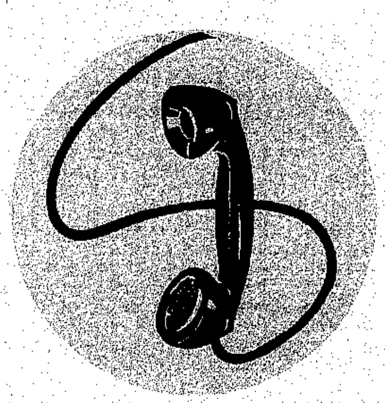
MONOGRAPH 1841

BELL TELEPHONE SYSTEM

TECHNICAL PUBLICATIONS

Single-frequency signaling system for long telephone trunks



by

N. A. Newell

A. Weaver

Presented at

The Winter General Meeting of the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

New York, N. Y., January, 1951

Published in

TRANSACTIONS OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Vol. 70, pt. 1, pp. 487-493, 1951

671157

Single-Frequency Signaling System for Supervision and Dialing over Long-Distance Telephone Trunks

N. A. NEWELL
MEMBER AIEE

A. WEAVER
ASSOCIATE AIEE

Synopsis: The single-frequency signaling system for long-distance telephone trunks frees dial calls from the range and other limitations imposed by d-c signaling methods. It uses alternating currents in the voice range as the signaling medium and so can be used with any trunk of any length or type of line facility which meets voice-transmission requirements. The signaling requirements, design problems, main features of the circuit and equipment arrangements, and the operation of this system are outlined in this paper. The system described is the first practical arrangement of its type satisfactorily to meet all the conditions of telephone service in the Bell Telephone System.

IN PLANNING for nation-wide dialing of long-distance telephone calls, the desirability of providing an a-c signaling system for dial telephone trunks soon became apparent. In the past long-distance calls were completed manually or by dialing over limited distances. For these dial calls d-c signaling was adequate and was the most economical and reliable method. The extensive growth in carrier line facilities which do not have associated d-c paths and the planned expansion in dialing ranges for long-distance calls make it necessary to supplement the existing d-c signaling arrangements with an a-c signaling system. The single-frequency signaling system is designed for this service. It employs alternating currents in the voice frequency range to pass supervisory and dialing signals over the voice path of long-distance telephone trunks.

A telephone trunk is a complete communication channel between manual or mechanical switches. These trunks are the major links in most telephone calls and provide 2-way speech transmission and 2-way signaling to facilitate build-up and breakdown of the temporary connections commonly required. Dial system trunks which terminate in mechanical switches have more exacting signaling requirements than any other type of trunk.

Paper 51-79, recommended by the AIEE Communication Switching Systems Committee and approved by the AIEE Technical Program Committee for presentation at the AIEE Winter General Meeting, New York, N. Y., January 22–26, 1951. Manuscript submitted October 25, 1950; made available for printing December 8, 1950.

N. A. Newell and A. Weaver are both with the Bell Telephone Laboratories, Inc., New York, N. Y.

Basic Plan

The single-frequency signaling system, although fairly complex in detail, is very simple in principle. It uses a distinctive frequency within the voice band which passes as readily as speech over the trunk transmission line. Normally, speech, and the signal frequency are not on the line simultaneously. The signal frequency is applied and removed at each trunk terminal to operate and release a relay at the other end. The operation is similar to that obtained by closing and opening a d-c loop circuit for each of the two directions of signaling. Independent operation is obtained in each direction with one signal frequency on 4-wire lines which have separate 1-way transmission paths from terminal to terminal and with two different signal frequencies, one for each direction of transmission, on 2-wire lines.

The signaling system is provided as a separate entity. It is connected at each end of a trunk to the relay equipment by two 1-way signaling leads and is put in series with the line circuit on a 4-wire basis; that is, through separate transmitting and receiving branches. A typical arrangement for a 4-wire line having 2-wire switching at the West terminal and 4-wire switching at the East terminal is shown in Figure 1.

In the case of 2-wire lines, the signaling equipment is applied to the E-W and W-E transmission paths of the terminal repeaters, using a different frequency for signaling in opposite directions. This is done to avoid difficulties which would otherwise be caused by echoes introduced by unbalances in the 2-wire repeaters.

Table I

Trunk Condition	Signaling Frequency Calling to Called End
Idle (disconnect)	On
Seizure and hold (connect)	Off
Dial pulsing*	On, then off; on pulses corresponding with dial break intervals
Re-ring (ring forward)	On, then off, one pulse
Disconnect (idle)	On

* Multifrequency pulsing[1] is a faster means of transmitting number information often used instead of dial pulsing. Its use eliminates only the dial-pulsing signals.

