Tone Ringing and Pushbutton Calling

Two Integrated Exploratory Developments

By L. A. MEACHAM, J. R. POWER and F. WEST

Forward-looking work on the telephone set has yielded attractive new solutions for the problem of signaling between the customer station and the central office. This work takes advantage of new electronic devices such as the silicon junction diode, the transistor and the ferrite coil. Two exploratory developments are described: a "tone ringer" and a "pushbutton caller," both of which employ signals within the telephone speech band. Although usable separately, as justified by economic and other considerations in particular telephone systems, the developments have been conceived primarily as an integrated and moderately long range attack on the signaling problem, with special regard for the field of electronic switching.

I. GENERAL

1.1 *Introduction*

The rapid advances of recent years in the development of electronic techniques and components have brought about both a need and an unusual opportunity for new station apparatus.

The need has appeared unmistakably in connection with the development of electronic switching systems,[1] themselves outgrowths of the new technology. To such systems, the relatively large currents and voltages that are associated with signaling functions in existing telephones would represent formidable design difficulties. For example, the conventional ringer draws nearly a watt from a 90-volt, 20-cycle generator, whereas the design of electronic switching networks is properly focused upon handling speech signals that are far smaller, of the order of a volt or a milliwatt. Roughly parallel remarks might be made with regard to dialing, to signals for controlling coin telephones, and even to the direct currents sent over the lines to power speech transmitters. Electronic switching clearly calls for a fresh attack upon station problems.

In a preliminary broad study of this need and opportunity, it was

recognized that exploratory development should strive toward certain long-term goals. For instance, it would be desirable to use the same frequency band as speech for signaling functions, thereby avoiding the need to transmit more than the one band; to provide party lines with full-selective ringing and with automatic party identification to facilitate automatic message accounting;[2] to eliminate the use of a "station ground" for purposes other than lightning protection, thus doing away with a troublesome source of transmission noise; and to replace the rotary dial with pushbuttons for the sake of speed, convenience and other benefits. Of course the actual adoption of any such changes must always depend upon a vast number of detailed considerations, human, technical, administrative, and economic, which are beyond the scope of this paper.

This paper describes two integrated developments that have grown out of the study — new arrangements for signaling to and from the customer's station. The "tone ringer" and "pushbutton caller" are closely related in that they both employ multi-frequency pulsing,[3] and in fact share a common series of signaling frequencies in the speech band chosen for their mutual benefit. They also share circuit components that can be transferred by switchhook contacts from one function to the other, and in numerous design details they profit from their interrelationship. An experimental telephone set of the 500 type, modified to include both the pushbutton caller and the tone ringer, is shown in Fig. 1.

Fig. 1 — Modified 500-type telephone set equipped experimentally with tone ringer and pushbutton caller.

1.2 *Signaling Plan*

One of the first problems to arise in this exploration was the choice between frequency division and time division or pulse coding of some sort. From the viewpoint of information theory, either ringing or calling involves only a few bits of information, and could be accomplished very rapidly and efficiently with time-division pulses in the speech band.[4] But on the local telephone line as it exists and will probably remain for a substantial period, information-carrying capacity is not at a premium during either ringing or calling; in fact this capacity may be spent rather liberally to minimize the cost and complexity of terminal apparatus. This is the basic argument behind the selection of multi-frequency signaling for the developments here described.

The tone ringer performs full-selective ringing of up to eight parties on the basis of a "1-out-of-8" code. Specifically, each ringer is arranged to be tuned upon installation to an assigned frequency; it will then respond to one and only one of eight alternative ringing tones sent from the central office. Each tone is a simple sine wave, interrupted about twelve times per second to give the resulting sound a distinctive character, and turned on and off at intervals of several seconds as in conventional ringing. The signal selected by the tuned circuit might conceivably be arranged to turn on an oscillator or other local sound generator in the station set, but here it is used directly, being amplified by a transistor and applied to a small sound radiator mounted in the base of the set. With the transistor biased for "Class C" operation, selectivity requirements can be met (with the moderate values of Q afforded by practicable coils in the audio range) at frequency spacings in the neighborhood of 10 per cent.

In the pushbutton calling arrangement under consideration, number information is sent to the central office in the form of oscillatory pulses, using a 1-out-of-10 code. As will be seen later, party identification is also provided. In earlier studies using reeds, a 2-out-of-5 code was employed; that is, five reeds with different frequencies were provided and two of them were plucked for each digit of the called telephone number. As compared with using a 1-out-of-10 code, this saved five reeds. But in the case of the tuned circuit, a single tapped coil can generate any reasonable number of frequencies, one at a time. The latter code therefore becomes attractive, because 2-out-of-5 would involve either a pair of tuned circuits (exclusive of party identification) or the difficulties of pulsing twice in sequence at different frequencies for each pushbutton

operation. Chiefly for this reason, ten frequencies are employed for the ten decimal digits.

In addition, party identification is desired. The resonant circuit of the ringer, tuned to a different frequency for each party, is fortunately well-suited for this purpose. It is therefore switched from the ringing to the calling function when the handset is lifted, with no change in its party tuning. Accordingly, when any pushbutton is pressed two simultaneous pulses of different frequency are generated. One, the "party pulse," is produced in the tuned circuit transferred from the ringer; the other, the "digit pulse," comes from a separate coil, differently tuned for each of ten pushbuttons.

1.3 *Frequency Plan*

From the foregoing it is clear that eighteen frequencies are required, eight for ringing and party identification and ten for digit transmission. In urban systems, only four ringing frequencies are likely to be needed but in this case the others may be found useful for special signaling functions such as those associated with pay stations.

In existing operator multi-frequency key-pulsing systems a set of six frequencies is used, spread between 700 and 1,700 cps at uniform intervals of 200 cps. If this series were to be extended to as many as 18 frequencies, it would cover, say, from 300 to 3,700 cps, and the steps would range from 66.7 to only 5.4 per cent. With such a frequency allocation the total bandwidth is excessive, the percentage spacing is extravagantly wide at low frequencies, and the spacing is too close at the high end to be compatible with inexpensive electrical tuning elements.

