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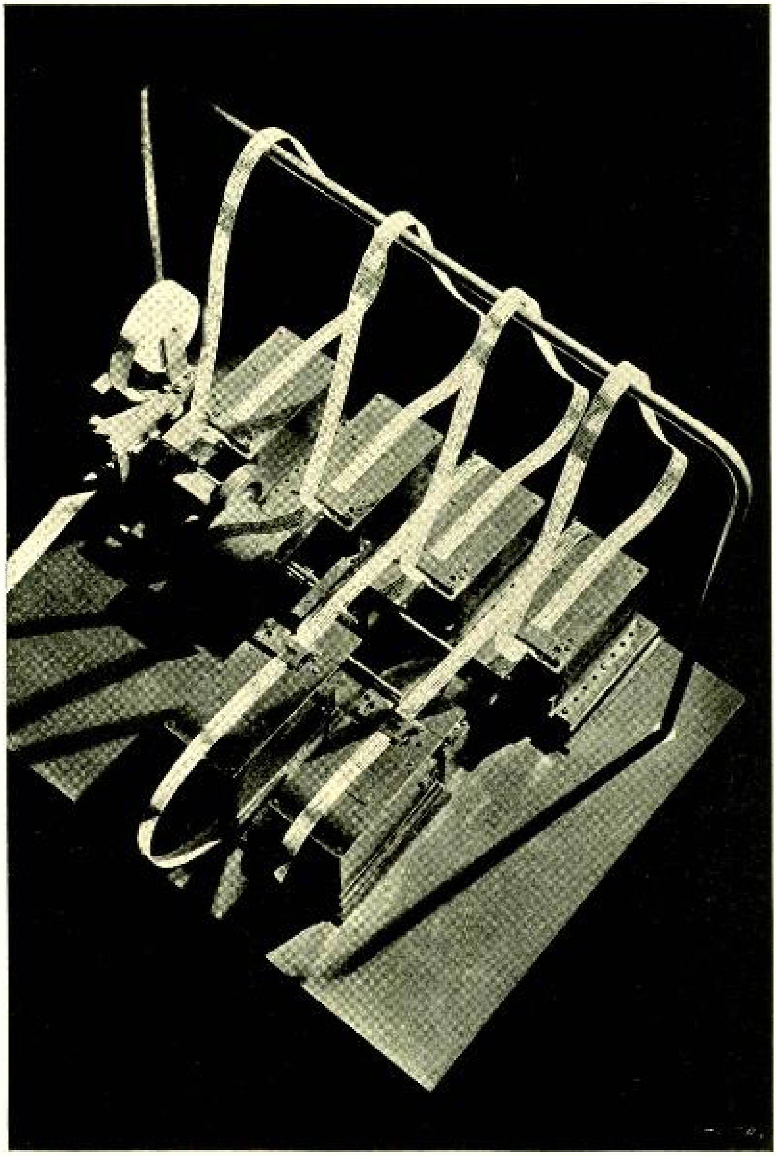

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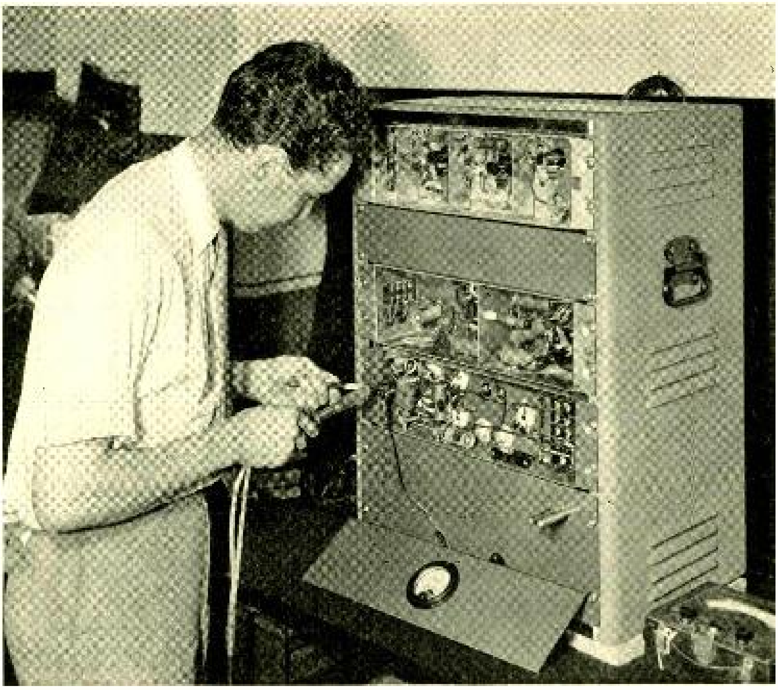
Equipment for probability studies of crossbar trunking



Television Transmission Over Telephone Cables

By C. L. WEIS, JR.
High-Frequency Transmission Development

MOST radio broadcasts originate in the studios of the broadcasting companies, and are transmitted thence to the radio stations over high-quality program circuits. There are many times, however, when the "pick-up" point is at a distance from the studio, and circuits to the studio must be provided over telephone cable pairs not normally employed for broadcasting. With television broadcasts such remote pick-up points are also required, but the utilization of ordinary telephone circuits to link them to the television studio is more difficult because of the much wider band of frequencies employed and certain exacting requirements for television transmission. Because of the experimental state of television broadcasting at the present time, no arrangements for transmitting from these remote pick-up points have as yet been standardized. As already noted in the RECORD*, however, an experimental circuit of this nature was provided for the National Broadcasting Company in May, and a somewhat similar one was more recently provided for the Columbia Broadcasting System.

The difficulties encountered in transmitting over such circuits are

*RECORD, *June*, 1939, *p.* 313.

due largely to the very wide frequency band required. For ordinary telephone circuits a frequency band of about 3,000 cycles is sufficient, while for both of these recent experiments the band extended from 45 to over three million cycles—a range a thousand times greater than the voice band. The effect of the difference in frequency range on loss is indicated in Figure 1. This shows the energy loss in one mile of local telephone cable made up mostly of 22 and 26-gauge paper-insulated pairs. The loss in a coaxial cable, which is especially suited for television transmission, is shown in the same illustration for comparison. At three million cycles, a mile of cable pair gives a loss a million times greater than that of a coaxial conductor of similar length. For satisfactory television transmission, equalizers must be provided to make the overall loss essentially the same for all frequencies. How effectively this is done is indicated in Figure 2, which shows the losses of one of these experimental circuits of 0.86-mile length, both before and after the installation of the equalizers and amplifiers. The variation in loss over the equalized line is within plus or minus one-half db.

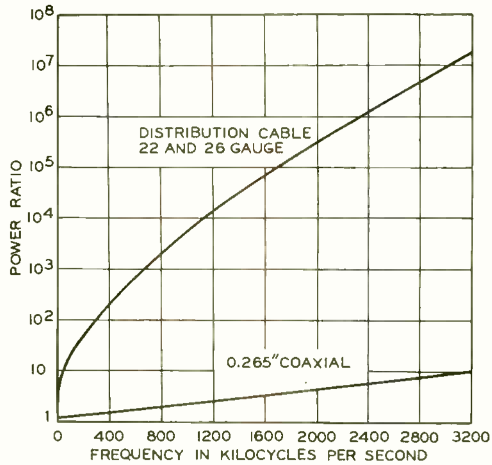


Fig. 1—Losses in one mile of experimental telephone and coaxial-cable circuits over the television frequency range

Besides this variation in loss with frequency, there is also a variation in the time of transmission. This variation is too small over the voice range to require correction for ordinary telephone circuits. For television transmission, however, if it is not kept extremely small the detail of the picture will be blurred, and spurious transients and

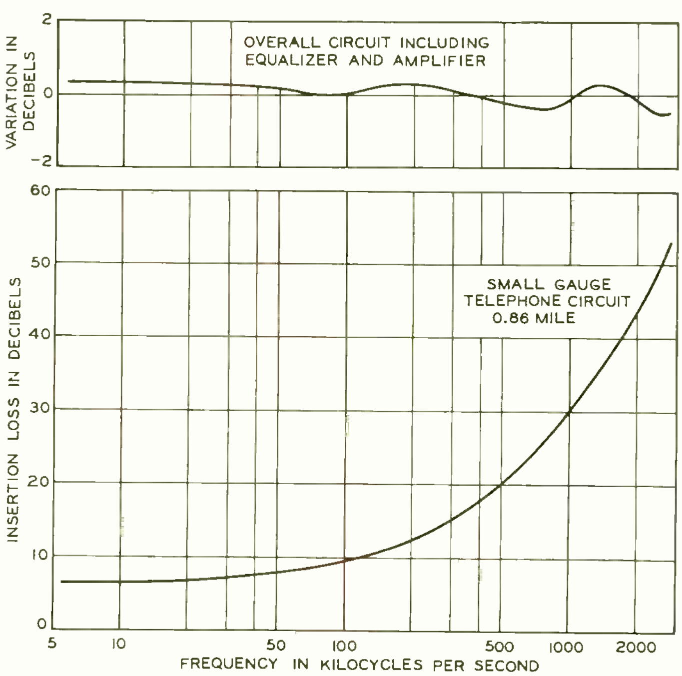


Fig. 2—Overall loss over the television band for a cable circuit plus amplifiers and equalizers

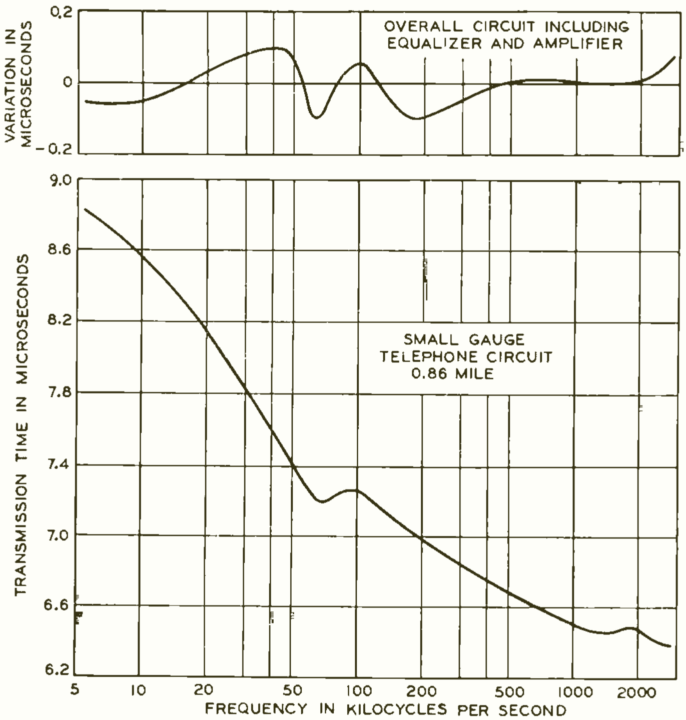


Fig. 3—Time of transmission before and after equalization for the same cable circuit

transmission time to within plus or minus 0.1 microsecond.

In addition to the phase and attenuation equalizers required by such circuits, high-gain amplifiers are needed to overcome the very large losses encountered. These amplifiers provide a flat gain over the entire range of frequencies from 45 cycles to 3,000,000 cycles. Their design is complicated by the fact that the cable pairs are balanced, that is, each wire of the pair has the same impedance to ground, while the television apparatus — in common with most high-frequency apparatus—is grounded on one side. Relatively large currents are likely to be induced on both conductors of a cable pair from nearby sixty-cycle power circuits and other noise sources. These currents flow equally over both conductors of a pair, which with the ground return comprise the longitudinal circuit. If the circuit, including its termination, is balanced throughout, these currents cannot affect the signal currents flowing in the metallic circuit. With an unbalanced amplifier terminating the circuit, the longitudinal currents would

"ghosts" will appear. The transmission time for one of the circuits used in recent tests is shown in Figure 3. Its variation amounts to about 2.5 microseconds—over ten times the allowable amount. Before a cable pair can be used for television, therefore, it is necessary to measure the transmission time, as already described in the Record*, and then to provide phase equalizers to correct it. As shown in the upper part of Figure 3, the equalized line maintains the same

*Record, *June*, 1939, *p.* 309.

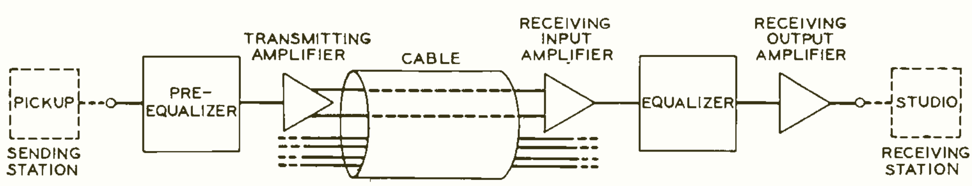


Fig. 4—Schematic circuit layout for the recent television experiment

enter the metallic circuit, and appear as bar patterns on the received picture. This difficulty is avoided in this case not by the use of transformers but by applying negative feedback in the amplifier—as suggested by S. Doba—to the longitudinal circuit but not to the metallic circuit currents. This, in conjunction with vacuum-tube balances, results in a reduction of 75 db in these induced currents. This feedback is applied both to the output stage of the transmitting amplifier and to the input stage of the receiving amplifier.

