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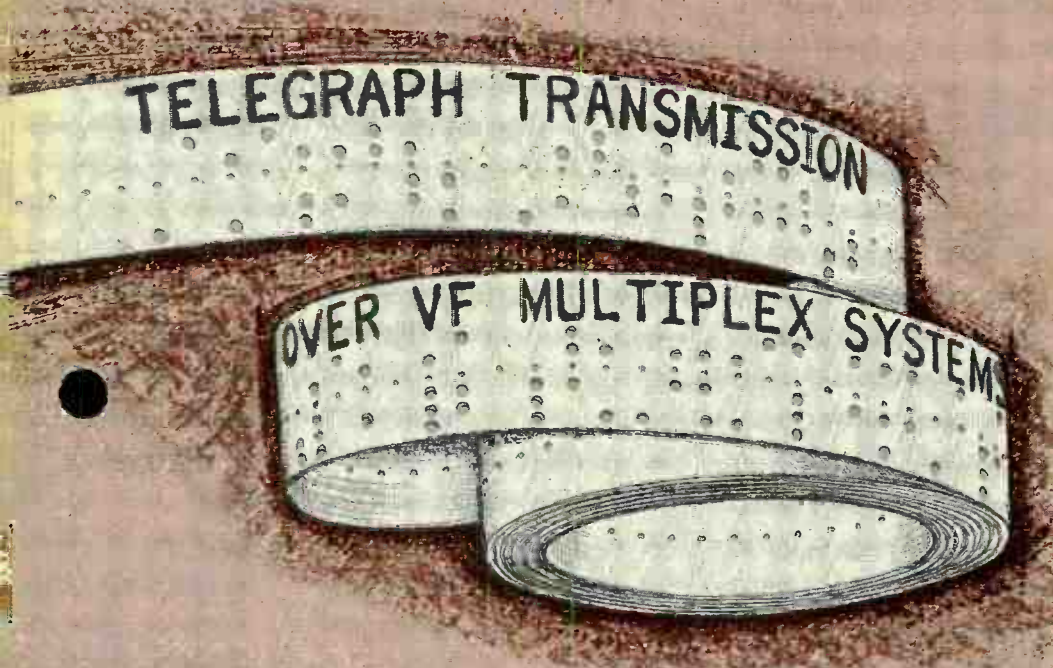
the Lenkurt® Demodulator



The techniques of modulation and frequency division multiplexing play an important role in the transmission of telegraph messages over voice-frequency channels. This is especially significant in view of the present need for more and more channels in which to handle the increasing amount of business information now being transmitted over telephone networks.

This article reviews briefly the techniques used to convert telegraph pulses to voice-frequency tones and describes several direct-current telegraph loops in common use. Also, the voice channel loading effect of multiplexed telegraph signals is discussed.

Telegraph systems provide a means of transmitting information using electrical pulses which conform to a preestablished code. In earlier days, telegraph messages were transmitted by hand-operated *keys* using the familiar Morse code. Modern telegraph systems, however, use electromechanical machines, called teleprinters, page printers, or tape printers, that employ some type of machine code.

Conventional telegraph machines use the standard 5-level Baudot code and normally operate at transmission speeds of 60, 75, and 100 words per minute, at pulse rates of 45, 57, and 75 bits per second, respectively. A new 7-bit code called ASCII (American Standard Code for Information Interchange) was recently developed and is expected to find wide application in data processing systems as well as for message processing. Telegraph systems currently using the new ASCII code have added an eighth bit to provide a parity check, thus making it an 8-level code. The new 4-row keyboard teleprinters designed to handle the new code operate at a transmission speed of 100 words per minute with a pulse rate of 110 bits per second. These various telegraph machines provide a printed copy of the message or a punched tape which is then used to operate a printer.