Geometric spacing was selected as the logical alternative, the set of frequencies being given by

$$f_n = a^{n-1} f_1 . \tag{1}$$

Here the constant percentage spacing is simply $100 \ (a-1)$. This series fits in naturally with the use of tuned circuits having uniform values of Q and uniform frequency stabilities — properties that are easy to attain. The transient rise and decay times associated with constant-Q tuned circuits vary inversely with their resonant frequencies, but these time differences have not led to serious difficulties.

The geometric series has an important advantage over other possible frequency distributions, in that by carefully choosing the factor a it is possible to make both the second and third harmonic of each frequency

fall approximately midway between two adjacent higher frequencies in the same series. This interlace is helpful in reducing the possibility of interference from non-linear distortion.

A method of choosing an optimum value for a is illustrated in Fig. 2. This shows the relative frequency of each term in a geometric series f_1, $f_2 \cdots f_{18}$ as a function of the spacing. Harmonics of f_1 up to the sixth are also displayed on the logarithmic frequency scale. Points where a harmonic coincides with any frequency f_n are marked by circles, and intervening points where a harmonic falls geometrically midway between f_n and f_{n+1} are shown as dots. An ideal spacing factor a, if one existed, would be represented as a vertical straight line passing through a dot for every harmonic. Actually, the dot alignment is not so fortunate, but two spacings do exist (near 8.5 per cent and 11.1 per cent) for which the
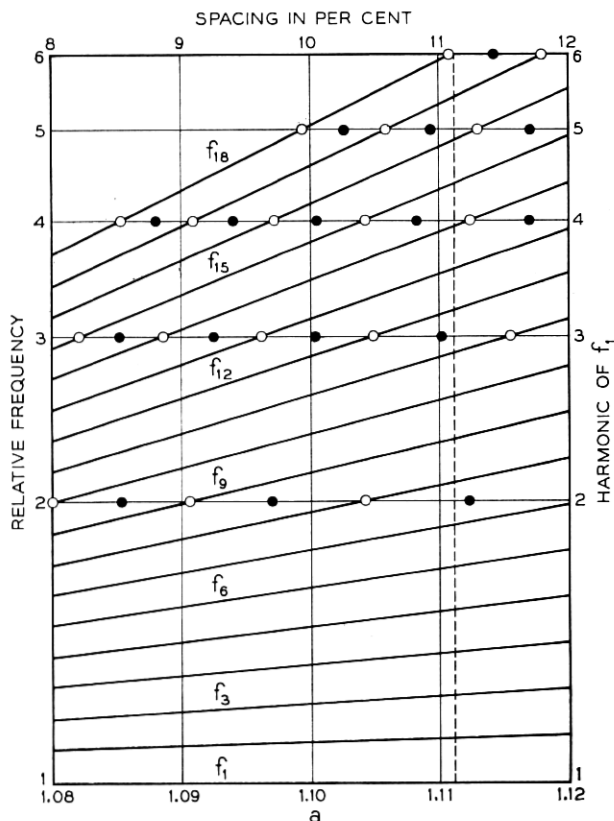
Fig. 2 — Interlacing of harmonics in geometric series of frequencies.

second and third harmonics are both fairly well interlaced. These two harmonics are of primary interest because in the system as planned all higher ones are not only weaker, but also fall above the frequency range of critical interest (the portion of the band devoted to the same function — party or digit). Since a larger spacing was preferred for the sake of selectivity, a figure of 11.11 · · · per cent was finally chosen, corresponding to a ratio of 10/9 between adjacent frequencies. This happens to give a range of almost exactly 6 to 1 for the whole set of eighteen. The spacing is indicated by a dashed line in Fig. 2.

Among many considerations affecting the choice of specific frequencies may be mentioned transmission, tuning elements, the acoustic radiator, and the sound of the ringing tone. The series used in the development extends from 478 to 1,000 cycles for ringing (also party identification) and from 1,111 to 2,868 cycles for calling. The lower frequencies were assigned to ringing chiefly because the resulting sounds were found to be more pleasing. As will be seen, strong harmonics of the fundamental ringing frequency are generated in the tone ringer, and such of these as fall within the pass band of the acoustic radiator form the actual sound output.

II. TONE RINGER

2.1 Basic Considerations

In addition to the fundamental choices affecting the tone ringer that have been presented in foregoing sections, a few others should be mentioned. A primary requirement of the sound of a ringer is that it must be effective (not readily confused with other common sounds) as well as pleasant. It must attract attention when the customer is in the far reaches of house or garden but must not be annoyingly loud or harsh when he is nearby. High pitched tones are not suitable for this purpose because they are shrill and because they are rapidly attenuated as they travel through passageways and around corners. On the other hand, low pitched tones are pleasant and carry well but require a large sound radiator and are likely to be masked by background noise. The chosen compromise is a complex tone in the region of 900 to 2,400 cycles per second. This tone is composed almost entirely of harmonics of the selected ringing frequency; in general, the fundamental lies below the band efficiently radiated. The result is a distinctive richness of quality, with the ear effectively supplying the missing fundamental. The tone is made still more distinctive by interrupting it about 12 times per second. A secondary requirement of the tone is that its loudness should

be reasonably independent of circuit and environmental conditions but that volume control with about 15-db range should be available to the customer.

A problem that arises when ringers are operated in the frequency and power range of speech is that of "talk-off" protection; i.e., the ringer must be prevented from responding to speech or other in-band voltages that appear on the line during conversation. This problem also is believed to have been effectively solved, in a manner to be explained.

2.2 *Tone Ringer Circuit*

The tone ringer circuit consists of four main elements — an input limiter, a frequency-selective network, an amplitude-selective output amplifier and a sound radiator — as indicated in the simplified schematic of Fig. 3. A volume control and a dc power filter are also included. Many variations in the details of circuitry have been explored; the example shown is one developed for the initial trial of electronic switching.

