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the Lenkurt Demodulator

dB and other logarithmic units

Decibels and many other logarithmic units are used extensively in the telecommunications industry to define the qualities and functions of transmission circuits. In view of the significance of these terms, the Demodulator is treating the subject for the third time, with an increased emphasis on understanding the usefulness of logarithmic terms.

This article explains the most commonly used dB terms, and includes a number of convenient conversion formulas.

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Dealing with very large and very small numbers is often necessary in the telecommunications industry. For example, the frequency of a typical microwave radio is 12,000,000,000 cycles per second. Or, the power represented in conversational speech is measured at about 1/100,000,000,000 watts/cm². These are obviously unwieldy terms.

Powers of Ten

However, there are various methods of handling them conveniently. Expressing numbers as *powers of ten* is a first step to simplicity. We know that $10 \times 10 = 100$, and can be written 10^2. Likewise, $10 \times 10 \times 10 = 1000$, or 10^3. By definition, the exponent 3 means that the number 10 is used as a multiplier 3 times. 12,000,000,000 cycles per second then becomes 12×10^9 cycles per second (or 12 GHz).

Note that $10^1 = 10$; $10^0 = 1$. Numbers smaller than 1 also can be treated using powers of ten. By definition, 10^{-1} is the same as $1/10^1$, or simply 1/10. In this way, the power rating for conversational speech mentioned previously can be written 10^{-11} watts/cm².

When discussing two relative values, it is sometimes convenient to use the term *orders of magnitude*. This is only another way of expressing powers of ten. That is, one order of magnitude (10^1) is 10 times as much; two orders of magnitude (10^2) is 100 times as much. Simple division indicates that a plane flying 1000 miles per hour is 100 times faster than a horse traveling at 10 miles per hour. It could be said that the plane is two orders of magnitude faster than the horse. Notice that orders of magnitude are really concerned with the exponent of the number. If a number is 1000 times greater than another, $1000 = 10^3$, or *three* orders of magnitude greater.

Logarithms

All of the figures in these examples have had the same "base" number of 10. If we treat the exponent of the base number separately, another useful shorthand is achieved, called *logarithms*. In $100 = 10^2$, the logarithm of 100 is 2. That is, the common logarithm (abbreviated Log_{10}) of a number is the power to which the base 10 must be raised to produce the number. The written form is $\log_{10} 100 = 2$. In practice the subscript $_{10}$ is usually eliminated when referring to common logs. Another log system used in mathematics has a base number of 2.718, and is written $\log_e$ or ln.

The use of logarithms is advantageous in many forms of complicated calculations. Remember that to multiply like numbers, it is only necessary to *add* their exponents ($10^2 \times 10^3 = 10^5$); to divide, *subtract* exponents ($10^5 \div 10^3 = 10^2$). Logarithms are used in the same way. Multiplications and divisions involving large numbers may be carried out by adding or subtracting the corresponding logs and then converting back. In fact, any series of events involving multiplication or division, if expressed logarithmically, may be handled by simple addition and subtraction. This is particularly valuable in the telecommunications industry, where a variety of measurements are necessary to describe the properties of a signal as it passes through the system. Voltages, currents, and powers are measured, noise identified, and losses assessed. These are all made much easier by the use of the logarithmic system.

Decibels

The basic unit of measure in communications is the *decibel*, derived from the less practical unit, the bel, named in honor of Alexander Graham Bell. A *deci*bel is a tenth of a bel.

DECIBELS	POWER RATIO
1	1.259
2	1.585
3	1.995
4	2.512
5	3.162
6	3.981
7	5.012
8	6.310
9	7.943
10	10.0
20	100.0
30	1000.0
40	10,000.0

Figure 1. The Relationship Between Decibels and Power Ratios.

