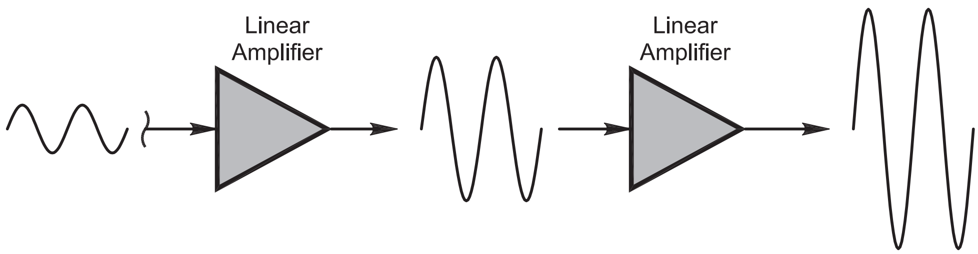
Appendix E

Decibels



Each of these amplifiers has a gain of 3 decibels (3 dB). That means the output signal is twice as strong as the input signal.

Contents

Defining the Bel

The *decibel* is one unit that you will hear used (and sometimes misused) quite often in electronics. Just what does this term mean? First we'll define the term, and then we'll take a look at some of the ways we use decibels in electronics.

You have probably recognized *deci* as the metric prefix that means one-tenth. So the unit we are really talking about here is the *bel*, and a decibel is just 1⁄10 of a bel. We often use a capital B to abbreviate *bel*. Since a lower case d is the abbreviation for deci, the proper abbreviation for a decibel is dB. The bel is named for Alexander Graham Bell. Most people remember Bell for his invention of the telephone. Bell was also very interested in working with deaf people and studying the way we hear sounds. Bell tried to invent a device that would amplify sounds, to help people with a partial hearing loss. The telephone is a result of this work.

We can hear very soft sounds, like a leaf rustling through the other leaves on a tree as it falls. We also can hear sounds that are extremely loud. A jackhammer pounding the pavement on a city street or the roar of a nearby jet engine are some examples. Some sounds can be so loud that they actually cause us pain. These painfully loud sounds can be nearly 1×10^{12} (yes, that's a million million) times louder than the soft rustling of the leaves or a quiet whisper, yet we can hear sounds within this full range.

To make the numbers easier to work with, we often use logarithms to represent the numbers on such a wide scale. We could say that our ears have a logarithmic response to sound loudness or *intensity*. The *bel* compares the loudness of two sounds with each other. One of these sounds serves as a reference for the comparison. To calculate how many bels louder or softer the second sound is, simply divide the reference intensity into the other value. Then find the logarithm of that result.

$$\text{bels} = \log\left(\frac{I_1}{I_0}\right) \qquad \text{(Equation E-1)}$$

where:

I_0 is the intensity (or loudness) of the reference sound

I_1 is the intensity of the sound compared to the reference

Use the quieter sound intensity (a smaller number) as the reference sound to get a positive value of bels. If you use the louder sound intensity as the reference sound, however, you get the same value but with a negative sign. So a positive value of bels indicates a sound is louder than the reference sound. A negative value of bels indicates a sound is quieter than the reference.

Painfully loud sounds can be as much as 1×10^{12} times louder than the softest sounds we can hear. Use that number as the ratio I_1/I_0 in Equation E-1, and calculate the range of our hearing, in bels.

$$\text{bels} = \log\left(\frac{I_1}{I_0}\right) \qquad \text{(Equation E-1)}$$

$$\text{bels} = \log\,(1 \times 10^{12}) = 12$$

We can hear sounds that differ in intensity by as much as 12 bels. Normal sounds in your home, like soft music, conversation or the TV are about 4 to 7 bels louder than the softest sounds you can hear.

Sound intensity is similar to sound power, so we can apply the bel to power levels in electronics. The bel is a rather large unit, even to compare sound intensity levels, so we normally use the decibel. It takes 10 decibels to make one bel. Therefore, the equation to compare two power levels in decibels is 10 times the equation to calculate bels.

$$\text{dB} = 10\log\left(\frac{P_1}{P_0}\right) \qquad \text{(Equation E-2)}$$

where

P_0 is the reference power level

P_1 is the power level compared to the reference

Let's look at an example to help you understand bels and decibels. Remember that we use a ratio of two power levels, which means we divide one power by a reference,

