The Lenkurt Demodulator

NEWS FROM LENKURT ELECTRIC

VOL. 5 NO. 4 APRIL, 1956

## *Telephone Channels for*

# DATA TRANSMISSION

*Although telephone channels are used primarily for the transmission of voice conversations, they can also be used to transmit a variety of other kinds of signals. These other signals are sometimes given the broad name "data."*

*This article discusses the meaning of data, various methods of transmitting data, and the conditions limiting the operation of voice telephone channels for data transmission.*

The purpose of a communication system is to transmit intelligence from one place to another. The intelligence may originate in many different ways, but before transmission it must be converted into either of two forms—continuous or pulse-type electrical signals. A generalization is sometimes made in which all communication by means of electrical impulses is called *data transmission.*

The most familiar forms of data transmission are telegraph, signaling, remote control, and telemetering. More recently, different forms have been developed which include photo facsimile, high-speed telegraph, air warning data from radar installations, and numerical information for the operation of electronic business machines. In each case, alphabetical, numerical, or symbolic data must be transmitted.

The high-speed operation of these new systems has created a need for rapid transmission of large amounts of data with minimum error. As a result of this need, scientists and engineers have been taking a closer look at what constitutes *information* and how it can be transmitted most efficiently with presently available types of facilities.

## Information

One of the first steps in determining the exact nature of information was the selection of a unit, or yardstick, by which information could be measured. This unit had to be such that it could easily be determined and did not depend upon the importance of the message, since a message's importance is difficult to evaluate mathematically.

It turned out that the simplest and most basic unit was the amount of information necessary for a receiver (person or machine) to make the correct choice between two equally possible messages. This choice may be between the messages yes-or-no, on-or-off, A-or-B, 0-or-1, black-or-white, etc. Since the two possible messages correspond to the two symbols in the system of numbers called the binary digit system, a unit of information based on two symbols (messages) came to be called a binary digit and was abbreviated *bit*.

A simple electrical pulse has the informational value of one bit because the presence or absence of the pulse permits the receiver to choose the correct message from a set of two. As shown in Fig. 1, the transmission of two pulses permits the receiver to select the correct message from four equally possible messages. Three pulses, or bits, will enable the correct selection from a set of eight. This selection process gives the average amount of information which must be transmitted to specify a message from a set of equal possibilities. There is no method of transmitting information which uses less than this amount of information per message.

The letters of the alphabet are an example of a practical set of possible messages. The desired message might be any particular letter. If all the letters appeared equally as often, about five bits of information would be needed to select an individual letter. However, only about two bits per letter are needed because certain letters appear much more frequently than others.

## Channel Capacity

An important factor in evaluating the utility of a communication channel for data transmission is its maximum information carrying capacity. Using the bit as a measure of information, the maximum capacity of a communication channel can be determined from

