense; it takes into account only the experimental data and ignores such other information as we may have about coins. In other words, it ignores our state of knowledge and ignorance before the experiment started.

In the mathematician's lingo, the importance of ignorance is measured by a probability; and in particular the ignorance which exists in our minds before we start to experiment is the "existence probability".

To illustrate, you may have seen a news item, which I have missed, to the effect that some two-headed coins have gotten into circulation. Your existence probability for heads-up is then greater than mine. On the other hand, to take an extreme case, the man who supplied the coin for the experiment may have rigged it up to be alike on both sides. For him the existence probability of a normal coin is zero, and that of a two-headed one is unity. For those who know nothing of his chicanery the probability of an abnormal coin is nearly zero.

For our experiment let us assume odds of 99 to 1 in favor of normality. The existence probability of a normal coin is then 0.99 and of a two-headed one, 0.01.

We now have numbers referring to our state of ignorance before the experiment was performed, and also numbers measuring the significance of the experimental evidence. We ought, therefore, to be able to bring them together into a single formula which will measure the importance of both kinds of evidence.

The formula which does this is known as Bayes' theorem. It states that if E is the existence probability for a particular hypothesis and L is the likelihood of the same hypothesis in the light of the experiments, then the probability P that the hypothesis is correct is EL/S. S is just a scale factor which adjusts the value of P so that the sums of the P's for the various hypotheses shall be unity.

The probability which Bayes' theorem computes is technically known as the *a posteriori* probability, since it looks back upon the events of experiment and seeks to interpret them, instead of looking forward and seeking to predict them, as does *a priori* probability. Existence probability is obviously of the *a priori* type. Likelihood also is essentially of that type since it states, upon some hypothesis, the chances that an event or succession of events will occur.

In the process of rational inference the existance probabilities which are involved remain the same regardless of the number of experiments performed. The likelihoods have new values with each successive experiment; and so, of course, does the *a posteriori* probability which is the mathematical expression of the total of inferences.

Applying Bayes' theorem to the problem of the coin, after three successive tosses have come heads up, we have for the first assumption, namely that the coin is two-headed, $E_1 = 0.01$ and $L_1 = 1$ giving $E_1L_1 = 0.01$; and for the second assumption, that of no normality, $E_2 = 0.99$ and $L_2 = 1/8$ giving $E_2L_2 = 0.124$. Then S is $E_1L_1 + E_2L_2 = 0.134$, and P_1 the probable correctness of the assumption of a two-headed coin is 0.075; conversely P_2 the probability of a normal coin is 0.925. These probabilities are much more in accord with our common sense than the likelihoods which the experiment indicated.

Now imagine the experiment to be extended by another toss which also gives heads. The corresponding values of the likelihoods are $L_1=1$ and $L_2=1/16$. Calculating the *a posteriori* probabilities gives $P_1=0.139$ and $P_2=0.861$. The experimental results have, as they should, a greater influence upon our mathematical inference. How successively similar results of the experiment will rapidly change the inference is shown in Table I.

TABLE I

$E_1=0.99$ $E_2=0.01$ (both estimated)

Number of Throw	Result	L_1	L_2	P_1	P_2
0	—	—	—	0.990	0.010
1	Head	0.500	1	0.981	0.019
2	"	0.250	1	0.962	0.038
3	"	0.125	1	0.925	0.075
4	"	0.062	1	0.861	0.139
5	"	0.031	1	0.756	0.244
6	"	0.016	1	0.615	0.385
7	"	0.008	1	0.444	0.556
8	"	0.004	1	0.286	0.714
9	"	0.002	1	0.167	0.833
10	"	0.001	1	0.091	0.909
Any Throw	Tail	Not Zero	Zero	1	0

$$S=L_1E_1+L_2E_2$$

In other words, if our estimate of 99 to 1 was a sensible one for the odds in favor of a good coin before we began our experiment, an uninterrupted run of six or seven heads should cause us to doubt whether there was not something wrong with it, while ten in succession should make us moderately sure it was queer. And, of course, if we ran the test long enough and got nothing but heads, P_2 would eventually become so large and P_1 so small that our doubts would disappear entirely.

