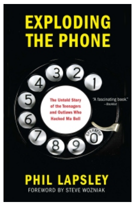

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Abstract	Earliest known as technical description of multifrequency signaling. "The first multifrequency pulsing system was installed at the toll board in Baltimore, Maryland to permit the toll operators to complete calls to local crossbar offices without the aid of another operator, and without the use of senders in the toll office. Multifrequency pulsing next was used in connection with the new toll crossbar office installed in Philadelphia, Pennsylvania. In this installation calls were received over toll on some distant points, as wells from switchboards within the city, by means of the multifrequency pulsing system. Today, installations of multifrequency pulsing arrangements are being made in many cities throughout the United States."
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Application of Multifrequency Pulsing in Switching

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MULTIFREQUENCY pulsing is a form of signaling with alternating current, which permits the rapid transfer over telephone trunks of the information required to select switch paths in local, toll, and tandem dial telephone systems. The multifrequency pulses consist of different combinations of two, and only two, of six frequencies. These six frequencies are spaced 200 cycles apart, from 700 to 1,700 cycles, inclusive. Each combination of two frequencies represents a pulse, and each pulse a digit. The pulses are sent over the regular talking channels and, since they are in the voice range, are transmitted as readily as speech. There are 15 pairs of frequencies possible from the group of six; ten of them are used for the digits 0 to 9, inclusive, and one each for signals indicating the beginning and end of pulsing. The remaining three possible pairs are available for future requirements.

The multifrequency system is arranged so that if more than two frequencies are received by the equipment, the operator who is setting up the connection receives a flashing cord lamp; then she must release the connection and start making the call over again in accordance with her instructions.

The first multifrequency pulsing system was installed at the toll board in Baltimore, Md., to permit the toll operators to complete calls to local crossbar offices without the aid of another operator, and without the use of senders in the toll office. Multifrequency pulsing next was used in connection with the new toll crossbar office installed in Philadelphia, Pa. In this installation calls were received over toll lines from distant points, as well as from switchboards within the city, by means of the multifrequency pulsing system. Today, installations of multifrequency pulsing arrangements are being made in many cities throughout the United States.

Applications of Multifrequency Pulsing

In applying multifrequency pulsing to the telephone plant, it must be kept in mind that the signals used in completing a normal connection in any of our dial telephone systems conveniently fall into two classes: supervision, and pulsing. Supervision includes the connect and disconnect signals going toward the called end, and the "on" and "off" switchhook signals going toward the calling end. The supervision signals can be used under certain conditions for other purposes; for example, to control the start of pulsing, and to recall an operator who may have been assisting in the establishment of the connection. The supervision channel must be ready at once to transmit signals, and, therefore, the supervision signaling equipment is provided individually to the trunk. On the other hand, pulsing signals are required only to set the switch paths and are sent toward the called end. Once the switch paths have been set, there is no longer any need for the pulsing channel, so the use of pulsing signals is limited to the time during which the connection is being established. Accordingly, the equipment used for pulsing can be detached from the connection as soon as it has been set up. In the case of multifrequency pulsing, therefore, the pulsing means are detached from the connection at both ends of the circuit as soon as the switching paths have been established.

Over-all Plan

The multifrequency pulsing system consists of:

1. The signaling current supply units and distribution arrangements with suitable protection and alarm features.
2. The signal transmitters, either manual multifrequency keysets or dial system multifrequency pulsing senders.
3. The signal receiver connected to the incoming sender or register.
4. The necessary additional maintenance facilities.

One arrangement of the system components for pulsing on a trunk between manual and dial system offices is shown in Figure 1. A local manual, dial system "A," or toll switchboard equipped with multifrequency key pulsing, is shown connected by a direct trunk arranged for multifrequency pulsing to a crossbar office equipped with incoming multifrequency pulsing senders. When an outward operator at a manual switchboard, as shown in Figure 2, handles a call which can be completed through the crossbar office, the first action is to connect a cord circuit to the trunk with the "talk" key operated and operate the *KP* (key pulsing) button of the keyset. The operation of the *KP* key operates a relay that transfers the cord from the telephone set to the keyset, lights a positional *KP* lamp, and prepares the keyset circuit to send the key pulse signal over the trunk as soon as the distant end signals that it is ready to receive pulses. Connection of the cord to the trunk gives a connect signal to the distant end which returns "off-hook" supervision to delay pulsing until a sender is found. When the sender at the distant end has been found, and the pulsing path has been completed, the supervision is changed to "on-hook" as a start-pulsing signal. This causes the *KP* pulse signal to go out automatically and lights the positional sender lamp.

