

# Online Radio & Electronics Course

## Reading 22

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### DECIBELS

For some reason decibels are disliked by many, and misunderstood by many amateur radio operators, engineers, technicians and the like. The unit is freely used in equipment handbooks and specification sheets.

This reading begins with the human senses of sight, touch and hearing.

Early man tiptoed through the jungle listening for:

Sounds indicating something to eat.

Sounds indicating something was going to eat him!

His ears would pick out quite faint sounds. They had to, or he would starve. He also heard some very loud noises from animals bellowing, trees falling, and landslides and the like. To avoid **overloading** the information centre in his brain, our hearing mechanism accommodated these sounds into a **compressed range**. Twice as much energy in a sound does not seem twice as loud. There is a lot less energy involved in a leaf rustling, compared to a tree falling.

If our ears (and other senses) interpreted noises as a direct proportion, then to be able to hear very weak sounds, strong sounds would be more than deafening! They would be painful, perhaps lethal.

Very early in the development of amplifiers, it was realised that the units for comparing output powers involved, must match the hearing of the operator or listener.

**For a sound to be perceived twice as loud, requires an increase in the power at the source of about 10 times.**

#### Some Examples:

For sound to seem twice as loud, the power increases 10 times.

For sound to seem twice as loud again, the power must increase 10 times.

→ The total increase so far is 100 times.

To seem twice as loud once more, the power increases by 10 times again.

→ The total power increase is now 1000 times.

You may see that this system of describing the power of a sound is very cumbersome. This could be written much more conveniently:

To seem twice as loud - increase the power by  $10^1$ .

To seem twice as loud again - increase the power by  $10^2$ .

To seem twice as loud once more - increase the power by  $10^3$ .

( $10^1 = 10$ ,  $10^2=100$ ,  $10^3=1000$ )

We can see that a convenient unit to use is the **index of 10**. This unit is called the **Bel**, after Alexander Graham Bell.

The Bel is a unit of **comparison**. We use it, just like with sound levels, to compare current, voltage, and power levels.

In mathematical terms the Bel is:

$$\text{BEL} = \text{Log} \left( \frac{P_1}{P_2} \right)$$

Where  $P_1$  and  $P_2$  are the two powers levels to be compared.

The Log of a number is the power, or index of, to which 10 must be raised to get that number.

## LOGARITHMS

The mathematical shorthand to indicate that the Log of a number is to be found, is  $\text{Log}(N)$ , where 'N' is the number whose logarithm is to be found. The base for the logarithm used with the Bel is 10. Other bases can be used but we are not interested in these in this course. If there is any possibility of confusion in texts about which base is being used, the shorthand is written as  $\text{Log}_{10}(N)$  and  $\text{Log}(N)$  for common (base 10) and natural logarithms respectively.

**Common logarithms**, which express a number as a power of the base 10, are the ones that interest us. Natural logarithms express a number as a power of the base 'e' where 'e' equals 2.71828. For the AOCPE exam, you need only concern yourself with the use of common logarithms (base 10). Throughout the rest of this reading you can consider  $\text{Log}(N)$  to mean  $\text{Log}_{10}(N)$ .

From the laws of indices it follows that we can say:

$$\begin{aligned} 10^2 &= 100 \quad \text{so } \text{Log}(100) \text{ is } 2 && (10 \times 10 = 100) \\ 10^3 &= 1000 \quad \text{so } \text{Log}(1000) \text{ is } 3 && (10 \times 10 \times 10 = 1000) \end{aligned}$$

$$\begin{aligned} 10^{-1} &= 1/10^{\text{th}} \quad \text{so } \text{Log}(0.1) \text{ is } -1 \\ 10^{-2} &= 1/100^{\text{th}} \quad \text{so } \text{Log}(0.01) \text{ is } -2 \end{aligned}$$

What is the logarithm of 10000? In other words, to what power must 10 be raised to give 10000? The answer is 4 since  $10^4$  is  $10 \times 10 \times 10 \times 10 = 10000$ .

The common log of a number between 1 and 10 lies somewhere between 0 and 1. The common log of a number between 10 and 100 lies between 1 and 2. The common log of a number between 100 and 1000 lies between 2 and 3.

To find out these 'in between' logarithms it was once necessary to look up large tables (books actually) of logarithms. Fortunately, most calculators have a 'Log' key. **Try the following numbers on your calculator:**

$\text{Log}(10)=1$ ,  $\text{Log}(50)=1.698$ ,  $\text{Log}(250)=2.3979$

Your calculator should have a "Log" key. Enter 10 into the display and press 'Log' and you should get 1. Enter 50 into the display and press 'Log' and you should get 1.698.