Certainly there is nothing to do violence to common sense in this. It merely says that an intelligent opinion has to be revised when the evidence against it becomes convincing enough.

Next let us see what happens if the run of heads is broken. That is, suppose that on one of the throws we get a tail. With an ordinary coin this is possible; so even though L_1 may be small it is not zero. On the other hand, if the coin had heads on both sides we would be unable to throw a tail at all. Hence L_2 is zero. Thus we are led to the last line of the table with $P_1=1$ and $P_2=0$. It has taken just one tail to overthrow completely the conclusion to which the accumulated data seemed to be leading, and establish the fact that the coin is normal. This, too, is as it should be.

Next let us see what difference the existence probabilities make. In other words, how does the amount of data required to convince us of an improbable result depend upon its degree of improbability. This may be illustrated by Table II, in which are listed the number of consecutive heads which would be required just to counteract existence odds of one to one, one hundred to one, ten thousand to one, and so on. That is, the last column contains the shortest run which would make P_2 greater than P_1.

TABLE II

Existence Odds: E_1/E_2	Length of run necessary to just turn the scales
1:1	1
100:1	7
10,000:1	14
1,000,000:1	20
1,000,000,000,000:1	40
∞:1	∞

Even for very heavy odds the length of run required is comparatively moderate. The figure 14 for existence odds of ten thousand to one, for example, does not appear unreasonable. Yet when the existence odds become infinity to one, which corresponds to a condition of infallible advance knowledge, it would require an infinite run to counteract it. That also is reasonable. I don't know how one is ever to arrive at infallible knowledge, but if one ever does, I am sure no amount of experimental data should then shake his faith.

Table II, then, illustrates the explanation given by Bayes' Theorem for the fact that even men of impeccable judgment may have various degrees of doubt about conclusions drawn from experiment. In so far as their collateral information warranted different degrees of uncertainty to begin with, they are justified in demanding different amount of experimental proof.

There is one final observation which must be made about Table II. Near the bottom of the table are some tremendous figures. One line, for example, says that if the odds against a two-headed coin were a million million to one to start with, a run of forty heads in succession ought still to turn the scales. Yet if any one were so tremendously sure that a coin could not have two heads, it is doubtful whether our experiment would convert him. Instead he would probably suspect that we had rigged up some scheme of making the coin jump through the hoop for us.

The explanation of this apparent discrepancy is found in the scale-factor S of Bayes' theorem about which little has been said, though it was one of the things that had to be computed after each step in the experiment in order to get the results presented in Tables I and II. This factor S is quite simple: in computing Tables I and II, for example, it was merely $E_1L_1 + E_2L_2$; and even in the most complicated experiments it would still be a sum of terms of this same form EL. But the number of terms in the sum is very important. There must be exactly one for every hypothesis which could conceivably explain the data.

In Tables I and II the term E_1L_1 accounted for the possibility that the experiment might have been honestly performed with an ordinary coin, and E_2L_2 for the possibility that the coin was a freak; but the possibility of any one being skillful enough to control the behavior of the coin was completely ignored. Hence to that extent all the results have really been wrong, though we have not drawn any misleading conclusions from them.

Table III is exactly like Table II except that it considers three possibilities: first, a normal penny with the existence probability 0.901; second a queer penny with the existence probability 0.009; and third, some sort of sleight-of-hand, which may be called "fraud" for short, with an existence probability 0.090 intermediate between the other two.

So long as the run of heads continues, either a queer penny or fraud would quite explain the facts. Hence, both the L_2 and L_3 columns contain nothing but ones, while the L_1's continually decrease, as before. But when we come to the columns of P's we see that though P_1 eventually becomes very small as before, P_2 never gets as big as P_3.