Trunk Signals

Before going into the details of the signaling system itself it seems appropriate

Table II

Trunk Condition	Signaling Frequency Called to Calling End
Idle (on hook supervision)	On
Stop pulsing*	Off
Start pulsing	On
Flashing**	Off, then on; off pulses corresponding with off hook supervision
Answer (off hook supervision)	Off
Ring back	On, then off; on for duration of ring
Hang up (on hook supervision)	On

* Stop-and-start pulsing-control signals are required only in connection with common control switching equipment.

** Flashing signals appear on a supervisory lamp in the cord circuit of the originating operator and are used to inform her of the condition of a call.

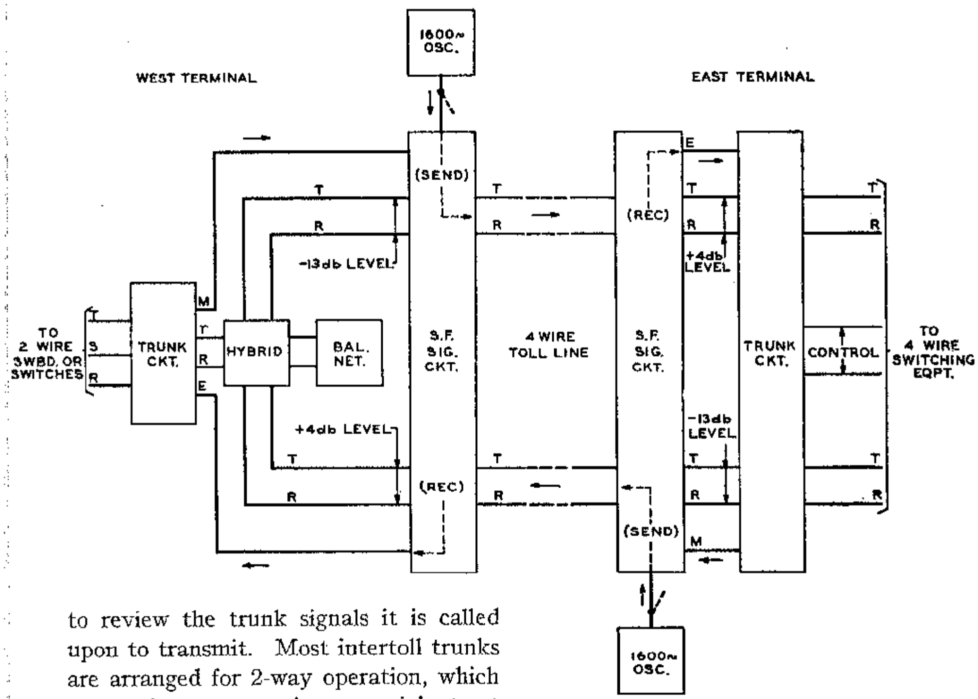


Figure 1. Trunk plan with 4-wire line and single-frequency signaling

to review the trunk signals it is called upon to transmit. Most intertoll trunks are arranged for 2-way operation, which means that a connection can originate at either end. To permit this operation, the signaling in each direction must be symmetrical and the trunk must allow the direction in which the connection is established to determine the signaling use. The latter is conveniently identified by different names for the trunk signals in the two directions. Only two signal conditions, that is, tone on or tone off, in each direction are required for all dial trunk signals. Tables I and II show the required dial intertoll trunk signals, together with the action taken in regard to the signaling frequency.

The signaling system must be able to handle the fastest signals needed. These are the dial-pulsing signals where the shortest signal element may be as low as 30 milliseconds. All other signals have longer durations.

The maximum permissible transmission time for signals between trunk terminals is determined by the allowable unguarded interval on 2-way trunks, during which double connections may occur, and also by the stop-pulsing signal recognition interval. This time is limited to 175 milliseconds.

The distortion permitted in the transmission of signals is proportional to the time duration of each signal. In general, variations in signal time should be within ±5 per cent. All effects of the trunk signal medium should be confined within the trunk terminals or be of such character as to have no adverse reaction in connected circuits. This is necessary for proper operation of switched connections.

General Design Factors

The single-frequency signaling system is an effective continuous (as contrasted to a "spurt") signaling scheme. Use of the voice path for this type of signaling is obtained only by compromise of a number of conflicting factors. The main problems in design are presented in this section in order to facilitate an understanding of this development, which has features that are quite different from those used for signaling in the past. These design problems are: Choice of signal frequency; interference to voice by signal frequency; impairment of voice by signaling equipment; imitation of signal by voice or other tone; interference to signal by voice, noise, or plant tone; impairment of signal by voice transmission equipment; and audibility of signal to operators and subscribers.

Choice of Signal Frequency

Although most lines transmit higher frequencies, the choice of a frequency for universal application is limited to the 300 to 1,700 cycles per second (cps) band, and in order to avoid signaling at the edges of the band, is restricted to a 400–1,600 cps range.