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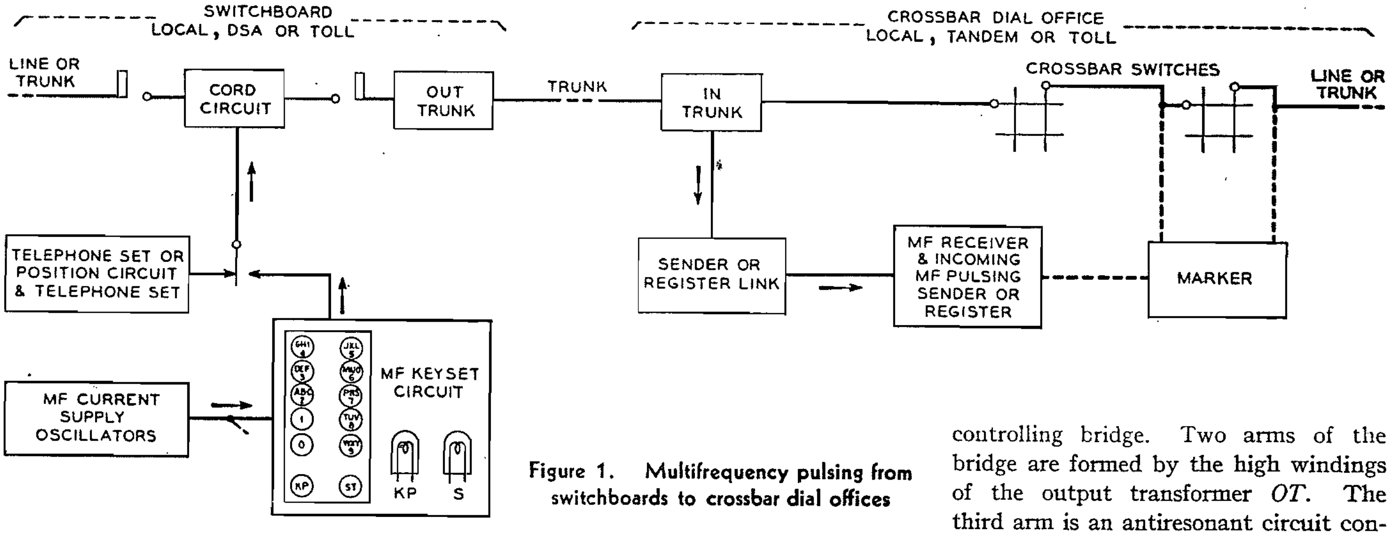


Figure 1. Multifrequency pulsing from switchboards to crossbar dial offices

Receipt of the *KP* signal at the distant end prepares the multifrequency receiver to accept the digits that are to follow. The operator may begin sending the digits of the called number as soon as the positional sender lamp is lighted. She will do this by pressing one button for each digit. Following the last digit, she presses the *ST* (start) button to indicate the end of pulsing. In addition to informing the distant sender that no more pulsing signals are coming, the operation of the *ST* key disconnects the keyset from the cord, reconnects the telephone set under control of the "talk" key, and also extinguishes the *KP* and sender lamps.

If the operator presses two buttons simultaneously, or if she presses the *KP* key after the positional sender lamp lights, a reorder signal is received from the distant end causing the cord supervisory lamp to flash, requiring the operator to release the connection and start the call over again.

Other Applications

In addition to the use of multifrequency pulsing from manual positions to local, toll and tandem crossbar offices, there is also a wide use of multifrequency pulsing between the incoming senders at the toll crossbar-switching offices and the local crossbar offices. In this case, the multifrequency pulses are sent out by a sender, instead of by a keyset. The rate of sending averages about seven digits per second, instead of the two digits per second normally keyed by the operators.

The toll crossbar and certain local crossbar offices are equipped to transmit, as well as receive, multifrequency pulses. A further application to toll switchboards has resulted in the use of multifrequency pulsing senders which will receive multifrequency pulses and transmit dial pulses. This arrangement is used to set up connections to the step-by-step type of office.

