Bob's TechTalk #2
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Decibels: (Part II of IV):

The Decibel

Last month we took a look at logarithms and how they allow us to express numbers of greatly differing magnitudes in a simple manner. This month we'll look at the origin and theory behind the *decibel* and its base unit the ***bel***.

The human ear is a very sensitive instrument. It can detect sound intensity from as low as one ten-billionth of a micro watt per square centimeter up to a tenth of a milliwatt per square centimeter (where sound begins to become painful.) Alexander Graham Bell, the inventor of the telephone, spent many years working in the field of sound and hearing. He discovered that sound perception is logarithmic, and a listener perceives the same change in volume each time the sound level is doubled, no matter where in the range of volume the sound is occurring. The unit of *bel* is named after him, and was originally used to measure the difference between two audio power levels. The bel is defined as the logarithm (which we'll abbreviate as *log*) of a power level (P_1) divided by a reference power level (P_0):

$$\text{bel} = \log (P_1 / P_0)$$

One bel represents a tenfold increase (or decrease) in power. This is rather coarse for many audio measurements so the decibel was defined. The decibel is one tenth of a bel. Thus, we get the equation seen in the *ARRL Handbook*:

$$\text{dB} = 10 \log (P_1 / P_0) \qquad \text{(eq. 1)}$$

Interestingly, one decibel is the smallest change in sound level that can typically be perceived by the human ear. See the Sidebar ***Audio Decibels***.

There are two important points that need to be made about the decibel. First, it relates to **power**, not voltage or current. We'll talk more about voltage and current later in this article. Second, one of the two powers has to be a reference or known power. By itself, 12 dB doesn't mean a thing unless the reference is implied (such as a signal to noise ratio). Often, an extra letter following "dB" gives the reference. Here are some common examples:

Name	Reference
dBm	one milliwatt
dBw	one watt
dBa	noise floor (typically -90 dBm)
dBi	gain of an isotropic radiator*
dBd	gain of a dipole antenna*

* in free space

Often, when measurements are taken at one point in a circuit, the reference is just the first of the measurements. For instance you measure the output of a circuit and then make changes to the circuit and measure the output again. The reference is the initial reading that either improved or didn't after the circuit change. Since decibels represent a ratio between two levels of power, they can represent gain or loss. A negative number is often used to represent a loss. The total gain or loss of a system can be calculated from the gain or loss of each stage by adding them together. If your transmitter output is 25 watts (+44 dBm), your feedline has 3.6 dB of <u>loss</u> and your antenna has 5.6 dBi of gain, the effective radiated power is 44 dB - 3.6 dB + 5.6 dB or 46 dBm (39.7 watts).

Voltage, Current and dB:

Earlier I empathized that dB relates to power, not voltage or current. However, if you are careful and understand an important concept, dB can be used to represent ratios of voltage and current. By using Ohm's power law for voltage:

$$P = E^2 / R$$

and substituting it into the equation for decibels, (eq. 1) we get:

$$\begin{aligned} dB &= 10 \log (P_1 / P_0) \\ &= 10 \log \{(E_1^2 / R) / (E_0^2 / R)\} \\ &= 10 \log \{(E_1) / (E_0)\}^2 \end{aligned}$$

Since log (X^n) = n log X, we can rewrite the equation as:

$$dB = 20 \log (E_1 / E_0) \qquad \text{(eq. 2)}$$

In a similar manner, using P = I2R, we get the equation for current:

$$dB = 20 \log (I_1 / I_0) \qquad \text{(eq. 3)}$$

The important point in these derivations is that the resistance terms disappear because it is assumed that the two resistance values are the same. *If they are not the same then the equation is not correct.*

Let's solve for the gain of a phonograph amplifier that has an input impedance of 10K ohms. With the volume control full, a 10 mV input signal produces a 4.5 volt signal into a 4 ohm speaker. If we use equation (2) we get the **incorrect answer**:

$$dB = 20 \log [4.5/0.01] = 53 \text{ dB}$$

If we convert the input and output to power first and then use equation (1) we get the **correct answer**:

$$PIN = 0.01^2 / 10{,}000 = 0.01\ \mu W$$

$$POUT = 4.5^2 / 4 = 5W$$

$$dB = 10 \log \{5 / (0.01 \times 10^{-6})\} = 87 \text{ dB}$$

The reason the first answer in incorrect is because at one point we're measuring the voltage at an impedance of 10K ohms, and at the second point at an impedance of only 4 ohms. Now let's look at a 2 meter amplifier that has an input and output impedance of 50 ohms. If you put in 22 volts of RF you get 47.5 volts of RF out. Since the impedance at each point is the same either equation works.

Using equation (2):

$$dB = 20 \log (47.5/22) = 6.7 \text{ dB}$$

Converting values to power, and then using equation (1):

$$PIN = 22^2/50 = 9.7W$$

$$POUT = 47.5^2/50 = 45.1W$$

$$dB = 10 \log (45.1/9.7) = 6.7 \text{ dB}$$

If you're working at one point in a circuit, for instance at the output of your transmitter, and measuring the change in voltage as you perform different modifications, then you can assume the resistance is fixed and either equations (1), (2) or (3) will work. The reference dB is the result you measure before you make the change. When you're not sure that the resistance is constant then use equation (1) even though you may have to convert your data to power first.

When you express volts using dB you still need a reference. Here are a few more common references:

Name	Reference
dBv	one volt
dBj	1000 mV (usually RF)

This month we may have gotten a bit heavier into the math than I intended. However, next month we'll look into a few simple tricks that allow you to convert dB into a power ratio and back in you head without over stressing your cranium muscle.

Audio Decibels:

Sound pressure is the RMS measurement of the difference between the pressure of the oncoming sound wave and the ambient atmospheric pressure with the sound not present. It is measured in Pascals, a unit of pressure. The smallest sound a person of good hearing can detect is 0.00002 Pascals (20 micro-Pascals). This is the reference used when measuring SPL (sound pressure level) in air. It is the equivalent of a sound intensity of one ten-billionth of a micro watt per centimeter. SPL is the logarithmic unit of sound measurement and is given by a very familiar formula:

$$SPL_{dB} = 20 \log (SP / SP_{ref})$$

Here are typical sounds and their equivalent SPL in dBSPL:

0 dB	Hearing Threshold
20 dB	Recording Studio
40 dB	Quiet Library
60 dB	Typical Conversation (1 m)
80 dB	Curbside on a Busy Road
100 dB	Jackhammer (1 m)
120 dB	Threshold of Discomfort
130 dB	Threshold of Pain
140 dB	Older Jet Aircraft (50 m)
160 dB	My Neighbor's Car Stereo at 25 m - or so it seems!

Sound pressure levels referring to a point sound source need to be related to the source by distance to be meaningful.

Thinking about these numbers and a long ago statistic that the Yankee Stadium PA system ran 80 watts, you have to wonder the value of 1.5 KW audio systems for cars?

73, from AF6C

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