The frequency most favorable to trunk-signaling circuit design and operation is thought to be the highest frequency that can be used. Primarily, this is because the energy in speech, which may interfere with signaling, in general decreases with ascent in frequency above 1,000 cps. Accordingly, 1,600 cps is used for all 4-wire applications.

Two-wire voice channels require different frequencies for signaling in opposite directions. The use of 2,000 cps for the second signal frequency permits application of this system on practically all 2-wire lines.

Interference to Voice by Signal Frequency

The signal frequency is applied during the trunk idle condition and is removed for the connect and off-hook signals. This

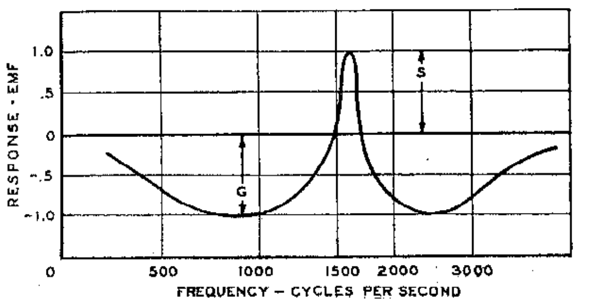
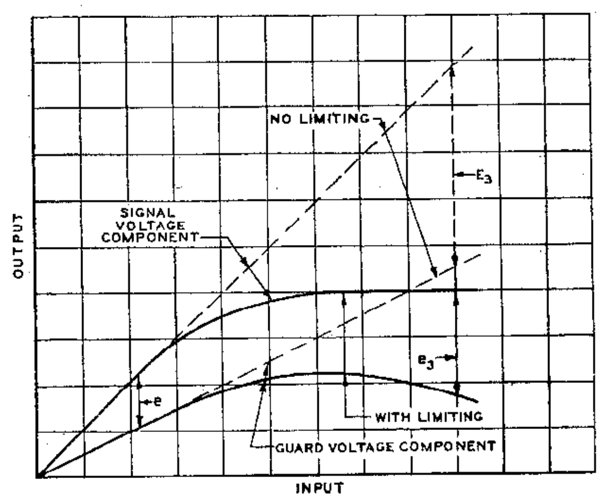


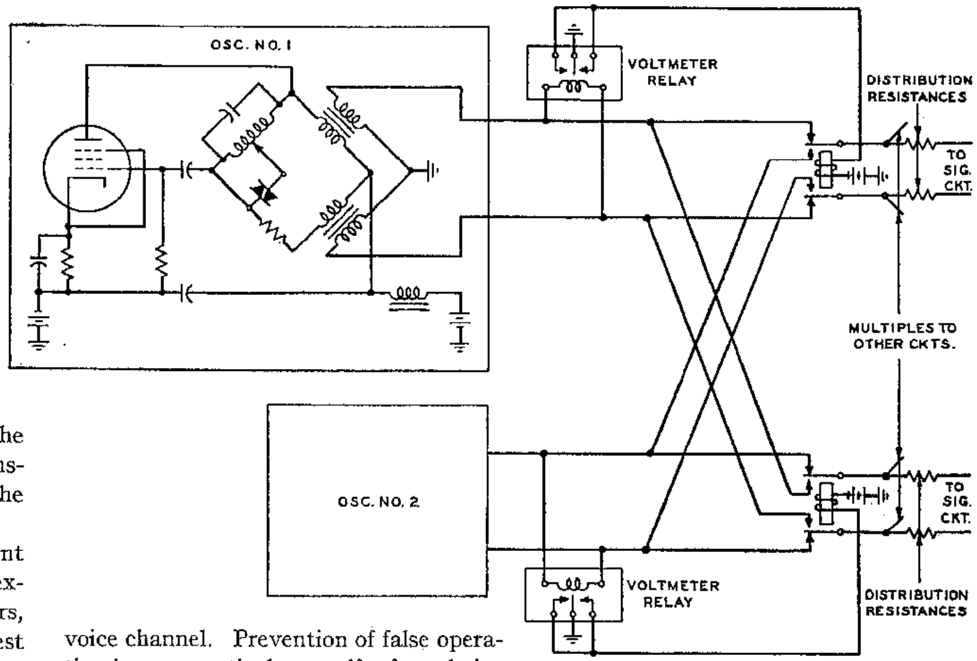
Figure 2 (left). Frequency response characteristic of signal, guard circuit



E_3 – NET SIGNAL VOLTAGE WITHOUT LIMITING
e_3 – NET SIGNAL VOLTAGE WITH LIMITING
e – VALUE OF OUTPUT REQUIRED TO OPERATE RELAY

Figure 3 (right). Limiter characteristics

Figure 4. Elements of supply circuit



arrangement allows alternate usage of the voice channel for signal and voice transmission in most cases and normally the two are not on the line simultaneously.