Multifrequency Current Supply

The current supply circuit consists of two groups of bridge-stabilized oscillators. Each oscillator group normally supplies one-half of the office load, but each oscillator group is capable of carrying the whole office load if failure occurs in either group. Each group consists of six oscillators operating at the frequencies 700, 900, 1,100, 1,300, 1,500, and 1,700 cycles respectively. The oscillator design is such as to provide constant frequency and amplitude output for normal variations in power supply and output load.

Description of Oscillator

One of the bridge-stabilized oscillators is shown schematically in Figure 3. It consists of a high-gain pentode vacuum tube *V*, operated as a class *A* amplifier, together with a frequency- and amplitude-controlling bridge. Two arms of the bridge are formed by the high windings of the output transformer *OT*. The third arm is an antiresonant circuit consisting of retardation coil *L* and capacitor *C* connected in parallel, while the fourth arm is a resistance *R* having a value slightly less than the impedance of the antiresonant circuit at the oscillator frequency. Part of the retardation coil is shunted by a thyrite varistor *VR*, whose impedance is responsive to amplitude variations. For low voltages, the varistor has a very high effective resistance, but its value decreases rapidly as the amplitude of the voltage is increased. Taps are provided to allow adjustment of the output voltage at the time of installation.

Figure 2. Outward operator at toll switchboard

For the normal frequency F_0 and output voltage E_0, the impedance of the antiresonant network is resistive and slightly larger than the resistance arm of the bridge. Thus, a small voltage unbalance is applied to the grid of the *V* tube, and the oscillations are sustained. For frequencies above or below F_0, the antiresonant circuit reactance becomes capacitive or inductive, respectively; the magnitude of the reactance depending on how far the frequency shifts from the antiresonant frequency. These effects of frequency upon the phase angle of the impedance near antiresonance, and of amplitude upon the magnitude of the antiresonant impedance, are used to stabilize the frequency and amplitude of the oscillations.[1] The frequency control exerted by the tuned circuit depends upon the fact that the phase shift of the amplifier tube must be equal and opposite to that through the bridge circuit.

Coding and Distribution of Frequencies

The output frequencies of the six oscillators are distributed to keysets, located in the various switchboard positions, and to outgoing senders in the switching equipment. A typical distribution plan is shown in Figure 4. The signaling frequencies have been desig-