Telegraph machine signals consist of a sequence of current and no-current pulses of equal length, known as *mark* and *space,* respectively. Using the 5-level Baudot code, for example, the letter A is indicated by a signal of mark-mark-space-space-space. Before these dc telegraph signals can be transmitted over standard voice frequency communication channels, they must be converted to ac tones. There are two basic methods used to convert the dc loop pulses to tones suitable for transmission over a voice-frequency multiplex channel. These are amplitude modulation, and frequency modulation.

In both AM and FM telegraph multiplex systems, a tone oscillator, in each transmitting channel, is used to provide the necessary voice-frequency carrier. Frequency division is the type of multiplexing ordinarily used and so the carrier frequency in each channel is different.

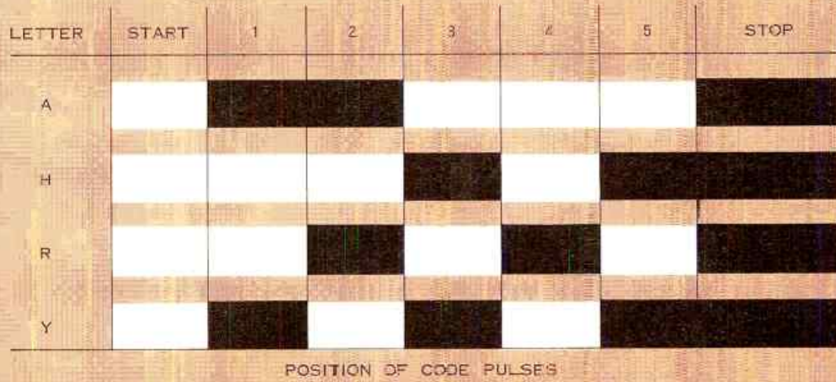
Amplitude Modulation

Amplitude modulation methods are historically related to direct-current telegraphy. In dc telegraph, a battery or other source of direct current is keyed on and off. At the receiving end, the signals are detected by some sort of magnetic device. In AM, the process is similar except that a tone oscillator is keyed on or off to indicate mark and space conditions and, for this reason, is sometimes referred to as on-off modulation.

This method has several disadvantages. It does not use bandwidth efficiently, since two sidebands of the carrier are produced and, unlike single-sideband voice communications methods, the carrier and one sideband cannot be completely eliminated and still do a satisfactory job.

Sidebands are produced when the modulating wave causes the carrier to change from one value or state to another. In voice communications, the modulating waveform is continuous, thus causing modulation products (sidebands) to be formed continuously. If the carrier and one sideband are eliminated, the other sideband remains to convey the modulating intelligence.

In telegraphy, where on-off pulses are the modulating signal, modulation products are formed only during the transition from "on" to "off," and from



	START	1	2	3	4	5	STOP
60 SPEED	22	22	22	22	22	22	31
75 SPEED	18	18	18	18	18	18	25
100 SPEED	13.5	13.5	13.5	13.5	13.5	13.5	19

PULSE DURATION IN MILLISECONDS

Figure 1. Examples of the 5-level Baudot code for the letters A, H, R, and Y, including pulse lengths for the three standard telegraph speeds. Mark pulses are shown in color while space pulses are shown in white.

"off" to "on." These modulation products are transients whose bandwidth is a function of the keying or switching rate. Except when a pulse is started or ended, no modulation products can appear in the transmission path. Thus, it would be impossible to continuously transmit a steady mark or space.

The information-carrying characteristic of an AM signal is its amplitude. For this reason, AM is particularly vulnerable to impulse noise and changes in transmission level. Impulse noise is particularly disturbing. Noise pulses caused by electrical storms, switching transients, and similar disturbances, may equal or exceed the information pulses in amplitude and duration. Under severe conditions, impulse noise may completely obliterate an AM information pulse.

Frequency Modulation

In FM systems, the carrier frequency is shifted in one direction for a mark condition and the opposite direction for a space condition. A *diode keyer* in the tuned circuit of the tone oscillator changes the circuit resonance so as to shift the tone back and forth between the two frequencies. Such frequency shifting does not occur instantaneously, however. The inherent resonance of the tuned circuit causes the resulting waveform to change smoothly from one frequency to the other. The amount of shift is the same for both directions and varies from about ± 30 to 42.5 Hz depending upon the operating speed of the telegraph equipment. This type of modulation is also referred to as frequency-shift keying (FSK).