In order to limit crosstalk into adjacent voice channels and to avoid adding excessive signal power to the repeaters, it is desirable to use the lowest practicable signal power on the voice channel. A power of −20 decibels below 1 milliwatt (dbm) at zero transmission level, which is just above the low quarter of the average voice power range, is satisfactory for steady application of the signal frequency. In order to obtain an over-all margin of 8 decibels (db) the operate sensitivity of the receiver is set at −28 dbm. A 14-db higher power is used for short intervals to overcome line noise and attenuation variations, as explained later.

Impairment of Voice by Signaling Equipment

Normally, no reduction in the frequency band width of the voice channel is permitted for signaling. An exception to this rule is necessary for single-frequency signaling on connections to intercept operators because off-hook supervision is not provided when speech occurs on these connections. Under this condition, the tone is cut off from the subscriber by a narrow 1,600 (or 2,000)-cycle filter. This filter also takes a "slice" out of the voice band, which results in an effective transmission loss of about 0.5 db.

The transmission loss to speech occasioned by the required continuous connection of the signal transmitter is about 0.1 db, and there is no loss for the signal receiver.

Imitation of Signal by Voice or Other Tone

Since the signal receiver must be connected at all times to the voice channel, precautions are necessary to prevent its false operation by any occurrence of the signal frequency in speech, music, plant tones, noise, and other energies on the voice channel. Prevention of false operation is comparatively easy if a free choice is permitted for any one of three design factors. These are (1) the signal frequency, (2) the operate sensitivity, and (3) the operate time of the signal receiver. The protection inherent in these items, however, is limited, the first two by the line requirements and the third by the trunk-signaling requirements. Additional protective devices therefore are provided through circuit design. These consist in (1) the use of "guard action," (2) the employment of as narrow a band width as practicable for the signal selection network, (3) the use of limiting, and (4) by means of relays the reduction of the operate sensitivity, the increase of the operate time, and the increase of guard action when the usual talking condition is established.

The "guard action" is the principal factor in protecting the receiver against operation on speech. Guard action consists of the use of all frequencies other than those in a narrow band on each side of the signaling frequency to generate a direct voltage and in the application of this voltage to oppose the direct voltage resulting from the signal frequency which is used to operate the receiver. The combination of these two voltages plotted against frequency is shown in Figure 2. A term which is used to specify the effectiveness of the guard action is "guard-signal ratio" (G/S in Figure 2) or just "guard ratio," a term also used by the British.[2] This is the ratio of the absolute value of the direct voltages at the grid of the d-c amplifier produced respectively by equal amounts of guard frequency (at maximum guard sensitivity) and signal frequency when separately applied. The provision of guard requires that more than the just operate power of signal frequency be available to operate a receiver when it is exposed to noise or other than signal frequency. Also, the provision of guard increases the operate time of a signal receiver. The amount of guard permitted is limited by the signal-to-noise relation when operation of the receiver is required and by the operate time requirement.

Protection is added by narrowing the frequency band accepted for operation of the receiver, since this reduces the effective operating power of voice and noise frequencies. However, the amount of this narrowing is limited, as the operating band width must be sufficient to allow for frequency variation in the signal supply, for carrier shift in the line, for variations in elements of the tuned circuit in the receiver, and for the proper relation of the minimum signal time duration and

