Working with Decibels

If you want to communicate effectively with EMC engineers, it's important to get comfortable with decibels (dB). Decibel notation is a convenient way of expressing ratios of quantities that may or may not span many orders of magnitude. It is also used to express the amplitude of various signal parameters such as voltage or current relative to a given reference level.

A power ratio, P_2:P_1, in dB is simply calculated as,

$$\text{Power ratio in dB} = 10 \log \left(\frac{P_2}{P_1} \right) \tag{1}$$

For example, if we are comparing a 10-watt received power to a 5-watt specification, we could say that the received power exceeded the specification by,

$$10 \log \left(\frac{10 \text{ watts}}{5 \text{ watts}} \right) = 3 \text{ dB} \tag{2}$$

If the impedance associated with two power levels is constant, then the power is proportional to the voltage (or current) squared. In this case, we can also express voltage (or current) ratios in dB,

$$10 \log \left(\frac{P_2}{P_1} \right) = 10 \log \left(\frac{V_2}{V_1} \right)^2 = 20 \log \left(\frac{V_2}{V_1} \right) \tag{3}$$

or,

$$20 \log \left(\frac{3 \text{ V/m}}{1 \text{ V/m}} \right) \approx 10 \text{ dB} \tag{5}$$

Antenna or amplifier gains are usually reported in dB. So are cable or filter losses. An amplifier that receives a 1-watt signal and produces a 100-watt signal has a gain of,

$$10 \log \left(\frac{100}{1} \right) = 20 \text{ dB} \tag{6}$$

A cable whose input signal has an amplitude of 3.0 volts and whose output signal has an amplitude of 2.8 volts exhibits a gain of,

$$20 \log \left(\frac{2.8}{3.0} \right) = -0.6 \text{ dB} \tag{7}$$

or a loss of,

$$20 \log \left(\frac{3.0}{2.8} \right) = 0.6 \text{ dB} \tag{8}$$

Note that the inverse of any ratio is expressed by changing its sign in dB. A ratio of 1 is 0 dB. Complex numbers, phase or negative values cannot be expressed in dB.

Quiz Question

A signal traveling one kilometer in a coaxial cable loses one-half its voltage. Express the,

a. input-to-output voltage ratio
b. input-to-output power ratio
c. input-to-output voltage ratio in dB
d. input-to-output power ratio in dB.

Of course, the input-to-output voltage ratio is 2:1, while the input-to-output power ratio is $(2)^2$:$(1)^2$ = 4:1. The voltage ratio expressed in dB is 20 log (2/1) = 6 dB. The power ratio is 10 log (4/1) = 6 dB. This illustrates one of the primary advantages to expressing gains or losses in dB. As long as the impedance is constant, it is not necessary to specify whether a ratio is power or voltage when it is expressed in dB. A 6 dB gain unambiguously means the power has quadrupled whether the original measurement was voltage, current or power. On the other hand, if we were simply to say that one signal was *twice as strong* as another, it would not be clear whether it had twice the power or twice the amplitude.

Example 1-1: Specifying ratios in dB

Specify the following ratios in dB:

200 μV/m : 100 μV/m	$20\log\left(\frac{200}{100}\right) = 6\,\text{dB}$
300 mV : 100 mV	$20\log\left(\frac{300}{100}\right) = 9.5\,\text{dB} \approx 10\,\text{dB}$
400 mA : 100 mA	$20\log\left(\frac{400}{100}\right) = 12\,\text{dB}$
500 μA/m : 100 μA/m	$20\log\left(\frac{500}{100}\right) = 14\,\text{dB}$
2 μW : 1 μW	$10\log\left(\frac{2}{1}\right) = 3\,\text{dB}$
3 mW : 1 mW	$10\log\left(\frac{3}{1}\right) = 4.8 \approx 5\,\text{dB}$
5 mW : 1 mW	$10\log\left(\frac{5}{1}\right) = 7\,\text{dB}$

Expressing Signal Amplitudes in dB

Signal amplitudes can also be expressed in decibels as a ratio of the amplitude to a specified reference. For example, a 100-μvolt signal amplitude can also be expressed as,

$$20\log\left(\frac{100\,\mu\text{V}}{1\,\mu\text{V}}\right) = 40\,\text{dB}\,(\mu\text{V}) \tag{9}$$

Quiz Question

Express the following signal or field amplitudes in their normal units,

a. 6 dB(μV)
b. 20 dB(μA)
c. 20 dB(A)
d. 100 dB(μV/m)
e. 100 dB(μW)

The units in parentheses following the "dB" indicate that the quantity being expressed is an amplitude.

