The Lenkurt® Demodulator

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A Discussion of "LEVELS" AND "POWERS" IN A CARRIER SYSTEM

Two of the most troublesome terms in communications language are "level" and "power." Although they are often used interchangeably in daily conversation, the two terms are not synonymous. This article discusses some of the reasons for the very common erroneous usage of the two terms, and reviews the actual meaning and proper usage of each term to show why they are necessary in communications work.

Basically, *level* is an expression of *relative* signal strength at various points in a communication circuit. *Power,* on the other hand, is an expression of *absolute* signal strength at a specific point in a circuit.

Generally speaking, the word "level" is used to indicate the value of a signal relative to an established reference signal. The reference signal is known as the "zero reference level." This general conception of level has many applications. For example, in the aircraft industry the speed of supersonic aircraft is measured with respect to the speed of sound rather than in terms of distance per unit time. The speed of sound is arbitrarily called Mach 1, and the speed of any aircraft can then be stated as a Mach Number to express that speed with respect to the speed of sound.

In telephone work the term "level" is used in a similar manner to express the relative amount of power at various

About This Article

This is a slightly condensed version of an article first published in the December, 1952 DEMODULATOR. *Widely acclaimed for clarifying certain confusing terminology, the article has been reprinted by several magazines. Today the* DEMODULATOR *reaches some 33,000 readers in 95 countries (five times the 1952 circulation), many of them relatively new to communications. Although the article is written in terms of American telephone practice, we think it has value for anyone concerned with the operation and maintenance of a communication system.*

points in a circuit. Just as the speed of an aircraft is expressed as a multiple of the speed of sound, the amount of power at the output of a telephone repeater can be expressed as one-half, two, or three times the power at the zero reference level.

In practice, relative levels in a telephone circuit are expressed in db (decibels) rather than in arithmetic ratios. This is done because of the convenience of using this logarithmic expression for the relatively large ratios involved. They are sometimes as great as 100 million to one (80 db).

Unless some other reference is stated, the zero reference level for a signal in a telephone circuit is the power which the signal has when measured at the two-wire input to the toll circuit.

The concept of level is illustrated in Figure 1. Since the level at the input to the toll switchboard has been defined as zero reference level, the level at the talking subscriber's subset is somewhat higher, depending on loop loss.

From the toll switchboard the transmitted speech passes to a carrier terminal which provides a gain of 17 db. The line attenuation between carrier terminals and the repeater is 42 db. Therefore, the level of the received signals at the repeater is −25 db. Since the gain of the repeater is 42 db, the transmitted level from the repeater is +17 db. With 42 db line attenuation between the repeater and the receiving carrier terminal, signals will be received at the terminal at a level of −25 db. The receiving branch of the