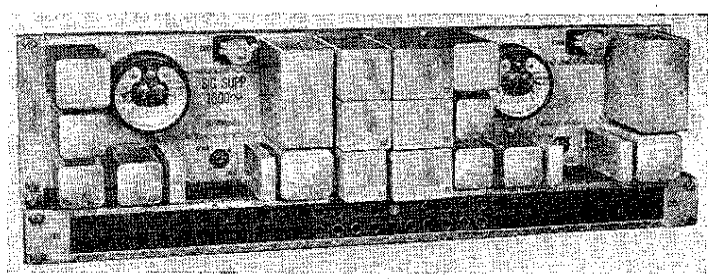


Figure 5. Supply unit

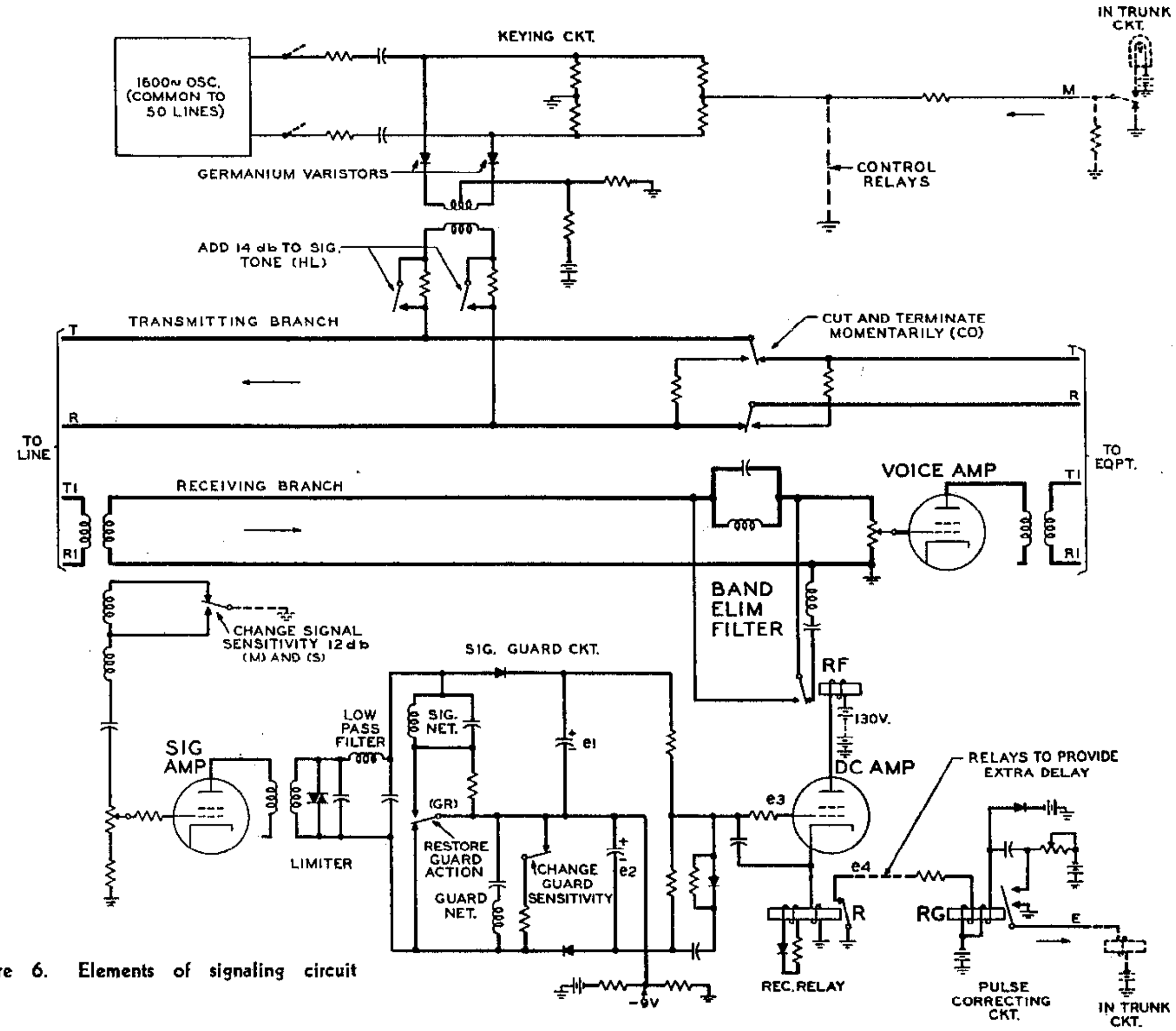


Figure 6. Elements of signaling circuit

the time required by the tuned circuit to reach a steady-state condition.

Volume limiting helps prevent false operation on high levels of speech. The theory of this action is illustrated in Figure 3. It is assumed that a burst of speech sounds contains a signal component, upper lines in Figure 3, and a guard component of one-half this value, lower lines. The dotted lines show a characteristic for a receiver with no limiting, while the solid lines are for one having limiting. As shown, a given large input will produce an output of E_3, the difference between the signal voltage component and the guard voltage component, in the former case and of e_3 in the latter, which is about one-half as much. This will be less likely to operate the receiver (operate value e) when applied for a short interval of time. Either one will, of course, produce an operation if applied long enough.

The change in the sensitivity and operate time of the receiver are practicable by reason of the higher signal power permitted for short intervals of time and the longer time durations of supervisory signals. The lengthened-operate time also requires that the re-ring signal transmitted from the sending end be lengthened by a corresponding amount.

Interference to Signal by Voice, Noise, or Plant Tone

The use of guard action to prevent false operation of the receiver introduces the liability that voice, noise, or tones may prevent the operation of the receiver by signal frequency or may cause it to release falsely once it is operated. By design this last effect is confined to the operate time of the receiver. After the receiver is operated the guard action is disabled and all voice frequencies hold the receiver operated. This shift is delayed for a short time in order to avoid increasing the hazards of false operation and does not occur during dial pulsing. To permit release of the receiver after the shift takes place, the voice and noise power going into it must be about 3 db less than its operate sensitivity.

