

Joe Carr's Radio Tech-Notes

DECIBELS
dB or Not dB? — That is the Question

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Decibels

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For some strange reason, many people misunderstand and have difficulty with the concept of *decibels* (abbr. "dB"). That's really a shame because decibels are used in a wide variety of radio and electronics applications. This form of notation is widely used because it makes the job of calculating things like gains and losses much easier. By using decibel notation we can replace multiplication (gains) and division (losses) with addition and subtraction, respectively.

The decibel is nothing more than an *expression of the ratio between two signals*. The signals might be voltages, currents or power levels. When rendered in the form of decibel notation, however, the logarithms of the ratios are used rather than the straight arithmetical ratios. It is the use of the log of the ratios that makes it possible to replace multiplication and division calculations with addition and subtraction.

The decibel was originally conceived by the telephone industry to describe audio signal gains and losses in telephone circuits. The original unit was named the *bel* after Alexander Graham Bell, inventor of the telephone. In most electronics work, however, the bel proved to be too large a unit, so the decibel (one-tenth of a bel) was adopted as the standard notation.

There are three ways to calculate the decibel depending on whether a current, voltage or power level is intended. Most radio receiver work is based on the power decibel, so let's look at that one first. Recall that the decibel finds the ratio between two power levels, and expresses it as a logarithmic number. If P1 and P2 are the two signal levels, then the ratio is P1/P2. To find the decibel equivalent:

$$dB = 10 \text{ LOG} \left(\frac{P1}{P2} \right) \quad (1)$$

Where:

dB is the decibel equivalent of the ratio P1/P2
P1 and P2 are the two power levels
LOG refers to the base-10 logarithms

Note: *P1 and P2 can be any power units (watts, milliwatts, microwatts), but they must both be expressed in the same units.*

Example:

A signal of 10-watts power is applied to a long transmission line. The power measured at the load end is 7 watts. What is the loss in decibels?

Solution:

$$dB = 10 \text{ LOG } (P1/P2)$$

$$dB = 10 \text{ LOG } (7/10)$$

$$dB = 10 \text{ LOG } (0.7) = (10)(-0.155) = -1.55 \text{ dB}$$

Notice that the sign of the answer, -1.55 dB, is negative. This indicates the the ratio represents a loss. If the ratio represented a gain then the number would be positive.

The voltage and current decibel expressions and similar to the power expression, except that the constants are 20 rather than 10:

For voltage ratios:

$$dB = 10 \text{ LOG } \left(\frac{V1}{V2} \right) \quad (2)$$

For current ratios:

$$dB = 10 \text{ LOG } \left(\frac{I1}{I2} \right) \quad (3)$$

These equations are easily solved on a pocket calculator. The table below lists some common ratios that are often found in electronics and radio work.

Ratio	Factor	Power Decibels (dB)	Voltage or Current Decibels (dB)
1:1	1	0.00	0.00
2:1	2	3.01	6.02
10:1	10	10.00	20.00
100:1	100	20.00	40.00
1000:1	1000	30.00	60.00
1/100	0.1	-10.00	-20.00
1/100	0.01	-20.00	-40.00
1/1000	0.001	-30.00	-60.00

Notice that the ratio 1:1 produces a result of 0 dB. This is because it represents neither a gain or a loss. Also notice at each level the voltage or current dB value is twice the power dB value. These are merely different ways of expressing the same phenomenon.

Special dB Scales

Over the years different segments of the radio and electronics industry have created special decibel scales for their own use. All of them are based on the three equations given above. The differences are in the specified conditions under which the measurements are

made, and the specific level used as a reference point. The standard reference voltage or power will be placed in the denominator of the equation, and is usually referred to as the "0 dB" reference level. This name comes from the fact that placing the same level in the numerator produces a ratio of 1:1, or 0 dB. Several different special dB scales are listed below.

dBm. These units refer to decibels relative to one milliwatt (1 mW) of power dissipated in a 50 ohm resistive impedance (defined as the 0 dBm reference level), and is calculated from either $10 \text{ LOG } (P_{\text{WATTS}}/0.001)$ or $10 \text{ LOG } (P_{\text{MW}})$. The dBm scale is used in describing receivers and amplifiers. For example, an input signal or an output signal may be defined in terms of dBm. Similarly, the noise floor of the receiver may be given in dBm.

