The Lenkurt Demodulator

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BASIC MEASUREMENTS

in communications

This is the first of a series of short articles which describe and discuss basic techniques and equipment used in measuring and testing the performance of carrier and microwave equipment. This introductory article discusses the philosophy behind the use of the decibel in communication measurements, and the growing practice of measuring all signal values in terms of power — a practice started by the telephone industry and now spreading into other branches of communications.

Communications engineers often prefer to measure signal levels in terms of power, and to express these power levels in terms of decibels. Power is preferred to voltage or current because it is an absolute quantity, rather than one that depends on other conditions or quantities to give it meaning. Voltage or current, for instance, can be traded off for one another without changing the actual power involved.

The decibel (db) is the preferred unit for expressing power because it is logarithmic. Two values can be multiplied or divided by adding or subtracting their logarithms. Since amplification and attenuation are multiplication and division processes, the decibel provides a handy means of expressing changes of power by simple addition and subtraction.

For example, if a signal is transmitted at a certain power and is received at *1/1,000* that power, it has suffered a 30 db loss. If this reduced signal is transmitted again and undergoes similar attenuation, the final signal is *1/1,000,000* its original strength *(1/1,000 x 1/1,000)*. It is much simpler to add 30 db and 30 db to get 60 db as the total attenuation of the signal.

By definition, the decibel is 10 times the logarithm (to the base 10) of the *ratio* of two power levels. The resulting decibel value expresses the power difference between the two levels. If a standard or reference level is used for one of the two values forming the ratio, the resulting value expresses the actual power of the signal.

The reference power most widely used in communications is 1 milliwatt (.001 watt). When this reference is used, the resulting power level is usually abbreviated *dbm,* and means "decibels above or below a reference power of one milliwatt." Thus, 0 dbm is .001 watt, +10 db is .01 watt, and +30 dbm is 1 watt. Remember that *db* refers to a *comparison* of two powers and does not express a fixed value unless it refers to db above or below *some specific reference.* For this reason, an amplifier may have a gain of 30 db, but produce a maximum output of only +10 dbm.

Another reference power occasionally used is 1 watt, and the power levels expressed are abbreviated *dbw.* Power levels expressed in dbw may be converted to the more commonly used dbm by adding 30 db to the dbw value. Thus, -60 dbw = -30 dbm, and -10 dbw = +20 dbm.

The decibel was first used in communications work as an improvement on the "standard cable mile," a telephone unit expressing the loss occuring in one mile of a standard 19-gauge cable. As transmitted bandwidth increased, this unit was found to be unacceptable because loss was different at different frequencies. The decibel which replaced it as a means of expressing loss, is purely relative and always states a specific *percentage difference* between two powers, regardless of frequencies or other characteristics involved.

It is easy to estimate the difference between two signals, in decibels, without a slide rule or table of logarithms by remembering that when power is doubled there is a 3 db increase in level. Thus, raising the signal level four-fold increases the level 6 db. Changing power by a factor of ten changes the level exactly 10 db. One decibel is equal to a power increase of 1.26.

As an example, the attenuation in decibels of an attenuator which reduces a signal to *1/600* its original value may be estimated by dividing 600 by 10 and by 2 as many times as required to reduce the attenuation to the smallest convenient value, and adding the equivalent decibels. Thus, dividing 600 by a factor of 10 and then again by 10 reduces it to 6 and represents 20 db attenuation. Dividing 6 by 2 and then again by 2 represents 6 db attenuation, and leaves only 1.5, or slightly more than 1 db. The total attenuation in decibels is 10+10+3+3+1+, or 27+ db.

Occasionally, some confusion occurs when the decibel is used to express voltage or current ratios as though they were power ratios. Voltages and currents may be compared in terms of decibels if the decibels are computed on the basis of db = 20 log $voltage_1 / voltage_2$. This is equivalent to multiplying a normal "power" decibel by an additional factor of two. This is necessary because power is equal to $voltage^2 / resistance$. If voltages are not squared, the power ratio is not correct. Since the expression involves the log of the voltage ratio, multiplying it by two is equivalent to squaring the voltages involved, and restores the correct relationship. Thus, doubling or halving voltage or current produces a 6 db change instead of the