The arrangement of the apparatus for the CBS television experiment is indicated schematically in Figure 4. Amplification and equalization were provided at both ends of the circuit. The effect of the equalizer at the transmitting end is to predistort the signals, sending out the high frequencies at a level much higher than if equalization were not employed. This tends to decrease the effect of any high-frequency noise, since the induced currents become smaller relative to the higher level of the signal currents. At the receiving end, the equalizer is placed between two sections of the receiving amplifier. This results in a higher level at the input to the receiving amplifier and minimizes the tube noise, the sixty-cycle hum, and the microphonic disturbances. The two amplifiers divide the total gain of about 75 db. They operate on sixty-cycle power circuits, and with their equalizers and power supply are mounted in small portable cabinets as shown on page 34.

The possible length of such circuits between repeaters is closely limited. The signal currents cannot be allowed to drop too low or else noise and other disturbances will be induced from the adjacent pairs. On the other hand, they cannot be allowed to become

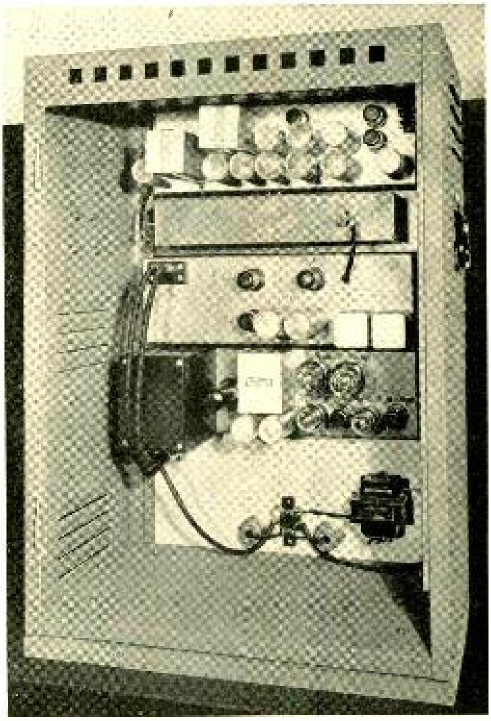


Fig. 5—Rear view of amplifier-equalizer unit with door removed

excessive or they, in turn, will induce disturbances in the telephone circuits. These two levels fix the distance that may be satisfactorily spanned. For average pairs in local telephone plants this appears to be slightly under a mile, but it may be somewhat greater where relatively quiet circuits or larger size wires are available. Further experiments to determine the possibilities of telephone pairs for television purposes are being conducted.

Crossbar Trunking Studies

By C. A. LOVELL
Physical Research Department

THE switching unit of the crossbar system is the crossbar switch* itself, which in its most commonly used form is an assembly of twenty ten-point switches, each capable of connecting one line or trunk to any one of a group of ten. This is a small unit compared to the other types used by the Bell System. With the step-by-step selectors, for example, one line can be connected to any of a hundred, and with the panel selector, one line can be connected to any of five hundred. The switch, and the system employing it, has many advantages over the previous types, but its smaller size requires that there be more switches in series in the connection between any two subscribers, and thus more inter-switch trunks, which in the crossbar system are of two types, called "links" and "junctors." The switches are mounted in frames consisting of two vertical rows each of ten switches, those in one row called primary switches, and those in the other called secondary switches. The trunks connecting the primary to the secondary switches in the same frame are known as links while those that are used to connect the switches of two frames are known as junctors.

The frames are given the same names as in the panel system,† "line," "district," "office," and "incoming" frames, but there is no "final" frame in the crossbar system—the line frame serving both as line and final frames. The various links take the name of the frame they are on, and there are thus line links, district links, office links, and incoming links. The junctors take the name of the frame they run to. Thus the trunks connecting the line frames to the district frames are district junctors, those connecting the district to office frames are office junctors, and those connecting the incoming to the line frames are line junctors. The latter are used only for incoming calls, and the district junctors only for outgoing calls. The connections between office and incoming frames are not called junctors, but inter-office trunks. The general arrangement of the switching chain is shown in Figure 1 which omits the sender and other control circuits except the markers.

The completion of a call between two crossbar subscribers* may be divided into three major steps. The first, under control of the line-group controller circuit associated with that particular frame, locates the calling line and finds an idle district junctor that can be used to connect it to a district frame. The second step, under control of an originating marker, finds a suitable outgoing trunk and an idle path through the district and office frames between this trunk and the district junctor already selected. The third step, at the office of the called subscriber and under control of a terminating marker, finds the line

*Record, *July*, 1937, *p.* 338.
†Record, *July*, 1931, *p.* 523.

*Record, *February*, 1939, *p.* 173.

called and an idle path through the incoming and line frames to this line from the incoming trunk selected in the second stage. These latter two stages, under control of the two markers, are very similar in many respects. Each has an incoming point indicated to it by the previous selecting stage, and must find a suitable outgoing trunk or line, and also a path to it through two frames.

This path through two frames has three links, referred to as the A, B, and C links respectively, although the B link is technically a junctor, and in the crossbar system three idle links capable of forming a path between the desired incoming and outgoing points are found simultaneously. This method is called ABC trunking. Since the situation is nearly the same at both of the ABC trunking points, the major problems involved can be illustrated by considering the incoming and line frames alone. In a representative symmetrical office having ten incoming frames and forty line frames, there are just ten possible paths between any particular incoming switch and any particular line switch. The three links of each path, however, are not used solely for that path, but may serve as links of other paths as well. To determine whether a particular path between a trunk and a line is idle, therefore, the three links that form that path must all be busy-tested. This triple test is performed by the marker, and is one of the novel features that have been incorporated in the crossbar system.

It is essential, of course, to know the load-carrying ability of such a system of trunking. How many calls per hour, in other words, may it handle with only a reasonable number of calls that fail to get completed because of busy conditions? Another way of putting this question is, given a normal busy-hour load, how many calls will fail to be completed, or what is the probability that any one call in the busy hour will find no path available to the called line?

If, when such an office is in service, time could be stopped at some instant during the busy hour, and all the links of all the paths be examined to see whether or not they were busy, a "busy" pattern could be obtained. From a study of such a pattern it would be possible to determine the probability that a call coming at it that instant would find an "all paths busy" condition. There are no means, however, for getting such patterns from an office in operation, and even if there were, the time and labor re-

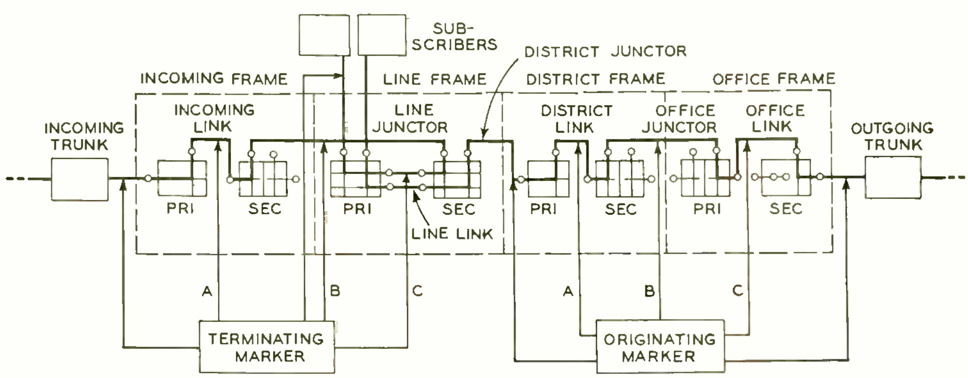


Fig. 1—Block schematic of crossbar system showing ABC trunking scheme

quired to gather patterns and interpret them would be so great as to make the method impracticable.

The problem may be worked out "on paper," however, and although far from simple, it does become practicable with the help of modern methods and machines. Information is already available, of course, on typical busy-hour loads. From traffic studies it is possible to say the number of calls that will be handled during the busy hour, and what their range of duration will be. Then by selecting at random the time at which the calls come in during the busy hour, the trunks on which they appear, and the lines they are calling, it is possible to tabulate for each call as it comes in the links it would select, and in this way to make complete record of all calls during that busy hour. Since the line frame is included in this ABC trunking group, outgoing as well as incoming calls would have to be considered. From a record of this type it is possible to determine at any instant during the hour just what links are busy, and thus to know whether or not any particular call would find an idle path.

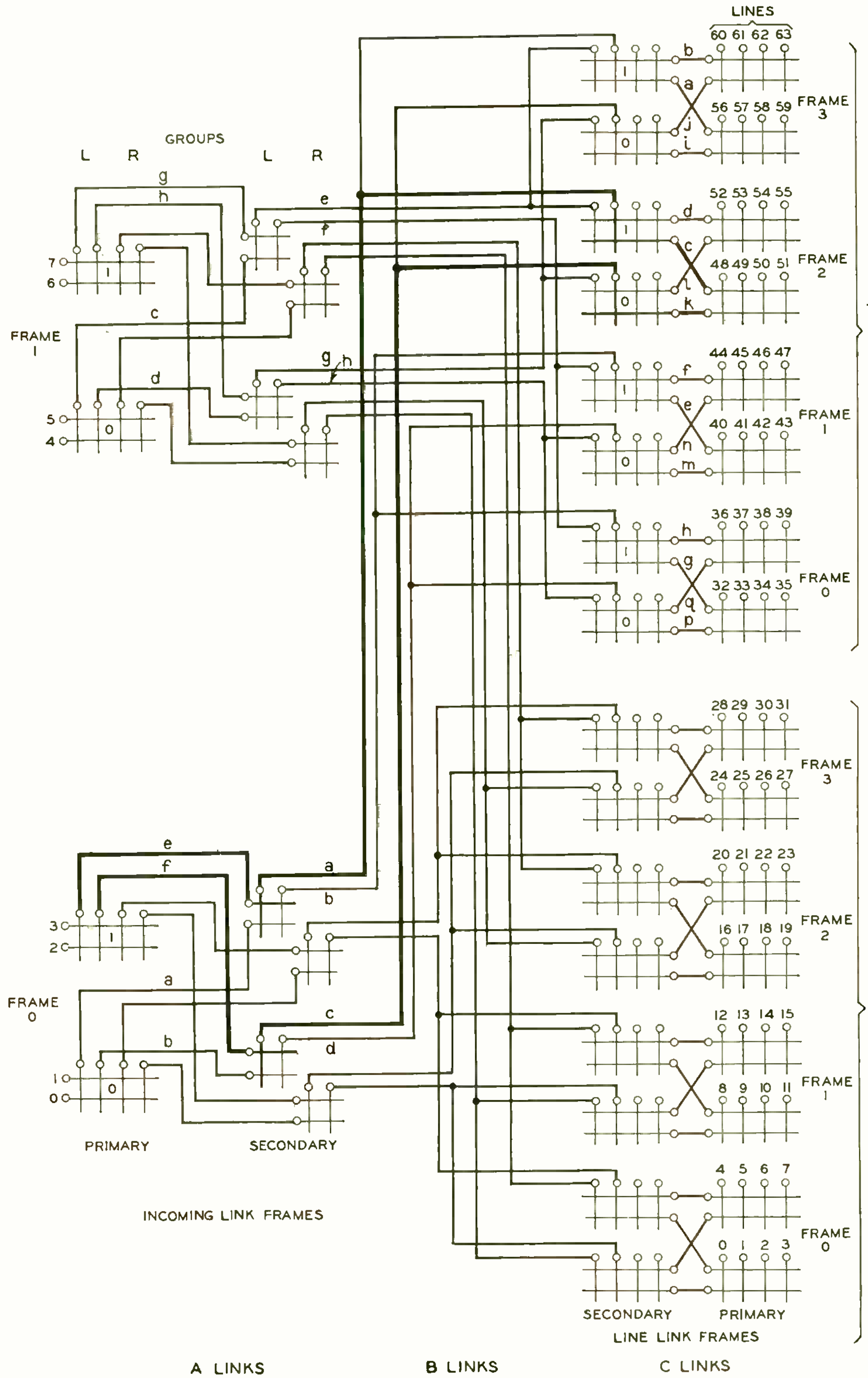
Such studies have been and are still being carried out. Because of the large number of possible calls, paths, and links, however, the procedure is involved, and can best be understood by considering a miniature office in which the elements are greatly reduced in number, but are retained in their correct proportional relationships. The number of links, paths, frames, etc., in a symmetrical crossbar office may be expressed as a power or multiple of the number of horizontal connections to the crossbar switch, which is ten. If, therefore, a miniature crossbar switch were considered with only two horizontal connections, all the other elements of this system could be expressed as multiples or powers of two. Such a system is shown in Figure 2.