Since the mark and space signals are represented by different frequencies of equal strength, amplitude variations have no effect on the signal unless the signal has the same or less amplitude than the noise. This contrasts strongly with amplitude modulation where a mark is represented by the presence of the carrier and a space is represented by the absence of the carrier. Level changes due to fading, noise, and other interference have a strong effect on AM signals. FM systems can tolerate level changes of about 40 to 50 dB, and are about 12 dB less sensitive to impulse noise than AM systems.

Bandwidth

The bandwidth required for a voice frequency multiplex telegraph channel depends on such things as the code pulse rate, noise, filter attenuation to adjacent channels, and whether or not both sidebands are transmitted (AM systems). A bandwidth of 120 Hz is usually satisfactory for 5-level code telegraph signals at speeds up to 100 words per minute for both FM and double-sideband AM systems. The usual bandwidth for 8-level coded telegraph signals is 170 Hz.

Since the required bandwidth is much smaller than that required for speech signals, a normal 3-kHz voice band can be divided by frequency division multiplexing into sub-bands or channels each capable of transmitting a telegraph signal. Approximately 18 channels can be obtained with 170 Hz spacing, while up to 26 channels can be obtained with 120 Hz spacing. This means that up to 18 or 26 voice-frequency multiplexed telegraph signals can be transmitted simultaneously over a single voice channel.

Telegraph Loops

The circuit between the telegraph machine and the multiplex terminal is called a *loop* circuit. Each telegraph loop is made up of two legs which are the conductors (full metallic or ground return) between the terminal points of the loop. In half-duplex operation, the same loop is used for sending and receiving. However, full-duplex operation, which permits simultaneous transmission in both directions, requires both a sending and a receiving loop.

Because of differences in applications and because of the variations in lengths, any one of a number of circuit arrangements may be employed in telegraph loops.

Neutral Loops

One of the simplest and most direct circuit arrangements is the *neutral* or *open-and-close* loop, illustrated in Figure 4(A). The neutral loop requires a battery only at the central office, and the difference between mark and space is determined by whether or not current is flowing in the loop.

When the printer is sending, closing of the printer contacts closes the loop circuit and the current flowing in the loop applies a potential to the multiplex-channel keying circuit. In the receiving direction, the carrier frequencies are applied to a discriminator. In the discriminator, the two frequencies that