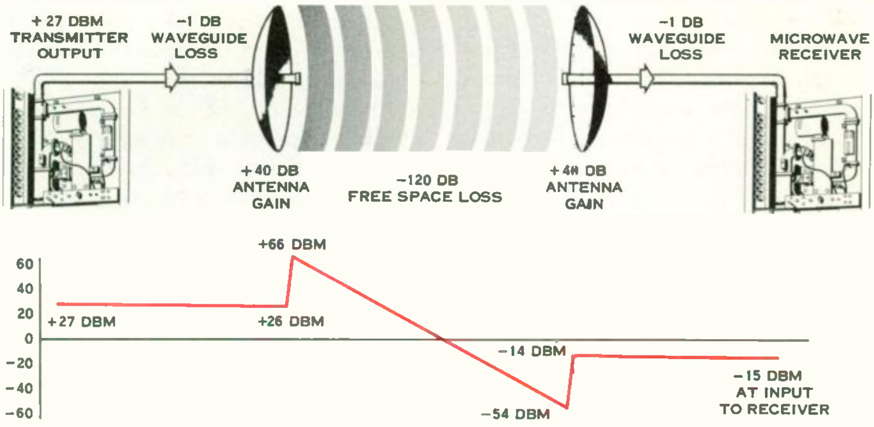

Figure 1. Rating each system element in decibels of gain or loss permits direct comparison of all elements on equal basis, and simplifies engineering calculations.

3 db change for doubling or halving power.

The advantage of measuring the signal levels in decibels becomes more evident when one calculates the performance requirements of a communications system. Carrier and radio equipment includes many elements which change the characteristics of a signal without adding to or taking away from its actual power. For instance, a transformer may raise signal voltage and reduce current without changing actual signal power. Other elements, such as antennas, amplifiers, and attenuators change signal level by a fixed amount. Thus, an antenna with a gain of 30 db always increases the effectiveness of a signal 1,000 times compared to a reference antenna. Such an antenna will provide this gain whether it is used for transmitting or receiving, and regardless of the signal level.

Figure 1 diagrams a simple radio system to show the ease with which system elements may be evaluated. If the transmission path causes too much loss, this may be compensated for by increasing the gain of other system elements such as antennas or transmitter power. Equivalent calculations using field strength, input impedance, peak-to-peak voltage, and other such values are much more complicated and provide no improvement in the results.

Measuring Power

Various methods are employed to measure power, depending on the conditions existing in the circuits where the power is to be measured. At high power levels or at radio frequencies, it is most convenient to measure the heat generated by the power. At the power levels and frequencies usually found in carrier systems, some form of voltmeter is used for measuring power.

As derived from Ohm's law,

$$\textit{power (watts)} = \frac{(\textit{voltage})^2}{\textit{load resistance}}.$$

In other words, a given power will cause a specific voltage to appear across a known load according to the relationship stated in the formula. When the load resistance or impedance is known, power can be easily calculated from the observed voltage. For instance, assume that a 2-volt potential is measured across a 600-ohm load resistance. Then from the formula above,

$$\text{power (watts)} = \frac{(2)^2}{600} = \frac{4}{(600)}$$
$$= .0066 \text{ watt, or } 6.6 \text{ milliwatts.}$$

To convert this into dbm,

$$\text{dbm} = 10 \log \frac{6.6 \text{ mw}}{1 \text{ mw (ref.)}} = 10(.82)$$
$$= 8.2 \text{ dbm.}$$

In order to eliminate the need for calculating power levels, most voltmeters used in communications work are calibrated in terms of db or dbm. This

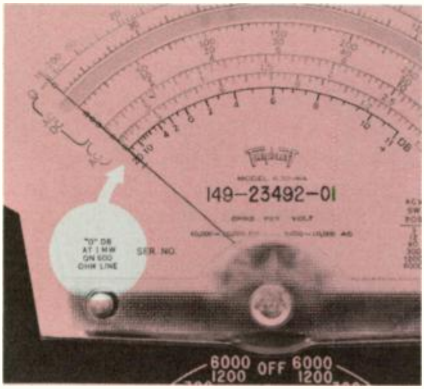

Figure 2. Typical meter face, showing basis for calibration of the meter decibel scale.

calibration is usually based on measuring the voltage appearing across a 600-ohm termination. This termination may be a resistance in the case of direct current circuits, or it may be an impedance in the case of alternating currents. Thus, when the circuit to be measured is terminated in the value specified on the meter (see Figure 2), the meter scale marked db or dbm provides a direct indication of the power level being measured.

