Lesson 8

DECIBELS AND VALVES

ACMA Syllabus February 2024 Chapter 2.7

Contents

Decibels

The first time most people hear the expression dB is in relation to sound. Looking at a noise chart, traffic is quoted at 70 dB (this really is 70 dB SPL (sound pressure level). I checked with a friend and her interpretation of this 70 dB value is that noise is measured in units of dBs. That is a fair assumption.

Most new amateur operators next encounter the dB while preparing for their Foundation licence. This is where some confusion can start. How can the measurement of noise be used to also measure electronics such as voltage and amplifier gain? A good question.
Let us look at the dB. Firstly, some very important facts about dBs.

1. The dB is a ratio of one level against a second level. More to come about this.
2. The measuring points for the dB levels must be at the same impedance / resistance.

Origin

The original unit was the Bel, in honour of Alexander Graham Bell, and was developed by Bell Telephone Laboratories to compare losses in telephony cables in the 1920s. The unit the Bel was found to be too large so the decibel (dB), meaning one tenth of a Bel, was implemented.
The dB is based on the logarithmic scale so that a large range of ratios can be represented by a convenient number. Example is that 100 dBW may be clearer than "10 billion times greater".
Using the numbers as a logarithm, to the base 10, also makes multiplication and division easier with a series of gains or losses.

The decibel is not an SI unit but follows the SI convention where the d is lowercase as deci- and the B is capitalized.

Logarithms

Quick rehash on logarithms (logs).
Logarithms are another way of thinking about exponents.

(1) $\text{Log}_b(a) = c$ or $b^a = c$ Both equations describe the same relationship.

b is the base. The base for any decibel calculation I always 10.

a is called the argument.

c is the exponent

For example, we know that 10 raised to the 2nd power is 100.
Writing this as per formula (1) above

$\text{Log}_{10}(100) = 2$ or $10^2 = 100$

Antilogarithms or antilogs

Antilogs are the opposite/ undoing of logs. Using the above example, $\text{Log}_{10}(100) = 2$, the antilog of 2 to the base 10 is 100.
$\text{Log}_{10}(100) = 2$ or $10^2 = 100$

Summary

For a logarithm, “What is the power I need to raise 10 too so it equals 100?”
$\text{Log}_{10}(100) = 2$ or $10^2 = 100$ Logarithm of 100 is 2

For an antilog, “What is the number I get if I raise 10 to the power of 2?”
Antilog of 2 = 10^2 = 100 Antilog of 2 is 100

Formulae

Power

$$q = 10\ Log\ (\frac{power\ out}{power\ in})$$

Example: An amplifier has an output of 100 w with an input of 1 w, what is the gain in dB?

q = 10 x Log $(100/1)$

= 10 x Log 100

= 10 x 2

= 20dB The gain of the amplifier is 20dB.

Example: An amplifier has an input of 1 w and a gain of 20dB. What is the output?

20dB = 10 x Log X/1

20/10 = Log x /1

2 = Log x/1 Log when transferred to the other side becomes an antilog.

Antilog 2 = x/1

100 = x / 1

100 x 1 = x

Output = 100 W

Voltage

$$q = 20\ Log\ (\frac{voltage\ out}{voltage\ in})$$

Example: An amplifier raises a signal from 3 V to 13 V, what is the gain in dB?

q = 20 x Log (13 / 3)

= 20 x Log 4.33

= 20 x 0.636

= 12.72 db

Example: An amplifier has an input of 3 V and a gain of 12.72 dB. What is the output voltage?

12.72 = 20 x Log (x / 3)

12.72 / 20 = Log (x / 3)

0.636 = Log (x / 3)

Antilog 0.636 = x / 3

4.32 = x / 3

4.32 X 3 = x

= 12.975 V (Slight round error)

Reference Points

There are many reference points regularly used for decibel comparisons as shown below. We will focus on the gain or loss in power and voltage. Decibels can be positive for gain or negative for loss.

The examples are interesting. The figures in both examples are the same with a ratio of five yet the dB results differ.

Why are the formulae different? The dB was originally defined with respect to power, not amplitude. Looking at Ohm's law, voltage and current can be calculated easily from a known resistance (E=IR). The power formulae with relation to resistance are more complex ($P=E^2/R$ or $P=I^2R$) so the squaring of the E or I need to be accounted for in dB formulae.
This means that conversions of voltage and current ratios to dBs must square the amplitude. As shown in Fig, 1 the factor of twenty is used in amplitude dBs and the factor of ten is used in power dBs.

Plotting the numbers visually requires a logarithmic graph. A semi log graph is reproduced at Figure 2, which provides a quick reference without doing complex maths.