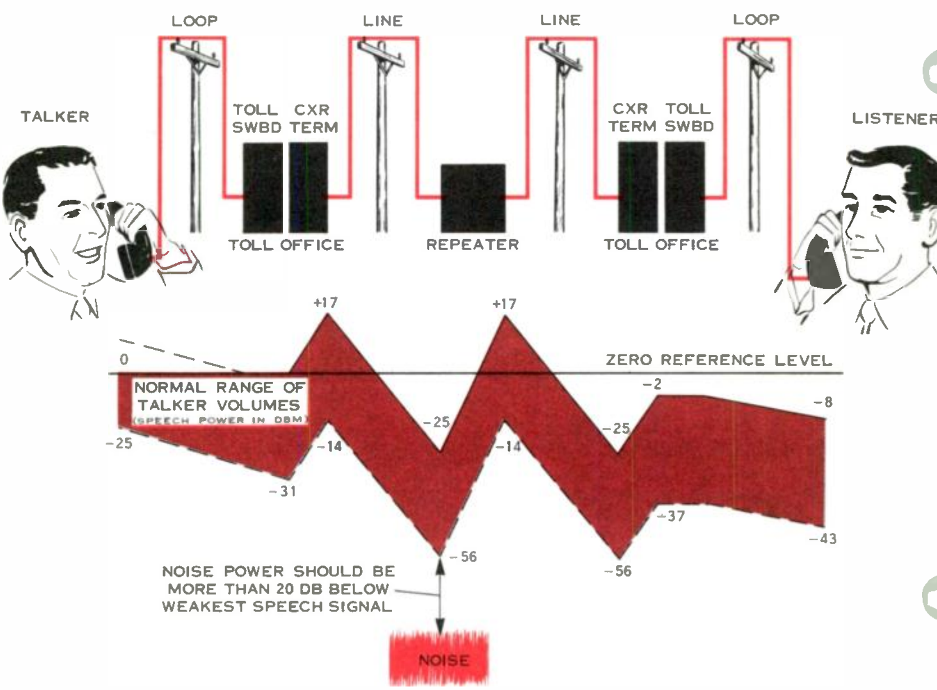

Figure 1. Relative power of transmitted signal varies widely during passage through circuit, but is measured with respect to zero reference level. Red area indicates the normal range of talker volumes.

carrier terminal provides a 23 db gain so the signals will be delivered to the toll switchboard at a level of −2 db. Then, since the loop attenuation is 6 db, the received level at the listener's subset will be −8 db. Thus, the range of speech signals from the talker will be heard by the listening subscriber at a level 8 to 12 db below the signal strength leaving the transmitter.

At all level points the strength of the transmitted speech has been clearly stated as having a definite ratio to the strength of the speech at the zero reference level. The statement of level at each point indicates only how much gain or loss the transmitted signals have received between the various points along the transmission path.

Level, therefore, is purely a relative term. Whenever level is expressed, the zero reference level is understood to be at the point where the circuit being considered becomes a toll circuit.

What is meant by "Power"

While level is always a ratio, "power" always designates a definite quantity. This quantity is defined in electrical terms as the rate at which electric energy is taken from or supplied to a device. The most common unit for expressing power is the "watt."

In addition to the watt, a number of other defined units are commonly used for expressing the amount of power in telephone equipment. Among these are "dbm," and "dba." Both of these units are based upon using the decibel to express the amount of power above or below a convenient amount of reference power.

Because of the use of the decibel and of a reference power in defining these units, powers expressed in decibels are sometimes erroneously called levels. They are not—because in every case a value stated in dbm or dba can be readily converted to a value in watts.

The difference between power and level can be shown more clearly by considering the use of "dbm." This unit is perhaps the most common of the three mentioned. Stating that the power at a certain point is $\pm X$ dbm simply means that the power is X db greater or less than one milliwatt.

A 1000-cps test tone with a power of one milliwatt is ordinarily available at toll switchboards. When this test tone is transmitted over a telephone circuit the test tone power in dbm at any point in the circuit is numerically equal to the level in db at that point. When the test tone power is any other amount, or when power is measured in any unit other than dbm, the numerical value of *level* is not the same as that of the power at that point. It is this similarity which can cause confusion between proper usage of level and power.

The distinction between level and power can also be illustrated by considering the two terms with respect to a fixed-gain amplifier, as shown in Figure 2. Two conditions are shown. In the first, the input to the amplifier is 0.001 watt. In the second the input to the amplifier is 0.0005 watt. In both conditions the amplifier has a fixed gain of 30 db.

In this example the input in both cases is arbitrarily considered to be zero level. Therefore, the output level in both cases is +30 db and it cannot change unless the amplifier gain changes.

The power input and the power output change in both cases, however. In the first, the input signal of 0.001 watt is amplified 1000 times to produce an output of 1 watt. In the second, the input signal of 0.0005 watt is amplified by the same amount since the gain of the amplifier is fixed at 30 db (or a factor of 1000). The output power is therefore 0.5 watt.