The arrangements of the switches and links on the incoming and line frames have already been discussed in the RECORD*, but the arrangement of the line junctors connecting the incoming to the line frames could only be indicated, because their number is far too great to allow their being drawn on a permissible size of illustration. By reducing the number of horizontals to two, however, the complete ABC trunking scheme can be shown in reasonable compass. The numbers of the various switches, frames, links, etc., together with their method of derivation, and the numbers of the various elements for the miniature and an actual telephone office, are shown in Table I.

Half of the verticals on the line-switch secondaries are used for outgoing calls, and so no leads are shown leaving them on the diagram. Because it is necessary for the C links to handle outgoing as well as incoming traffic, however, there are twice as many of them as there are of the A or B links, but the number that can be assumed available for incoming calls alone is the same. The line frames are divided into two groups, designated right, (R), and left, (L), corresponding to the two halves into which the secondaries of the incoming frames are split. The B links leaving the left half of an incoming frame run to the left group of line-link frames. Similarly the A links leaving the left

*RECORD, *May*, 1939, *p.* 266.

Fig. 2 (Opposite page)—ABC trunking arrangement at the incoming and line-link frames for a crossbar system using a switch with only two horizontals



LINES
GROUPS
L R L R
FRAME 1
FRAME 0
PRIMARY
SECONDARY
INCOMING LINK FRAMES
FRAME 3
FRAME 2
FRAME 1
FRAME 0
GROUP L
GROUP R
SECONDARY
PRIMARY
LINE LINK FRAMES
A LINKS
B LINKS
C LINKS

side of the incoming primary switches run to the left side of the incoming secondary switches. The arrangement of the links can be illustrated by considering, for example, a call from trunk 3 to line 48. The two possible A links will be *e* and *f*; the B links will be *a* and *c*; while the C links will be *c* and *k*.

The A link *e*, however, may also be used for calls to seven other line switches: L00, L01, L10, L11, L21, L30, and L31. The B link *a* may also be used for calls from incoming primary switch 00 and to line secondaries L21, L30 and L31, while the C link *c* may also be used for calls to line frame L20 from incoming primaries 00, 10 and 11, and also for certain outgoing paths. In all cases the paths are between switches and not between lines and trunks. All lines on line primary L01, for example, have access to the same paths, and likewise all trunks connected to each incoming primary have access to the same paths.

To make a probability study of the ABC trunking in such a miniature office, it may be assumed that the number of calls per busy hour is 240, and for convenience in determining times, the hour may be divided into 1000 equal parts. To load the office it will be necessary to pick at random 240 numbers to represent the line number calling or being called, 240 numbers to represent the time at which each call will begin, and similarly three other

TABLE I

	Generalized Number	Derivation	No. for n = 2	No. for n = 10
1. Horizontals per switch	n	...	2	10
2. Primary or secondary switches per frame	n	...	2	10
3. Incoming frames*	n	...	2	10
4. Total incoming primary or secondary switches	n^2	(2) x (3)	4	100
5. Trunks accommodated	n^3	(4) x (1)	8	1000
6. Verticals per switch	2n	2 x (1)	4	20
7. "A" links	$2n^3$	(6) x (4)	16	2000
8. Line frames†	4n	4 x (3)	8	40
9. Secondary verticals per switch available for incoming calls on line frame	n	(6) ÷ 2	2	10
10. Total secondary verticals available for incoming calls on line frame	$4n^3$	(2) x (8) x (3)	32	4000
11. "B" links	$2n^3$	(6) x (4) or (10) ÷ 2	16	2000
12. "C" links	$4n^3$	(1) x (2) x (8)	32	4000
13. Paths between any incoming primary and any line frame primary	n	...	2	10
14. Total paths between incoming and line frame primaries	$4n^5$	(4) x (8) x (2) x (13)	128	400,000
15. Total paths per "A" or "B" links	$2n^2$	(15) ÷ (7)	8	200
16. Total paths per "C" link	n^2	(14) ÷ (12)	4	100

*Number of incoming frames normally determined by the number of incoming trunks, but with the assumptions on which this table is based, it is equal to "n."
†Usual, but not always true.

sets of 240 random numbers to represent the trunk involved, the duration of the call, and whether the call is incoming or outgoing. Since the line designation will require two digits; the time, three; the trunk, one; the duration, one; and a designation as to whether the call is incoming or outgoing, one; there will be a total of eight digits required to designate each call. It is possible, therefore, to select at random 240 eight-digit numbers, and to let the first two digits designate the line; the next three, the time; and the next one, the trunk; and the next the duration; and the last whether the call is incoming or outgoing.

With these numbers available it is then possible to set up the office load by going through the calls and assigning the A, B and C links as they would normally be selected. The call with the earliest beginning time will be taken as the first call, and the first A, B and C links will be used. Its duration added to its beginning time gives its terminating time. The next call will be set up in a similar manner, using the next available links. As each call is tabulated it will be necessary to notice what links are available, since a set becomes available as each call terminates. It may not be possible to complete some of the calls because of busy links, so that more than the 240 calls will have to be selected to give 240 completed calls during the hour. For a somewhat similar reason, it will be necessary to discard the first few minutes to give the office time to get loaded up, and to extend the time of the last call so as to give full load for a complete hour. During this process work may frequently be stopped and a record of the condition of the entire office taken.

The probability that a call coming in at a particular moment will fail to find an idle path to the called line can be determined by counting the number of paths that cannot be used because either an A, B, or C link comprising it is busy, and dividing this number by the total number of paths. A probability so determined would vary somewhat, depending on the time the test was made, but by making a large number of tests equally spaced

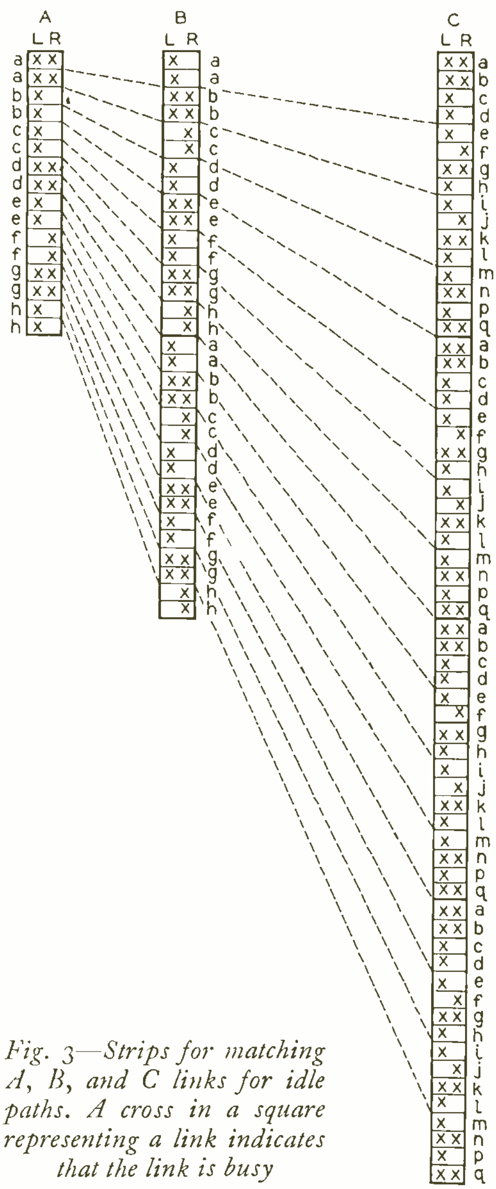


Fig. 3—Strips for matching A, B, and C links for idle paths. A cross in a square representing a link indicates that the link is busy

over the hour, and averaging these probabilities together, the result will be the probability that a random call placed at random time during the busy hour will fail to complete. For each time, this requires the matching of each A link with every B and C link with which it may be associated, and noting the paths that because of a busy link are not available.

This may be done by marking the state of the links on three strips of paper—one for the A, B and C links each. Such a set of three strips would be required for each time during the hour at which a check is to be made. The hour for this miniature system has been divided into 1000 divisions, and a set of matching strips might be made out for every ten of these divisions, thus making the checks forty-five seconds apart. Before making up these strips, one fact about the possible matchings should be noted. Considering, for example, the A link numbered L*a*, it will be noted that it must be matched against two B links, L*a* and L*b* respectively. Each of these B links in turn must be matched against four C links. B link L*a*, for example, must be matched against C links *a*, *b*, *c*, and *d*, and B link *b* must be matched against C links *e*, *f*, *g*, and *h*. If we follow through a similar matching for A link L*b*, it will be seen that they must be matched against B links *c* and *d* and C links *i*, *j*, *k*, *l*, *m*, *n*, *p* and *q*, which completes the C links in the L group. A links L*c* and L*d* would then be matched against B links *e*, *f*, *g*, and *h* and the same group of C links. At each stage two matches must be made: one for the L and one for the R groups.

This may be conveniently done by making the B-link strip twice as long as the A-link strip, and the C-link strip twice as long as the B, and marking them as indicated in Figure 3. To start the comparison, the links on the top row would first be matched—the L*s* against L's and the R's against R*s*. Then holding the A and B strip stationary, the C strip would be moved up one step and another match made. Then both B and C would be moved up one step and another check made. The procedure can be followed with the help of the diagram by remembering that C moves eight steps while B moves four, and A two. An equivalent method would be to make the strips all of the same length, but to join their ends together and mount them on a drum. Then four rotations of the C drum, and two rotations of

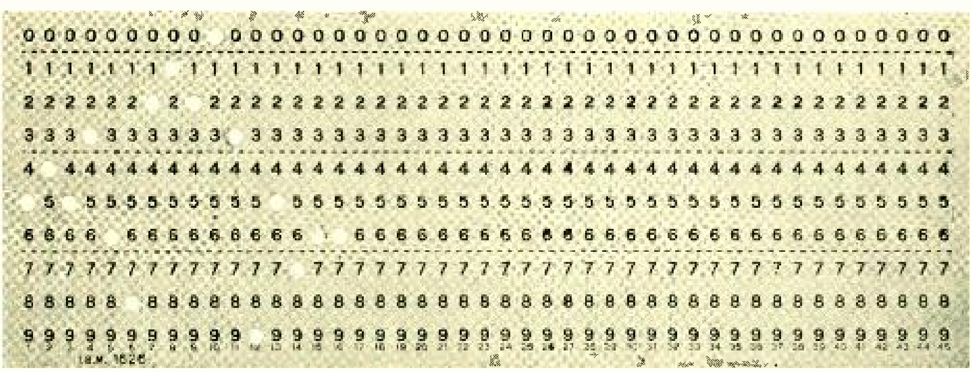


Fig. 4—One of the types of cards used for recording the sixteen-digit numbers used to represent each call. The number represented by this card is 4,829,330,312,066,466

the B drum, would be made for one rotation of the A drum.

In a probability study of an actual office, the procedure is far more complicated, and the work far more extensive because of the greater number of all elements as indicated in Table 1. A sixteen-digit random number is required, instead of an eight, for setting up the office load, and these numbers are punched on cards as shown in Figure 4 to facilitate sorting on accounting machines. A number of precautions must also be taken in the selection sequence of links. The strips of Figure 3 would each have to be ten divisions wide, instead of two, and there would be 4,000 steps instead of the sixteen for the miniature system, and the C strip will make 100 rotations while the B makes ten, and the A one. Moreover the hour is divided into 100,000 parts, and a check is made at a sufficient number of intervals to give reliable results. The final matching is done automatically by punching a hole in the strip for each position of an idle link, instead of leaving them blank as in Figure 3. Actually the strips were replaced by narrow tapes designed for use on teletype machines, on which fingers make an electrical contact whenever a hole is found in the tape. The contacts for the three tapes are in series so that when a hole is in each at corresponding positions, indicating idle links, a circuit is completed and a record is made on an electrically operated printer. The machines available employed only five-column tapes, so that two machines were used for each set. A drive was provided that moved the C tape 100 steps while the B moved ten and the A one. There was no necessity of making the A tape continuous since it runs through the machine only once, while the B and C tapes make ten and 100 revolutions respectively.

The set-up employed is shown on the first page of this issue. The A machines are the two at the lower right, the B machines at the upper right, and the C machines at the left of them. The small machine with a separate tape at the extreme left is the recorder. The serial number of each call that could not be completed is marked on this tape. During a run on one set of tapes, the machine makes one test on each of 40,000 sets of paths, and records every failure to match. The total number of failures divided by 40,000 gives the probability that a call would fail of completion if it were equally likely to appear on all switches. However, the calls reach the system under consideration over a group of heavily loaded junctors. The number of idle junctors in the subgroups serving the individual switches varies, and the probability of a call appearing on any switch is proportional to the number of idle junctors in its subgroup. The final result, therefore, is obtained by weighting each of the losses indicated by the machine according to the number of idle junctors in the subgroup involved. A large number of precautions and special steps must be taken that have not been indicated, but the general procedure is the same. The method that has been employed has proved very satisfactory, and is giving valuable information as to the capabilities of the system.