The voice frequency signal voltage at the customer's end of the line may have any value between 0.5 and 2.5 volts. It is the primary function of the input limiter to convert this variable voltage to a constant-current drive for the frequency-selective elements. Some amplification is also provided. The limiter draws a constant direct current of 100 microamperes plus the leakage current, I_{co}, of the transistor. The ac output is a symmetrically clipped sine wave that approaches a square wave, its peak-to-peak value being limited to the 100 microamperes drawn from the line.
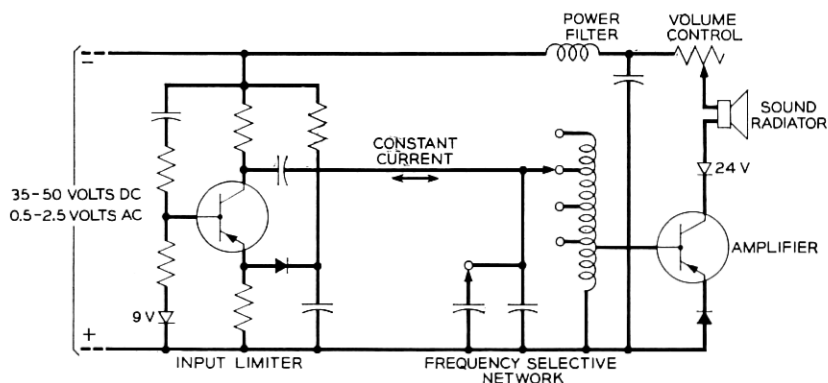

Fig. 3 — Simplified circuit schematic of the tone ringer.

The frequency selective network is simply a parallel resonant circuit consisting of one coil with four taps and either one or two capacitors. Eight resonant frequencies in the range of 478 to 1,000 cycles per second are available by various tap-capacitor combinations, an adjustment readily made by the installer. The inductor has a ferrite core consisting of two molded cups with a cylindrical coil nested inside them. This design is simple and provides stability, small size and reasonably high Q. In addition, the inductance can be adjusted during assembly of the set to any value within ± 10 per cent of the nominal value by rotating one half of the core; thus, accuracy requirements for the tuning capacitors are reduced.

The constant current from the input limiter flows through the resonant circuit. At or near resonance the circuit impedance is high and a correspondingly high voltage is developed, which drives the power amplifier. Away from resonance this voltage is small.

The output amplifier consists of a transistor in a common emitter Class C circuit, the bias being provided by the forward voltage drop of a silicon junction diode in series with the emitter. Such a diode changes quite sharply from a very high impedance to a low one at a forward potential of about 0.6 volt. This circuit has many advantages. A principal one is that it does not respond until the input voltage from the resonant circuit exceeds the bias voltage and a small increase in voltage above this threshold value drives the transistor to its maximum output, i.e., to overload. This effect not only sharpens the selectivity of the tone ringer but also holds the output constant over a frequency band of several percent centered about resonance, thus providing a margin for small inaccuracies in central office and resonant frequencies. Another advantage is that the input impedance of this amplifier is high, up to the overload point, and does not seriously lower the Q of the resonant circuit. Still another, the amplifier output consists of current pulses which are rich in harmonics of the driving frequency. It is these harmonics that are reproduced by the sound radiator. A final advantage is that, when not operating, the amplifier does not draw any direct current except the I_{co} of the transistor — a few microamperes.

A second silicon diode, having an avalanche breakdown at about 24 volts, is connected in series with the collector, which it thus holds at a value some 24 volts less than the dc line voltage; that is, at not more than 26 volts. This is within the permissible range of presently available transistors. The diode also provides talk-off protection as will be described later.

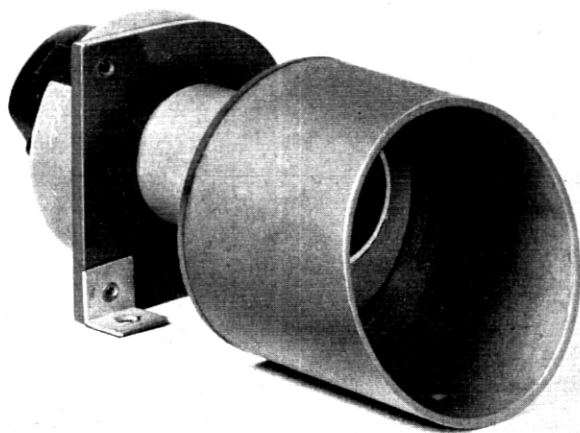The sound radiator, shown in Fig. 4, consists of a ring-armature

Fig. 4 — Sound radiator of the tone ringer.

telephone receiver[5] and double-tube resonator. The usual acoustic damping of the receiver is omitted, giving the response a resonant peak at 1,500 cycles per second, and the resonator introduces other peaks at 950 and 2,200 cycles per second. This results in efficient electro-acoustic transformation in the frequency band from 900 to 2,400 cycles per second and in very little response outside that band. The characteristic curve is shown in Fig. 5. The figure also shows the frequencies present in the pulses supplied to the radiator when the tone ringer is driven at its lowest frequency (478 cps). This illustrates the dominance of harmonics in the sound output. Volume control is provided by means of an adjustable resistance in series with the sound radiator.

A low-pass filter must be interposed between the line and the output circuit. This has the dual function of maintaining a high ac input impedance and of minimizing feedback from the output circuit to the line. A series inductor and shunt capacitor are adequate for these purposes.

One of the previously mentioned basic requirements of the tone ringer is that it must not operate on speech voltages. One way of assuring this is to disable all ringers on a line by means of the reduction in dc line voltage that occurs whenever any associated handset is removed from its cradle. This drop is from nearly 50 volts to less than 24 volts. Since the latter value is not sufficient to break down the diode in series with the collector of the amplifier transistor, the diode becomes essentially

"open circuit". This prevents the flow of any current in the sound radiator, and so the ringer remains silent.

2.3 *Performance*

The tone ringer will operate over as much as five miles of 26-gauge cable (2,200 ohms loop resistance) when the voice frequency ringing power is +6 dbm at the central office end of the line. It requires less than 1.5 ma of direct current per operating ringer from a 50-volt office battery.

About 0.5 milliwatt of sound power is generated by a tone ringer operating at full volume on a short loop, which is roughly the same as for a conventional ringer in a 500-type set under the same conditions. When several ringers are operated simultaneously at the end of a long loop, their individual outputs may be reduced as much as 4 db. Tests conducted in the laboratory have indicated that the carrying power and attention attracting qualities of the ringer tone are actually better than those of the conventional bell and that the tones are considered pleasant by most people and acceptable by nearly all the others. These results have been substantiated by a field trial of a few tone ringers on rural lines at Americus, Georgia, and by a more extensive trial at Crystal Lake, Illinois.

