dB versus dBm
Which is correct?

(Addendum, October 2015, scroll to end.)

A frequent problem found in technical communications, both written and verbal, is confusion between dB and dBm. This probably results from a fundamental lack of understanding, perhaps of the basic mathematics. This brief note presents the fundamental definitions and illustrates some of their uses.

Both dB and dBm are based upon the logarithm function. We don't use log functions with the daily frequency they saw in the past. Today, computers and hand held calculators are available for the arithmetic we perform when we insert number into an equation. We used tables of logarithms or slide rules for the calculations in the past. We needed to understand logarithms to use those tables, and even to understand the slide rule. Alas, the tools are history and so is our understanding.

The reader who has not seen this material for a while might look at an enjoyable little paper dealing with the slide rule and logarithms: Cliff Stoll, "**When Slide Rules Ruled**," Scientific American, May, 2006, pp80-87. Alternatively, review that dust covered math book or even look up logarithm, dB, and dBm in Wikipedia.

dB and dBm Definitions

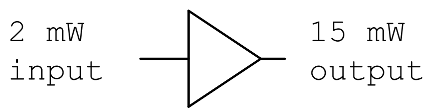
Consider first the dB: The dB is a method for comparing two powers. The formal definition is

$$\mathbf{dB = 10 \cdot Log\left(\frac{P_1}{P_2}\right)}$$

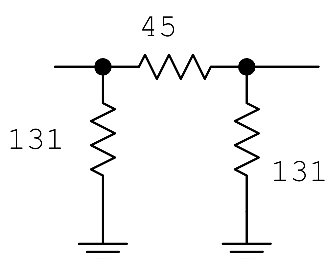
Eq. 1. Power ratio ➔ dB.

Consider an example: Roy uses a low power transmitter that runs 5 Watts output while Stan uses one that runs 4000 Watts output. They each have a similar antenna. Substituting 4000 for P1 and 5 for P2 into Eq. 1 shows us that Stan's signal is 29 dB stronger than Roy's.

A place where dB might be useful is to specify the gain of an amplifier. P1 would be the amplifier output power while P2 is the input power. The gain can be specified as a power ratio, P1÷ P2, or as the related value in dB. Consider a measurement example: A signal generator has an output of 2 milliwatts which is applied to the input of an amplifier. We then measure an output of 15 mW. Gain as a power ratio is 7.5, or 8.75 dB from Eq. 1.



An amplifier.



A “pi” attenuator.

Another place where dB is used is for attenuation. If a “pad,” or “attenuator” is built from resistors, the output power is less than the input. In this case, P1 is the input while P2 is the output, still resulting in a positive number. For example, a pad has an output that is one fifth the power that is applied to the input. The attenuation is a power ratio of 5, or 7 dB. (Be careful: the attenuation is not -7 dB. We could, however, say that the gain of the attenuator is -7 dB. One of the useful properties of the log function is that if we replace P1/P2 with the inverse ratio P2/P1, the log of the ratio, and hence, the dB value merely changes sign.)

There are many places where dB is a legitimate unit.

Now, the dBm: Consider a special case for the dB equation. For this special situation we always measure power P1 in **milliwatts** and always let P2 be one milliwatt. We will call the result the dBm. Insert these conditions into Eq. 1 to find out how many dB the power is above 1 mW.

The formal definition for dBm is

$$\mathbf{dBm = 10 \cdot Log\left(P_{mW}\right)}$$

Eq. 2. Milliwatts ➔ dBm.

Again, power in dBm is calculated with the power inside the Log function specified in milliwatts. Again, a power in dBm as a measure of how much, in dB, the power exceeds one milliwatt. We had an output of 15 milliwatts during measurement of the amplifier example used above. The output power is then, from Eq. 2, 11.76 dBm. The input power for the same amplifier measurement was 2 milliwatts, or 3.01 dBm. The difference between the two dBm levels is the gain value, 8.75 dB.

There is something special here. We have subtracted two numbers to get another number. This is the virtue of the logarithm function: Sums and differences of logarithms of numbers correspond to products or ratios of the original numbers. That was easier than multiplication or division when it was done on paper. There is a reason for the logarithm function, and there is a also a reason to use dB and dBm. (See the sidebar on page 7.6 of Experimental Methods in RF Design [ARRL, 2003] for further discussion of *dB arithmetic*.)

Or how about Stan's monster transmitter of 4000 Watts. This is 4 million milliwatts, or +66 dBm.

Gain is usually a positive number. The same is true for attenuation. In contrast, we often encounter negative dBm values. For example, one microwatt is .001 milliwatt. Hence, one microwatt is -30 dBm. Negative numbers are common when dealing with powers in dBm. Don't become cavilier about the sign, for it makes a profound different in the results.

Very small dBm values are common in RF applications. For example, a common value for the minimum detectable signal in a reasonable communications receiver with a bandwidth of 500 Hz is -137 dBm.

Testing the waters

The definitions given above are all comfortable for the fellow or gal who already understands and uses the dB and dBm definitions with confidence. But they still don't help the person who is not so confident. There is a simple, informal test that we can apply that may help: Convert the dB or dBm value back to a non-log based value and see if the result, including the related unit, makes sense.

A gain or attenuation value in dB is converted it to a simple power ratio with

$$\mathbf{Power\_Ratio} = 10^{\frac{dB}{10}}$$

Eq. 3. dB ➔ Power Ratio

For example, an amplifier specified for a gain of 13 dB will have a power ratio gain of 19.95, or about 20.