It is obvious that the power output

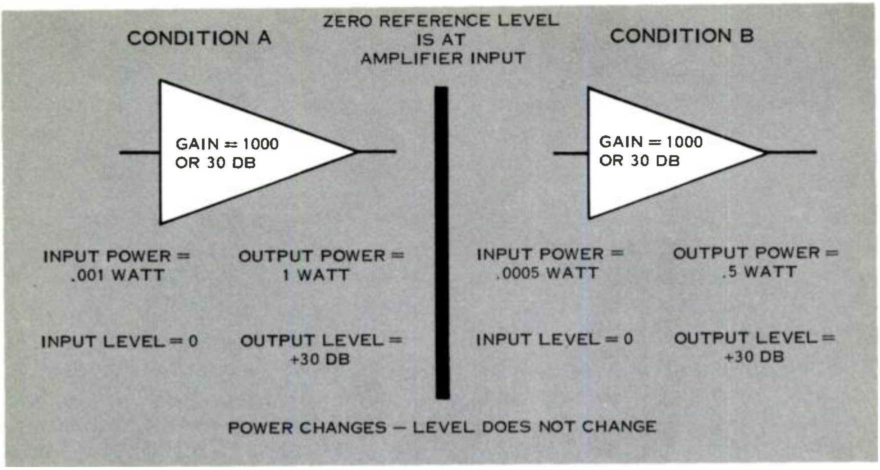

Figure 2. Halving the input power to a fixed-gain amplifier also halves the output power, but does not change the relative *output level because the zero reference level is at the input.*

of a fixed-gain amplifier will change when the input power changes. *But the level remains the same* so long as the gain or loss (in decibels) between zero or reference level and the output of the amplifier remains the same.

Why "Level" is Used

Transmitted speech consists of a large range of frequencies and powers which vary widely for different speakers. For this reason it is impossible to determine exactly what power will exist at any point in a circuit when the circuit is in use. However, regardless of the specific power at any point, the level, or in other words, loss or gain between the point in question and other points in the circuit, can be determined either by calculation or by measurement of the test tone which is transmitted at the reference level.

When laying out telephone circuits it is necessary to know the net loss which the circuit imposes on speech currents passing through it. It is neither necessary nor practical in this type of planning to know exactly what the *actual power* will be at any point, particularly since the power will vary over wide limits depending upon the talker and the words spoken.

Since the gain or loss of a circuit is independent of power (within the power handling capacity of the equipment) it is convenient to have the concept of relative level to express the relative strength of a signal at any point and to determine net loss of the circuit between any two points.

Why "Power" is Used

Although level has definite value in circuit planning, it is necessary to consider the actual power involved when designing and operating the electronic equipment used at voice and carrier frequency terminals and repeaters.

Operation of electronic equipment depends upon the minimum and maximum powers which can be supplied to the input of the equipment and delivered from the output. Equipment sensitivity and the amount of noise and other disturbances present in the circuit usually determine the lowest practical input power. Maximum output power (and consequently the maximum input) depends upon the power handling capacity of the equipment.

Specifications for carrier equipment normally give the test tone power at the inputs and outputs of each channel. In some cases it is desirable or necessary to know the total peak power that may be delivered to common equipment or to the line by several channels.

Pre-channel power is normally stated in dbm. Because dbm is a logarithmic value, two powers expressed in dbm cannot be added to obtain the total power. Instead, each channel power must be converted to watts, added, and the total then reconverted to dbm. Alternatively, the powers can be added graphically with the aid of Figure 3.

If the per-channel power of all channels is the same, doubling the number of channels increases the total power by 3 db. Thus, if a system has 8 channels, each with a signal output power of +10 dbm, the total power delivered to the line is +19 dbm.

In speech communication circuits it is unlikely that all channels of a carrier system will be transmitting signals of the maximum value simultaneously. Therefore, the common equipment is usually designed to handle the total expected power rather than the total possible power.

Although levels are more important than actual power to the engineer laying out a telephone circuit, the transmission engineer interested in the installation or operation of a carrier system must usually know the actual power at the various points. Otherwise, there is a possibility of operating a circuit with either less input power or more output power than the equipment is designed to handle.

Any consideration of power in a carrier system can be divided into two sections—the amount of power at the connections to the carrier equipment, and the amount of power at various points inside the carrier equipment. Power values inside the carrier equipment are of interest primarily to the design engineer.

The signal power which appears at the line and drop terminations of the transmitting and receiving branches is of great importance to the operator of carrier equipment. These power values determine where carrier systems may be operated, how repeaters must be spaced, and how coordination may be achieved.