A Level Compensator for Carrier-Telegraph Systems

By V. P. THORP
Telegraph Facilities Department

WITH the carrier-telegraph systems used extensively in the Bell System, both voice frequency and high frequency, the marking signals are spurts of carrier, while the spacing signals are intervals of no carrier. At the end of a section of line the marking signals are rectified to operate teletypewriters or sounders, or relays that repeat the signals over the next section of line. The marking signals as they leave the sending relay are square-topped carrier pulses. If the effect of the line were only to reduce them in magnitude, considerable variation in attenuation could be tolerated, since the only requirement would be that at the receiving end the signals when amplified and rectified be of sufficient magnitude to operate the sensitive relays. Actually, however, the effect of the line and of the tuned circuits at each end is to round off the beginnings and ends of the pulses. As a result the pulses when repeated by relays are different in length from the pulses sent, since the receiving relays operate and release at some point along the sloping ends of the pulses.

This situation is illustrated in Figure 1. Along the upper line of this diagram are represented three rectified pulses, each of which, previous to rectification, had been rounded and had been attenuated a different amount in passing over the transmission system. The receiving relay is supplied with a constant local current that holds its armature to the open or spacing contact when no cur-

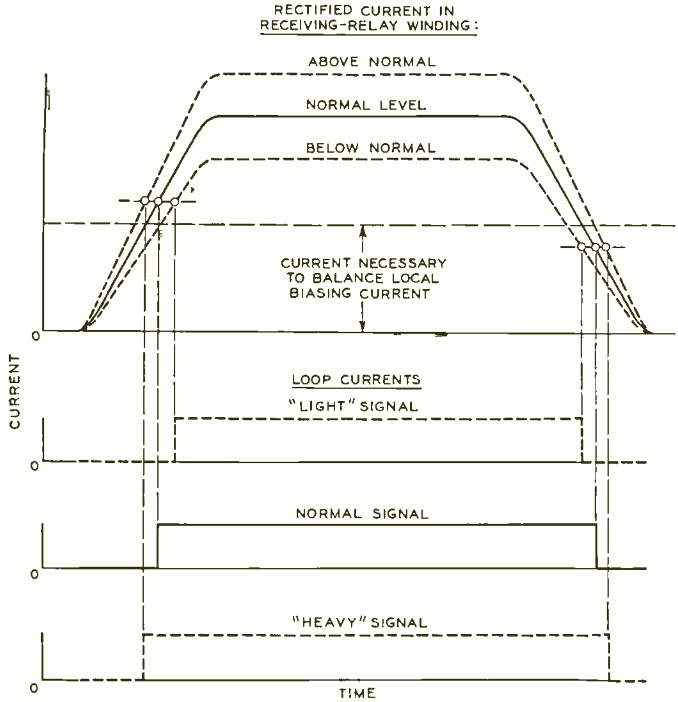


Fig. 1—Telegraph signals of various levels, shown on the upper line, result in received signals of different lengths

rent is being received. The relay will not be operated until the incoming pulse has attained a value slightly greater than this holding current, and will not release until it has dropped to

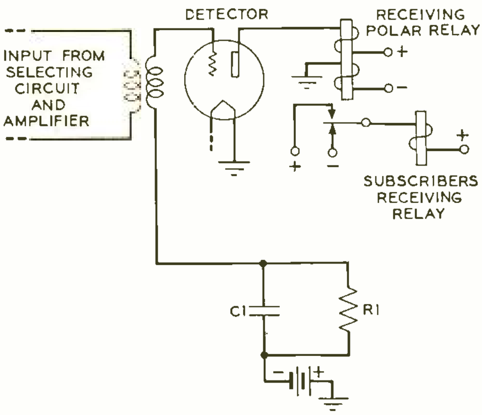


Fig. 2—Schematic of level compensator

a value somewhat below it. The operating and releasing points of the relay are indicated by circles, and as a result of the different attenuation of the three pulses shown, the lengths of the signals repeated by the receiving relay differ as shown on the three lower lines. This shortening or lengthening of the signal pulses is called "biasing" — the amount of biasing being proportional to the deviation of the signal length from its normal value. This change in length of the signals may become particularly objectionable when several circuits are connected in tandem, since its effects are cumulative.

To avoid excessive change in the length of signals passing over long carrier-telegraph circuits, a level compensator has been developed along lines originally suggested by J. Herman.

The output of the rectifier, and thus the current that flows to the receiving relay, depends on the relative values of the input voltage and the negative bias on the detector. The level compensator stabilizes the rectifier output by changing the biasing voltage automatically in proportion to the input voltage. If the grid bias were constant, the output from the detector would increase in proportion to the input. By making the bias increase in proportion to the input, the difference between input and bias—and thus the output—tends to remain constant.

A simplified form of the circuit with which this control is obtained is shown in Figure 2. The fixed-negative grid bias of the rectifier is supplied by a battery through a condenser C1 and a resistance R1 in parallel. The normal input level during a marking interval is such that the positive halves of the carrier cycles exceed the negative bias, and grid current flows. In passing through R1, this current results in a potential difference across the condenser, which assumes a charge

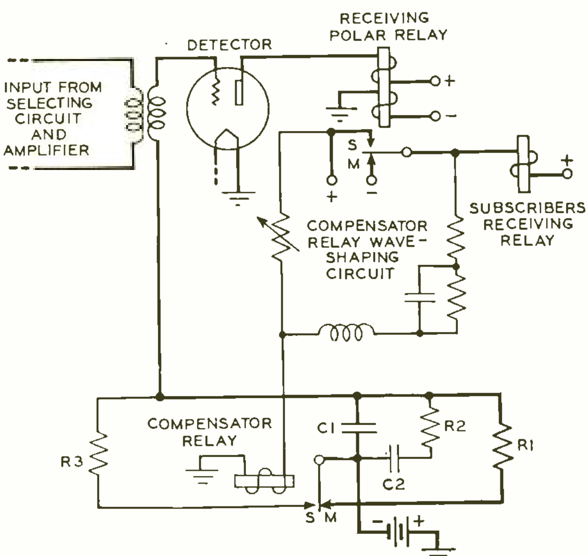


Fig. 3—Complete diagram of level compensator

as a result. This voltage across the condenser adds to the original bias of the battery, and since it varies with the input voltage, the bias also varies in the same manner, and the output tends to remain constant.

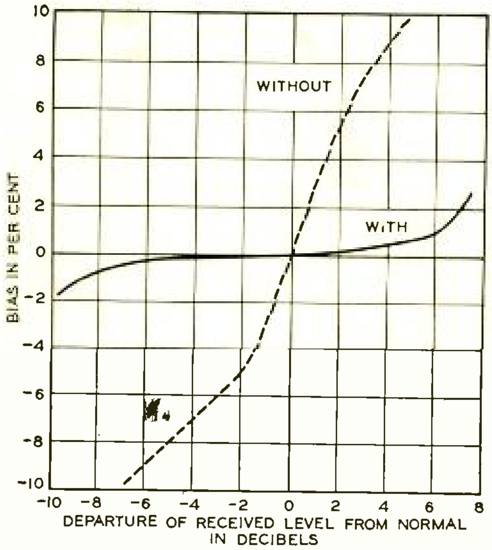


Fig. 4—Improvement in variations in signal bias by the level compensator

For continuous sending such a circuit would work fairly well, since the resistance R1 is so large that there is no serious leakage of charge from the condenser during the spacing periods. To avoid the large loss of charge that would occur during prolonged intervals of no sending, however, a compensator relay is incorporated to open the circuit through R1 when no grid current is flowing in the detector tube. This relay is connected to the armature of the subscriber's receiving relay, and the R1 shunt is closed when the relay moves to its marking contact and opened when it moves to its spacing contact. Since the receiving and compensator relays act at the beginning of a signal, before grid current starts to flow, and releases somewhat after the grid current ceases to flow, the compensator relay is biased toward its spacing contact, so that the shunting circuit will remain open until grid current starts to flow and will open when it ceases.

To secure more satisfactory behavior under all operating conditions likely to occur, several other circuit elements are added, as shown in Figure 3. In the voice-frequency carrier systems, C2 and R2 are omitted. If, for example, a sudden and large reduction in level should occur, the relays would move to their spacing contacts, leaving a large charge on the condenser. Since the circuit through R1 would be open, the charge could not leak off, and it might be so large that subsequent incoming marking pulses would not be large enough to overcome the high bias, and the relays would remain on their spacing contacts. The high resistance R3 avoids this by permitting the charge to leak off slowly.

Another condition that must be provided for in the high-frequency open-wire carrier systems is sudden large increases in level, such as "hits" that sometimes occur during lightning storms. Without precautions to take care of such occurrences, the large charge resulting from the increase in level would increase the bias sufficiently to cause the relays to move to their spacing contacts, since the bias might be higher than even a marking pulse could overcome. By connecting a large-capacity condenser C2 in series with a resistance R2 across condenser C1, the effects of such hits are for the most part avoided. This condenser acts as a reservoir to absorb the momentary excesses of charge. Because C2 is large in comparison with C1, the sudden increase in charge on C1 during a hit flows into C2 and drains off through R1 and R2.

I

Twisting a pair of wires for experimental purposes

II

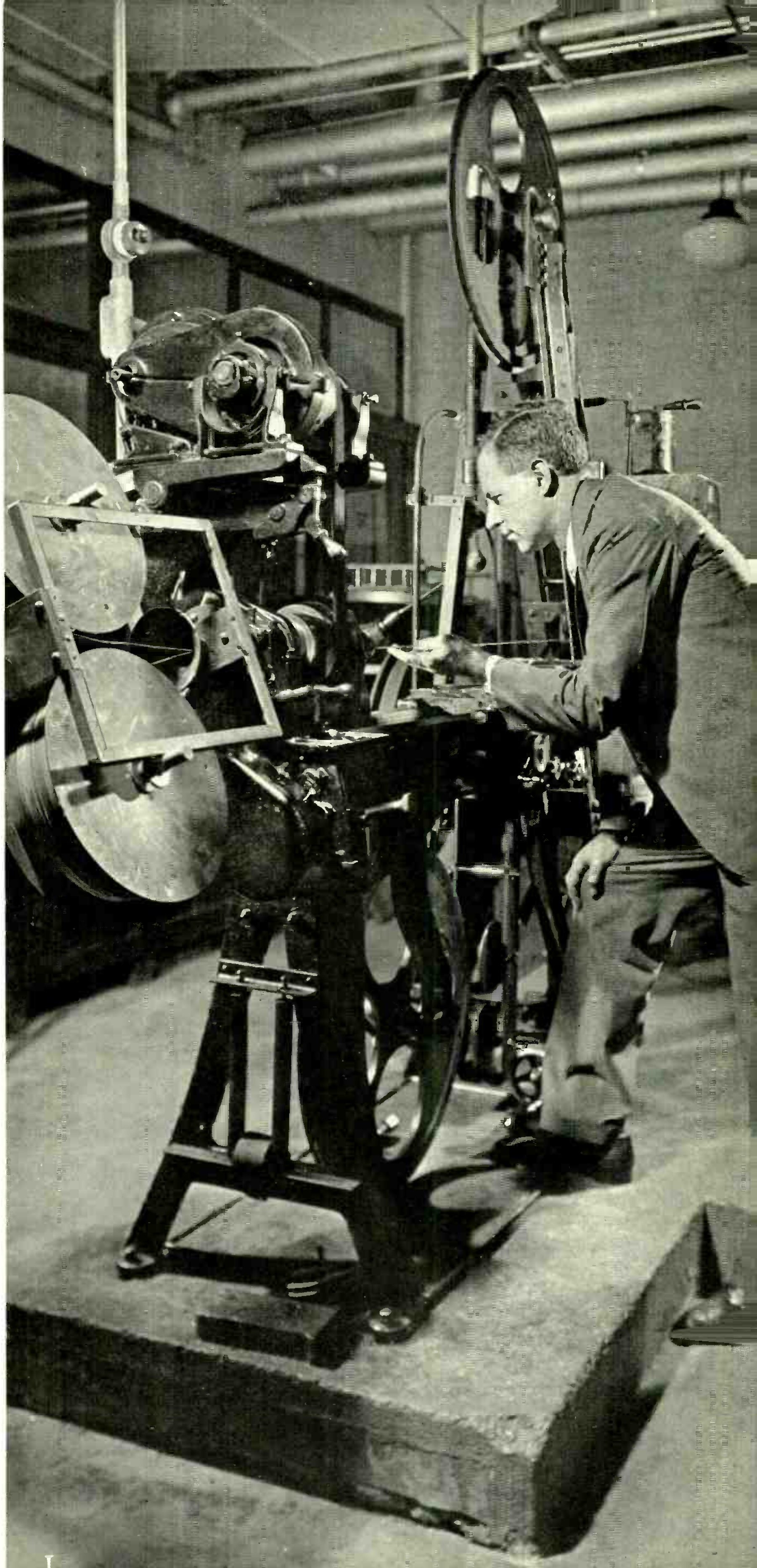
Measuring permeability with a Babbitt permeameter (shown at the right of the photograph)