dBmV. This unit is used in television receiver systems in which the system impedance is 75 ohms, rather than the 50 ohms normally used in other RF systems. It refers to the signal voltage, measured in decibels, with respect to a signal level of one millivolt (1 mV) across a 75 ohm resistance (0 dBmv). In many TV specs, 1 mV is the full quieting signal that produces no "snow" (i.e. noise) in the displayed picture.

dB μ V. This unit refers to a signal voltage, measured in decibels, relative to one microvolt (1 μ V) developed across a 50 ohm resistive impedance (0 dB μ V).

dB (Old). An archaic dB unit used in the telephone industry prior to World War II used 6 milliwatts dissipated in a 500 ohm resistive load at the 0 dB reference level.

Volume Units (VU). This unit is used in audio work, and largely replaces the old dB scale given above. In the VU scale 0 VU is 1 milliwatt dissipated in a 600 ohm resistive load.

Antenna dB Notation

Decibel notation is frequently seen in specifications for radio antennas. The gain, the front-to-back ratio and/or the front-to-side ratio are typically specified in decibels. In the case of the front-to-back or front-to-side ratios the values are measured by having the antenna look at a constant power RF source while it is rotated. The signal levels are measured at the front, side and back so that the ratios can be calculated.

The matter of gain is a little different, however. What do you use as a reference for antennas? There are two basic forms of gain specification: *gain relative to isotropic* (dBi) and *gain relative to a dipole* (dBd).

Gain relative to isotropic (dBi) uses a theoretical construct called an *isotropic radiator*, which is a spherical source of RF energy that radiates equally well in all directions. The available power is distributed equally across the entire surface of the sphere. Gain antennas distribute the same amount of power over a much smaller portion of the sphere, so calculations can easily be made. The isotropic gain method is preferred by professional antenna designers.

Gain relative to a dipole (dBd) uses a half wavelength dipole as the reference. When both antennas are set up to intercept the same signal, then the gain of the test antenna is found by measuring the signal levels of both the test antenna and the dipole reference antenna, and then performing the calculation. The dBd measurement is about 2 dB higher than the dBi measurement.

Decibel Calculations

The beauty of decibel notation is that it makes radio and electronics calculations easier. Let's consider the system in Fig. 1.

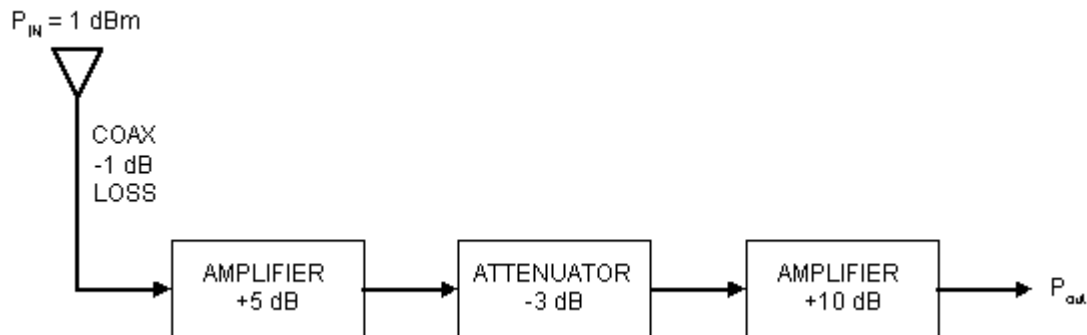


FIG. 1

Assume that a 1 dBm signal is applied to the antenna (I know, that's one bodacious signal! I just want to keep the arithmetic easy to follow). There is loss in the coaxial cable (-1 dB), loss in a fixed attenuator (-3 dB), and gain in two amplifiers (+5 dB and +10 dB). How much power is observed at the output (P_{OUT})? The output power level is:

$$1 \text{ dBm} - 1 \text{ dB} + 5 \text{ dB} - 3 \text{ dB} + 10 \text{ dB} = +12 \text{ dBm}$$

Notice that the gains and losses were handled with simple addition and subtraction. If decibel notation were not used, then it would be necessary to multiply for gains and divide for losses. Also note that dBm and dB are mixed in the same problem. That establishes the parameters of the problem, and is a valid use. However, don't mix two different special dB scales (e.g. dBm and dB μ V) unless you are fond of invalid "apples and oranges" comparisons.