Early experimentation proved that a listener cannot give a reliable estimate of the absolute loudness of a sound. But he can distinguish between the loudness of two *different* sounds. However, the ear's sensitivity to a change in sound power follows a logarithmic rather than a linear scale, and the decibel has become the unit of measure of this change. A difference of 1 decibel, abbreviated dB, in the power supplied to a listening device produces approximately the smallest change in volume of sound which the normal ear can detect. The relationship between any two power values can be calculated in decibels as:

$$dB = 10 \log \frac{P_1}{P_2}$$

where

P_1 is the larger power

It should be emphasized that a given number of decibels is always the relationship between two powers, and not an absolute power value by itself (Figure 1). For example, the gain in an amplifier, or the attenuation of a pad, can be expressed in decibels without knowledge of the input or output power of the device.

dBm

Frequently, it is convenient to represent absolute power with a logarithmic unit. One milliwatt is generally accepted as the standard reference for such purposes in the telephone industry, and signal powers can be written as being so many dB above or below this reference power. When this is done, the unit becomes dBm, in the expression:

$$dBm = 10 \log \frac{P_1}{P_2}$$

where

$$P_2 = 1 \text{ milliwatt}$$

By adding a definite reference point, dBm becomes a measurement of absolute power, rather than just a ratio, and can readily be converted to watts. 10 dBm indicates a signal 10 times greater than 1 milliwatt, or 10 milliwatts; 20 dBm is 100 times greater than 1 milliwatt, or 100 milliwatts. A 30 dBm signal applied to an amplifier with 10 dB gain will result in a 40 dBm output. Or, a standard test tone (0 dBm) will be measured as −15 dBm after passing through an attenuator of 15 dB.

It is important to note at this point that most meters used in the telephone industry are calibrated for measurements of voltage appearing across a 600-ohm termination (standard transmission line impedance). If the circuit to be measured is of a different impedance than that for which the meter is calibrated, the indicated power level will be wrong, and a correction factor must be taken into account. The relationship is:

$$dB\ (corrected) = dB\ (indicated) + 10 \log \frac{600\ ohms}{circuit\ impedance}$$

For example, a +6 dB reading across a 500-ohm line is calculated:

$$\begin{aligned} dB &= 6 + 10 \log \frac{600}{500} \\ &= 6 + 10 \log 1.2 \\ &= 6 + 0.792 \\ &= 6.792\ dB \end{aligned}$$

Level Point

In most telephone systems the toll switchboard is defined as the zero transmission level point (0 TLP), and the levels of both signal and noise at other parts of the system are usually referred to that point. A point in the transmission system where a signal has experienced 16 dB attenuation relative to the toll switchboard is known as the −16 dB level point. Note that *level* used this way is purely relative and has nothing to

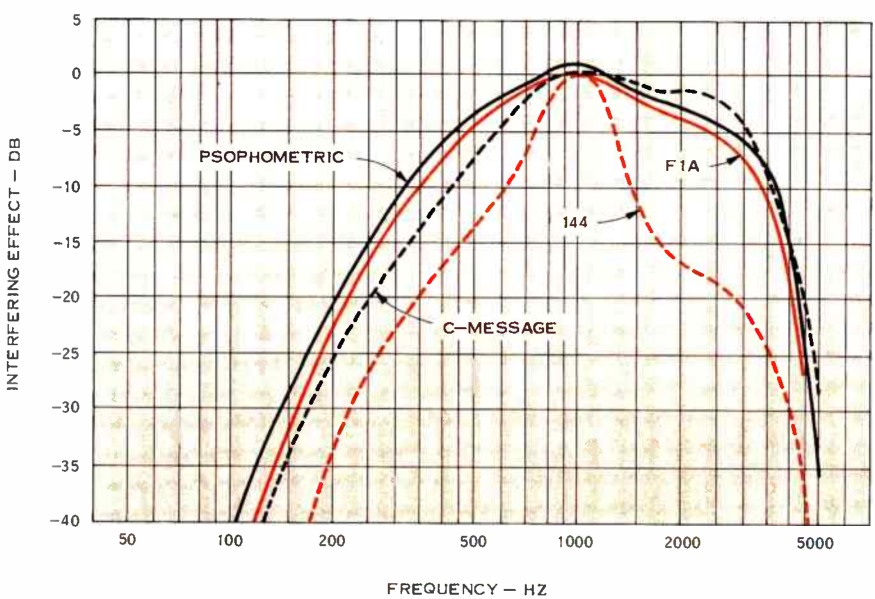

Figure 2. Weighting curves, based on listener response, show the relative interfering effect of noise on speech. All curves are referred to 1000 Hz except psophometric, which is based on measurements at 800 Hz.