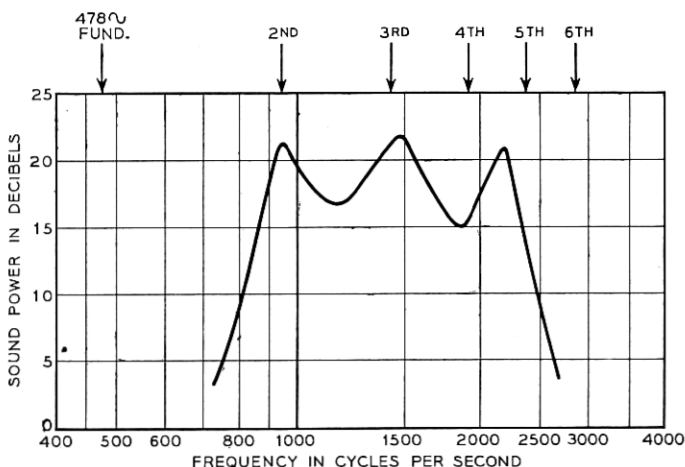The frequency selectivity and sensitivity of the ringer are illustrated

Fig. 5 — Frequency response of the sound radiator, and harmonic spectrum of a typical party frequency. Sound power is given in decibels relative to 1 microwatt for 1 milliwatt of available electrical input.
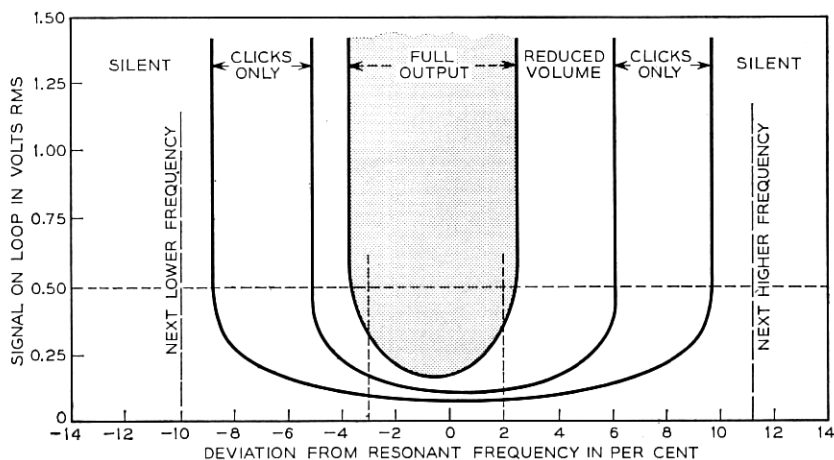
Fig. 6 — Selectivity and sensitivity of the tone ringer.

in Fig. 6. The coordinates of this chart are the amplitude of the ringing voltage on the line at the telephone set and the deviation of its frequency from the resonant value. The curves define areas within which various output levels are obtained. Full sound output is delivered whenever the intersection of frequency and voltage falls within the central shaded area, which extends to beyond +2 per cent and −3 per cent from resonance at all voltages above 0.5 volt. This range is wide enough to tolerate the expected frequency deviations due to possible manufacturing variations and to changes in ambient temperature from −20°F to 130°F. In a band just outside the full output area the tone ringer operates with a reduced volume. Surrounding this is a band in which no sustained tones are produced but a transient click is generated each time the ringing voltage is turned on. As the ringing frequency departs further from the resonant frequency of the ringer, the clicks become fainter and finally no sound at all is produced. As this silent condition prevails at the adjacent frequencies in the ringer series, complete selectivity is obtained. The dissymmetry which may be noted between the left and right portions of the "reduced volume" area is a result of feedback from the output of the Class C amplifier to the input of the tone ringer.

The voice-frequency input impedance of a tone ringer that is not operating is between 20,000 and 25,000 ohms. Its phase angle is a function of frequency, varying from 40° lagging (inductive) at 350 cycles per second, to 15° leading at 3,000 cycles per second. When the ringer is operating, its impedance is lowered by feedback associated with the

ripple voltage across the filter capacitor, the reduction being a complicated function of frequency, length of loop and number of ringers. Under extreme conditions the impedance may be as low as 9,000 ohms. However, as this value is still much higher than the characteristic impedance of the loop, the termination represents almost an open circuit, even with several extensions sounding simultaneously. During ringing, this mismatch aids in providing ample signal voltage at the set. During talking, the still higher standby impedance avoids any appreciable effect on speech transmission.

The direct current standby drain of this ringer consists of the 100 microamperes drawn by the input limiter and the I_{co} of the two transistors. For the units presently used, typical values of I_{co} are 5 microamperes at 75°F and 40 microamperes at 130°F. All sets on an eight-party line are unlikely to be at 130°F simultaneously, but on a hot day their combined standby drain may be slightly over 1.0 milliampere. This drain is trivial if the ringers are associated with existing systems having conventional talking and supervisory arrangements, but somewhat objectionable in connection with projected electronic switching systems in which the talking and supervisory currents are materially reduced. The continuing development of transistors which have values of I_{co} several orders of magnitude smaller promises to permit use of simpler circuitry, in which the limiter draws no direct current and the total standby drain of the ringer is negligible.

III. PUSHBUTTON CALLER

3.1 *Basic Considerations*

To generate pushbutton calling pulses, magnetic energy derived from the dc loop current is stored in the coils of the "party" and "digit" tuned circuits while no pushbutton is pressed, and released in the form of damped oscillatory transients upon operation of a button. It is found that ample signal energy can be obtained in this way without the use of amplification, either to prolong the oscillations or to increase the useful output. With its energy thus derived, the design must depend to some extent upon the associated talking arrangements, particularly with regard to whether they are "high-current" as in existing systems, or "low-current" as they may possibly be for electronic switching. In laboratory studies of the two cases, however, it has been found that the circuitry to be described is applicable to both with only quantitative variations (assuming that the low-current talking arrangements draw on the order of 10 milliamperes). Little if any generality is lost, therefore, in con-

fining our attention to a design for the pushbutton set and associated central office receiver which is based on conventional speech networks.

3.2 Station Set Circuit

In the station circuit shown in Fig. 7 the pushbutton caller is associated with a 500-type telephone set, the talking portions of which are only slightly modified. Most of the calling components are connected in series with the speech network on one side of the line.