Some dB Lore

Because radio signals are discussed in decibels some rather odd notions pop up. Let's take a look at some of those that historically have been quite popular.

The S-Meter Folly. Amateur radio operators and shortwave listeners use the S-meter to compare signal strengths. The standard signal reporting system, worked out by ARRL many years ago, uses S1 through S9, in which S9 represents "...an *extremely* strong

signal." Receiver S-meters are often calibrated to +60 dB over S-9. What does this mean? Well, it means that telling someone they are "60-dB over S-9" means that their signal is one-million times stronger than an extremely strong signal. Why, that signal level ought to melt the insulation off your transmission line?

Another S-Meter Folly. Swapping S-meter stories back and forth is basically a useless exercise. Why? *Because there are multiple standards for calibrating S-meters.* There will be a reference input signal level to establish the 0 dB point, and then an increment for each S-unit. I've seen S-meters calibrated such that 50 μV across the 50-ohm input impedance constitutes an S-9 signal, while other receivers required 100 μV for an S-9. I've seen receivers calibrated at 3-dB/S-unit, while others are calibrated at 6-dB/S-unit (more common).

Note: *A signal that is "60-dB over S-9" should have an rms input level of (pick a standard level) 50 mV \times 1,000,000 = 50 volts! Wow! That oughta knock your socks off!*

CBer's Folly. In the early days of Citizens Band the transceivers used vacuum tube technology. It was quite common for CBers to boost the power of their rigs by either changing the DC power supply voltage to all elements of the tubes, or (more common) upping the positive voltage applied to the screen grid of the power amplifier tube. A common modification of one series of models raised the power from the legal 5-watts to a whopping (and illegal) 7-watts. The gain in dB is $10 \text{ LOG } (7/5) = 1.46 \text{ dB}$. OK, so now they have an illegal rig, but have they accomplished anything? Let's see.

The S-unit on receivers is usually defined (loosely) as the *smallest change that is easily noted by the average listener*. If the conservative 3-dB/S-unit applies, then 1.46 dB represents around half an S-unit...or about half the change that the other person can detect with their ears! What a waste. The reliability of those circuits was reduced, the owner exposed to legal sanctions, all for a change that no one could detect. Wow...that's smart!

Ham's Folly. Knock the CBers and you gotta knock hams as well. I once owned a 1,200-watt linear amplifier. A friend of mine also had the same model, but he traded his in on a 2,000-watt linear amplifier. He claimed "I'm really getting out now!" Was he? The gain at the other end would be $10 \text{ LOG } (2,000/1,200) = 2.2 \text{ dB}$...or a bit less than an S-unit.

Because of the way power changes and signal strength are related, the FCC for a long time restricted commercial and broadcasting stations to power increases of at least five times the old level. Thus, a 500-watt station would not normally be allowed to go to 1,000-watt, but rather a minimum of 2,500-watts. Or the "standard" 1,000-watt local AM station might go to 5,000-watts. A 5:1 change results in 6.9 dB increase, so it's about two S-units.

As to me and my friend? I kept my money in the bank while he spent his...and no one could tell the difference between our signals.

The Huge, Monster VSWR Loss. Hams and SWLs spend a lot of time and money reducing the VSWR of antennas to as close to 1:1 as humanly possible. But there is a point of diminishing returns. According to one method of calculating VSWR mismatch loss, a 2.5:1 VSWR could be as much as 1.43 dB or as little as 0.89 dB. Big deal! How does that affect an S-meter? The reason for reducing the VSWR for solid-state transmitters is the sensitivity of the transistors in the output, not the loss.

In general, the only people who have to worry a lot about tweaking a system to squeeze out every fractional decibel of signal are those who work with extremely weak signals. Radio astronomers, for example, go to great lengths to get as much gain as possible, and reduce losses to the bare minimum. But then again, they are dealing with power levels most conveniently measured in millimicronanofemtowatts. Mere mortals can worry a little less and get on with the prospect of enjoying our hobby!