Finding the Antilog of a number converts it back to the original number. On most calculators, an antilog is found by entering the number into the display and then pressing "INV" and then "Log". Try the following:

$$\begin{aligned}\text{Antilog of } 2 &= 10^2 = 100 \\ \text{Antilog of } 3 &= 10^3 = 1000 \\ \text{Antilog of } 1.5 &= 10^{1.5} = 31.622\end{aligned}$$

For example, to find the Antilog of 2 – enter 2 into the display and press 'INV' then 'Log' and your display should read 100.

Logarithms are very useful in radio work. Many test and measuring instruments have their scales calibrated logarithmically to enable a greater dynamic range of measurement to be displayed on one scale.

Dynamic range means the range between the lowest (weakest) and highest (strongest) level.

The 'S' meter on a receiver has (or should have) a logarithmic response.

## BACK TO THE BEL

If  $P_1$  is 30 watts and  $P_2$  is 2 watts (this is a change in power from 2 to 30 watts which is a numerical increase of 15 times – 30 divided by 2 is 15 ) then this change represents  $\text{Log}(30/2) = \text{Log}(15) = 1.1761$  Bels (try it).

The Bel as a unit is too large. It is more convenient to use one tenth of a Bel and call it a **decibel** or just dB.

$$10\text{dB} = 1 \text{ Bel.}$$

The formula you will always use for calculating the difference in **power** levels in decibels is:

$$\text{dB} = 10\text{Log} \left( \frac{P_1}{P_2} \right) \quad \text{You should remember this formula.}$$

An increase in power level of 15 times is a change of 11.76 dB (as we calculated above but multiplied by ten to convert it to decibels).

So, a change of 11.76 dB is an increase of 15 times. For example:

- From 2 watts to 30 watts – is 11.76 dB.
- From 2 milliwatts to 30 milliwatts – is 11.76 dB.
- From 10 watts to 150 watts – is 11.76 dB.

A **decrease** rather than an increase, is shown by adding a minus sign. A decrease from 15 watts to 1 watt (a decrease of 15 times) is a change of -11.76 dB. To put it another way, 1 watt is 11.76 dB below 15 watts.

## USING DECIBELS WITH VOLTAGE AND CURRENT

We know that power is  $E^2/R$  or  $I^2R$ , so **provided the input and output impedance** are the same (and they normally are and will be for exam purposes, just remember for the future, that this explanation assumes the above) then:

$$P_1/P_2 = E_1^2/E_2^2 = (E_1/E_2)^2 = I_1^2/I_2^2 = (I_1/I_2)^2$$

What this means is that to **express a change between two voltages or two currents**, the formula must be modified to have a 20 in it rather than a 10.

$$\text{dB} = 20 \text{Log} \left( \frac{E_1}{E_2} \right)$$

$E_1$  and  $E_2$  are the two voltages that we want to express as a change in decibels.

$$\text{dB} = 20 \text{Log} \left( \frac{I_1}{I_2} \right)$$

$I_1$  and  $I_2$  are the two currents that we want to express as a change in decibels.

As an example, suppose a signal going into the input of an amplifier has a level of 2 volts. At the output of the amplifier, the signal has a level of 50 volts. What is the voltage gain of the amplifier in decibels?

$$\begin{aligned} \text{dB} &= 20 \text{Log} ( E_1 / E_2 ) \\ \text{dB} &= 20 \text{Log} ( 50 / 2 ) \\ \text{dB} &= 20 \text{Log} ( 25 ) \\ \text{dB} &= 20 \times 1.3979 \\ \text{dB} &= 27.95 \end{aligned}$$

The amplifier has a voltage gain of approximately 28 dB.

Remember to use **“20”** in the formula for voltage and current, and **“10”** for power. Suppose an amateur station has an output power of 25 watts. The operator connects a power amplifier to the transmitter which amplifies the power to an antenna from 25 watts to 200 watts. What is the gain of the amplifier in decibels?

$$\begin{aligned} \text{dB} &= 10 \text{Log} ( P_1 / P_2 ) \\ \text{dB} &= 10 \text{Log} ( 200 / 25 ) \\ \text{dB} &= 10 \text{Log} ( 8 ) \\ \text{dB} &= 10 \times 0.903089 \\ \text{dB} &= 9.03 \end{aligned}$$

The amplifier on the transmitter has a power gain of approximately 9 dB.