As indicated in Fig. 7, which shows the state of the circuit when no pushbutton is operated, substantially all of the loop current flows through the low resistance of the two tuning inductors, storing energy in their magnetic fields. One tuned circuit, which generates the digit signals, employs the tapped inductor associated with capacitors C1, C2 and C3. The other, which generates the party-identification signal, employs a duplicate tapped inductor and capacitors C4 and C5. If one imagines points A and B to be strapped together, two parallel resonant circuits become apparent. Further, if the closed contact of K1 were suddenly opened, the energy stored in the fields of the two inductors would be dissipated in two independent oscillatory discharges, both of which would pass through the A-B strap. Actually, the assumed strap is replaced by a low-impedance winding added to the induction coil, T1, of the conventional speech network, as a means of coupling signal energy from both tuned circuits to the line. Since the telephone receiver
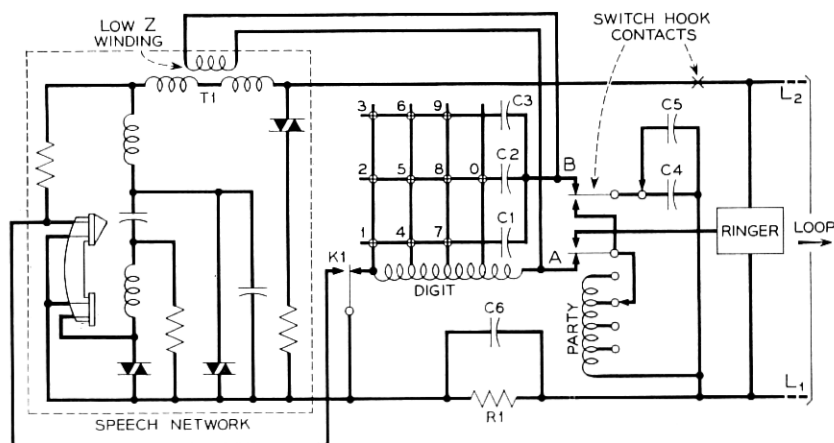

Fig. 7. — Circuit schematic of a pushbutton telephone set. Switchhook contact arrangements are indicated for sharing use of the party tuning elements with a tone ringer.

is also coupled to the induction coil, the pulse may be heard at a moderate level, being attenuated to some extent by sidetone balance. The rate of decay of the oscillations as well as the coupling between the tuned circuits is affected by the impedance of the added winding. Since a minimum of damping and inter-coupling is desirable, this impedance is made as low as is consistent with a satisfactory output amplitude. When switch K1 interrupts the current in the inductors, the dc loop current would drop to zero except for the presence of the resistor R1. This resistor maintains the current at a value sufficient to hold the central office supervisory relay operated and thus prevents loss of the call. Capacitor C6 shunts R1 to bypass voice frequencies. The abrupt drop in line current produced by switch K1 is used in "talk-off" protection as described in the following section.

The damped oscillations are frequency coded to convey the party and digit information. As noted earlier, the party frequency is preset at the time of installation by use of combinations of C4 and C5 and the four taps on the inductor. The ten digit frequencies are associated respectively with the ten pushbuttons by means of a crosspoint switching device.

This switch, as shown diagrammatically in Fig. 7, is associated with the digit inductor and capacitors C1, C2, and C3. Four parallel wires are connected to the inductor taps and three others perpendicular to these are connected to the capacitors. Thus 12 crosspoints exist in the switching mesh any one of which can associate a coil tap with a capacitor and establish a resonant frequency. Since only ten frequencies are
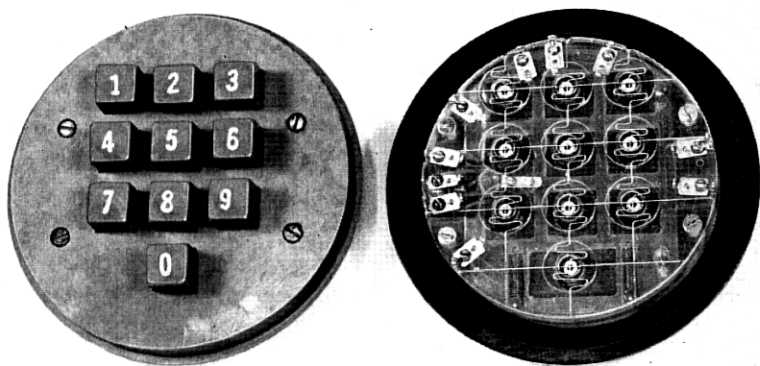

Fig. 8 — Front and rear views of a pushbutton crosspoint switch.

required for the digits, two of the crosspoints are not implemented. The ones used are shown circled and labeled with digit numbers in Fig. 7.

The crosspoint switch is part of the pushbutton assembly, a photograph of which appears in Fig. 8. The back view shows the crosspoint wires supported in clear plastic details. One set of wires is straight and the other provided with "S"-like bends at each crosspoint to give it the proper elasticity. Each pushbutton is aligned axially with a crosspoint, and when depressed closes the corresponding contact through a spiral spring which permits overtravel of the pushbutton. This overtravel allows crosspoint closure to occur early in the travel, thereby establishing the tuned circuit before interruption of the direct current by the switch K1. The actuation of K1 is accomplished by means of a slide-plate free to move transversely to the direction of motion of the pushbutton and driven during the overtravel period by a wedge-shaped portion of the pushbutton body. In order to prevent arcing, the break contact of this switch is arranged to open rapidly, using a toggle action, regardless of the speed of the customer's finger. Fig. 9 illustrates the slide-plate mechanism and the switch action.