III

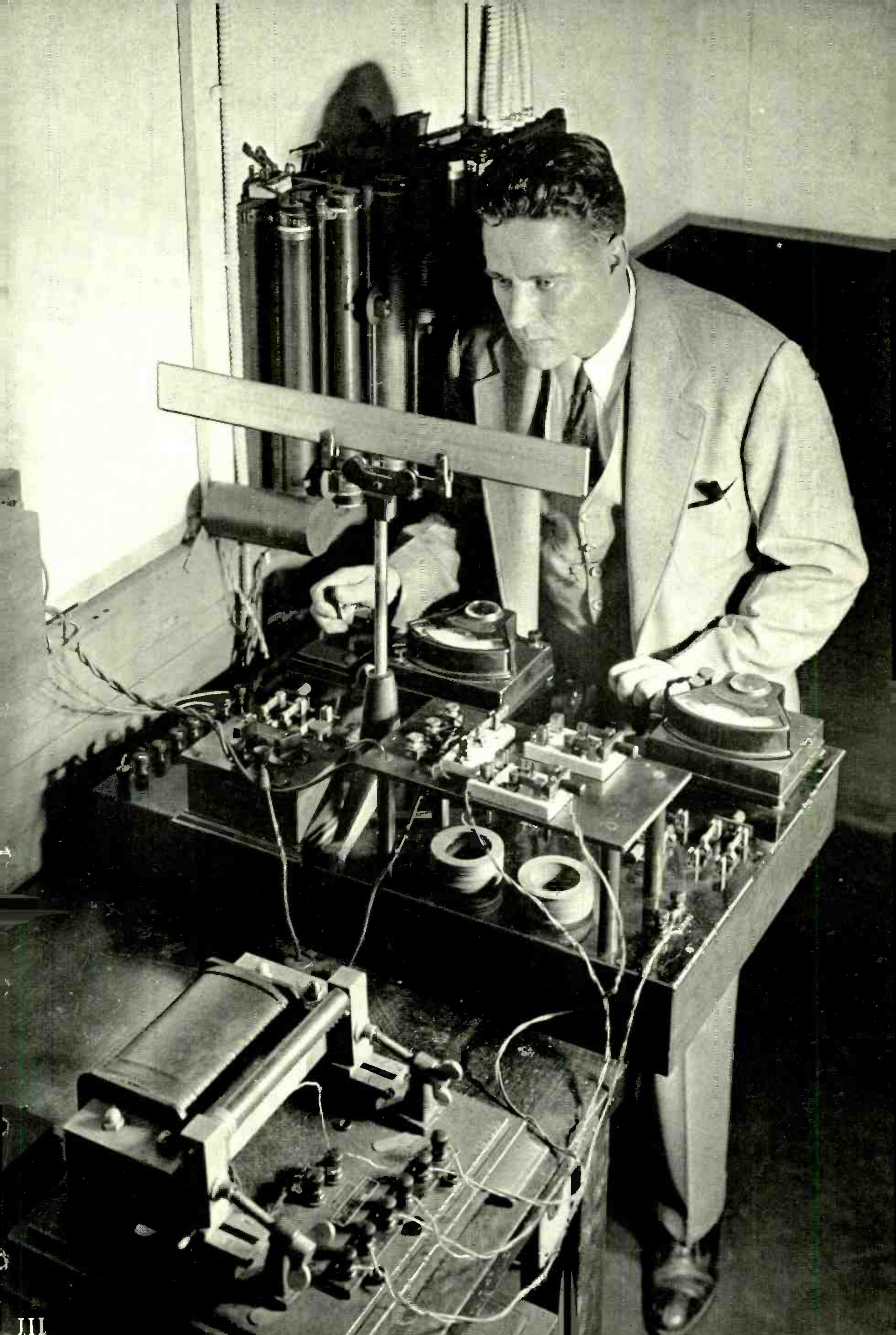
Measuring permeability with a Fahy Simplex permeameter (shown at the lower left). The Simplex and Babbitt permeameters are described on pages 49-53 of this issue

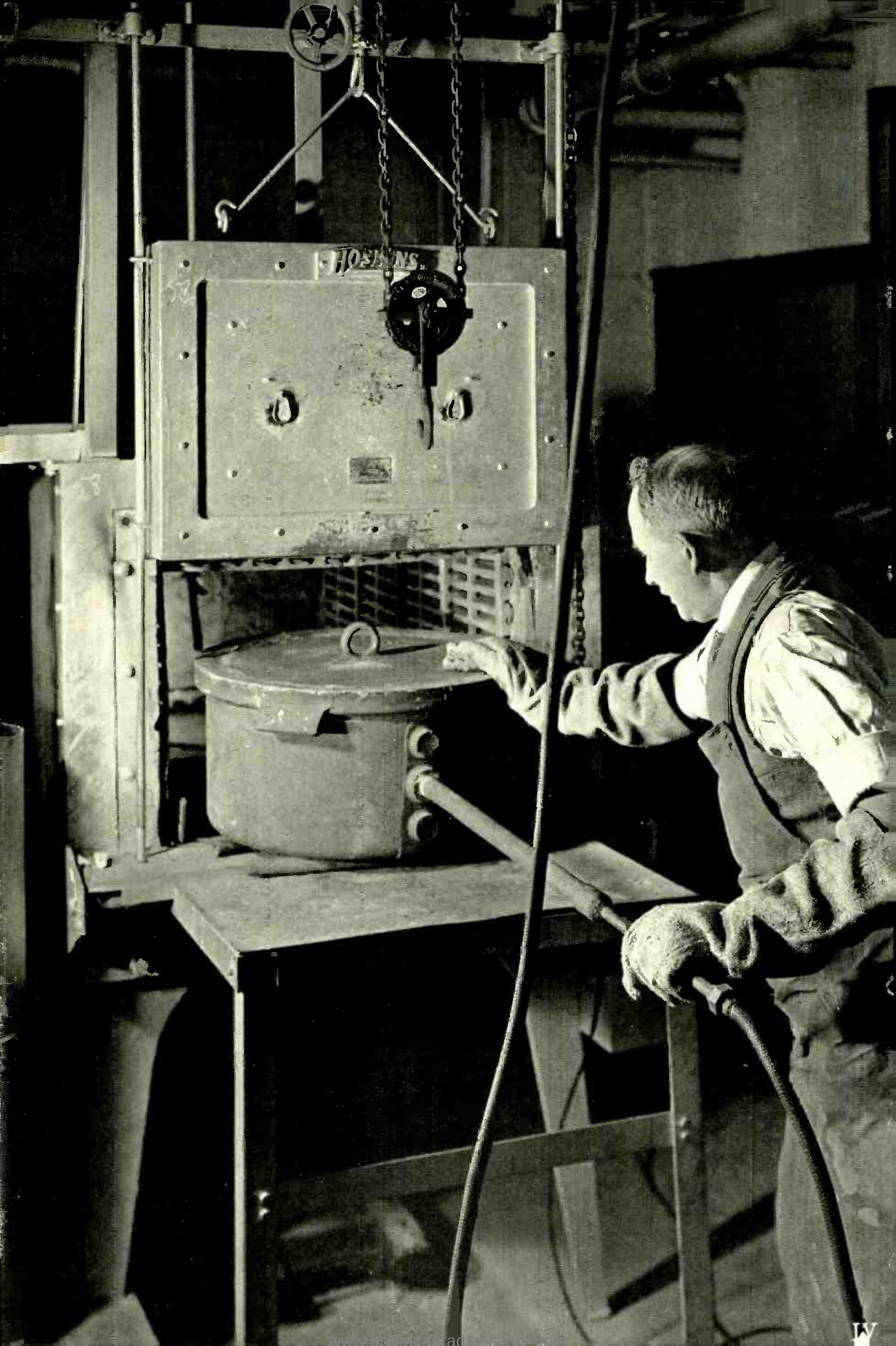
IV

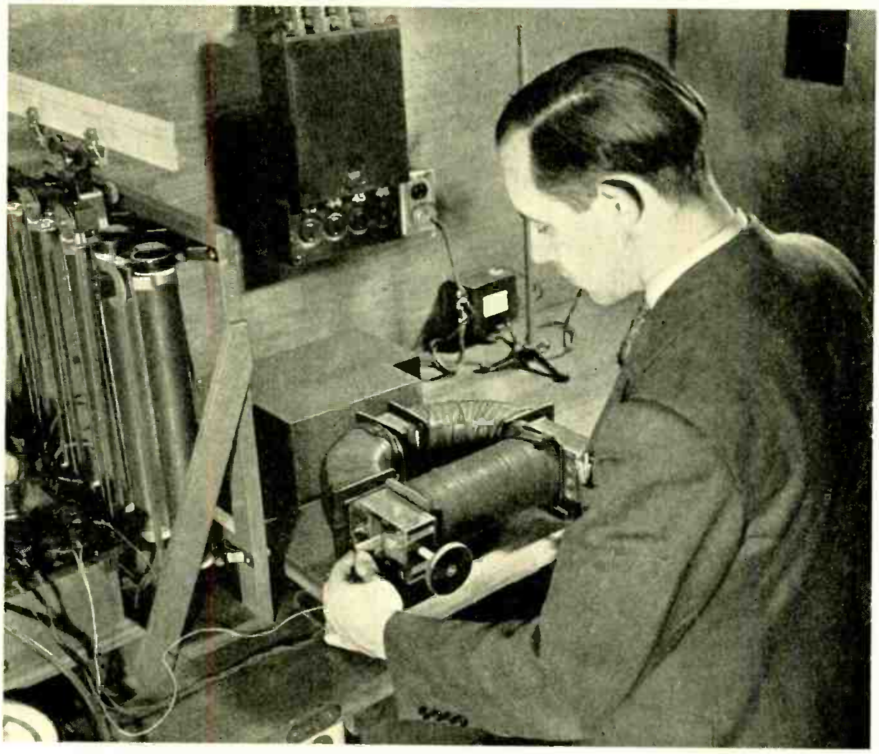
Pot-annealing magnetic parts



I







Magnetic Materials Testing

By J. A. ASHWORTH
Electro-Mechanical Apparatus

THE basic characteristics of magnetic materials may be determined for the most part from the various relationships between the flux density and the magnetizing force. These relationships are represented graphically by a magnetization curve, and a series of hysteresis loops. The magnetization curve represents the relationship between flux density, B, and magnetizing force, H, as the latter is increased from zero up to such a value that further increase produces no appreciable increase in flux. The hysteresis loops represent a complete cycle of flux change as the magnetizing force is decreased from some value HI to zero, then reversed to a value −HI, and then increased to the original positive value. The areas of these loops represent the magnetic losses in the material over such a cycle when the change in magnetizing force is made slowly.

A large part of the magnetic materials testing consists in determining these curves for the various materials used in the Bell System, but since these materials vary widely not only in magnetic characteristics but in the form or shape in which they are obtained, no single procedure can be applied to all of them. In general the flux is measured by placing a winding on a sample of the material and measuring the quantity of electricity caused to flow through this coil when a change is made in the magnetizing force. The determination of magnetizing force, however, is not always so easy. When the material can be formed into a ring of uniform cross-

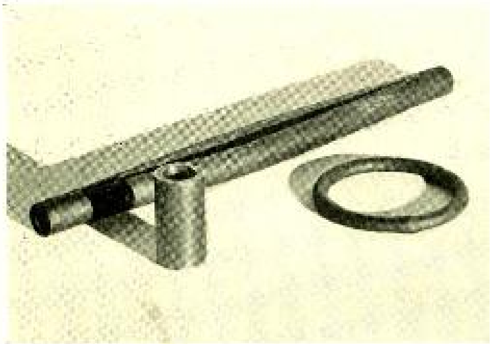


Fig. 1—Typical specimens of magnetic materials made from bars

section, it is determined by placing a winding of a known number of turns on the ring and passing a measured current through it. This gives the magneto-motive force in ampere turns, which may be converted to the magnetizing force by dividing by the length of the magnetic path. This is the simplest and most satisfactory method, and is always used when possible. Where large numbers of similar size samples are to be measured, special jigs* are employed to avoid the necessity of placing separate windings over each. This method is particularly suitable for measurements on toroidal cores, such as are commonly used for loading coils and for certain forms of transformers or repeating coils.

In other cases, this type of specimen can be approximated in one of several ways. Where the material is a straight rod of such physical characteristics that it can be bent, it may be formed into a ring and then welded by one of several methods that are known not to have a harmful effect on the material. Where this bending is not desirable, the equivalent of a ring may be formed by milling a narrow slot lengthwise down the rod and then spreading the sides to form a link. Coils may then be placed around the two sides of the link. Both of these methods give the magnetic properties in the direction of drawing. At right angles to this direction, however, the magnetic properties are occasionally different, and to determine them the rod may be drilled out to form a bushing, which may then be tested as a simple ring. Typical specimens of this type are shown in Figure 1.