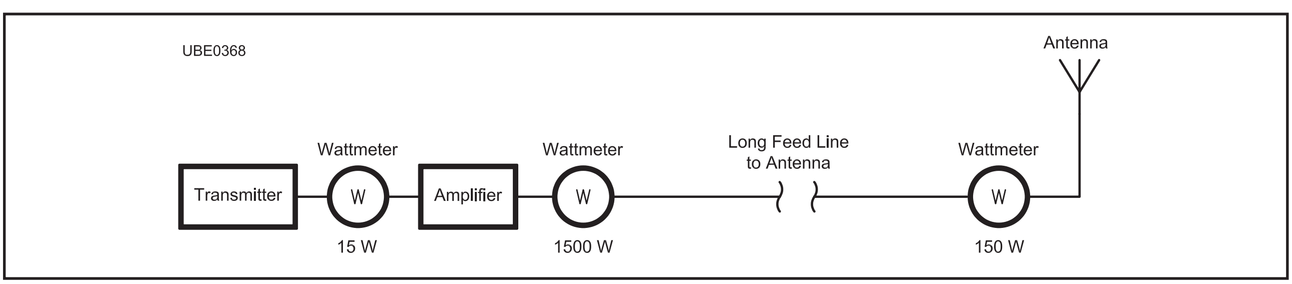


Figure E-1 — This diagram shows a power level measured at the output of an Amateur Radio transmitter. The diagram also shows power levels after the signal goes through a power amplifier and a long length of coaxial cable.

or comparison, power.

Suppose we measure the output power from an Amateur Radio transmitter, and find that it is 15 watts. If we use a power amplifier after the transmitter, and measure the power again, we measure 1500 W, as shown in **Figure E-1**. What is the gain, or power increase, provided by this amplifier? To solve this problem, we will use the 15 W power as the reference. We want to compare the amplified power with this value. Equation E-2 will help us answer the question.

$$dB = 10 \log \left(\frac{P_1}{P_0} \right)$$

$$dB = 10 \log \left(\frac{1500 \text{ W}}{15 \text{ W}} \right)$$

$$dB = 10 \log (100) = 10 \log (10^2)$$

$$dB = 10 \times 2 = 20 \text{ decibels}$$

The amplifier provides a 20 dB increase in power. This example shows how to do the calculation. In a real Amateur Radio station, we would probably use one amplifier to go from 15 to 150 watts. Then another amplifier would increase the power from 150 to 1500 watts. Each amplifier would have a gain of 10 dB, which is a more realistic figure.

Did you notice in the equations above that the log of 100, which is the log of 10^2, is 2. Log is short for logarithm, and two words that mean the same as logarithm are *exponent* and *power*. So the log of 1000 equals the log of 10^3 equals 3. What's the log of one million?

If you thought that one million is 10^6, and the log of 10^6 is simply 6, you're right! When you need to find the log of a number that's not 10, or 100, or 1000 (etc.), that's when your calculator will come in handy. Find the log of 500 on your calculator by pressing the following calculator keys:

LOG 5 0 0 =

The answer is that the log of 500 = log (500) = 2.7.

What happens if the power decreases? Well, let's look at an example and find out. We can continue with the problem above, and measure the actual power arriving at the antenna. In this station, a long length of coaxial cable connects the transmitter to the antenna. Because some power is lost in this cable, we measure only 150 watts at the antenna. This time we'll use the 1500 W amplifier output as our reference. We want to compare the power at the antenna with the amplifier power. Again, Equation E-2 helps us answer our question.

$$dB = 10 \log \left(\frac{P_1}{P_0} \right)$$

$$dB = 10 \log \left(\frac{150 \text{ W}}{1500 \text{ W}} \right)$$

$$dB = 10 \log (0.10) = 10 \log (10^{-1})$$

$$dB = 10 \times (-1) = -10 \text{ decibels}$$

The negative sign tells us that we have less power than our reference. Of course, we knew that because there was less power at the antenna than the amplifier was producing. What happened to that power? Some of the energy going through the coaxial cable changed to heat, and there may be other losses in the cable. All coaxial cables would have some loss. If you have a cable with 10 dB of loss in any reasonable length, however, it's probably no good! 10 dB of cable loss means that 90% of the power entering it is lost to heat, and that leaves only 10% at the cable output. If the loss were 20 dB (a *really bad* situation), then 99% of the power entering it would be lost to heat, and that would leave only 1% at the cable output. It would be time to change something: either move the antenna and transmitter closer together (shorter cable means less loss), or get a much better cable.

Decibels and Power Ratios

We often use decibels to compare power levels in electronic circuits. How do you find the number of decibels? First select the power you want to use as the *reference power* to which other power levels will be compared. This reference power often is the beginning power. It may be the power before the signal goes through an amplifier or through a line to an antenna. Next, divide the new power (the amplifier output power, or the power that reaches the antenna) by your chosen reference power. Now find the logarithm of that power-level ratio. Finally, multiply the result by ten. A few examples will show you how easy it is to calculate decibels.