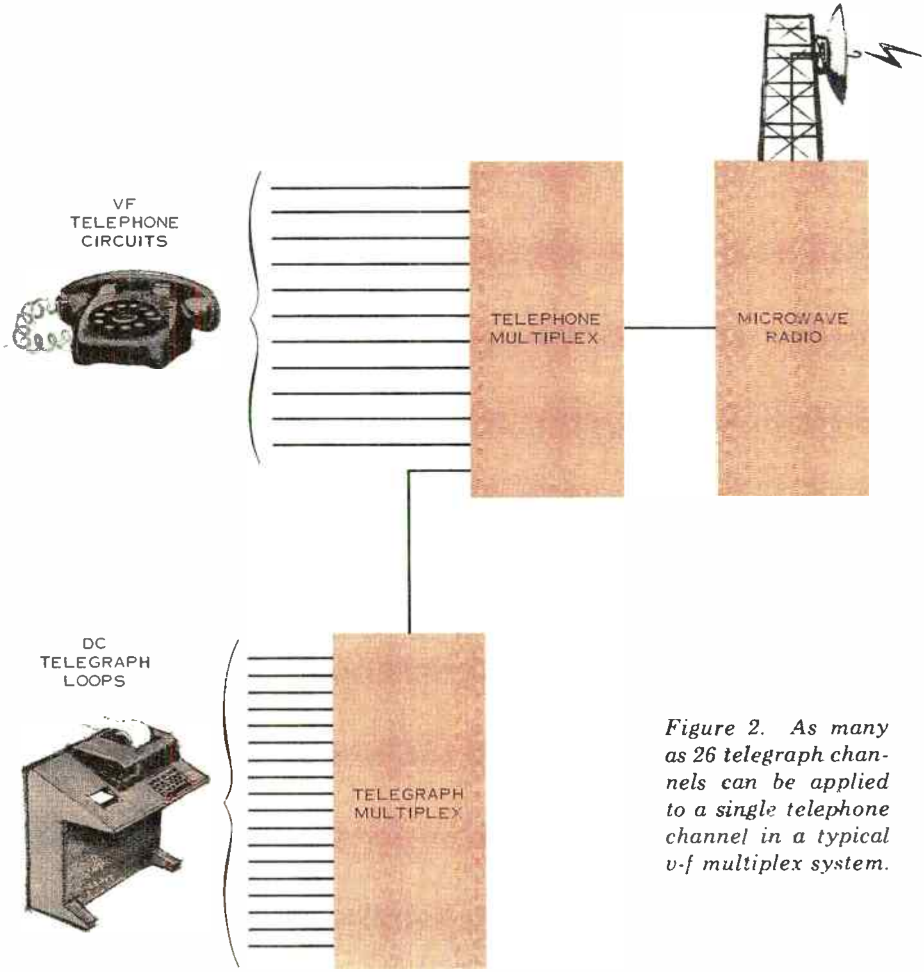


Figure 2. As many as 26 telegraph channels can be applied to a single telephone channel in a typical v-f multiplex system.

are used to transmit the marking and spacing conditions are separated and are rectified to obtain dc for operation of the polar receiving relay. The contacts of this relay open or close the receiving neutral loop to reproduce the transmitted character at the receiving printer.

Balanced Loop

While neutral loops offer the advantage of simplicity, they are restricted to the shorter loops in which either leakage or the distributed capacity of the path does not severely affect the signal. To reduce these problems a balanced loop (also called effective polar loop) may be used. An example is shown in Figure 4(B).

A balanced loop is similar to a neutral loop in that the difference between mark and space is determined by whether or not current flows in the loop. However, the balanced loop differs

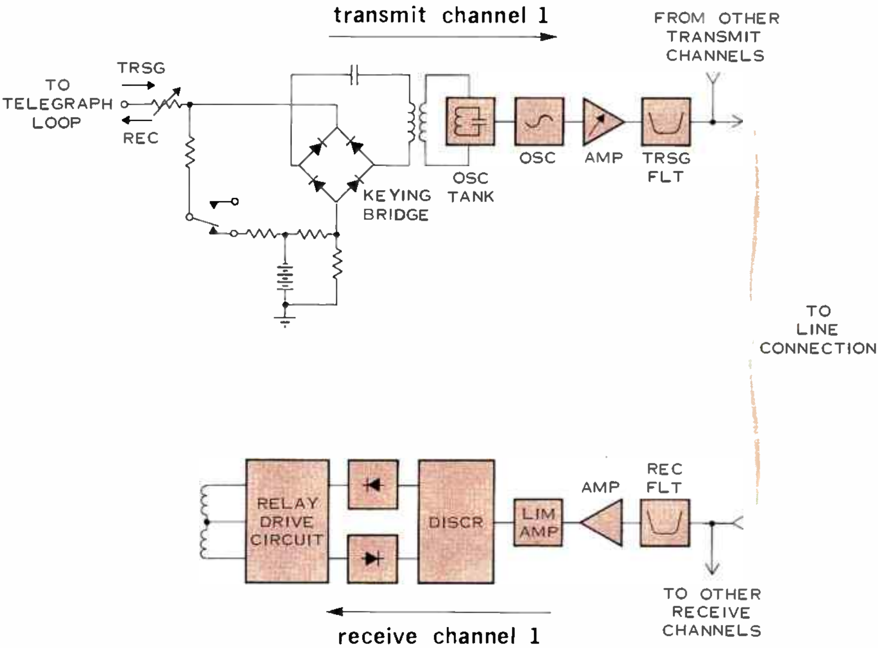


Figure 3. Simplified schematic diagram of telegraph multiplex terminal operating into a half-duplex neutral loop.