Again Bayes' theorem has given a sensible result, for if an experiment can be interpreted either as a result of fraud or of a natural law and if the natural law was, to begin with, less plausible than fraud, it continues to be

TABLE III

No. of Throw	Result	L_1	L_2	L_3	P_1	P_2	P_3
0		–	–	–	0.901	0.009	0.090
1	Head	0.500	1	1	0.820	0.016	0.164
2	"	0.250	1	1	0.695	0.028	0.277
3	"	0.125	1	1	0.532	0.043	0.425
4	"	0.062	1	1	0.360	0.058	0.582
5	"	0.031	1	1	0.220	0.071	0.709
6	"	0.016	1	1	0.127	0.079	0.794
7	"	0.008	1	1	0.068	0.085	0.847
8	"	0.004	1	1	0.035	0.088	0.877
9	"	0.002	1	1	0.018	0.089	0.893
10	"	0.001	1	1	0.009	0.090	0.901
10	Tail	0.001	0	1	0.010	0	0.990

so even after the experiment is performed. The only way we can use experimental findings in such a contingency is by changing the conditions under which the experiment is performed so as to make the existence probability E_3 less than E_2. In the case of our experiment, for instance, this could probably be done by giving the penny to somebody else and letting him perform the experiment. We would then know it was honestly done and E_3 would be very small.

I have used the word "fraud" because it is really an important consideration in interpreting some types of experimental data. But the really essential point is broader than this. It is, that if our inferences from experimental results are to be reliable, we must be sure that we have given attention to every hypothesis which could conceivably explain our data.

So in the end every letter in Bayes' formula proves to have a definite purpose in estimating the reliability of a rational judgment: L takes account of the experimental evidence; E takes account of common sense; while S sees to it that all possible explanations are given their due weight in the final estimate.

Contributors to This Issue

R. A. Leconte was born in Grenoble, France, graduated from the Electrotechnical Institute of Grenoble, and later attended the University of that city. Previous to the war he had been employed by Jacquet Frères and later by the Cie Française Thompson-Houston, with both of which concerns he was engaged in the design of direct and alternating current motors and generators. At the outbreak of the war he obtained an engineering commission and after a period at the front was sent to this country as a member of the French commission charged with the purchase and inspection of materials. In addition to his other duties here, he served as instructor in army camps, and, except for trips to France, has been here ever since. He has recently become an American citizen. In 1922 he joined the Laboratories and, with the toll group, has been engaged in the development of amplifiers for program broadcasting circuits, and of repeaters for four-wire toll circuits.

R. A. Leconte

H. T. Wilhelm joined the Electrical Measurements group of the Laboratories in 1922. In 1924 he left to complete his studies at the Cooper Union Institute of Technology, working at the Laboratories during the two following summers. Upon graduation in 1927 with a B.S. in E.E. degree, he resumed his work with the Electrical Measurements group. He has since been engaged in measurement and calibration work, preparation of testing specifications, and in the design and development of impedance bridges. During this time he has taken graduate work in physics and electrical engineering.

A. W. Clement received a B.S. degree in electrical engineering from the University of Washington in 1925, and immediately