An additional function of switch K1 is to short-circuit the transmitter in the telephone set as shown in Fig. 7. This provides protection against "talk-off", i.e., against false operation due to party or digit frequencies
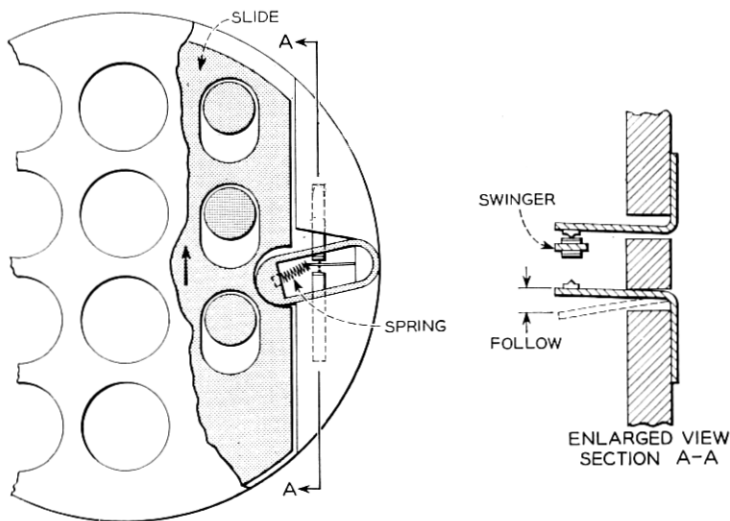

Fig. 9 — Switch detail, showing the slide plate and follow arrangement for toggle contact K1.

that might be present in the transmitter output. Since K1 is actuated only while a pushbutton is depressed, however, it affords no protection during idle periods before and between operations. Protection required during these idle periods is provided by letting the central office receiving equipment be continuously disabled except for a brief enablement triggered by the aforesaid sudden reduction in dc loop current. This method, combined with the transmitter shorting function of K1, affords substantially absolute protection.

Fig. 10 is a representation of the wave forms appearing at the line terminals of the station set as it is taken off hook and a button is pushed
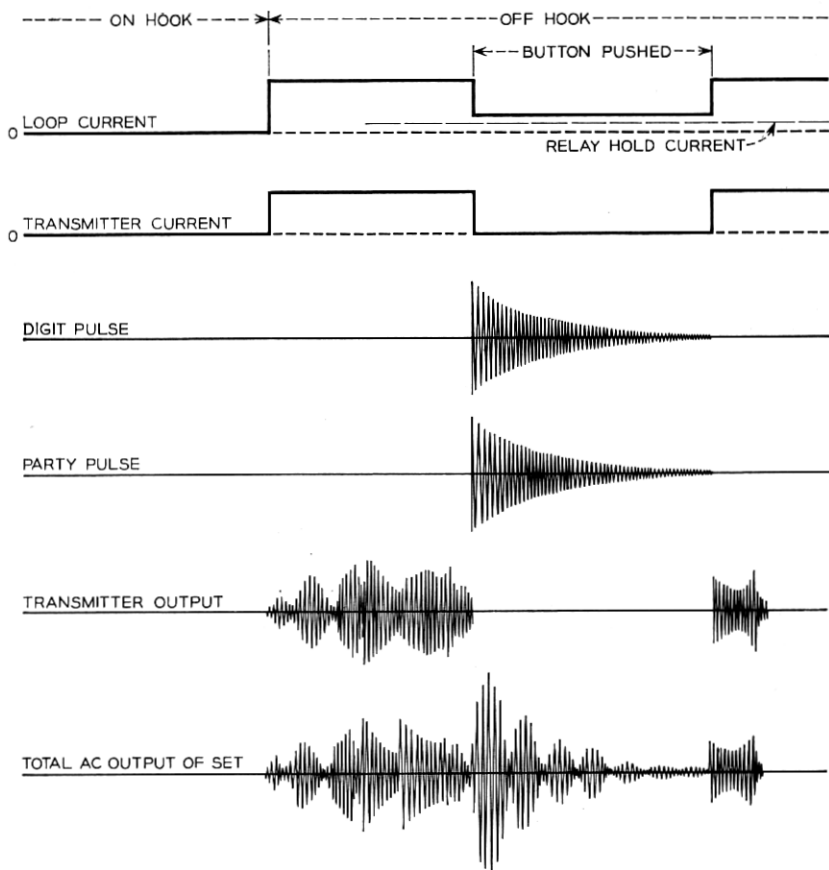

Fig. 10 — Waveforms illustrating operations at a station set in pushbutton calling.

and released. This figure summarizes the processes described in foregoing paragraphs.

3.3 *Central Office Receiver*

Concurrently with work on the station set, it was necessary to provide some suitable receiving equipment for the calling signals, to permit over-all tests in the laboratory. A schematic diagram of an experimental receiver is shown in Fig. 11. Voice frequency signals from the station set are transmitted through a line circuit to a "cutapart" filter, where the party identifying frequencies (478 cps to 1,000 cps) are separated from the digit frequencies (1,111 cps to 2,868 cps). Each group is then sent through one of two similar analyzing circuits, each consisting of an amplifier-limiter, selective circuits, a translator, and trigger circuits. A common enabling circuit is provided for talk-off protection. Both analyzing circuits terminate in a register where the information is available to subsequent elements of the switching system. In the laboratory model the received information is merely displayed on indicating lamps.

The line circuit is conventional except for the pair of diodes connected across one of the repeat coil windings. These serve to absorb large voltage surges such as those due to switchhook operation, which if not suppressed, might excite troublesome resonant frequencies in the cutapart filter.