You won't even need a calculator to find the logarithm when the ratio is a number like 10, 100, 1000 and so on! Multiples of 10 less than 1, like 0.1, 0.01, 0.001 and so on are also easy. Use your calculator as we work through a few examples. You'll soon be doing logarithms like these without it, though. Here are some simple examples.

$\log(1) = \log(10^0) = 0$

$\log(10) = \log(10^1) = 1$

$\log(100) = \log(10^2) = 2$

$\log(1000) = \log(10^3) = 3$

$\log(0.1) = \log(10^{-1}) = -1$

$\log(0.01) = \log(10^{-2}) = -2$

$\log(0.001) = \log(10^{-3}) = -3$

Let's suppose you have an amateur transmitter that operates on the 2-meter band. Your transmitter has an output power of 10 watts, but you would like a little more power to use to make contact with a distant station. An amplifier is just what you need. After connecting your new amplifier, you measure the output power again, and find it is now 100 watts. How many dB increase is this? We'll use the 10-W signal as the reference in this case. Divide 100 W by 10 W to find the power ratio.

$$\text{Power Ratio} = \frac{P_1}{P_0} \qquad \text{(Equation E-3)}$$

where

P_0 is the reference power level
P_1 is the power level compared to the reference power

$$\text{Power Ratio} = \frac{P_1}{P_0} = \frac{100\text{ W}}{10\text{ W}} = 10$$

Now find the logarithm of the power ratio.

$\log(10) = \log(10^1) = 1$

Finally, multiply this result by

$10 \text{ decibels} = 10 \times 1 = 10$

Your amplifier has increased the power of your 2-meter signal by 10 dB!

Now suppose the amplifier increased your signal to 1000 watts. Choose the reference power to be 10 W again, and divide the new power by the reference.

$$\text{Power Ratio} = \frac{P_1}{P_0}$$

$$\text{Power Ratio} = \frac{P_1}{P_0} = \frac{1000\text{ W}}{10\text{ W}} = 100$$

Find the logarithm of the power ratio.

$\log(100) = \log(10^2) = 2$

Multiply this result by 10 to find the number of decibels.

$\text{decibels} = 10 \times 2 = 20$

If we put all these steps together into a single equation, we have the definition of a decibel.

$$\text{decibels (dB)} = 10 \log\left(\frac{P_1}{P_0}\right) \qquad \text{(Equation E-4)}$$

where

P_0 is the reference power level
P_1 is the power level compared to the reference power

Use this equation to calculate the number of decibels between power levels.

You should be aware of certain power ratios, because they occur so often. For example, let's see what happens if we double a given power. Suppose we start with a circuit that has a power of 2 mW. What dB increase occurs if we double the power to 4 mW? We'll start with the basic definition of a decibel.

$$\text{dB} = 10 \log\left(\frac{P_1}{P_0}\right)$$

$$\text{dB} = 10 \log\left(\frac{4\text{ mW}}{2\text{ mW}}\right) = 10 \log(2) = 10 \times 0.3 = 3.0\text{ dB}$$

When we double the power, there is a 3 dB increase. This is true no matter what the actual power levels are. Let's look at an example with higher power levels to show that the dB increase is the same.

We measure the transmitter output power at an Amateur Radio station like the one shown in **Figure E-2**, and find that it is 10 W. Use this power as a reference power for the station. After making some adjustments to the circuit, we measure the transmitter output power again. This time we find that the output power has increased to 20 W. What is the power increase, in dB? Equation E-4 will help us answer this question.

$$\text{dB} = 10 \log\left(\frac{P_1}{P_0}\right)$$

$$\text{dB} = 10 \log\left(\frac{20\text{ W}}{10\text{ W}}\right) = 10 \log(2) = 10 \times 0.3 = 3.0\text{ dB}$$