do with actual power — a signal of any power will be down 16 dB at the −16 dB level point. When a standard test tone is transmitted over the circuit, its power in dBm at any point is numerically equal to the level in dB at that point.

dBm0

Another term, dBm0, is used to refer measured power back to the zero transmission level point, and has useful significance in system planning. Measurements adjusted to dBm0 indicate what the power would have been had it been measured at the zero transmission level point. For example, a tone measured at the −16 dB level point with a meter reading of +8 dBm, is equal to +24 dBm0.

In addition to dBm, there are a number of other logarithmic units used in the telephone industry which are expressed as dB above or below some reference power. One of the most common of these is dBrnc, used in the measurement of noise.

Noise Measurement

The Bell Telephone Laboratories and the Edison Electrical Institute did original research to determine the transmission impairment caused by noise interfering with speech. A large number of listening tests were made with different tones introduced as interference. The degree of interference was determined by comparing the power of each interfering tone with the power of a 1000-Hz tone that created the same degree of interference. A power of 10^{-12} watts, or −90 dBm, was selected as the reference power because it was found that a 1000-Hz tone at this power had a negligible interfering effect. Any noise power encountered that was greater than this could be given a positive value in *dB above reference noise,* or dBrn. These first measurements were made with the deskstand-type telephone popular in the 1920's, known as the Western Electric Type 144. From these measurements curves were plotted, called weighting curves.

dBa

Later, an improved handset (Western Electric Type F1A) came into general use, exhibiting a more uniform frequency response. Listener tests indicated that the new instrument gave approximately 5-dB improvement over the 144. Rather than change existing standards, a new reference noise power of −85 dBm (3.16×10^{-12} watts) was introduced. This also necessitated a change in the units, resulting in the adoption of dBa — decibels *adjusted.*

dBrnc

When the new 500-type handset was put into service in the 1950's, another line weighting was introduced, called C-message weighting. Since the new equipment improved on the old, an even higher reference power would have been required to express equal interfering effects with equal numbers. But this might have resulted in some unrealistic "negative" values of noise interference. So the reference power was returned to −90 dBm, and the units became dBrnc — decibels reference noise C-message weighted.

Weighting curves (Figure 2) for each handset compare interfering effects for various frequencies as referred to 1000-Hz interference. Noise measuring sets are frequency weighted in the same way so that meter readings obtained are meaningful in terms of what the ear detects. That is, the instrument does not measure noise intensity alone, but takes into account the frequency of the noise and how that particular frequency affects the ear.

Since there is no weighting effect on a 1000-Hz tone, straight forward conversion between dBa and dBrnc is possible by comparing reference power. A 1000-Hz signal having a power of 0 dBm yields 85 dBa and 90 dBrnc (Figure 3). But because weighting networks attenuate other frequencies differently, a uniform 3-kHz band of noise (flat or white noise) will not be measured the same as a 1000-Hz tone. White noise at 0 dBm will produce a noise reading of 82 dBa and 88 dBrnc. Approximate conversion is then accomplished by adding 6 dB to the dBa value:

$$dBrnc = dBa + 6.$$

For instance, if measuring with an instrument F1A weighted, a reading of 20 dBa would be equivalent to 26 dBrnc. The conversion factor is due to the 5 dB difference in noise reference power and an approximate 1 dB difference in weighting over the voice band.