In the enabling circuit, the drop in line current produced whenever a pushbutton is depressed is used to control a relay closure which briefly provides for recognition of the ac signals. When the line current decreases, it produces a rise in voltage across the blocking capacitor of the line circuit. This rise is differentiated and the resulting pulse of limited duration is applied to the base of a transistor, which is thereby energized to operate the relay for a period of about 40 milliseconds. This operation is delayed a few milliseconds by the capacitor shunted across the relay winding in order that any prior excitement of the tuned circuits may have time to decay before enablement. Enablement is thus made to occur only at a time when the station set transmitter is short-circuited, a proper signal is being sent, and the selective circuits are free of extraneous energy. It follows that all unwanted signals, except possible rare accidental bursts, are precluded and talk-off protection is made substantially absolute. One exceptional condition is the sending of an enabling pulse (dc step) by an accidental switchhook operation having too short a duration to lose the call. Such enablement is not troublesome as the
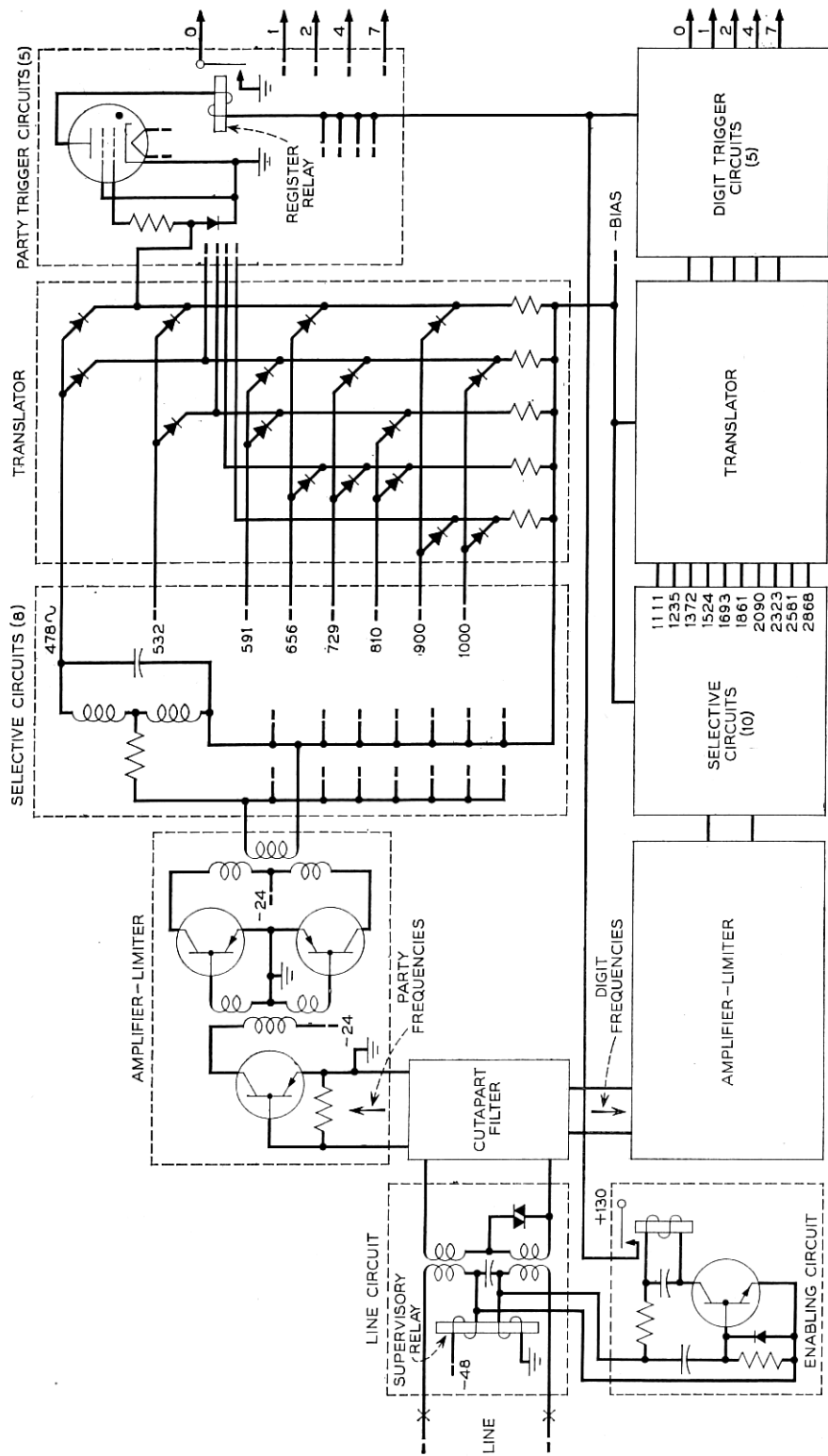
Fig. 11 — Schematic diagram of an experimental pushbutton calling pulse receiver.

set, disconnected from the loop by the same action, cannot send an interfering signal.

Each of the two channels emerging from the cutapart filter is applied to a symmetrical amplifier-limiter which provides, for a certain time, a substantially square wave of constant amplitude having the fundamental frequency of the received signal. This square wave affords a constant-amplitude drive for the tuned circuits, a technique employed also in the limiting amplifier of the tone ringer. An important feature of the limiter is that, whenever the wanted signal is at least slightly larger than any existing interference, the well-known effect of limiter capture tends to discriminate in favor of the wanted signal and thus aids in selectivity.
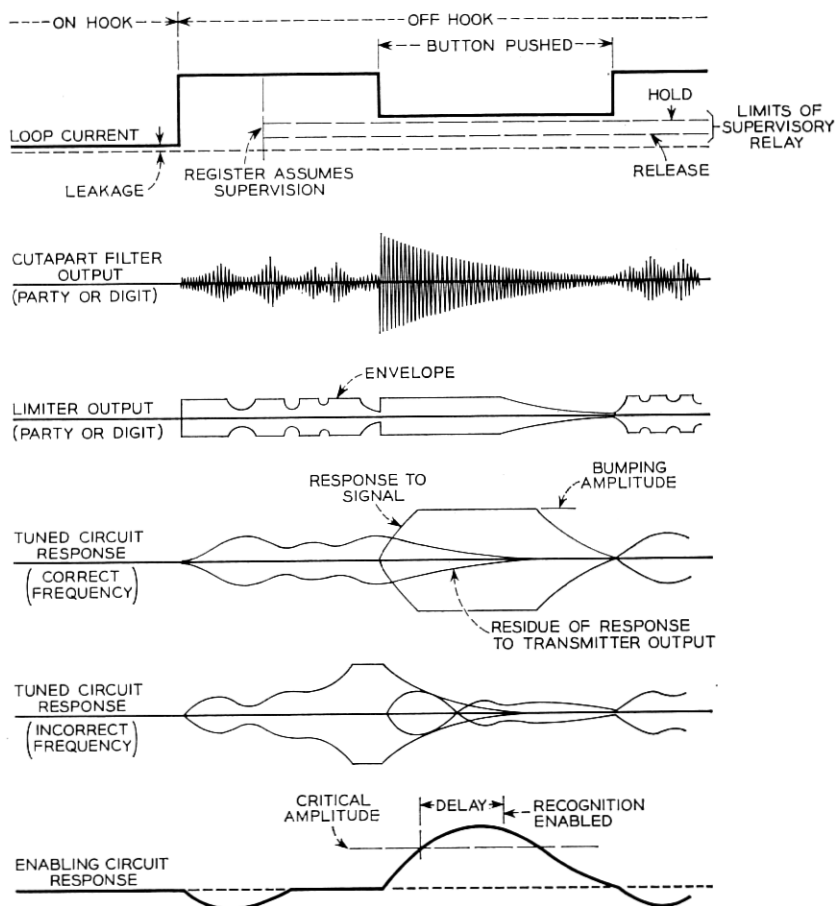

Fig. 12 — Waveforms illustrating operations at a pulse receiver in pushbutton calling.