from the neutral loop in that a battery potential is applied at the printer location as well as at the central office. The printer battery, in conjunction with the battery potential applied to the marking contact, applies a higher potential to the loop. The increased potential improves the rise time of the marking pulse which tends to increase the length of the pulse. In addition, the increase in potential permits operation over longer loops.

When a spacing signal is received, application of equal potentials to both ends of the loop discharges the line more rapidly than simply opening the loop, resulting in an improvement of the pulse shape. Adjustments can be made in battery potentials to eliminate bias in the loop as required for changing conditions in the loop.

Polar Loop

The most effective transmission method commonly employed is called polar operation. In this case equal currents of opposite polarity are used for the marking and spacing conditions. In addition to the two voltages, this method requires the use of a polar relay in which the direction of current flow in a winding causes the relay to operate to either the marking or spacing position. Since printers normally oper-

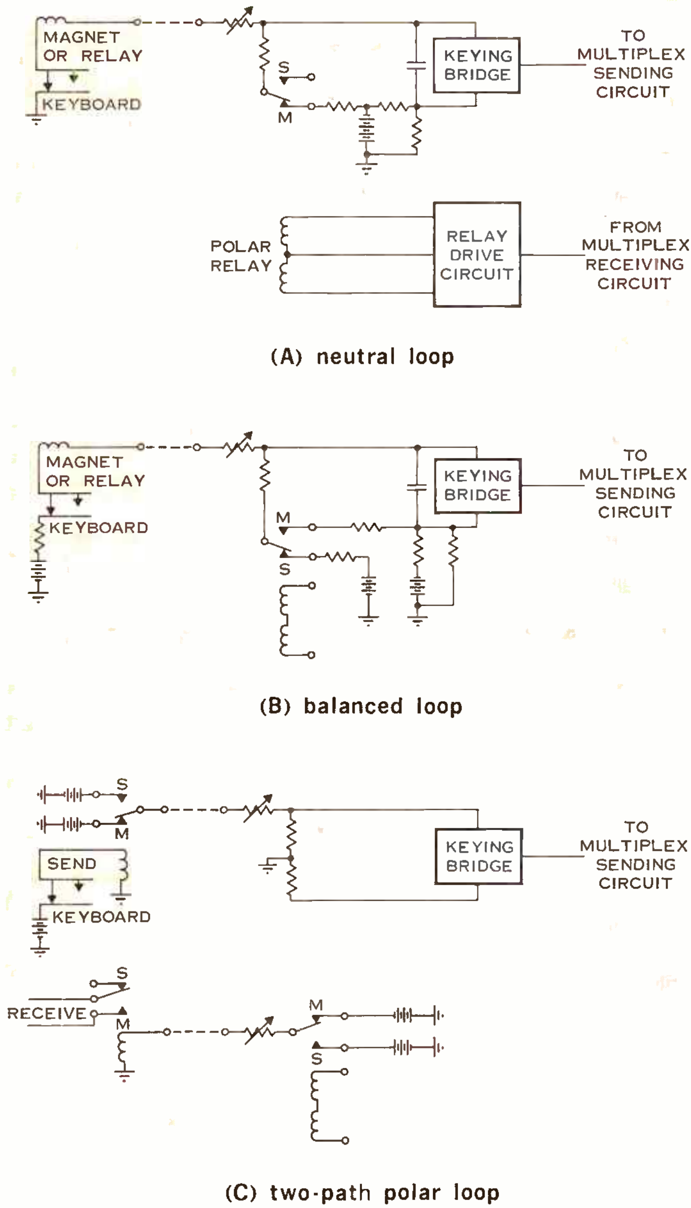


Figure 4. Three types of basic telegraph loop circuits. (A) neutral, (B) balanced, and (C) two-path polar.

ate only from on and off signals, a relay is usually required at the printer location. An example of a polar loop is shown in Figure 4(C). Where battery potentials are the same, the loop characteristics do not change between the sending of a mark or space signal, and if the relay is properly adjusted, the mark and space signals are equal and no bias is obtained.