Decibels do *not* measure an absolute value. Decibels are a measure of the ratio of two levels. It is ridiculous to say the power or voltage (or anything else) is so many decibels. Such a statement is meaningless.

Amplifiers increase power levels, so we can say an amplifier has a gain of XX decibels. Attenuators reduce power so we can say they have a loss of XX decibels. Antennas can increase transmitter power by focusing the radiation into a narrow beam – much like you can increase the water pressure on a hose by placing a nozzle on it. So antennas have a gain expressed in decibels.

Measurements such as volts, amps and watts are absolute measurements.

## ABSOLUTE MEASUREMENTS USING DECIBELS

So far we have dealt with dB as a method of comparing two values. However, there are some related units which can be used with the dB to refer to **absolute values**. To do so, a reference point must be given, such as 1 watt. If the reference level is 1 watt, the unit is called the dBW. So 3dBW is 3db above a watt, and -3dBW is 3dB below a watt.

You do not need to know this for exam purposes, however you will come across it, and it is worthwhile to know this for a more complete understanding of decibels.

By far the most common absolute and useful unit used in radio and communications is the dBm, which is the number of decibels above or below one milliwatt.

$$\text{dBm} = 10\text{Log} \left( \frac{P}{1\text{mW}} \right)$$

For example, what is the power of a 50 watt radio transmitter expressed in dBm?

To express 50 watts in dBm we use the equation above:

$$\begin{aligned} \text{dBm} &= 10\log(50/1\text{mW}) \\ &= 10\log(50000) \\ &= 46.98 \text{ dBm (usually rounded to 47 dBm)}. \end{aligned}$$

This is a good figure to remember as many transmitters are 50 Watts. Now, a doubling of power is an increase of 3 dB, which means 50 dBm is 100 Watts, or 44 dBm is 25 Watts. Remember, if you **increase power by 3 dB you double the power**. If you **decrease power by 3 dB you halve the power**.

Another commonly used unit is decibel relative to a volt or a microvolt. By now you should have the idea. To express something in decibels relative to a volt dBV, you place 1 Volt in the denominator. To express decibels relative to a microvolt dBuV, you place 1uV in the denominator of the equation.

Below is the formula for expressing something in decibels relative to a volt.

$$\text{dBV} = 20\text{Log} \left( \frac{E}{1\text{Volt}} \right)$$

Remember, if you are using voltage or current multiply the log by **20**, for power multiply the log by **10**.

A decibel is a ratio unless it is relative to something. Radio communications hobbyists will often use decibels without a ratio, which is fine as it is meant to be used either way. Just remember that you can't say, for example, the transmitter power is 30dB - this is a nonsense statement. You would have to say 30 dB higher or lower than what it was. You could say, I am going to decrease the transmitters power by 3dB (-3dB). Shortly I will give you an example of a radio system using decibels, and I am sure you will then see the advantages. Though this method is not popular with Amateur Radio operators it is used by everyone else.

For the exam you will need to know the basic equations to express either a voltage ratio or a power ratio in decibels. You may be asked what an increase or decrease of XdB means.

For example, we have said that an increase in power by a factor of 2 is 3 dB, so how do we convert 3db back to a ratio ie. 2.

$$\text{dB} = 10\log(\text{ratio})$$

This formula can be transposed in terms of the ratio  $P_1/P_2$

$$(\text{ratio}) = \text{Antilog}(\text{dB}/10)$$

Let's try it for 3 dB:

$$(\text{ratio}) = \text{Antilog}(3/10)$$

(ratio) = Antilog(0.3) Enter 0.3 into your calculator and find the antilog (usually 'INV' 'LOG') and you get 2.

So we have worked backward to show that 3dB is an increase of 2 (two times) while -3dB is a halving.

Do remember for voltage or current use 20 and not 10 – I know I harp on this BUT it is a very common mistake made by many students.

The examiner will not expect you to do this calculation. Though it is in my view the easiest way. What the examiner will expect is for you to know some common power and voltage/current ratios expressed in dB.

Table 1 below has the most important ratio's expressed in decibels.

Power ratio	Decibels	Power ratio	Decibels
One thousandth	-30	One eighth	-9
One hundredth	-20	On quarter	-6
One tenth	-10	One half	-3
Unity	0	Unity	0
Ten times	+10	Twice	+3
One hundred times	+20	Four times	+6
One thousand times	+30	Eight times	+9

Table 1.

This table is power ratios (not voltage or current).