Psophometric Weighting

In Europe and many other parts of the world, circuit noise is expressed in units established by the CCITT (International Telegraph and Telephone Consultative Committee). The unit, which is linear rather than logarithmic, is in terms of power measured in picowatts (10^{-12} watts), psophometrically weighted — written pWp. (Psophometric is from the Greek *psophos*, meaning noise.) The reference level, 1 pWp, is the equivalent of an 800-Hz tone with a power of −90 dBm, a 1000-Hz tone with a power of −91 dBm, or a 3-kHz band of white noise with a power of approximately −88 dBm. The shape of the psophometric curve is essentially identical to the F1A curve and similar to the C-message curve. Approximate conversions may be made as follows:

$$dBrnc = 10 \log pWp$$
$$dBa = -6 + 10 \log pWp.$$

Note that these terms all have absolute reference values of 10^{-12} watts, and are customarily written dBa0, dBrnc0, and pWp0 to relate the measurement to 0 TLP.

Noise Measuring Set Weighting	1000 Hz 0dBm	0-3 kHz 0dBm
F1A (dBa)	85	82
C-Message (dBrnc)	90	88

Figure 3. Relative readings received on F1A and C-message weighted noise measuring sets for single tone and white noise signals.

Signal/Noise

Occasionally the term signal-to-noise ratio (S/N) is encountered. The term, usually expressed in dB, indicates the number of dB the signal is above the noise. To obtain dBrnc from S/N, it is only necessary to calculate how many dB the signal is above reference noise power. For flat noise channels, the corrected reference (as mentioned previously for 3-kHz white noise) is −88 dBm. Conversions are, therefore:

$$dBrnc0 = 88 - S/N$$
$$S/N = 88 - dBrnc0$$
$$S/N = 88 - 10 \log pWp0$$

When it is necessary to measure speech or program volume in a transmission system, the simple dB meter or voltmeter is not adequate. The complexity of the program signal, as compared to pure sine waves, will cause the meter needle to move very erratically, trying to follow every fluctuation in power. This would obviously be difficult to read, and has no worthwhile meaning.

Volume Units

To provide a standardized system of indicating volume, a special instrument was created. Called a VU meter, it measures *volume units,* abbreviated vu. The VU meter is calibrated to read 0 vu across a 600-ohm line with a signal of 1 milliwatt (0 dBm) at 1000 Hz. The scale is logarithmic and reads vu above or below this zero reference. The instrument is not frequency weighted in any way, and while not designed for the purpose, it will read single frequencies directly in dBm. Its prime function, however, is to indicate the volume of complex signals in a way corresponding to the response of the ear. The reading is not an instantaneous value, but a value somewhere between the average and the peak value of the complex wave.

Other Units

Various other logarithmic units are used in the telephone and communications industries to conveniently compare like values. Crosstalk coupling in telephone circuits is indicated in dBx, or dB above reference coupling, and may be measured with a noise measuring set such as used to obtain dBrnc. Reference coupling is defined as the difference between 90 dB loss and the amount of actual coupling. Two circuits having a coupling of −40 dB could be said to have a coupling of 50 dbx.

Decibels may take on many other absolute values depending on their reference. Whereas dBm is a unit of power referred to one milliwatt, dBw is power referred to 1 watt. 0 dBw = 1 watt = 30 dBm. Similarly, dBk are decibels referred to 1 kilowatt.

Likewise, dBv is defined referencing 1 volt. However, in writing the equation for such a measurement, it is necessary to observe the following relationship:

$$dBv = 20 \log \frac{E_1}{E_2}$$

where

$$E_2 = 1 \text{ volt}$$

Note that the log of the voltage ratios is multiplied by 20, rather than 10 as in power ratios, expressing the square relationship between voltage and power ($P = E^2/R$). It is assumed that all measurements are across the same impedances.

Speech energy is commonly rated in terms of the intensity level of a speaker's voice measured one meter from his mouth. The standard reference accoustical power, 0 dBrap, is defined as 10^{-16} watts/cm².

Two other terms come into use in broadcasting: dBu, with 1 microvolt as the reference, and dBj, referred to 1000 microvolts. Both are measurements of signal intensity or receiver sensitivity. Any number of logarithmic units could be devised to suit special purposes, using decibels referred to some standard unit of power, voltage, or current.

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