However, because of the requirement for two batteries, the method is normally only used in transmission from the office to the subscriber, and either neutral or effective polar transmission is used in transmitting from the subscriber to the office.

Break Feature

In a half-duplex loop it is sometimes necessary for the operator at the receiving printer to interrupt the sending printer. This requirement led to the use of an additional relay in the telegraph loop, called the break relay, arranged to accomplish this purpose. The receiving operator may interrupt by opening his loop.

When the receiving loop is opened (effective spacing condition) signals received from the distant terminal are applied to the local-terminal keying circuit, but are inverted. The combination of the retransmitted signals with the original signal causes a continuous spacing signal condition at the sending terminal. When this occurs, the sending operator knows that the receiving operator wishes to interrupt.

Hub Operation

In some telegraph applications, it is occasionally desirable to connect a number of telegraph circuits together in such a way that telegraph signals originating in one circuit are transmitted to all other interconnecting circuits. A method of doing this is through a *hub* board. In this arrangement the dc sides of the multiplex channels are connected together on a high impedance basis. Thus, only a small amount of current is required.

Battery potentials of ± 130 volts are required in the hub equipment unit. The hub is supplied with a $+130$ volt potential through the hub potentiometer. The hub circuitry is such that in the normal marking condition the hub voltage is $+60$ volts.

The changes in current that result from one circuit sending a space signal into the hub changes the hub potential from $+60$ volts for marking to -30 volts for spacing. When applied to the sending portion of the remaining channels, these potentials effect simultaneous transmission of the desired signal condition. Three telegraph circuits are interconnected in the simplified diagram of a hub shown in Figure 5. Each circuit is connected to a multiplex channel through a hub-equipment unit.

Hubs may be operated either half or full duplex as with normal telegraph loops. Like the normal telegraph loop, it is sometimes necessary on half-duplex hubs for a receiving operator to break in.

Interruption is accomplished as in the normal loop by a receiving operator sending a spacing signal into the hub. The circuit is arranged so that the hub potential drops to -60 volts when two or more machines are sending spacing signals into the hub. This low potential causes all machines to go to spacing, including the original sending machine, and the sending operator then knows that someone wants to interrupt.

Channel Loading

When transmitting several telegraph tones over a voice frequency channel of a multiplex system, great care must be exercised in establishing the levels at which the signals are applied. Multiplex telegraph signals have greater average power than voice signals. If the power handling capability of the multiplex system amplifiers is exceeded, intermodulation products from the telegraph tones have far greater interfering effect on other channels than do voice signals.

For this reason, a standard signal level is usually specified for voice frequency telegraph signals transmitted over multiplex voice channels. This level is conservative, and is based on the loading effect produced by the maximum number of telegraph channels that can be handled by the voice channel. A common standard per-channel level is −21 dBm at the zero transmission level point. For most applications,