The frequencies that might interfere with receiver operation come from sources outside the trunk terminals either through connected circuits or by induction into the line. Ordinarily the power from connected circuits is much higher than that of line noise. This interference coming through the trunk terminals is eliminated effectively on 4-wire lines and its occurrence greatly reduced on 2-wire lines by use of a cutoff relay in the signal transmitter and a blocking amplifier in the signal receiver to isolate the signal path in the trunk. The cutoff relay is operated just long enough when the signal frequency is applied or removed to prevent noise at the transmitter terminal from interfering with the operation or release of the far-end signal receiver. The 1-way path of the blocking amplifier, which is the sole reason for its use as it is arranged for zero gain, is between the signal path of the receiver and its trunk terminal to shut out noise from that direction. Interference by line noise is overcome during operation by an increase of 14 db in the

Table III

Factor	Idle, Dialing, and Intercept Condition	Talking Condition
Signal frequency, cps	1,600 or 2,000	1,600 or 2,000
Receiver sensitivity (0 level), dbm	−28	−16
Receiver signal band width, cps	60	60
Guard-signal ratio, db	0	10
Start of limiting above just operate, db	5	5
Minimum signal duration for operate, ms	35	100
Minimum signal duration for release, ms	7	

signal power for a short initial period when it is applied to the line by the signal transmitter.

671157

Impairment of Signal by Voice Transmission Equipment

Echo suppressors are examples of voice transmission equipment which may interfere with signaling arrangements using the voice channel. Only terminal echo suppressors can be used with single-frequency signaling and these must be located on the equipment side of the signaling equipment.

Single side-band carrier channels are subject to frequency shift, and this must be held within reasonable limits to avoid too much impairment of the signal frequency.

Audibility of Signal

The addition of signal frequency to the voice channel must not annoy subscribers or operators. When the call is established, the tone is cut off, except on calls to intercept operators. In this case, low-level signal frequency is transmitted over the line, but is reduced by a band-elimination filter, with the result that the power at the calling subscriber's telephone does not exceed about −60 dbm. At this time the power at the intercept operator's telephone does not exceed about −45 dbm. These levels are considered low enough to be inoffensive.

Summary

The values of the design factors used for the equipment described in this paper are given in Table III.

The design based on these factors is so nearly free from false operations caused by speech that these average fewer than one per 1,000 conversations.

General Description

The components of the single-frequency signaling system (Figure 1) consist of the following: The signal frequency supply; the signal transmitter and receiver; the auxiliary 1-way transmission path and filter; and associated test arrangements.

Signal Frequency Supply

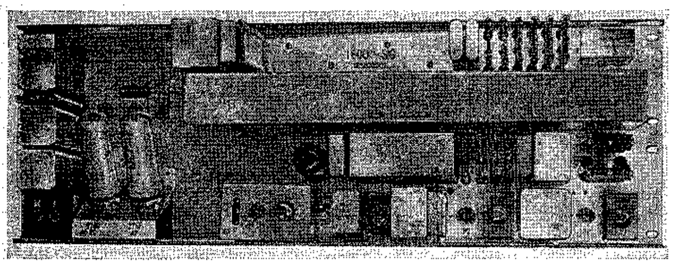
The signal supply includes a pair of single vacuum tube oscillators, a trouble alarm and transfer circuit, test and patching jacks, and distribution resistances. The signal frequency is distributed on a 2-wire metallic basis. The basic elements of the oscillator supply and transfer circuit are shown in Figure 4, and the equipment unit, which is the same for either 1,600 or 2,000 cps, is shown in Figure 5. The output capacity of one supply unit is sufficient to provide signal frequency for 100 signaling circuits. The two oscillators operate continuously and normally share the load equally. In case of trouble in one oscillator its load is transferred automatically to the other. The oscillator circuit is basically the same as that used in multifrequency pulsing[1] and so is not described here in detail.