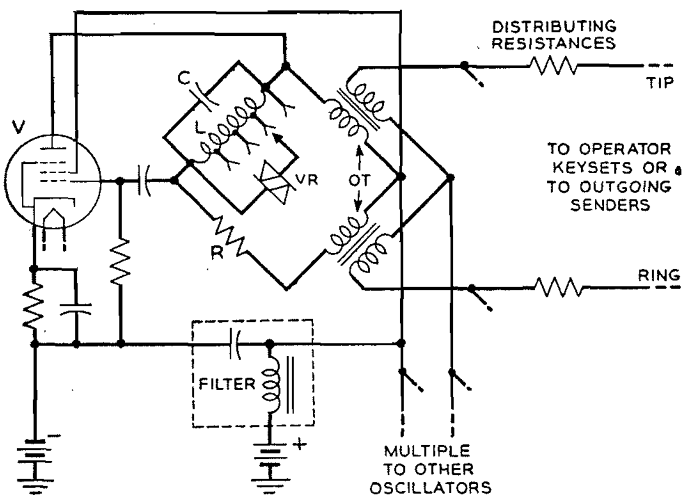


Figure 3 (left). Bridge-stabilized oscillator, schematic diagram

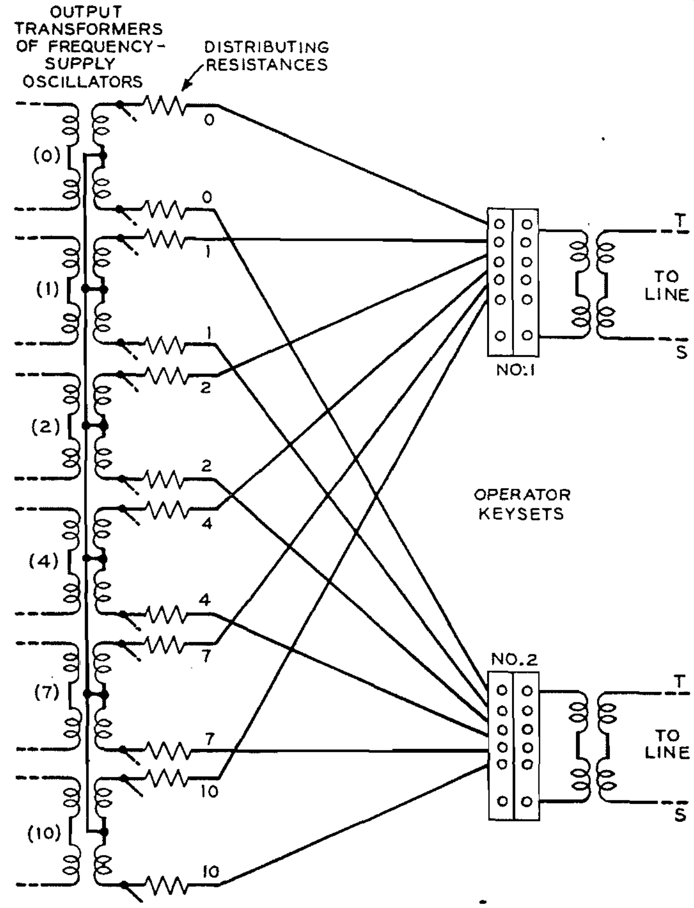


Figure 4 (right). Frequency-distribution plan

nated 0, 1, 2, 4, 7, and 10 for the 700, 900, 1,100, 1,300, 1,500, and 1,700 cycle frequencies, respectively. Frequencies 0 to 7 are used for the digit codes while frequency (10) in combination with the (2) or (7) frequency is used for special signals. The code which is referred to as an "additive code" is shown in Table I. Except for 0, *KP*, and *ST*, the frequency designations add to give a sum equal to the digit being transmitted. This feature of the code assists the maintenance forces when clearing troubles which may occur.

Alarm Features

Each group of oscillators is equipped with various types of alarm features. To guard against failure in the output, sensitive voltage relays are connected across the output circuits of the oscillators in pairs in differential relation. Therefore, if the output voltage of one individual oscillator departs more than 1.5 decibels from the output of its mate, the voltage relay operates and causes the load to be transferred automatically to the other oscillator group, and in addition sounds an alarm. Trouble grounds and power failures also are guarded against, and necessary alarms are given. In addition, an arrangement is provided whereby the transmission of number information, by

Table I. Coding of Frequencies

Digit	Frequencies in cycles per second	Frequency designations
1	700+ 900	0+ 1= 1
2	700+1,100	0+ 2= 2
3	900+1,100	1+ 2= 3
4	700+1,300	0+ 4= 4
5	900+1,300	1+ 4= 5
6	1,100+1,300	2+ 4= 6
7	700+1,500	0+ 7= 7
8	900+1,500	1+ 7= 8
9	1,100+1,500	2+ 7= 9
0	1,300+1,500	4+ 7=11
KP	1,100+1,700	2+10=12
ST	1,500+1,700	7+10=17

sender equipment, is halted during the transfer interval and either transmission is resumed when the transfer is completed, or a reorder signal is given to the originating operator.

Figure 5 shows a typical installation of multifrequency supply oscillators, together with alarm relays.

Multifrequency Signal Receiver

The signal receiver is shown in Figure 6, and a simplified circuit schematic diagram is shown in Figure 7. Starting at the input from the line, there is: a shielded repeating coil, a gain adjusting pad, an impedance-controlling resistance, and a volume-limiting amplifier. The circuit branches at the output of the limiter, one branch going through the six channel filters, detectors, and relays, and the other going through a high-pass filter, detector, and a low-pass filter to the signal present *SP* relay. The operation of these relays controls the registration of the received signals in the sender which is associated with the receiver.

Operation of Receiver by Key Pulsing Signal

When the receiver is first connected to the line, possible false operation by speech prior to the start of pulsing is prevented by means of a slightly different relay arrangement from that shown in Figure 7. With this arrangement, it is necessary that the *KP* signal operate channels 2 and 10, and that all other channels remain unoperated, for a period of at least 55 milliseconds. At the end of this interval, the receiver is changed to the condition shown, and is prepared to accept the digits that are to follow.