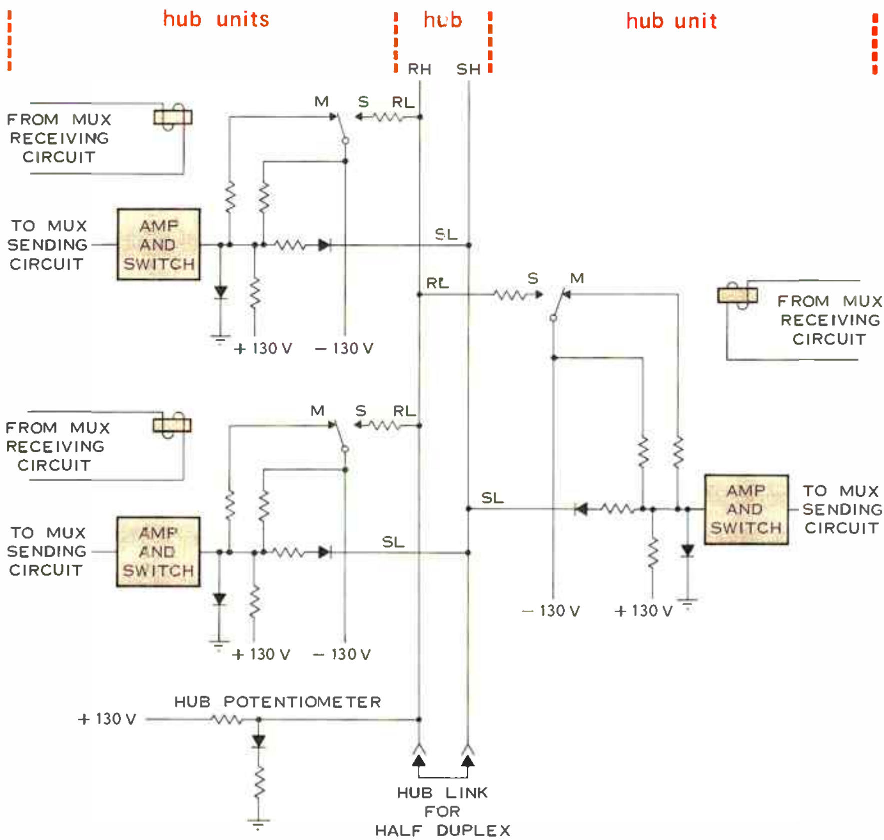
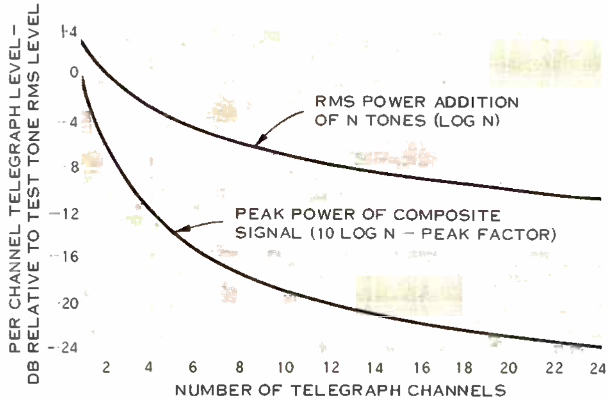


Figure 5. Hub operation, showing three multiplex telegraph channels interconnected on the d-c loop side.

Figure 6. Theoretical maximum transmission levels for various numbers of telegraph tones transmitted over a multiplex voice channel.



this level is high enough to provide good service over a voice frequency multiplex channel.

However, in applications where the maximum telegraph channel capacity is not used, it may be desirable to increase the level of each telegraph tone in order to improve the signal-to-noise ratio. The increased level is a function of the number of telegraph tones to be transmitted.

In calculating the loading effect, peak power must be used, since distortion will occur if the peak power exceeds the load handling capacity of the multiplex equipment. When telegraph signals are applied to a single voice frequency channel of a multiplex system, the permissible peak power is normally +3 dBm at the zero transmission level point. This value is assumed in the following discussion.

For a single telegraph channel, the calculation of peak power is straightforward. A sine wave is normally assumed. Peak voltage of a sine wave is 1.4 times the rms value of the wave, or 3 dB greater in power than the rms power value. When only one telegraph channel is involved, the level of the telegraph tone may be equal to the level of the normal test tone, since both signals are sine waves.

As the number of telegraph channels increases, the peak power that the composite waveform may reach also increases. Since there is a possibility that this value can become quite high for a large number of tones, a *peak factor* is used. This peak factor is based on the statistical probability that the peak power of a complex wave will almost never add up in such a way as to exceed the sum of the rms value of the wave and the peak factor. For a single tone, the peak factor is 3 dB. Peak factor increases as the number of channels is increased, reaching a maximum of 13 dB for approximately 20 channels.