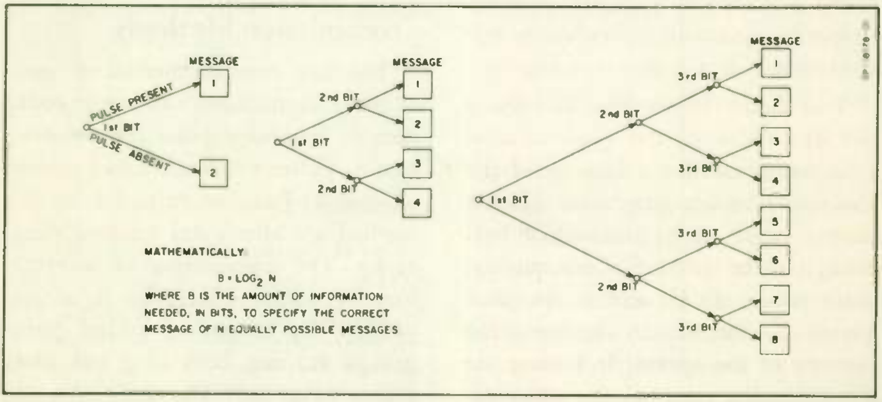



*FIG. 1. Information requirements for specifying a particular message.*

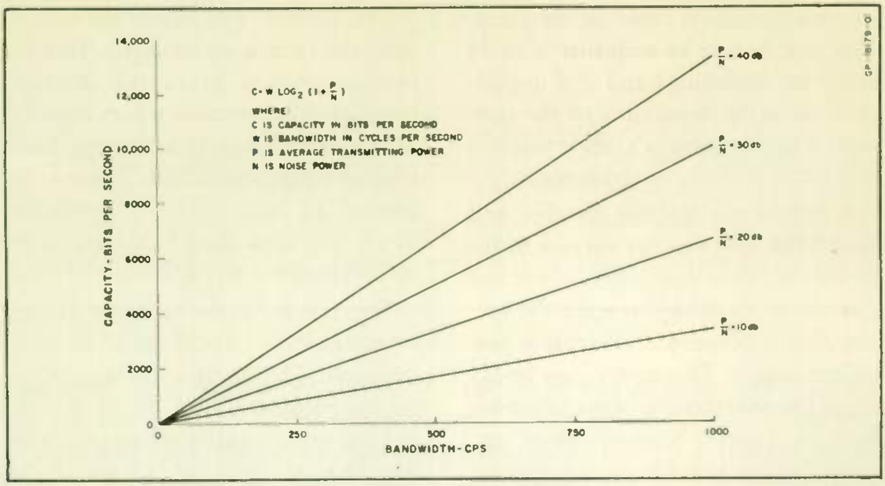



*FIG. 2. The relationship between bandwidth, signal-to-noise ratio, and capacity.*

the channel bandwidth, signal power, and noise.

The relationship between bandwidth, signal power, and noise is complex and depends upon many factors such as the kind of noise present in the channel, the nature of the power limitation, the type of modulation used, and the method of encoding the information. The relationship for the particular case where the noise in a channel of limited bandwidth is assumed to be random noise (equal noise power across the frequency band) and the channel is operating at a particular signal-to-noise ratio is shown in Fig. 2.

This figure shows that increasing the bandwidth or the signal-to-noise ratio will increase the capacity of the channel. A wider bandwidth permits shorter pulses to be transmitted well enough to be detected. Consequently, more pulses can be sent in the same period of time, thereby increasing the capacity of the system. Increasing the signal-to-noise ratio permits easier detection of the pulses. This permits faster transmission and results in an increase in capacity.

Because of the inter-relationship of factors affecting channel capacity, it is possible to exchange bandwidth for signal-to-noise ratio and still maintain the same channel capacity. For a given system, the occupied bandwidth can be decreased provided that the signal-to-noise ratio is increased sufficiently, or vice versa. Roughly, the bandwidth can be decreased one-half if the signal-to-noise ratio in db is doubled.

## Transmission Methods

The most common method of transmitting alphabetical and numerical data is by binary pulse transmission; that is, pulses which are either present or absent. Familiar examples of this method are Morse and machine telegraphy. The transmission of information by Morse telegraphy is accomplished by means of coded pulse groups utilizing both long and short pulses (Fig. 3a). The more frequent characters are given the shortest code

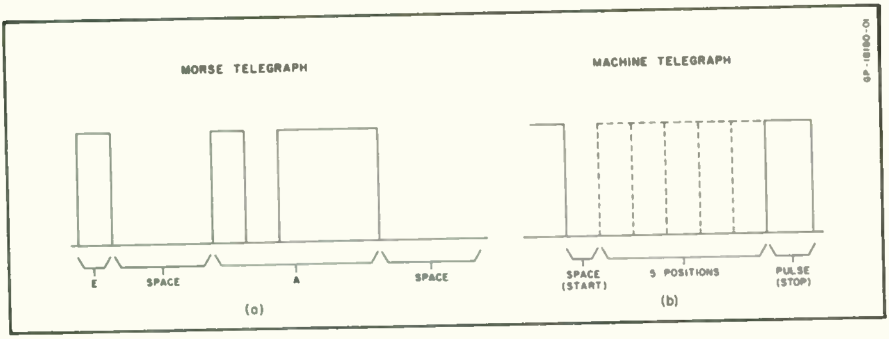



*Fig. 3. Pulse code systems for two types of telegraph.*

groups. For example, one short pulse represents E while a short and a long pulse represents A. The use of different length pulses permits the transmission of an extra bit of information which shortens the code groups.

Machine telegraphy is a somewhat different type of data transmission. It utilizes a standard length code group in which there are five possible information carrying pulse positions (Fig. 3b). A pulse may or may not appear in any of these positions. The five bits of information contained in the code group would permit selection of only 32 characters if each character appeared equally as often. However, since certain characters appear very infrequently, the information necessary to transmit over 50 different characters averages less than five bits per character.