Magnetic material frequently comes in the form of thin sheets, and these may be formed into the equivalent of rings in several ways. Such sheets also occasionally have different characteristics in different directions. Where the characteristics are to be determined in one direction, the material may be cut into a narrow strip and

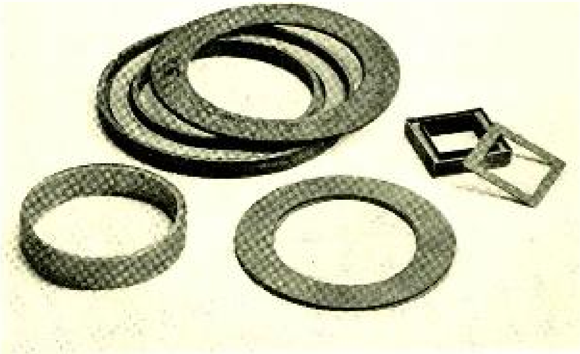


Fig. 2—Typical specimens made from sheet material

*Record, *April,* 1933, *p.* 227.

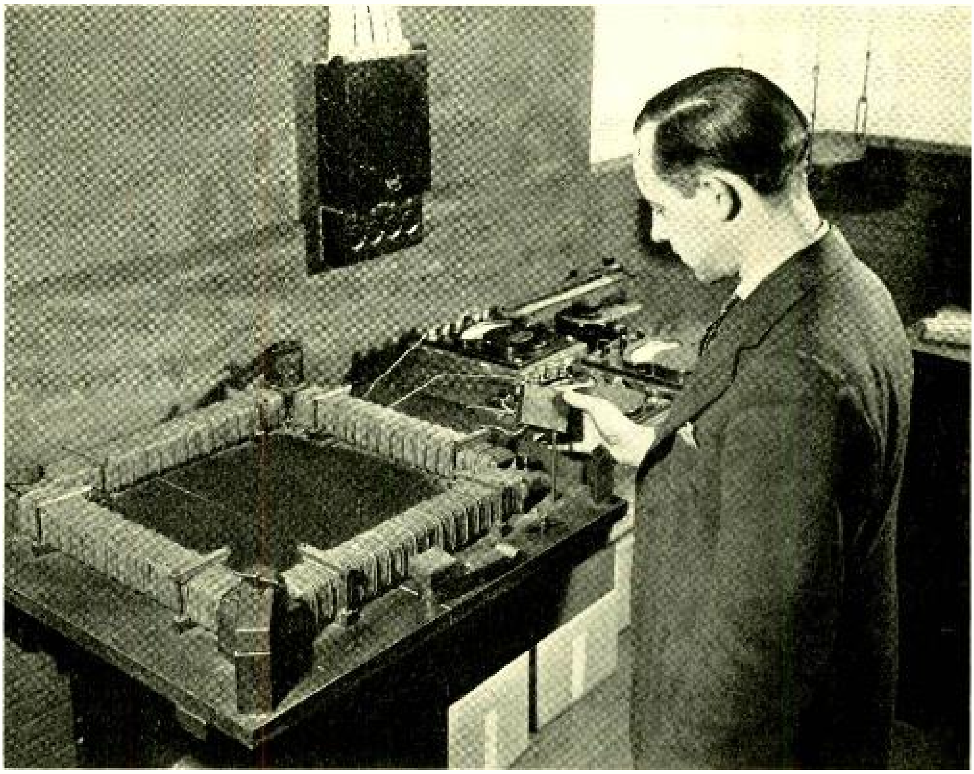


Fig. 3—An Epstein testing set employs primary and secondary windings on a rectangular core made up of specimen strips

then wound into a coil consisting of a number of layers, over which a winding is placed. Where the material is very thin, the tape is often wound on a spool of refractory material, which serves as a support during heat treatment and test. With material of such a nature that the pressure of a winding might change the magnetic characteristics, the wound tape is placed in a toroidal box which serves as a support and protection for the coil. Sometimes the sheet, due to its crystalline structure, has two directions in which the magnetic characteristics are the same, but different from those in other directions. Under these conditions hollow parallelograms are cut from the material to form a core. Specimens of sheet materials in various forms are shown in Figure 2.

Some materials, such as the steels used for permanent magnets, are too hard mechanically to be treated in any of these manners, and must be tested in their rod or bar form. Several types of d-c permeameters are available for such tests. They consist primarily of yokes of high permeability and large cross-section to complete the magnetic circuit of the bar specimen, and coils for creating the magnetizing force. Although there is a closed magnetic circuit carrying the same flux throughout, as when a ring specimen is used, the determination of the magnetizing force in the specimen is not so simply obtained because of the difference between the magnetic material of the yoke and of the specimen. The magneto-motive force divides itself across the various sections of a magnetic circuit in direct proportion to their length and in inverse proportion to their cross-section and permeability. Since both permeability and magnetizing force vary over different sections of the magnetic circuit, the correct values for any one section cannot be deter-

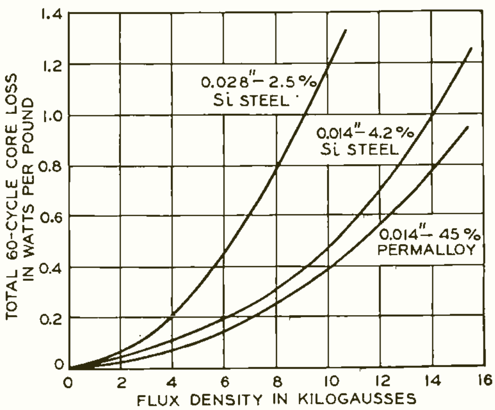


Fig. 4—Core losses in typical materials determined with an Epstein testing set

mined with sufficient accuracy from the total magneto-motive force and total flux. The magnetizing force must be found, therefore, by other means, and is determined differently with the two types of permeameters described below.

With the Fahy Simplex permeameter, shown in the foreground of the third illustration in the picture section of this issue, the yoke is U-shaped and the entire magneto-motive force is supplied by a winding on the base of the yoke. With this arrangement the magneto-motive force acting on the specimen is determined from the flux through an air-core coil bridged across two high-permeability posts in contact with the ends of the specimen.

With the Babbitt permeameter, shown in the photograph at the head of this article, the magneto-motive force is supplied by two windings connected in parallel electrically. One is on the U-shaped yoke and the other across the sides of the U, and the specimen is placed inside this latter coil. These two windings are proportioned so that the one on the yoke produces just sufficient magneto-motive force to maintain the flux through the yoke while that around the specimen maintains sufficient magneto-motive force to maintain the same flux. With this arrangement the magneto-motive force in the specimen can be calculated from the current flowing in its exciting winding, and the flux is determined from an auxiliary winding placed over the specimen. The ratio between the two exciting windings should theoretically be varied for each change of specimen, but since these permeameters are used only for low-permeability materials, while the yoke is of very high permeability, the magneto-motive force applied to the yoke is only a small part of that applied to the specimen, and small changes in it are negligible.

The properties of magnetic materials under the influence of a-c fields differ from the d-c characteristics, and for low magnetizing forces are determined for the most part by bridge measurements of the inductance and resistance of a winding placed on them, as already described.* For sheet material used in power transformers, however, the sixty-cycle loss at high flux densities is of particular importance, and is measured with an Epstein testing set shown in Figure 3. Strips of the specimen sheet are placed inside four coils forming a hollow square, and the coils—connected in series—are supplied from an a-c source through a wattmeter. The reading of a voltmeter connected across a secondary winding with the

*Record, *March*, 1932, *p.* 261.

same number of turns as the primary is a measure of the flux, and the loss is obtained from the wattmeter reading. The losses of typical materials are shown in Figure 4.

Because of the very extensive use of magnetic materials in the telephone plant, almost every known magnetic property is utilized. Not only must a very great variety of materials and shapes be tested, but a wide variety of types of tests is also required. Those described above, of course, are only a few, but they are representative and give an indication of the types of tests that must be made.

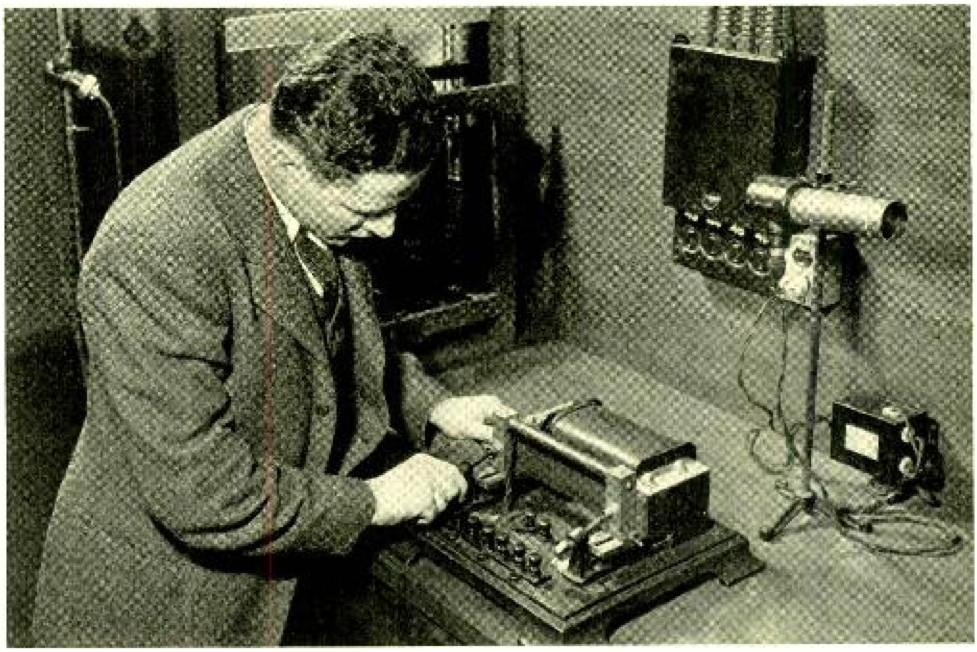
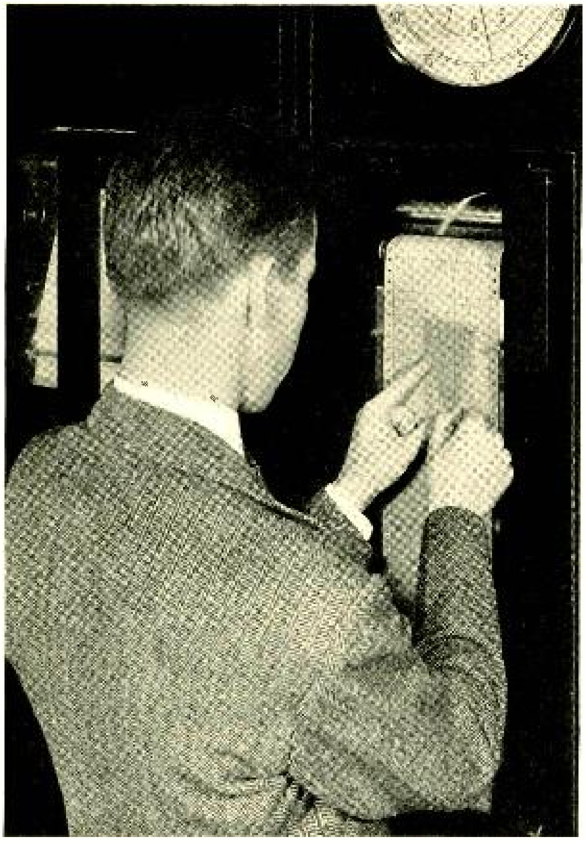


Fig. 5—Clamping a specimen in a Fahy Simplex permeameter



The Spark Chronograph

By W. A. MARRISON

TO KEEP a continuous check on the relative rates of the crystal clocks which comprise the Bell Laboratories' frequency standard, and also of their absolute rates in terms of radio time signals, a spark chronograph is used. It permits a continuous intercomparison of the timekeepers by automatically recording on a slowly moving chart a curve for each clock. These curves indicate at any point the difference in time between the clocks.

The record is made on waxed recording paper which is drawn slowly by a sprocket over a long knife-edged electrode mounted with small clearance below a rotating drum. The drum has raised above its surface a metal spiral which just clears the paper and forms with the electrode a short spark gap which traverses the width of the chart once for each revolution of the drum. Sparks perforate the paper at positions which depend on the angular position of the rotating drum and leave very small but readily visible marks where the wax melts around the hole. The visibility of these marks can be varied by controlling the intensity of spark.