A power in dBm is converted to milliwatts with

$$\text{Milliwatts} = 10^{\frac{\text{dBm}}{10}}$$

Eq. 4. dBm➔Milliwatts

Assume, for example, that we adjust a signal generator for an indicated output of +7 dBm. The power is then 5.01 milliwatts.

Let's now consider a few test cases.

1) An experimenter built an attenuator into a piece of equipment and referred to it as having a " 3 dBm loss." The unit used is dBm, so we insert the value of -3 into Eq. 4 that converts dBm to milliwatts and find that the experimenter is trying to tell us that the pad has an output that is 0.5 milliwatts less than the input. But this does not make sense. What if the input to the pad was 0.1 milliwatt? The *calculation* would then say that the output would be -0.4 milliwatts, and power is not a negative.

Pads provide an output that is below the input by a constant fraction, or ratio. A ratio implies two numbers, which is consistent with dB rather than dBm. What if this was a pad with a 3 dB loss? Converting 3 dB to a power ratio with Eq 3 shows that the power ratio is 2, meaning that the pad has an output that is always half the input. This makes more sense.

2) An experimenter built a spectrum analyzer (yes, some folks do) and then used it to examine the output of an oscillator for use in a transmitter. He measured the level as "5 dB." The unit he applied is dB. To find if this is correct, we convert the dB value to a power ratio. Using Eq. 3, our 5 dB corresponds to a power ratio of 3.16. This means that the output is 3.16 times the input. What does this mean? What input? Is this what we were looking for? No, not really. The spectrum analyzer really measures signals in dBm. Equation 4 tells us that +5 dBm is 3.16 milliwatts, which is a result that is much more comfortable.

3) Another experimenter is working on an IF amplifier for a microwave receiver. She uses a cascade of three Mini Circuits ERA amplifiers and measures a gain of "41.1 dBm." Is this the right unit? Because it is dBm, we used Eq. 4 which converts dBm to milliwatts, with the result that the "gain is 12,882 milliwatts," which is about 13 watts. These are the wrong units. Gain should be in dB, not dBm. If we assume 41.1 dB, that converts to a power ratio of 12,882. This just tells us that the output is over 10,000 times the input, but does not say anything about how many watts are coming from the circuit. The dB unit makes sense, but the dBm one does not.

4.) An experimenter has built a UHF circuit called a Wilkinson power divider. This circuit uses transmission line sections to provide two identical outputs when driven with one source. If the circuit had no internal loss, each output would be half of the power that is applied at the input. One of many interesting properties of this divider is that the two outputs are isolated from each other. But how well are they isolated?

To evaluate this, the input was left un-terminated, a 1 milliwatt signal generator was attached to one of the outputs, and a spectrum analyzer was attached to the other output. The experimenter then described the output as 23 dBm below the input, so he specifies the isolation as 23 dBm. Does this make sense? Because the parameter used is dBm, we use Equation 4 to convert it to milliwatts. 23 dBm is just over 200 milliwatts. This can't be right. How can a passive circuit (one with no power supply and no transistors) deliver 200 milliwatts when supplied with just 1 mW? If we use the unit of dB, we convert 23 dB to a power ratio of 200. That says that the power at the opposite output port is less than that applied by a factor of 200. This is a useful circuit and a useful way to describe it.

5.) Finally, a more subtle case is presented. A receiver experimenter has built a weak signal source that he uses to align and evaluate his receiver. He put the homebuilt source in his pocket and took it to his neighbor's house where he used the resident, lab quality generator to calibrate his homebrew instrument. They listened to the two sources in a receiver, adjusting the high quality, calibrated generator until the two responses were equal. The meter on the neighbor's generator then read -109 dBm. Application of Eq. 4 tells us that this is a power of 1.26×10^{-11} milliwatts. This is a weak signal, but still strong compared to the noise that the experimenter normally encounters in his homebuilt receivers. Milliwatts is a proper and reasonable unit and dBm is properly used.

But then the subject of accuracy comes up and the two experimenters discuss it. They reason that the error should be a small fraction of the power around the observed one. They conclude that the lab generator is probably delivering a signal somewhere between -109.5 dBm and -108.5 dBm when the generator output meter reads -109 dBm. So they say that the output is -109 dBm, +/- 0.5 dBm. Is this correct? No, not quite. We already concluded that the 109 dBm was a correct use of dBm. But what about the error of "1 dBm?" Using Equation 4 to convert dBm to milliwatts suggests that this whisper of a signal has an error of +/- 1.12 milliwatt. This says that the implied error is 100 billion times the actual power.

What if the error was 0.5 dB? This is a power ratio, by Eq. 3, of 1.12. That is, the actual power is the specified 1.26×10^{-11} milliwatts multiplied or divided by 1.12. Restated, the error is +/- 12 %, an accurate signal generator. The generator power of -109 dBm, +/- 0.5 dB makes more sense. This confusion with units for errors is a very common difficulty, even in professional circles.

Summary.

dB and dBm are different units and are used for different, although related measurements. **dB relates to power ratios** while **dBm describes an absolute power.** Careful examination of the units that we use will not only avoid embarrassment, but will enhance our communications and, ultimately, our basic understanding of our circuits and measurements.

Addendum: A good reference that I found in 2015 is an applications note from Rohde & Sshwarz, "1MA98: dB or not dB?" This note is extremely detailed and complete.