Machine telegraph systems usually transmit information at a rate of 60 words per minute. This is achieved with a pulse rate of 30 pulses (bits) per second, plus the necessary synchronizing pulses, over a channel 120 cps wide.

The transmission rate of a binary system, such as machine telegraphy, can be increased by transmitting more pulses per unit of time. Information theory shows that this can be most easily accomplished by increasing the bandwidth of the channel, enabling the transmission of shorter pulses at a faster rate.

Another method of transmitting information more rapidly is by causing each pulse to contain more information. This permits the pulse repetition rate to remain constant, but more information is transmitted per pulse. The increase in the information carried by the pulse is accomplished by pulse modulation.

## Pulse Modulation

The informational content of a pulse can be increased by modulating it with respect to amplitude or position. In pulse amplitude modulation, the distance between pulses remains constant, but the height of the pulse may be any one of a specified number of possible amplitudes. By modulating a pulse's position, its amplitude remains constant and its time of occurrence is varied over a range of discrete positions. These methods are shown in Fig. 4.

In either type of pulse modulation, each step of amplitude or position has

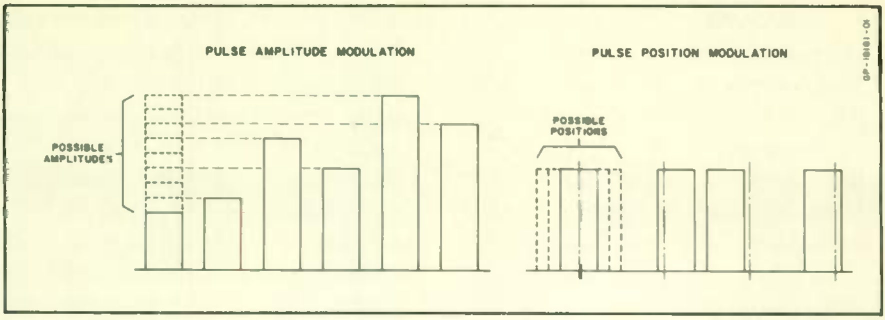



*FIG. 4. Methods of increasing the informational content of a pulse by modulation.*

a definite code value. As a pulse is permitted to occupy more steps, its informational capacity increases. For example, the correct message of a set of eight can be specified by a pulse which has eight possible steps. The pulse therefore contains three bits of information as compared to one bit when a single step pulse is transmitted.

Systems utilizing pulse modulation are relatively sensitive to noise because it obscures the transmitted amplitude of a pulse and also causes a slight variation in the precise location of the pulse. Therefore, as the number of modulation steps is increased, the signal-to-noise ratio must also be improved to enable the receiver to detect exactly the transmitted amplitude or position.

The limiting capacity of a channel can be approached most closely by using modulated pulses with a large number of steps. Of course, as this is done the transmitters and receivers must become more complex to interpret the large amount of information contained in each pulse. Consequently, a point is reached where the maximum theoretical capacity of a channel is not yet reached, but where further increase of the information rate is impracticable.

## A Data Transmission System

A practical example of a high-speed data transmission system using telephone channels is the SAGE (Semi-Automatic Ground Environment) network. This network is being established to increase the speed of information processing and weapon direction in the national air defense system.

Data transmission for SAGE is basically similar to machine telegraphy; however, information must be transmitted at rates up to 1600 bits per second. This is equivalent to a telegraph system operating at a speed of over 2000 words per minute. While maintaining this high speed, the system must operate with a maximum error rate of 1 bit per 100,000.

SAGE transmission consists of pulse groups of standard length. The beginning of the pulse group is signified by a high-amplitude pulse, and the transmitted information is contained in pulses which may or may not be present in 11 positions following the start pulse. Also being transmitted continually at the pulse repetition rate is a low-amplitude pulse which maintains synchronization of the system.

Because the system is binary, the receiver must determine only if a pulse is present or absent at every position. Therefore, a well-shaped, square pulse is not necessary for proper detection. This results in conservation of bandwidth because the higher component frequencies of the pulse need not be transmitted. It is necessary, however, that the component frequencies which are transmitted remain at the same amplitude and that they all be delayed by the same amount of time.

Most telephone channels can transmit the component frequencies without amplitude distortion because they normally have a flat attenuation characteristic over their passband; however, they may require delay equalization.