If the circuit to be measured is terminated by a resistance value other than that for which the meter is calibrated, the indicated power level will be wrong. In such a case, the meter reading must be corrected by adding or subtracting a correction factor. In some alternating current circuits, an impedance-matching transformer may be employed to correct the termination and the meter indication.

When both the meter termination and the actual circuit termination are known, the correction factor may be calculated in exactly the same way that power levels in decibels are calculated. The correction factor in decibels is

$$\text{db} = 10 \log \frac{\text{calibration termination}}{\text{circuit termination}}.$$

As an example, when measuring a circuit terminated in 130 ohms, with a meter calibrated for 600 ohms termination,

$$\text{db to be added} = 10 \log \frac{600}{130}$$
$$= 10 \log 4.61 = 6.64 \text{ db.}$$

This means that the meter indication must be increased 6.64 db in order to correctly state the power in the measured circuit. (This particular value is often rounded off to 6.5 db for convenience.) If the circuit impedance (or terminating resistance) is higher than that for which the meter is calibrated, the meter reading will be too high. In this case it is customary to invert the ratio to avoid the nuisance of taking the logarithm of a value less than unity. When this is done, the sign of the correction factor changes, indicating that it must be subtracted from the reading rather than added to it.

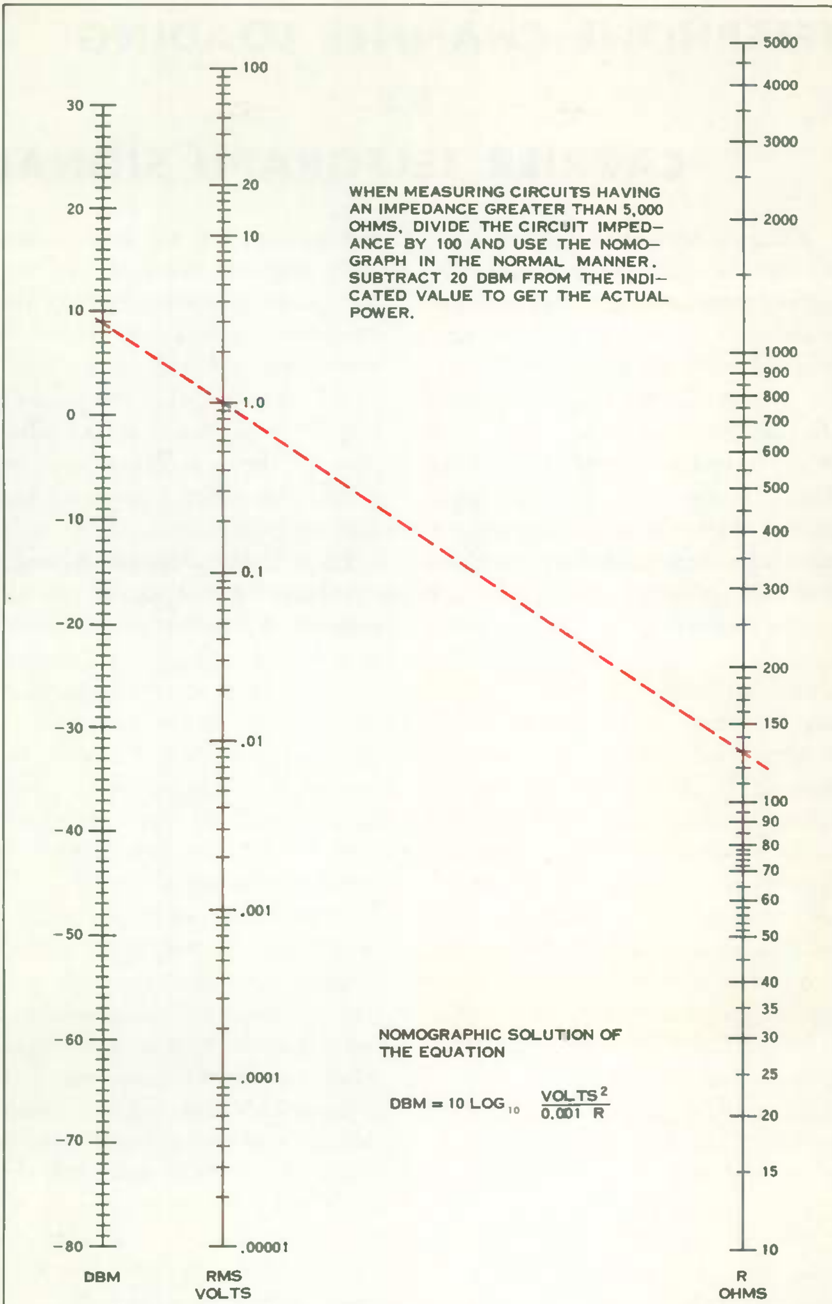

Figure 3. Nomograph for determining power in dbm from voltage measurements. Voltmeter should have high internal impedance.

TELEPHONE CHANNEL LOADING BY CARRIER TELEGRAPH SIGNALS

When using carrier-derived voice channels to transmit carrier telegraph signals, great care must be exercised in establishing the level at which the telegraph channels are applied to the carrier system. Carrier telegraph signals are transmitted as tones which have greater average power than voice signals. If the power handling capability of the carrier 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 telegraph channels transmitted over carrier 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, this level is high enough to provide good service over a carrier-derived voice channel.