Operation of Receiver by Digit Signals

When the receiver is in the pulsing condition, the two signal frequencies applied to the input are amplified or limited depending upon the received-signal power. The frequencies are selected then by the two appropriate channel filters and are detected. In the absence of incoming signals, plate current normally flows in the detectors. The presence of a signal biases the tube to reduce this current to a low value, which is more or less independent of the strength of the signal. The channel relays are energized by current from a battery through the *P* windings, and are prevented from operating by the plate current flowing in the *S* windings, which produces a flux which opposes and balances that caused by the current in the *P* winding. Consequently, when plate

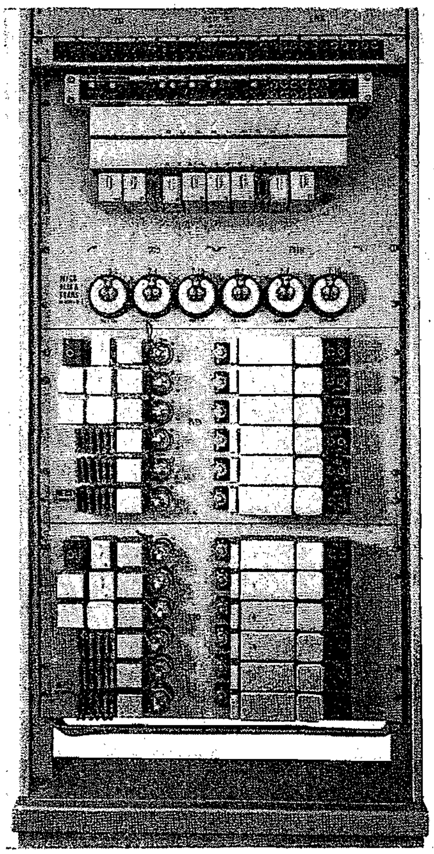


Figure 5. Oscillator and alarm unit

current is reduced sufficiently, the relay will operate. When the back contact of a relay is opened, ground is removed from a resistance and battery to reduce the screen voltage of the tube, which in turn further reduces the plate current, thereby producing a "snap" action to insure rapid and positive operation of the relay armature to the front contact. The reduction in plate current by this means is sufficient to prevent the release of the relay, even though the signal is subsequently removed. Thus, the relay is locked in the operate condition until the current in the P winding is interrupted by the sender after the registration has been completed.

Both signal frequencies enter the signal-present SP circuit and pass through a high-pass filter, the purpose of which is to reduce the effects of low-frequency noise, and operate the detector. The low-pass filter in the output of the detector serves to limit the fluctuations in the detector output, which occur at a frequency equal to the difference of the input frequencies, and to delay the operation of the signal-present relay. The front contact of this relay controls the operation of the sender to prevent duplicate registration of a digit in case a signal is unduly prolonged, and causes ground to be applied to the operate or P windings of the channel relays. This operation is delayed to reduce the effect of transients produced in the channel filters, which otherwise would operate falsely other channel relays. The back contact momentarily alters the grid biases of the limiter and signal-present detector to reduce effectively the relative sensitivity of the signal channels to avoid false operation by transients. The sensitivity is restored to normal as the capacitor associated with the back contact of the relay becomes charged.

Code Self-checking Feature

Noise may cause false operation of one or more channels, or more than two frequencies may be received if an operator falsely operates two keys simultaneously.

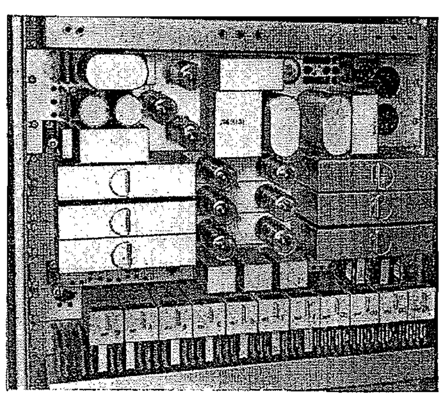
Since each digit consists of exactly two frequencies, a check can be made that a bona-fide signal has been received. This is done as follows:

Removal of ground by the back contact of a channel relay permits current to flow through a resistance to the relays *CK1*, *CK2*, *CK3*, and the current through the operate windings of these relays is proportional to the number of channel relays which are operated. The non operate bias of the *CK* relays are adjusted so that none will operate with a single channel relay operated, *CK1* and *CK2* will operate with two channel relays operated, and all three will operate when three or more channel relays are operated. These relays control the operation of the sender in such a way that the operation of a single channel relay is ignored, two channel relays operated permits registration of the appropriate digit, and with three operated the sender is informed that the signal is incorrect, where upon a reorder signal is transmitted to request retransmission of the number.