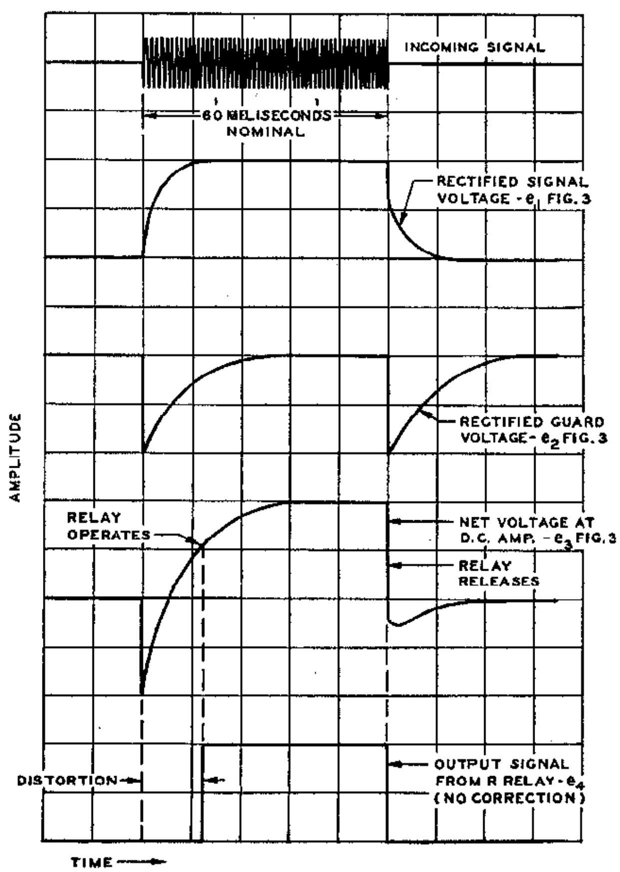
Signal Transmitter and Receiver

This is the main unit of the signaling system and one is required for each trunk terminal. The essential elements of this circuit are shown in Figure 6, and the equipment panel is shown in Figure 7. It connects with the trunk relays over two leads, *E* and *M*, and into the line circuit with eight leads, *T*, *R*, *T1* and *R1*, on both the line and equipment sides. The signal transmitter uses d-c biased germanium varistors to control the application of signal current through a low transmission loss bridge on the line and has four relays designated *M*, *CO*, *HL*, and *RR*. The principal functions performed by the first three of these relays are shown in Figure 6. The *RR* relay (not shown) in conjunction with the *M* relay lengthens the sent pulse for the re-ring signal because the far-end receiver at this time has a long operate time. The signal receiver, which is connected through a low transmission loss shunt path on the line, operates the signal relay in response to the appearance of signal frequency. In addition it introduces blocking between the terminal equipment noises and the signal

Figure 7 (below). Signaling panel

Figure 8 (right). Typical wave forms





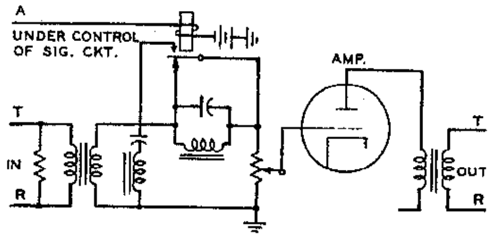


Figure 9. 1-way path and filter circuit

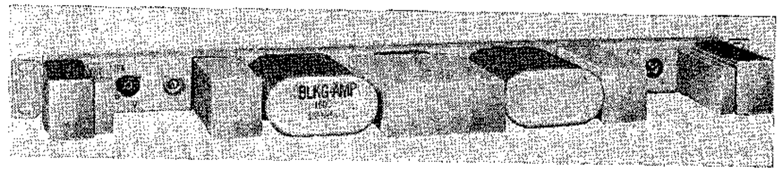


Figure 10. 1-way path and filter unit

path. Also, the level of signal frequency going past the signal receiver is reduced by a band-elimination filter.

The receiving portion of the circuit is shown in the central and lower portions of Figure 6. It is wired in series with the receiving branch of the line and translates signals coming in from the line to ground on the *E* lead, which in turn connects to the trunk circuit. The idle condition of the trunk is shown, tone is being received, and all relays shown are operated. The band-elimination filter is inserted to prevent the signal frequency from getting into a connected trunk and interfering with signaling there. The voice amplifier has zero gain and is used to prevent noise and other voice frequency currents, originating in switching equipment or connected circuits, from interfering with the operation of the receiver.

The signal currents, received from the line, are amplified by the signal amplifier, passed through a limiter and low pass filter, and applied to the signal-guard network, from which signal voltage is applied to the d-c amplifier to operate the *RF*, *R*, and *RG* relays and thus control the *E* lead, which extends into the trunk terminal equipment. Typical wave forms at several points in the circuit are shown in Figure 8. The extra operate time provided during the talking condition is obtained from a slow release relay, which is inserted at this time, in the path from the *R* to the *RG* relay. Relays *M* and *S* are provided, but not shown, to cut in and out as required, the lesser sensitivity, the increased guard sensitivity, and the extra delay in operation.

The *R* relay, because of guard action and the effect of its secondary winding being closed through a varistor and resistance, is relatively slow to operate and fast to release. For this reason some sort of pulse correction is necessary to get good dial operation. This is obtained with the *RG* relay and an associated condenser-resistance timing network, which results in an output pulse within the needed limits, even though the signal on the *R* relay is shortened considerably. To convert the receiver from operation on 1,600 cps to operation on 2,000 cps, it is necessary only to substitute networks.

Auxiliary 1-Way Path and Filter

This circuit is shown in Figure 9 and the equipment unit which provides two circuits is shown in Figure 10. The circuit consists of a simple zero-gain vacuum tube amplifier with optional arrangements for the addition of a signal frequency band-elimination filter and control relay. The circuit is connected into the voice-transmitting branch of the line on the equipment side of the single-frequency signaling main unit under two conditions: (1) on trunks equipped with terminal echo suppressors to prevent their false operation on signal current (the control relay and the filter are not provided for this application); (2) on trunks terminated in switchboards which are not arranged to disconnect the voice-transmission path while the operator is dialing. This is done to prevent false operation of the signal receiver when it is in the dialing condition, as at this time it is more susceptible to speech. This same circuit also is connected into the voice-receiving branch of 2-wire lines on the line side of the main signaling unit to prevent interference from the transmitted frequency at the same end.