H. T. Wilhelm

A. W. Clement

F. H. Hewitt

N. Insley

G. H. Lovell

T. C. Fry

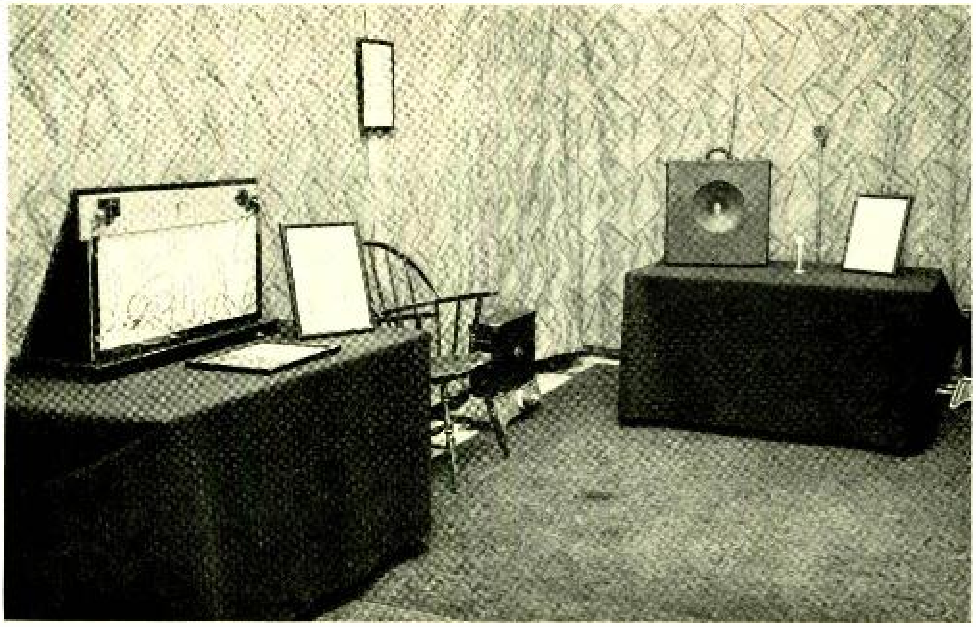
joined the Technical Staff of Bell Telephone Laboratories. Here, with the Apparatus Development Department, he has been primarily engaged in the design of transmission networks, such as filters and equalizers. While at the Laboratories he has carried on part time study at Columbia University and received an M.A. in physics in 1929.

AT THE CLOSE of the War, soon after returning from military service in France, F. H. Hewitt joined the Engineering Department of the Western Electric Company. After spending a summer in the Dial Apparatus Laboratory, he left to complete his interrupted studies at Rensselaer Polytechnic Institute. On receiving the E.E. degree in 1921, he returned to the Dial Apparatus Laboratory, where he has since been concerned with testing panel and step-by-step apparatus. In 1930 Mr. Hewitt was placed in charge of this work.

N. INSLEY received a B.S. degree from Hamilton College in 1918 and an S.B. from Massachusetts Institute of Technology in 1921. He joined the Laboratories early in the following year, and for four years worked on specifications and instruction bulletins. Since 1926 he has been engaged in the development of switchboard lamps, lamp caps, and resistance lamps. During this period he has also been concerned with the development of improved photometrical methods for measuring the signalling ability of switchboard lamps.

G. H. LOVELL came to New York in 1927, after graduating from Texas Agricultural and Mechanical College. The following year, after working in the Test Department of the New York Edison Company, he joined these Laboratories. Here he has been associated with the filter-design group, and has most recently been occupied with the development of new types of high-frequency filters.

THORNTON C. FRY is well-known in mathematical circles, and is the author of two widely-used mathematical textbooks—"Elementary Differential Equations" and "Probability and its Engineering Uses"—as well as of a number of monographs covering his more important contributions to the field of mathematical physics. He is a graduate of Findlay College and has received the degree of Ph.D. from the University of Wisconsin. As Research Mathematician of the Laboratories he has charge of mathematicians whose consulting services are available to the entire organization.



Considerable interest was evinced in the Bell Laboratories demonstration at the Cambridge meeting of the American Association for the Advancement of Science. The magnetic speech recorder, since widely nicknamed the "voice parker" by newspapers, is shown at the left of the photograph. As described in the Record *last June, the recorder registers the speech supplied to it as variations in the magnetization of a steel tape, from which the speech can subsequently be reproduced. At the right is shown the vacuum tube with a fluorescent plate pictured in the frontispiece to the* Record *for last July. The variations in the glow of the plate show how the plate current of a vacuum tube varies with the intensity of the signal passing through it.*