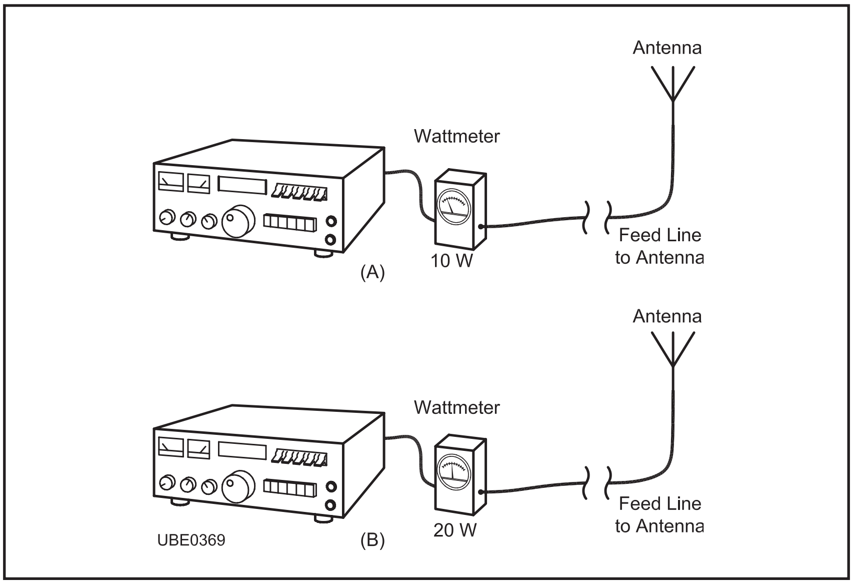


Figure E-2 — The output power from an Amateur Radio transmitter is 10 watts. After making some adjustments to the transmitter tuning, you measure the power again. Now you find the power has increased to 20 watts. The text describes how to calculate the decibel increase that occurred.

So our transmitter adjustments gave us a 3 dB increase in transmitter power.

Suppose you measured the power output from another transmitter, and found it to be 100 W. Later, after experimenting with a new circuit in the transmitter, you measure the output power as 50 W. What effect did your experiment have on the output power? What is the power change in decibels? Again, Equation E-4 will help answer this question.

$$\text{dB} = 10 \log \left(\frac{P_1}{P_0} \right)$$

$$\text{dB} \quad 10 \log \left(\frac{50 \text{ W}}{100 \text{ W}} \right)$$

$$10 \log (0.50)$$
$$= 10 \times (-0.30) = -3.0 \text{ dB}$$

Although the power levels in our two examples were much different, we still had a 3 dB change. This is an important point about the decibel. It compares two power levels. The number of decibels depends on the ratio of those levels, not on the actual power. The 3 dB value is also important, because it shows that one power level was twice the other one. Increasing a power by two gives a 3 dB increase and cutting a power in half gives a 3 dB decrease.

Whenever you multiply or divide the reference power by a factor of 2, you will have a 3 dB change in power. You might guess, then, that if you multiplied the power by 4 it would be a 6 dB increase. If you multiplied the power by 8 it would be a 9 dB increase. You would be right in both cases!

Suppose the power in part of a circuit such as the one shown in **Figure E-3** measures 5 milliwatts and in another part of the circuit it measures 40 mW. Using the 5-mW value as the reference power, how many decibels greater is the 40-mW power?

$$\text{dB} = 10 \log \left(\frac{P_1}{P_0} \right)$$

$$\text{dB} = 10 \log \left(\frac{40 \text{ mW}}{5 \text{ mW}} \right)$$
$$= 10 \log (8.0) = 10 \times 0.9 = 9.0 \text{ dB}$$

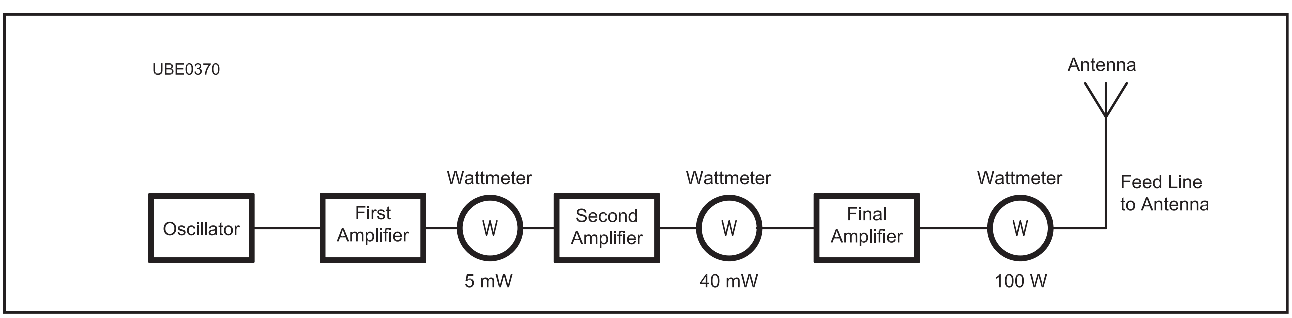


Figure E-3 — A simple amateur transmitter amplifies the signal from an oscillator and then feeds that signal to an antenna. It uses several amplifier stages. The input power to one of those stages is 5 milliwatts and the output from that stage is 40 milliwatts. The text describes how to calculate the gain of that amplifier stage.