It connects into the voice branch with four leads, *T* and *R* on its line and equipment sides and, when the filter is provided, to the main unit over lead *A*. The band-elimination feature of the filter in all cases is tuned for the transmitting signal frequency of the signaling circuit. This filter normally is switched out during conversation. The 1-way path feature prevents interference with the operation of echo suppressors by signal frequency. The amplifier circuit provides a convenient way to place the filter, which is of the same design as that used in the signaling circuit, in a transmission path without changing its impedance relations.

Associated Test Arrangements

Test jacks are provided in eight of the ten leads connecting the main signaling unit. These provide direct access for checking the performance of the operating features of this circuit. Two other test jacks are provided in the unit for checking internal portions of the circuit.

A fixed testing assembly is provided for each full or partial group of 100 signaling circuits. These facilities are supplemented by portable test sets. A full discussion of all the testing arrangements for this system is outside the scope of this paper.

Operation

It is assumed in the following brief outline of a typical operation that 4-wire lines are used and that the echo suppressor and blocking amplifier are not required.

Normal Idle Trunk Condition

The trunk circuits have ground on the *M* leads to the 1,600-cps signaling transmitters, which apply the signal frequency to the transmitting branch of the line circuit at each end. The signal frequency is received in the receiving branches and holds the relays in the signaling receivers. This keeps an open on the *E* leads to the trunk circuits.

Call Originating at West End

When a connection is made to the intertoll trunk, say at the left or West end, through the switchboard or switches, the West trunk circuit takes ground off and puts battery on the *M* lead there. The new signal to the West signaling transmitter causes it to remove 1,600-cps signal frequency from the West to the East branch of the line. The absence of signal frequency in the East receiving branch releases the signal relay in the East signaling receiver and this puts ground on the *E* lead to the East trunk circuit. This ground is the connect signal, which prepares the East terminal for an incoming call.

Pulsing

Pulsing now takes place. This may be either multifrequency pulsing[1] or dial pulsing, which consists in applying tone to the line for each break interval of the dial.

Called Subscriber Answers

When the connection is completed at the East end, the called subscriber answers and an off-hook signal is received

Table IV

	Rate Interruptions per Minute	Duration Time in Seconds On Hook	Off Hook	On Hook	Off Hook
Subscriber line busy	60	0.5	0.5	Repeat	Repeat
Trunks busy, reorder	120	0.3	0.2	Repeat	Repeat
Trunks busy, hold (overflow)	30	1.7	0.3	Repeat	Repeat
Master busy	Uneven 60	1.3	0.2	0.3	0.2
Recall by subscriber	Irregular	Not less than		0.3	0.2

at the East intertoll trunk circuit, which takes ground off and puts battery on the M lead there. This signal to the East signaling transmitter causes it to remove 1,600-cps signal frequency from the East to the West branch of the line. The absence of signal frequency in the West receiving branch releases the signal relay in the West signaling receiver, and this puts ground on the E lead to the West trunk circuit. Since the call originated at the West end, ground on the E lead here is an off-hook or subscriber answer signal.

Conversation Takes Place

At this time there is no signal frequency on the line and no impairment to the voice transmission.

Called Subscriber Hangs Up

On normal calls when conversation is completed, the called subscriber hangs up his receiver and an on-hook signal is received through the switches at the East intertoll trunk circuit. This changes the condition on the M lead there, from battery to ground. Ground on the M lead causes the East signaling transmitter to apply 1,600-cps signal frequency on the East to West branch of the line. Presence of signal frequency in the West receiving branch operates the signal relay in the West signaling receiver and opens the E lead to the West trunk circuit, giving it the called subscriber's on-hook signal.

Disconnect

Release of the intertoll trunk at the calling end causes a disconnect signal at the called end in a similar manner to that just described for the passing of the on-hook signal. Trunk, signaling, and line circuits return to the normal idle condition.

Flashing

On some calls flashing signals from the called end may occur. Typical signals of this type are shown in Table IV.

References

1. Application of Multifrequency Pulsing in Switching, **C. A. Dahlbom, A. W. Horton, Jr., D. L. Moody.** *AIEE Transactions*, volume 68, part I, 1949, pages 392–96, and *Electrical Engineering*, volume 68, June 1949, pages 505–10.

2. The Influence of Signal Imitation on the Reception of Voice Frequency Signals, **G. T. Flowers, D. A. Weir.** *Proceedings*, Institution of Electrical Engineers (London, England), volume 96, part III, 1949, pages 223–35.