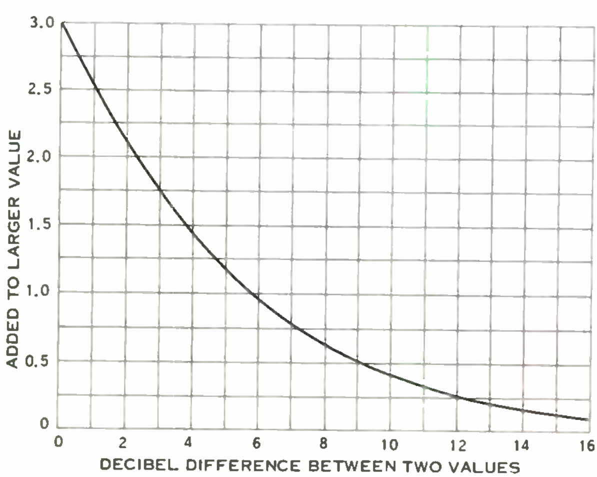

Figure 3. Graph for adding noise or signal power expressed in decibels. If signals differ by more than 16 db, smaller signal makes no significant contribution to total.

A typical two-wire carrier circuit with a four-wire termination at one drop and a two-wire hybrid termination at the other is shown in Figure 4. Typical test tone power values at the equipment connections are indicated.

Voice-Frequency Power

The voice-frequency (v-f) power required at the input to the transmitting branch of a carrier system is primarily based on the normal amounts of power delivered to the line from the toll switchboard. Because many telephone offices are arranged for patching circuits on a four-wire basis at a level of −16 db, and the usual test tone power at the transmitting toll switchboard is 0 dbm, the input stages of carrier systems are often adjusted to receive a test tone power of −16 dbm on a four-wire basis. This really means that the input to the carrier system is at a −16 level or at a circuit point 16 db removed from the two-wire v-f level at the transmitting toll testboard.

The amount of v-f power obtained from the receiving branch of a carrier system is also determined primarily by switching requirements. If all of the other values indicated in Figure 3 are within proper limits, the v-f output power for each channel with 0 dbm test tone at zero level would normally be about +7 dbm on a four-wire basis.

Although the traditional test tone power has long been 0 dbm, modern equipment may require lower values. As the quality of communications has improved over the years, speech volumes have tended to become lower. When this is reflected in the design of multiplex equipment, the 0 dbm test tone is excessive. Accordingly, lower test tone levels are often specified. For example, the Lenkurt Type *81A* and Panhandle Type *X* exchange trunk carrier systems specify a test tone of −10 dbm.

Transmitted and Received Power

A number of factors influence the amount of power which can be transmitted or must be received from the line. Since the difference between these

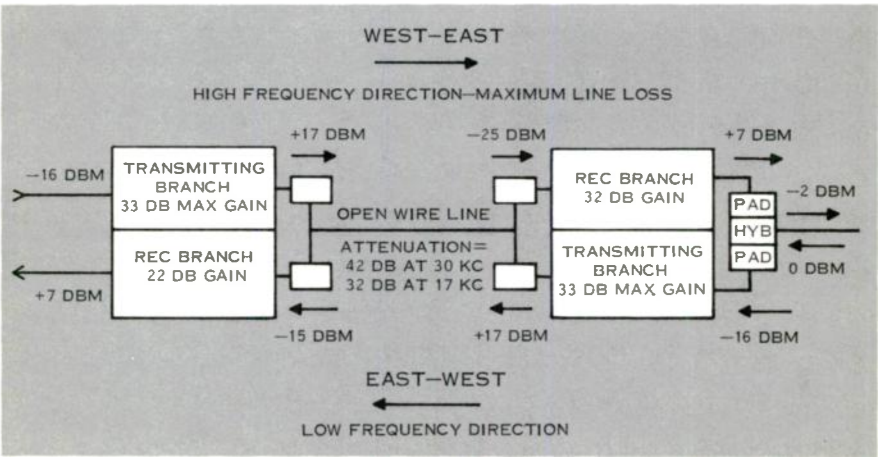

Figure 4. Simplified block diagram of a two-wire carrier system illustrating typical test tone power values at the connections to the carrier equipment.

two values is the maximum span attenuation, these factors also influence repeater spacing for a carrier system. Among these factors are the noise level of the line, the line attenuation, the system operating frequencies, the characteristics of the directional filters, and crosstalk considerations.