As an example, assume that ten telegraph channels are to be applied to voice frequency multiplex channel normally adjusted to a −16 dBm test tone level. In this example, peak power should not exceed −13 dBm. Each telegraph channel transmitting level must be lower than −13 dBm by the sum of the combined power of the ten tones (rms power addition) and the peak factor.

First, the combined tone level is calculated by taking ten times the logarithm of the number of channels (10 log 10 = 10 dB). Adding a 12-dB peak factor to this 10-dB level gives a peak value 22 dB above a single channel peak. The per-channel transmitting power is then obtained by subtracting the 22-dB peak level from the maximum permissible level (—13 dBm minus 22 dB = —35 dBm). Similar calculations may be made for different numbers of telegraph channels. Figure 6 shows how the telegraph tone levels must be reduced as the number of channels increases. It is important to note that these calculations yield *theoretical* maximum levels for telegraph tones and pertain to the loading of a *single* voice channel in a multiplex system.

Conclusion

The transmission facilities provided by telephone communications systems constitute a vast network which is capable of interconnecting locations almost anywhere in the world. Although these facilities are made up in many forms and have different types of transmission media, they do have one very important thing in common — the standard voice frequency channel, which has a useful bandwidth of about 3 kHz.

While this vast network of multiplexed telephone channels was designed primarily to handle speech signals, the circuits can be used to transmit other forms of information such as telegraph. The techniques of modulation and multiplexing provide a practical means of converting the dc telegraph signals to ac tones suitable for transmission over telephone circuits.

Through the use of frequency division multiplexing, as many as 26 narrow-band voice frequency telegraph channels can be derived within a single 3 kHz telephone channel.

Such efficient use of a single telephone channel is a tremendous asset in view of the present growth of machine communication to process business information.

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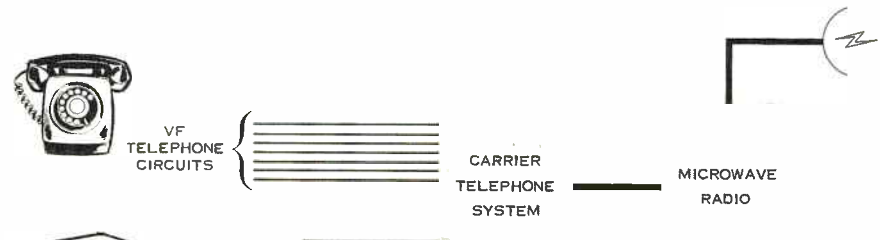

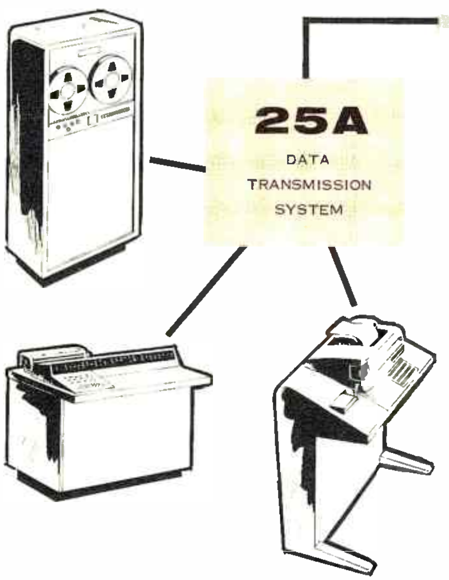

The Lenkurt 25A is a versatile telegraph and data carrier transmission system. It can handle a variety of multi-channel telegraph applications with speeds up to 100 wpm or data applications with speeds up to 200 bps. The 25A works over many types of transmission facilities such as open-wire, cable, or radio multiplex — or 2-wire or 4-wire physical circuits. More information about this high-performance system is contained in Form 25A-P4, available on request.

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