The group of eight (or ten) tuned circuits may employ simple adjustable coils similar to those used in the station set. The outputs of these circuits are connected to a translator comprising a diode matrix which transmits the output of any one tuned circuit to two of five trigger circuits. In this manner the one-out-of-eight party (or one-out-of-ten digit) indication is translated into a two-out-of-five code with a resultant reduction in the required number of triggering devices. Other codes could be used but this one is commonly employed in existing dial pulse registers.

Each trigger circuit consists simply of a suitably biased thyratron, with its anode voltage supplied through a contact of the relay in the enabling circuit. When fired, the thyratron operates a register relay. It is extinguished when voltage is removed by the enabling circuit.

An essential feature of this trigger device, or of possible alternative circuitry, is that it must provide a fairly sharp drop in input impedance at or slightly above the triggering threshold, even when actual triggering is not enabled. This change in impedance (afforded by the grid-cathode diode of the thyratron) "bumps" the tuned circuit, restricting its amplitude to little more than that required for triggering. As a result, the amount of extraneous energy that can be stored in the tuned circuit
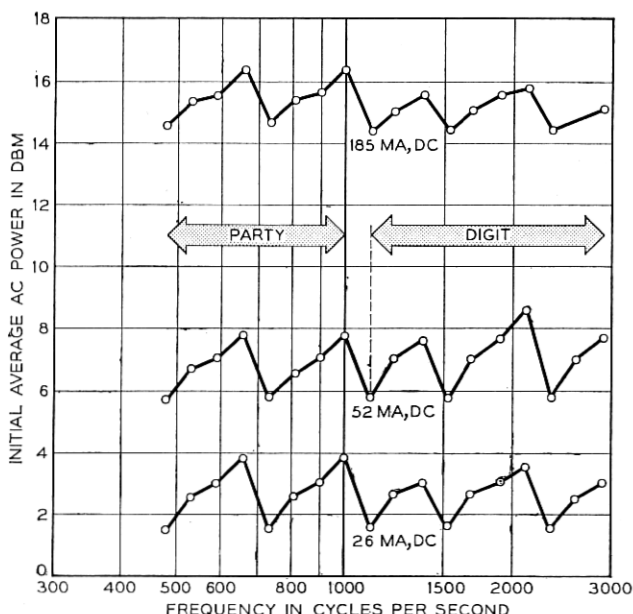

Fig. 13 — Power delivered to the line at the beginning of the damped oscillatory party or digit pulse is shown as a function of frequency and loop current.

is regulated, and the period of its decay to a negligible value, after transmitter disablement, is shortened.

Fig. 12 shows the waveforms at the central office corresponding to those at the station set as shown in Fig. 10. This figure also summarizes the action of the receiver in registering a signal. The loop current, limiter, and enabling diagrams are self-explanatory. The diagram for the cutapart filter shows random output in the first portion of the off-hook period resulting from speech or noise components in its pass band. When a button is pushed the transmitter output ceases and is replaced by the damped digit or party pulse. Release of the button restores the random output. The tuned circuit diagrams show representative types of response to the "correct" or resonant frequency and to the "incorrect" or non-resonant frequency. It is assumed for illustration that the "incorrect" circuit happened to be excited to the "bumping" amplitude by a component of the transmitter output just before the transmitter was disabled and the dial signals began. An appreciable time is seen to exist between the fall of the "incorrect" signal from, and the rise of the "correct" signal to, the bumping amplitude. It may also be noted that enablement does not occur before the correct signal has grown to the bumping amplitude.

3.4 *Performance*

The system as described was assembled for study and demonstration of the voice frequency signaling scheme. It has served this purpose well
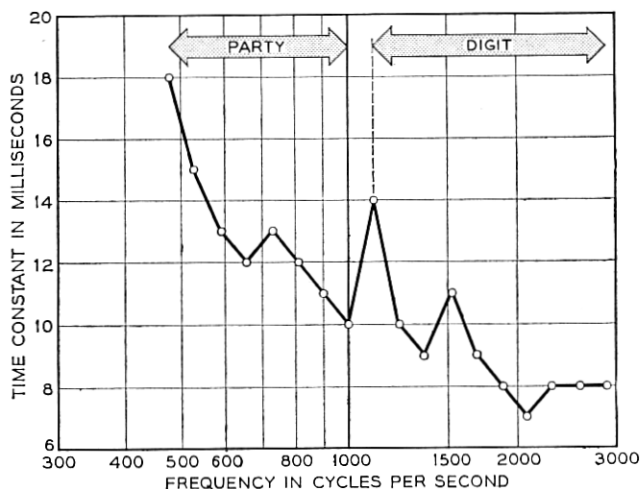

Fig. 14 — Time constant of the damped oscillatory party or digit pulse is shown as a function of frequency.

and in fact has operated dependably in the laboratory over a period of many months and over wide ranges of simulated operating conditions. However, the arrangement is only exploratory and numerous simplifications and improvements are known to be possible. Therefore, inclusion here of extensive performance data would be unwarranted. A few significant items are given below.

Fig. 13 shows the average ac power in dbm at the beginning of the oscillatory transient delivered at the station set terminals to a 900-ohm line for the 18 calling frequencies. Three curves are shown for dc loop currents of 185, 52, and 26 milliamperes representing loops of 0, 2, and 4 miles of 26-gauge cable, respectively. The saw-toothed appearance of Figs. 13 and 14 is related to the use of taps on the inductors of the signal generating circuits for tuning purposes. This results in progressively more rapid energy dissipation as capacitor connections are made to lower coil taps. Fig. 14 shows the time constants representing the decay rate of the voice frequency signal voltages across the 900-ohm line for a dc loop current of 26 milliamperes. For the least available power in a 4-mile loop and the shortest time constant, the duration of limiting at the receiver is about 16 milliseconds which is adequate for proper signal registry.

IV. ACKNOWLEDGEMENTS

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