Transient Protection by Timing

The receiver is required to operate on signals transmitted over lines which differ in attentuation and which have attenuation distortion or "twist." This requires that each channel shall be sufficiently sensitive to operate when the attenuation is a maximum, and not falsely operate on the filter transients when the attenuation is a minimum. To illustrate the significance of this problem and the methods used to satisfy the requirements, we will employ the formulas for the transient response of an ideal band-pass filter given by Guillemin,[2] and use only the envelopes of the filter response. When the applied frequency is at the midband frequency of the filter, the envelope of the response to a sine wave of unit amplitude is given by

Figure 6. Multifrequency signal receiver unit



$$E(t)=\frac{1}{2}+\frac{1}{\pi}Si\left[\frac{w}{2}(t-t_d)\right]$$

where

$$Si(x)=\int_0^x \frac{\sin x}{x}dx$$

$$w=2\pi(f_2-f_1)$$

and f_2 and f_1 are the cut-off frequencies of the filter and t_d is the delay time of the filter. When the applied frequency is outside the pass band of the filter, the envelope of the response is given by

$$e(t)=\frac{1}{\pi}\frac{w}{\omega_m}\frac{\sqrt{\omega_m^2\cos^2\theta+\omega^2\sin^2\theta}}{\frac{\omega^2}{\omega_m^2}-1}\cdot\frac{\sin\frac{w}{2}(t-t_d)}{\frac{w}{2}(t-t_d)}$$

$\omega_m=\omega_1+\omega_2/2$ is 2π times the midband frequency, and θ is the phase angle of the applied wave. A plot of these equations is shown in Figure 8 for the case of a filter with a pass band 100 cycles wide and a midband frequency of 900 cycles. Since the results obtained with the filters actually used differ materially from those obtained with an ideal filter for times below 10 milliseconds, these portions of the curves are not shown. The top curve corresponds to an applied frequency of 900 cycles, and the bottom curve (drawn on an expanded amplitude scale) corresponds to an applied frequency of 700 cycles and a phase which yields the maximum amplitude. t_d was chosen arbitrarily as ten milliseconds. The first maximum of $e(t)$ is approximately 21 decibels below the final value of $E(t)$. Since we may have two frequencies present in channels adjacent to the one under consideration, the transient discrimination is 6 decibels less or only 15 decibels. Since the wanted signal does not reach its final value until about the time that the unwanted transient reaches its first minimum, it should be possible to increase the discrimination by about 9 decibels if operation of the channels is prevented until after the first minimum of the transient has occurred. This is ac-