So what is an increase in power of 5 times?

We can look at the table and see that 10 times is +10, and halve it (-3dB); or 5 times is 10dB - 3dB = 7dB.

I would much prefer if you could remember the two basic equations for power and voltage/current. I think it is easier to convert 5 times as a power ratio to dB by doing:

$$10\log(5) = 6.989 \text{ dB}$$

Much simpler I think, than remembering tables.

A voltage is increased from 1 to 100 volts, what is the change expressed in decibels?

$$20\log(100) = 40 \text{ dB}$$

By now you are probably wonder why bother with all this decibel stuff. Well, its sort of like metric and imperial - once you get used to it, it is just so much easier. Test equipment is frequently calibrated in decibels. How do you measure antenna gain (or loss)? In decibels of course. A filter connected to you transmitter has a loss expressed in decibels. The list goes on and on. For me, saying my transmitter power is +50dBm is just the same as saying 100 watts, and decibels are more realistic. Increasing a transmitters power from 100 Watts to 120 Watts is insignificant. It only sounds significant because 120 sounds a lot more than 100, after all it is 20 Watts more! It is not significant at all, but for some it gives a warm cosy feeling!

Here is an example of the use of decibels. Refer to the block diagram in figure 1, of a transmitter and receiver system.

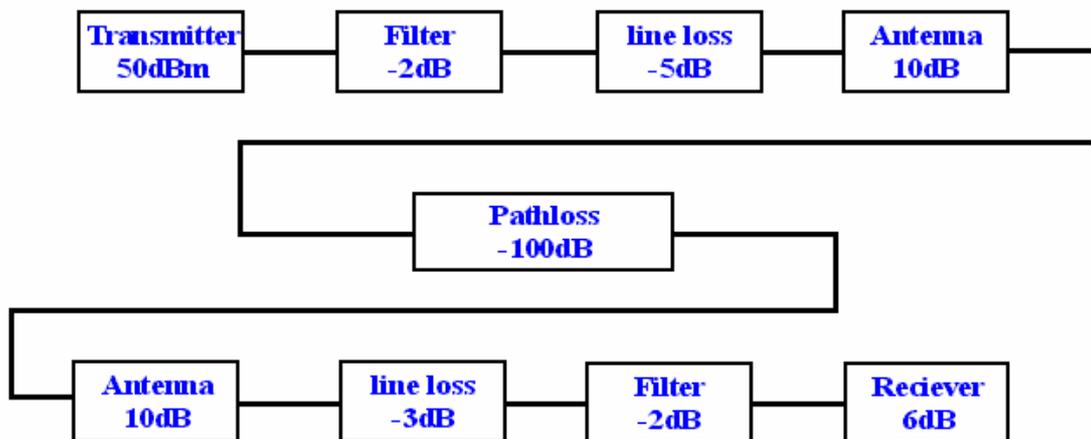


Figure 1.

The diagram shows an entire transmitter receiver system. The pathloss block represents the radio propagation path loss. Line loss (coax or whatever) is shown for the receiver and transmitter. Filter losses in dB (it's written on them) are also shown. The receiver has a 6dB gain preamplifier in it. The antenna gains are shown. The transmitter power is shown in dBm (100 watts). Now, without working in decibels, if I were to ask you what the received power was, this would be a nightmare.

What is the power after the 6dB amplifier in the receiver?

Just simply add and subtract.

$$50-2-5+10-100+10-3-2+6 = -36\text{dBm.}$$

Was that easy? -36 dBm is a strong signal while -120dBm is verging on a noisy signal.

In summary, I hope I have helped you understand the value of the decibel.

For the exam:

$$\text{Power: dB} = 10\log(P_1/P_2)$$

$$\text{Voltage or current: dB} = 20\log(\text{the voltage or current ratio})$$

Make sure you know how to convert a ratio expressed in decibels into a numeric ratio (this is an AOCB topic).

Both the NAOCP and AOCB exams are not very mathematical. For AOCB you need a calculator but the math is not hard, particularly with the experience you gain in this course. In the NAOCP exam the calculations always can be worked out in your head. I suggest a calculator anyway as it helps with the self-doubt of mental calculations that is exacerbated under exam conditions.

### Further reading.

Jerry Bartachek KDOCA has written a very good article "Decibels without a calculator". You will find this in the supplementary downloads section of the web site <http://radioelectronicschool.com>. Jerry has even provided a handy pocket chart. The article is placed on the site with Jerry's permission.

End of Reading 22.

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