When successive sparks occur at intervals which correspond exactly to any whole number of revolutions of the spiral, the perforations lie on a straight line parallel to the direction of motion of the recording paper. If the sparks come earlier or later by amounts proportional to the elapsed time, the corresponding indications lie on a straight line inclined to the direction of motion. The slope of this line is an accurate measure of the rate of the clock mechanism which produces the sparks, relative to the rate of the chronograph drum. Thus, any mechanism that produces electrical impulses at intervals simply related to the period of the rotating cylinder may be compared with it as a timekeeper.

Any accurate source of alternating current may be used to drive the chronograph, and this source then becomes the reference standard. When a crystal oscillator or other high-frequency source is used to control the speed of the drum, a submultiple of the high frequency is used to drive it.

The chronograph shown in the photograph operates from a 100,000-cycle crystal oscillator through a frequency converter which gives a 100-cycle output, and is designed so that the spiral makes two revolutions every second. The time interval corresponding to the entire chart width is therefore one-half second and the smallest divisions represent hundredths of a second. If the record changes its position by five small divisions per day, the clock which made it is gaining or losing five hundredths of a second per day relative to the rate of the drum. Whether a given slope means "gaining" or "losing" depends on the direction of rotation of the spiral. The instrument described here has a left-hand spiral and a clockwise rotation when viewed from the left, so that a slope upward to the left corresponds to a gaining rate relative to the chronograph. The chart is moved at the rate of three inches per day by gearing from the main motor and the record of the entire past week is kept continuously in view before it is wound automatically on the take-up reel.

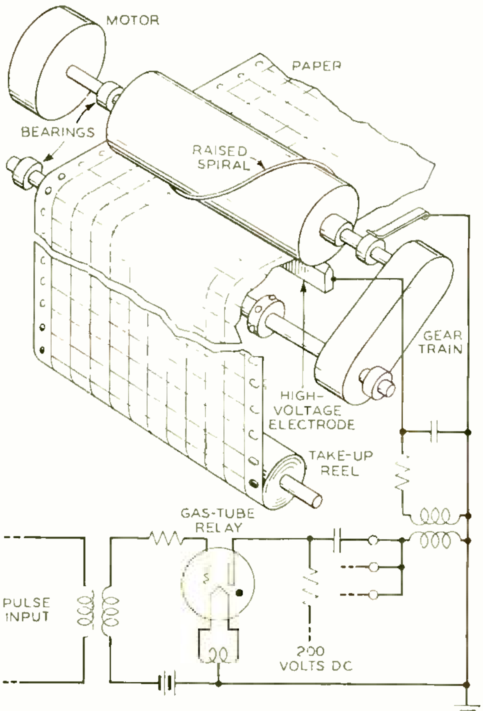


Fig. 1—A metal drum with a spiral raised above its surface rotates above a moving sheet of recording paper which passes over a long knife-edged electrode. Sparks from the knife edge to the spiral perforate the paper at points which depend on the angular position of the rotating drum

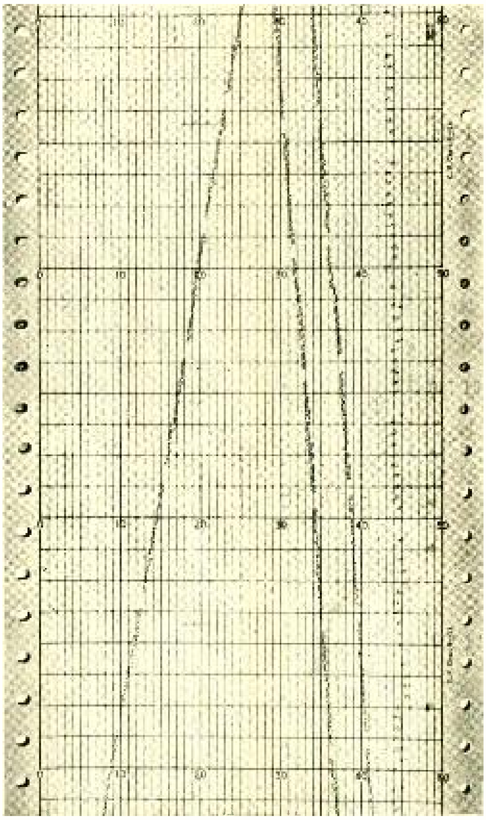


Fig. 2—Chronograph chart. The three records at the left were made by three crystal clocks. The other trace is a record of time signals received hourly by radio

The electrical circuit used with the spark chronograph permits making several clock records on the same chart without mutual interference. The rate of any clock mechanism which produces regular electrical pulses at intervals of a half-second, or multiples thereof, can be measured by allowing the pulses to operate a gas-tube relay. The condenser in the plate circuit of the relay tube is charged slowly to about 200 volts through a high resistance, and discharged very abruptly through the primary of an induction coil when the operating pulse arrives. This creates a high potential in the secondary winding which breaks down the gap between the knife-edged electrode and the grounded rotating spiral. The passage of the spark through the paper makes a permanent record on the chart and indicates the instant of occurrence by chronograph time. As the chart moves, and more sparks occur in succession, the traces form a line which is straight when the rates are constant.

The points on the record scatter somewhat because a spark does not always choose the most direct path. This accounts for most of the normal scattering which amounts to about one and a half milliseconds either side of the mean. Mean observations can be made with an accuracy of better than one millisecond by measuring to a line drawn through the center of the line that is traced.

Several gas-tube relays can be used with one induction coil so that many records can be made on the same chart without mutual interference. Figure 2 shows a chart with four records, of which the three at the left are comparisons of three crystal clocks against a fourth which controls the chronograph. The fourth trace is a record of time signals received hourly by radio. The somewhat greater scattering in this record is largely due to irregularities in radio reception, such as those caused by fading and static. The radio signal is allowed to record for one minute during each transmission. There is no observable movement of the chart during a single transmission and the record appears as groups of points spaced hourly along the chart.

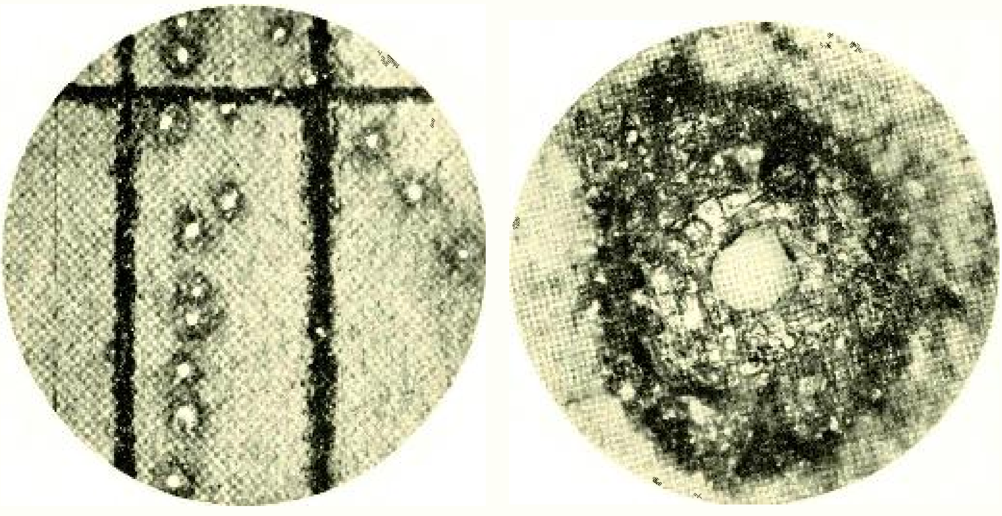
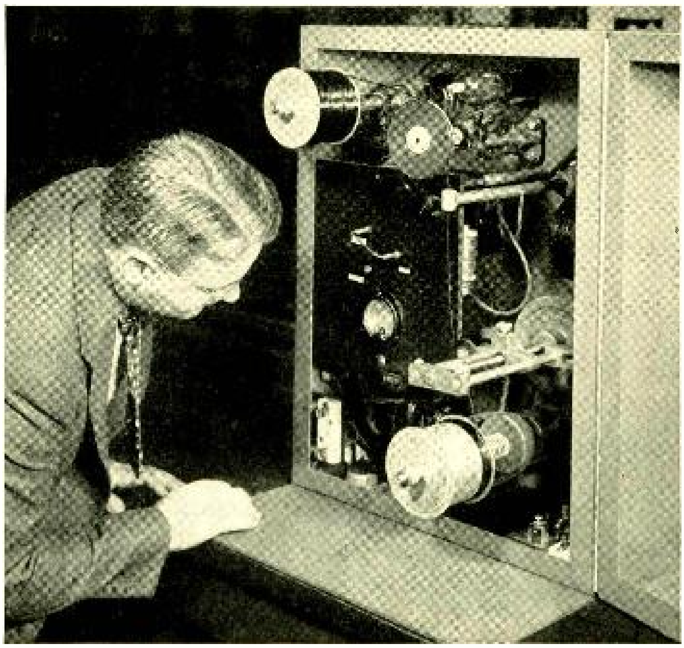


Fig. 3—Photomicrographs of spark records which show the perforations in the chart and the dark rings where the wax was melted by the spark. The divisions on the chart represent hundredths of a second

The three similar records are identified by the use of a simple timing device which deletes a small portion of each trace every twelve hours in a prearranged sequence. This method can be used to label any number of records and does not impair the value of the long-time comparisons.

The section of chart shown includes records for somewhat over three days and indicates relative rates accurately to somewhat better than one part in thirty million between the crystal clocks. Thus the precision of measurement with the spark chronograph can be very great although it involves apparatus and methods of great simplicity and reliability. The only moving parts, aside from the recording paper, execute simple rotation at slow speeds. In four years of continuous use no operating trouble has developed. The only maintenance involved, apart from infrequent oiling and changing of the chart roll, is to remove a thin layer of wax from the cylinder about once a year. This wax, which is vaporized from the paper by the spark, condenses on the cylinder and increases somewhat the scattering of the record.

By increasing the speed of rotation of the cylinder or by enlarging the physical dimensions of the recording parts, the resolution and hence the accuracy of time comparisons can be increased considerably. The dimensions and speed of operation of the Laboratories' chronograph were chosen to give the best practical compromise for accuracy, convenience of mounting, and long life. The result is an instrument which has served very satisfactorily as the chief visual means of checking continuously the performance of the frequency standard.



Continuous Breakdown Test for Enameled Wire

By N. R. PAPE
Chemical Laboratories

MICROSCOPIC examination of fine copper wire, on which the enamel insulation has failed, shows that failure is due to pin-holes in the enamel and to ruptures in the film caused by tiny projections from the surface of the wire or by copper particles detached from the wire and floating in the enamel bath. Irregularities which are even too small to penetrate the coating lower seriously the overall dielectric strength of the insulation and may cause trouble when the wire is wound into coils. Gas bubbles may also vary the thickness of the insulation; but trouble from this source is less frequent.

Irregularities in enamel insulation have been studied by coating wires with a definite weight of enamel per unit length and measuring the voltage required to break down the insulation.* The number of breakdowns which occur in a given length of wire at each of a series of progressively increasing voltages are plotted, as in Figure 2.

In the testing apparatus voltage is applied across the insulation of the wire by passing it, at constant speed, through a pool of mercury which is connected to one of the high-tension terminals of a 5000-volt variable autotransformer. By grounding the other

*RECORD, *April*, 1932, *p.* 287; *Nov.*, 1936, *p.* 76.

terminal to the metal case of the instrument and grounding one end of the wire under test, the entire voltage of the transformer is applied across the enamel film while it passes through the mercury. This voltage can be varied from 0 to 5000 volts by a variable inductance. The number of breakdowns is registered on a counter which is operated by a thyratron tube and the number of feet of wire passed through the mercury cup is recorded at the same time by a wheel and counter. A metal casing which is grounded protects the entire mechanism and counting circuit. The controls to start the motor and vary the potential are mounted on the outside so that they can be operated when the door is closed. A safety switch on the door protects the operator by breaking the transformer circuit when the case is opened to change spools or make adjustments. Full view of the voltmeter, counters, and winding mechanism is obtained by making the entire front of the door of safety glass.

When the insulation on the wire breaks down at the mercury cup a voltage appears across the resistance

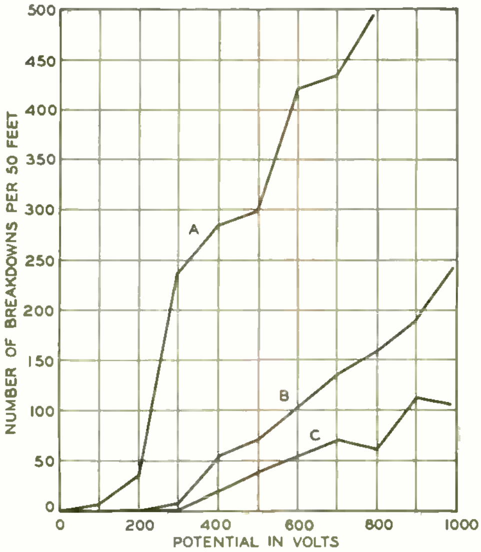


Fig. 2—Enamel wire with smooth conductor showed fewer breakdowns than wire with rough conductor. A, artificially roughened; B, original wire; C, artificially smoothed

R, Figure 1, and raises the potential of the grid of the tube enough to fire it by opposing its grid-bias. The condenser C maintains the grid potential high enough to keep the tube discharging until the register M has acted. Chatter is prevented by maintaining, through the rectifier unit, Y, the current in the magnet during the negative part of the cycle. No battery is required for the equipment except the small biasing battery B which will last for a considerable time.