Each of the quantities above is simply converted as follows:

a. $6\,\text{dB}\,(\mu\text{V}) = 20\log\left(\frac{X}{1\,\mu\text{V}}\right) \rightarrow X = 10^{6/20}\,\mu\text{V} = 2\,\mu\text{V}$
b. $20\,\text{dB}\,(\mu\text{A}) = 20\log\left(\frac{X}{1\,\mu\text{A}}\right) \rightarrow X = 10^{20/20}\,\mu\text{A} = 10\,\mu\text{A}$
c. $20\,\text{dB}\,(\text{A}) = 20\log\left(\frac{X}{1\,\text{A}}\right) \rightarrow X = 10^{20/20}\,\text{A} = 10\,\text{A}$
d. $100\,\text{dB}\,(\mu\text{V/m}) = 20\log\left(\frac{X}{1\,\mu\text{V/m}}\right) \rightarrow X = 10^{100/20}\,\mu\text{V/m} = 10^5\,\mu\text{V/m}$
e. $100\,\text{dB}\,(\mu\text{W}) = 10\log\left(\frac{X}{1\,\mu\text{W}}\right) \rightarrow X = 10^{100/10}\,\mu\text{W} = 10^{10}\,\mu\text{W}$

Using Decibels

Why bother expressing signal amplitudes in dB? After all, there's never any ambiguity concerning whether a quantity is a power or voltage when the amplitude and its units are provided. The real power of working in dB is calculating ratios.

Previously, we mentioned comparing a 10-watt receiver to a 5-watt specification. In Equation (2), we showed that the receiver was 3 dB over the specification. In this case, if the powers had been expressed in dB(W),

$$10\,\text{W} = 10\log\left(\frac{10\,\text{W}}{1\,\text{W}}\right) = 10\,\text{dB}\,(\text{W}) \tag{15}$$

$$5\,\text{W} = 10\log\left(\frac{5\,\text{W}}{1\,\text{W}}\right) = 7\,\text{dB}\,(\text{W}). \tag{16}$$

We could have calculated the ratio as,

$$10\,\text{dB (W)} - 7\,\text{dB (W)} = 3\,\text{dB} \ . \tag{17}$$

Rather than dividing amplitudes to determine the ratio, we can simply subtract amplitudes expressed in dB(·). Again, as long as the impedance is constant, it won't matter whether we are working with units of power, voltage or current.

Example 1-2: Specifying ratios in dB

Specify the following ratios in dB:

46 dB(μV/m) **:** *40 dB(μV/m)* → 46 dB(μV/m) - 40 dB(μV/m) = 6 dB
50 dB(mV) **:** *40 dB(mV)* → 50 dB(mV) - 40 dB(mV) = 10 dB
52 dB(mA) **:** *40 dB(mA)* → 52 dB(mA) - 40 dB(mA) = 12 dB
54 dB(μA/m) **:** *40 dB(μA/m)* → 54 dB(μA/m) - 40 dB(μA/m) = 14 dB
3 dB(μW) **:** *0 dB(μW)* → 3 dB(μW) - 0 dB(μW) = 3 dB
7 dB(mW) **:** *0 dB(mW)* → 7 dB(mW) - 0 dB(mW) = 7 dB

dBm

One of the most common units expressed in decibels is dB(mW) or dB relative to 1 milliwatt. This is almost always written in the abbreviated form, dBm (i.e. without the "W" and without the parentheses). Many oscilloscopes and spectrum analyzers optionally display voltage amplitudes in dBm. Since dBm is a unit of power, we must know the impedance of the measurement in order to convert dBm to volts. For example, a voltage expressed as 0 dBm on a 50-Ω spectrum analyzer is,

$$0\,\text{dBm} = 10\log\left(\frac{X}{1\,\text{mW}}\right) \quad \Rightarrow \quad X = 1\,\text{mW} \tag{18}$$

$$\text{X} = \frac{|\text{V}|^2}{50\,\text{ohms}} \quad .$$

$$V = \sqrt{(1\,\text{mW})\,(50\,\text{ohms})} = 0.2236\,\text{volts}$$

Example 1-3: Specifying voltages in dBm

Specify the following voltages in dBm assuming they were measured with a 50-Ω oscilloscope:

1 μV → $\frac{(1\,\mu V)^2}{50} = 2 \times 10^{-11}\text{mW} \to 10\log\left(\frac{2\times10^{-11}}{1}\right) = -107\,\text{dBm}$

2 μV → $\frac{(2\,\mu V)^2}{50} = 8 \times 10^{-11}\text{mW} \to 10\log\left(\frac{8\times10^{-11}}{1}\right) = -101\,\text{dBm}$

10 μV → $\frac{(10\,\mu V)^2}{50} = 2 \times 10^{-9}\text{mW} \to 10\log\left(\frac{2\times10^{-9}}{1}\right) = -87\,\text{dBm}$

1 V→ $\frac{(1\,V)^2}{50} = 20\,\text{mW} \to 10\log\left(\frac{20}{1}\right) = 13\,\text{dBm}$

2 V → $\frac{(2\,V)^2}{50} = 80\,\text{mW} \to 10\log\left(\frac{80}{1}\right) = 19\,\text{dBm}$

10 V → $\frac{(10\,V)^2}{50} = 2000\,\text{mW} \to 10\log\left(\frac{2000}{1}\right) = 33\,\text{dBm}$

In this example, we can see that doubling the voltage adds 6 dB (e.g. 13 dBm + 6 dB = 19 dBm) and increasing a voltage by a factor of 10 adds 20 dB. This is true no matter what units of voltage are being used and is an example of why it is often convenient to work with decibels.

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