However, in applications where the maximum telegraph channel capacity is not used, it may be desirable to increase the telegraph transmitting level in order to improve the signal-to-noise ratio. The increased signal level may be calculated from the number of telegraph channels 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 carrier equipment. When carrier telegraph channels are applied to a single carrier-derived voice channel of a multi-channel carrier 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 as great as the rms value of the wave, or 3 db greater in power than the rms power value. However, in the case of a single telegraph channel, transmitting level may be equal to the normal test tone power, since both signals are sine waves.

As the number of telegraph channels is increased, the peak power which the complex 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; for two tones it is 6 db; for ten tones it is 12 db. Peak factor increases to a maximum of 13 db for a large number of tones.

As an example, assume that ten telegraph channels are to be carried over a carrier telephone 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 the 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 1 shows how the telegraph tone levels must be reduced as the number of channels increases.

While higher transmitting levels should not be used, it is permissible to reduce the per-channel level below that indicated on the chart.

Note — The method of computing levels described in this article yields theoretical maximum values. Many manufacturers specify lower levels to provide operating margin, since the nature of the circuit, its transmission characteristics, or other factors affecting cross-talk in a specific application, are unknown.

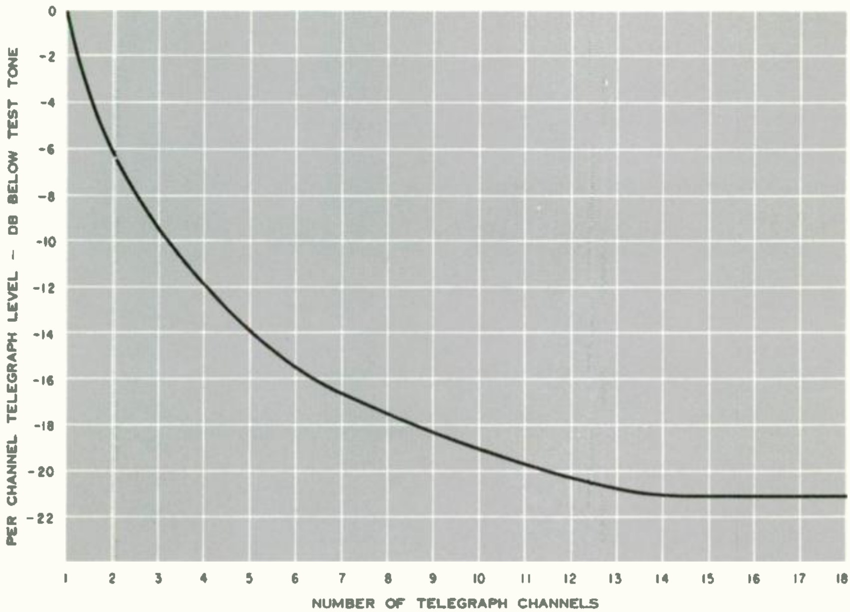

Figure 1. Theoretical maximum per-channel transmission levels for various numbers of telegraph channels transmitted over a carrier voice channel.

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