The wire is placed on the upper spool support and the loose end is passed over the footage-counting pulley, through the cup containing the mercury pool, over the pulley of the spacing

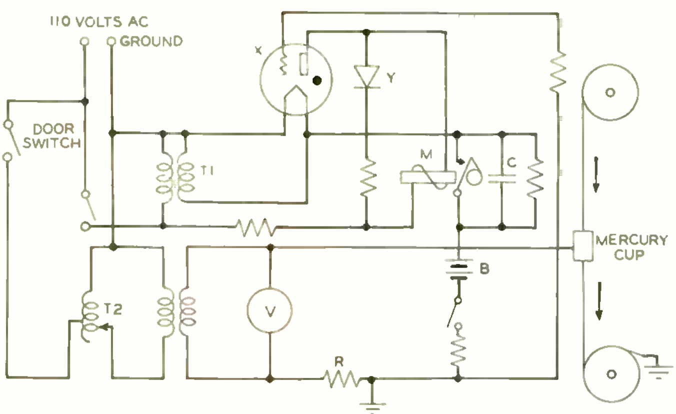


Fig. 1—When the insulation on the wire breaks down at the mercury cup the grid potential of the thyratron tube changes to make it conduct and operate the register M

device, and finally to the large metal spool below which pulls the wire through the machine. After the number of breakdowns in a given length of wire, say fifty feet, has been recorded, with some low breakdown voltage, the voltage is raised two hundred volts and the number of breakdowns in the next fifty feet noted. This procedure is repeated with higher voltages until the counter approaches the maximum rate at which it will operate.

To determine the effects of gross differences in the surface condition of the bare wire, specially prepared samples having different surface characteristics were enameled with the

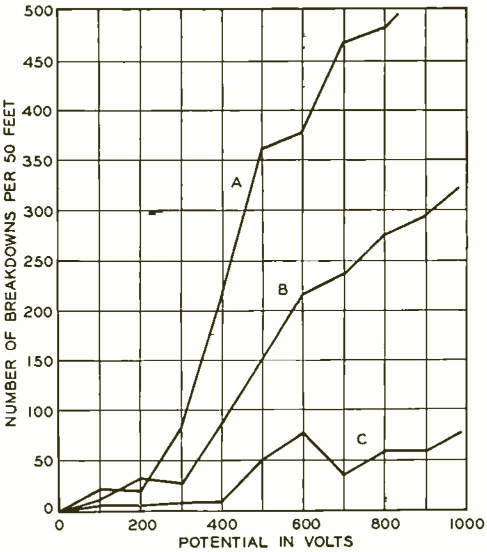


Fig. 3—Thick enamel showed fewer defective places than thin. Thickness—A, .0004 *inch; B,* .0006 *inch; C,* .0008 *inch*

same weight of coating per unit length. Figure 2 illustrates the results obtained by plotting the number of breakdowns per fifty feet for a normal wire and with samples which had been artificially roughened and others artificially smoothed. The beneficial effect of a smooth conductor is indicated by the much fewer breakdowns at all voltages.

Effects of different average thicknesses of enamel on the same bare wire are shown in Figure 3. This shows that to secure a close comparison of the surface nature of two conductors, a very accurate control of the average thickness of enamel on these conductors is necessary. This can be accomplished by maintaining the same weight of enamel coating per unit length of wire.

Figure 4 illustrates how widely the surface smoothness of copper wires may vary in practice. All of the wires shown are of the same gauge and carry the same weight of enamel baked under identical conditions. Curve A represents a very smooth wire and a uniform coating whereas curve C indicates the presence of numerous large irregularities. Microscopic examination of the surfaces of these wires showed that the wire of curve C had a sharp edge running along its length, apparently a result of a faulty die, whereas wire A presented a smooth cylindrical surface. Curve B represents a wire of intermediate grade.

An ideally smooth conductor coated with a uniform insulating film would be expected to give an abrupt rise in the number of breakdowns at some definite voltage. No such behavior is found in practice. Instead, the voltages at which breakdowns occur are distributed as shown by the curves of Figures 2-4. The character of this distribution can be seen from the curve. For example, a wire in which the breakdown rises in the low voltage range and falls again at intermediate voltages indicates the presence of large irregularities, perhaps penetrating the coating. On the other hand, a curve such as c of Figure 3, which rises only at high voltages, indicates a surface in which the irregularities are very small.

The apparatus may also be used for an overall evaluation of enameled wires. For example, one wire may be undesirable because the enamel has not been concentrically applied, or it may have been injured by rough or sharp surfaces, or the enamel itself may have a low dielectric strength. If a given wire does not conform to a specified breakdown-voltage curve, it probably has one of the above defects. Finally, the continuous breakdown test has shown the fallacy in many of the so-called dielectric strength values of enamels for wire. Often low values of dielectric strength have been reported for a coating material when actually the wire on which the material has been applied is at fault. In fact, data have been obtained which indicate that the dielectric strength of enamel films may be as high as 4000 volts a-c per mil in contrast to the values of 500-2000 volts often reported.

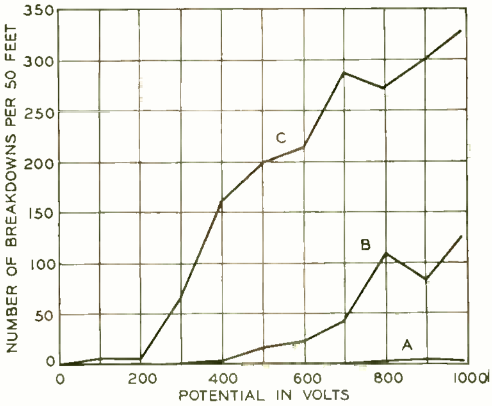
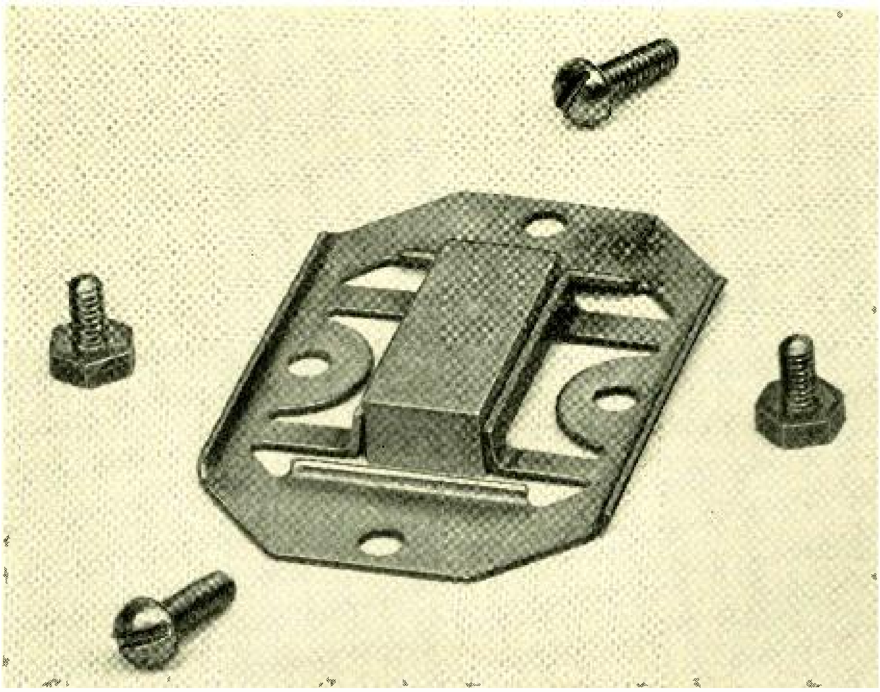


Fig. 4—Wide variations in the quality of the insulation on commercial enameled wire are caused by surface irregularities in the conductor. A, smooth wire; B, intermediate; C, numerous large irregularities

Beryllium Copper

BERYLLIUM copper, used for the armature holder of the bone-conduction receiver of the new Western Electric Audiphone, combines the corrosion resistance of copper with the hardening characteristics of steel. It can be easily formed into intricate shapes in the soft or semi-soft condition and then hardened by heat treatment. The alloy is made by adding about 2¼% of beryllium to copper, and its high cost in the past, which has greatly limited its use, has been due to the high cost of beryllium, which in 1926 was $200 a pound. The price has now dropped to about a tenth of this value and even further reductions are possible. Its cost is still great enough, however, to warrant the use of the alloy only where the less expensive non-ferrous alloys are not satisfactory. Its application to the armature holder of the bone-conduction receiver — shown below magnified to about three times actual size—was necessary because of the extremely short-radius bends and the spring characteristic required.



Contributors to this Issue

V. P. Thorp, after serving a year and a half in the U. S. Army Air Service, returned to Purdue University from which he graduated in 1919 with a B.S. degree in Electrical Engineering. He joined the Engineering Department of the New York Telephone Company where he was engaged in studies of toll fundamental plans until his transfer in 1921 to the Department of Development and Research of the American Telephone and Telegraph Company. Since that time he has been continuously engaged in problems of development, trial, and standardization of carrier-telegraph systems. This included the first transcontinental high-frequency carrier-telegraph system, systems for the Cuba cables, and the present widely used voice-frequency carrier-telegraph systems. Since 1934, when the D. and R. merged with the Laboratories, he has been a member of the Telegraph Facilities group of the Systems Development Department.

C. A. Lovell received the B.A. degree from Mississippi College in 1922, and between 1922 and 1929 was occupied in teaching and graduate study. In 1928 he received the M.A. degree from the University of Pennsylvania, and in 1932 the Ph.D. degree from the same institution. In 1929 he joined the Technical Staff of these Laboratories to engage in loud-speaker design in the Acoustic Research Department. After a short absence from this Department, during which he worked on television terminal equipment for the New York-Philadelphia coaxial cable, he returned to take charge of the design of mechanical means for making experimental studies of telephone traffic. At present he has charge of fundamental investigations on a variety of problems including improvements in subscribers' dial apparatus, signals for coin collectors, magnetic tape recording, electric wave synthesis, and other problems related to these.

J. A. Ashworth entered the Research Department of the Laboratories in 1928 as a Technical Assistant, and until 1933 worked on submarine cable loading and loading coils. During this time he completed the Student Engineering Course

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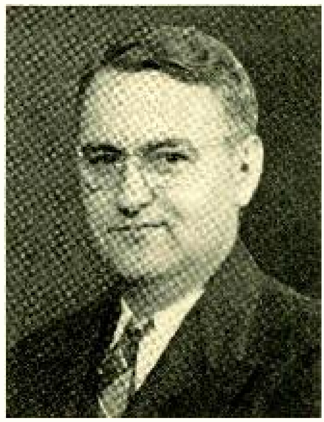

C. L. Weis, Jr. *W. A. Marrison* *N. R. Pape*

and also engaged in night study at Brooklyn Polytechnic Institute. In 1933 he resigned from the Laboratories to attend the California Institute of Technology, where he received a B.S. degree in Physics in 1935, following which he spent a year in post-graduate study at Duke University. He returned to the Laboratories in 1936, with the Apparatus Development Department, and has since been engaged in a study of the properties and applications of magnetic materials.

C. L. Weis, Jr., received a B.S. degree in Electrical Engineering from the Massachusetts Institute of Technology in 1922, and joined the Engineering Department of the Western Electric Company upon graduation. He first worked on the development of the type-C and type-D carrier-telephone systems. More recently he was engaged in the design of terminal equipment for the one-megacycle coaxial telephone and television trials between New York and Philadelphia. Since 1938 he has been in charge of a group which is developing carrier and video television terminals.

After receiving the degree of B.S. from Queens University, Canada, and a master's degree from Harvard, W. A. Marrison joined these Laboratories in 1921. He was soon engaged in the study of constant frequency sources of alternating current and of methods for the precise measurement of frequency and time. His chief contribution in this field was the development of the quartz crystal clock, which with later modifications is now used for precise time and frequency measurements in industrial and national physical laboratories throughout the world.

N. R. Pape joined the Research Department of the Laboratories in the spring of 1928 as a Technical Assistant, after having been previously employed as a Technician in the laboratories of the American Smelting and Refining Company and the Anaconda Copper Company. He attended night classes at Pratt Institute while in New York and since his transfer to the Summit Laboratories has continued night school at Rutgers University. Mr. Pape has been concerned with the preparation and testing of enamel-type insulations for wire. For the past year he has been engaged in studies on organic plastic materials.