For SAGE data transmission, telephone channels are required to be relatively flat between 500 and 2500 cps (no more than 3 db deviation from midband to band edge). Also, the difference in transmission time of any two frequencies in the band from 1000 to 2500 cps should not exceed 500 microseconds, and the number of impulse noise peaks which come within 18 db below the synchronizing signal level should not exceed 1 per minute.

SAGE-type data transmission usually can operate over any type of facility which provides these necessary requirements. However, certain types of facilities require special treatment such as delay equalization and impulse noise reduction to make them suitable. When the circuits are provided by carrier, the delay equalization requirement is not too great a problem since most of the data circuits are expected to be relatively short and simple in make-up. Thus, the primary consideration on carrier data circuits is the suppression of impulse-type noise.

The control of impulse noise on carrier channels is principally a matter of plant layout, since very little such noise is contributed by the carrier equipment itself. In general, a conservatively designed system which provides high-grade toll service without compandors is probably satisfactory for data transmission. In some cases, data transmission may be possible on normally compandored circuits if the impulse noise level can be controlled.

All Lenkurt 45-class equipment, if installed in a suitable plant layout, can meet SAGE requirements. In addition, it has certain particularly desirable features—significant when used for data transmission—such as channel regulation and carrier frequency interconnection.

## *Paul C. DeMuth Assumes New Duties*

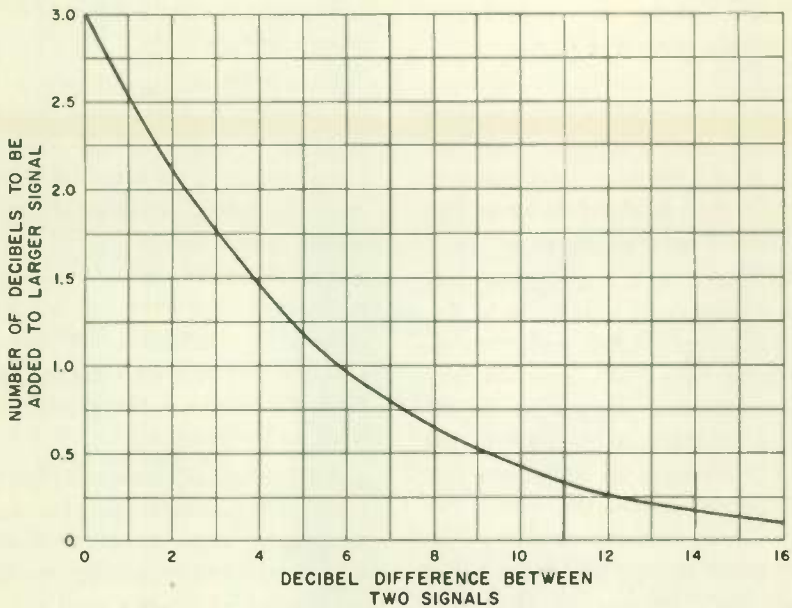
Paul C. DeMuth, Editor of the *Demodulator* for the past year, has relinquished his editorial duties and is now associated with Lenkurt's Bell System Relations Department as a full-time Engineering Consultant.

Beginning with this issue Asa M. Seymour, former Editor and now Manager of the Technical News Department, will supervise the *Demodulator*, and will be assisted by Staff Writers Joseph R. Mensch and John A. Dippel.

*A Graph for*

# DETERMINING COMBINED POWER

*of Two Signals*




The above chart simplifies the power addition of two signals whose levels are expressed in decibels. It is especially useful for determining the resulting power when two sources of crosstalk, speech, or noise are combined.

To use the chart, locate the decibel difference between the two known signals on the horizontal axis. The point on the vertical axis corresponding to this difference shows the number of decibels to be added to the larger quantity to get the combined signal level.

For example, a cable carrier and a microwave system are to be connected in tandem—the cable carrier producing 29 dba of noise and the microwave 26 dba. Since there is a 3 dba difference, a value of 1.76 dba (according to the graph) must be added to the larger quantity. The total noise is therefore 30.76 dba.

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### *Texas Towers*

This microwave channelizing system (both terminals shown) will provide telephone and data transmission facilities between an off-shore Texas radar tower and the mainland.

Lenkurt ELECTRIC CO. SAN CARLOS, CALIF. VANCOUVER, B. C.

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