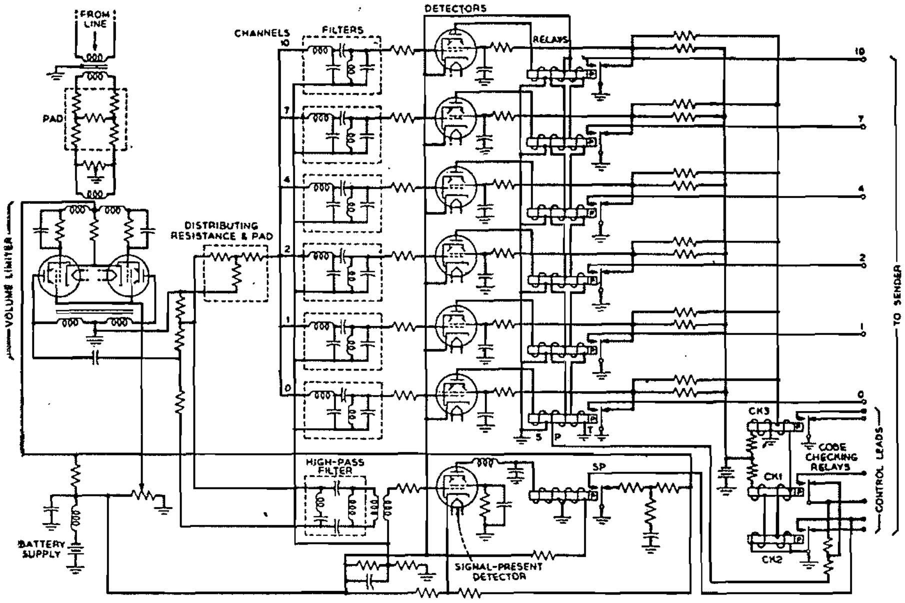


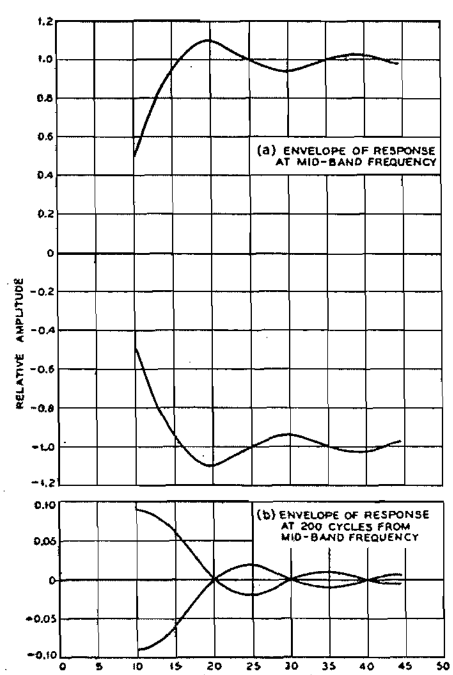
Figure 7. Multifrequency signal receiver, schematic diagram

complished by delaying the operation of the signal-present relay by means of a low-pass filter. To obtain this advantage, the time of occurrence of the minimum response must be the same in all channels. Reference to the foregoing formula shows that this requires the same bandwidth in cycles, and the same delay time for all the channel filters. With these conditions met, approximately equal discrimination, transient or steady state, is obtained with equal spacing of signal frequencies.

Transient Protection by Limiting

Additional protection against false operation by transients is secured by the use of a peak-limiting amplifier which acts as a linear amplifier for inputs up to a certain definite point called the point of limit; above this point the output is held constant. With a 2-frequency input to the limiter, it is necessary that the point of limit be at least six decibels above the single-frequency input which is just sufficient to operate a channel detector. If there is a difference in amplitude of the two input frequencies, the point of limit must be raised still further. For the case of n applied frequencies, let $V_1, V_2 \dots V_n$ be the voltage amplitudes at the output of the limiter without limiting, and let V_L be the output voltage when limiting occurs. The point of limit is defined by

Figure 8. Envelopes of response of band-pass filters to applied sine wave



$$V_1+V_2+\dots V_n=V_L$$

If L is the loss in decibels introduced by the limiter above the point of limit, we have

$$(V_1+V_2+\dots V_n)10^{-\frac{L}{20}}=V_L$$

Without loss of generality, we can assume

$$V_1 \leq V_2 \leq \dots \leq V_n$$

To insure operation on the minimum amplitude when limiting occurs, we must have

$$V_1 10^{-\frac{L}{20}} \geq V_0$$

where V_0 is the voltage required to just operate a channel detector. M is the margin in decibels between the just-operate voltage and the point of limit, measured with a single frequency, or

$$V_0 10^{\frac{M}{20}}=V_L$$

From the preceding equations we obtain as a condition for operation

$$\frac{V_1 10^{\frac{M}{20}}}{V_0+V_2+\dots V_n} \geq 1$$

or

$$M20 \log_1 \geq_0 \left(1+\frac{V_2}{V_1}+\dots\frac{V_n}{V_1}\right)$$

Thus, the margin between "just limit" and "just operate" is determined by the number of frequencies, and is a function of the ratios of the larger voltages to the smallest one. For the case of $n=2$, M is shown in Figure 9 as a function of the difference in decibels of the tow voltages. With a nominal margin of 12 decibels, the maximum difference between two voltages is about 10 decibels.

When allowance is made for variations in components of the frequency sources and the receivers, the following operating characteristics are obtained:

Digit and *ST* signal duration, 27 milliseconds or greater.

KP signal duration, 55 milliseconds or greater.

Interval between signals, 20 milliseconds or greater.

Maximum receiver input power, 2 decibels above one milliwatt at each signal frequency.

Minimum receiver input power, 27 decibels below one milliwatt at each signal frequency, provided the difference in power between the two frequencies making up the signal does not exceed 6.5 decibels.

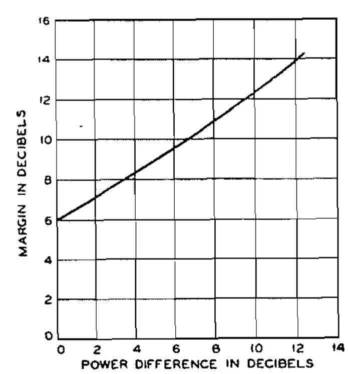


Figure 9. Required margin between "just limit" and "just operate" as a function of the power difference of two frequencies

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