Basically, the amount of power transmitted must be high enough that sufficient power will reach the receiving terminal to permit recovery of the transmitted intelligence unimpaired by excessive noise. The power received must be sufficient so that the proper v-f output power can be delivered with the receiving branch gain available, and so that the received power will be sufficiently higher than the line noise to maintain the proper signal to noise ratio.

The amounts of power commonly transmitted were established as a result of attenuation studies conducted during many years of experience with telephone lines used for carrier circuits. These studies provided engineers with information concerning line characteristics and their effect on carrier systems under a variety of conditions. By using this information, standardized transmitted power values and levels were adopted for various carrier applications.

Among the factors which determine the minimum amount of power which should be received from the line at a carrier terminal are the receiving branch gain and the noise level of the line.

The ultimate objective of a carrier circuit is to deliver a certain amount of signal power to the telephone "drop." Therefore, the minimum received power must be such that, after being amplified an adequate amount, the signal will have the proper amount of power at the drop.

Higher receiving branch gain will not necessarily permit lower minimum amounts of power to be received since the received signal must be sufficiently greater than the noise level of the line to maintain the desired signal to noise ratio. Since noise is amplified as much as the desired intelligence, the signal-to-noise ratio at the output of the receiving branch cannot be any better than at the input.

Loop Gain and Level Coordination

Loop gain is defined as the sum of the gains experienced by a signal of a particular frequency in passing around a closed loop. The loop can be a carrier terminal, a repeater, or a complete carrier circuit.

Excessively high gains in the transmitting or receiving branches of a carrier system terminal or repeater can cause "singing." This occurs if the gain around the loop for any frequency is greater than the losses around the same loop at that frequency.

Loop gain is affected by a number of complex factors. Among them are the suppression supplied by directional filters, the losses due to hybrid balance, and the effect of the other frequency-selective elements in a carrier system. All of these factors are considered by design engineers when they determine operating levels and the amounts of power which will be transmitted and received by a carrier system when operating under various conditions.

A further limiting factor which must be considered when determining the amounts of power which will be transmitted or received by a carrier system is coordination of the levels and powers between two or more systems operating at the same frequencies on the same lead. If all systems transmit the same amount of power, they are not subjected to power differentials along the line. Any crosstalk between adjacent line conductors is then not further increased by a difference in power. •

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Carrier Coordination Paper Offered

Lenkurt Monograph 188, which discusses the problems of interference between carrier circuits used by railroads for signaling and communication, is now being prepared. The paper approaches the interference problem mainly through the techniques of level coordination and frequency allocation. Copies of Monograph 188 are available on request from

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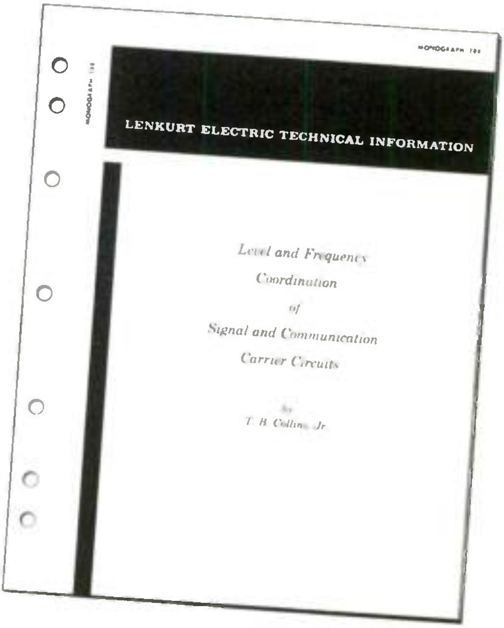

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