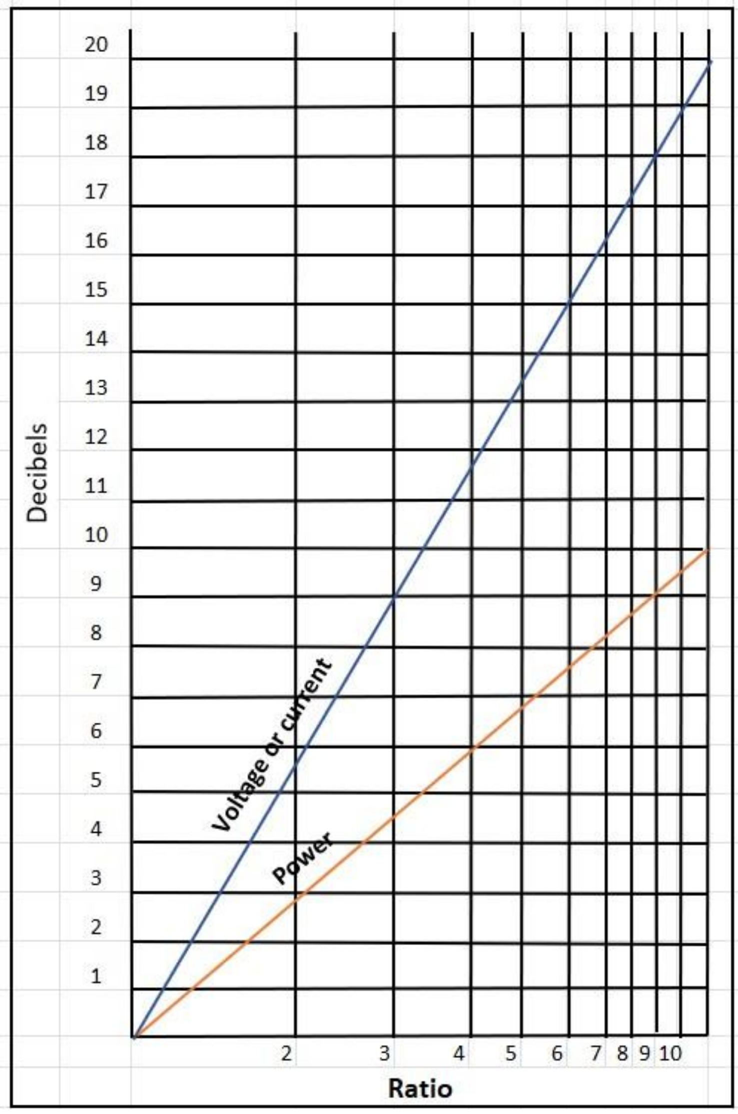

Figure 2: Approximate Decibel Graph showing power and amplitude lines.

Using the previous numbers, we see that in both cases the ratios are 5 (10W to 2W and 10V to 2V). Using figure 2, plot the dB levels on the graph. Follow the line up from the ratio of 5 till it meets the voltage / current line. Follow the line across to the left and we see this is a gain around 15 dB. This would be a loss and equal to approximately – 15 dB. Not highly accurate but is a handy reference.

If an article quotes a 6 dB power gain, you can use the graph and find this is an increase of three times.

Decibels	Ratios	
	Power	E or I
1	1.2589	1.122
2	1.5849	1.2589
3	1.9953	1.4125
4	2.5119	1.5849
5	3.1623	1.7783
6	3.9811	1.9953
7	5.0119	2.2387
8	6.3006	2.5119
9	7.9433	2.8184
10	10	3.1623
11	12.589	3.5481
12	15.849	3.9811
13	19.953	4.4668
14	25.119	5.0119
15	31.623	5.6231
20	100	10
26	398.11	19.953
30	1000	31.623
40	10000	100
50	10000	316.23
60	1000000	1000
70	10000000	3162.3
80	100000000	10000
90	1000000000	31623
100	10000000000	100000

Figure 3: Decibel Table.

Figure 3 provides a more detailed listing of dB equivalents and demonstrates the benefit of using dB over the longer numbers.

Again, using the numbers from Figure 1, plotting the power ratio of five gives level of 7 dB. While the amplitude ratio of five gives a dB level of 14 dBs.

Base Levels

In the first fact, I stated that dB is a ratio. There are many dB measurements with prescribed base level reference points. I selected only a few examples, and they are listed in Figure 4.

Term	Reference Base
dB SPL	dB SPL (sound pressure level) – approximately the quietest sound a human can hear.
dBV	dB(V_{RMS}) – voltage relative to 1 volt
dBμV	Voltage relative to 1 microvolt
dB(μV/m)	Electric field strength relative to 1 microvolt per metre
dBm	dB(mW) – power relative to 1 milliwatt.
dBW	dB(W) – power relative to 1 watt.
dBk	dB(kW) – power relative to 1 kilowatt.
dBi	dB(isotropic) – the gain of an antenna compared with the gain of an isotropic antenna.
dBd	dB(dipole) – the gain of an antenna compared with the gain a half-wave dipole antenna. 0 dBd = 2.15dBi
dBC	Noise level relative to carrier power in a transmitted signal.

Figure 4: Example of Decibel base levels.

If a gain of 15 dBm was quoted as an example. Referencing Figure 4, dBm is referenced to 1 milliwatt. Using Figure 2 or Figure 3, a 15 dBm gain is 31 times greater or approximately 31 mW.

Practical Examples

TH3 Jnr Yagi — The Yagi is rated as having a gain of 5.8 dBd (avg). This means the ratio between a dipole and the Yagi will provide a gain of 5.8 dB or nearly four times better than a dipole. (dBd is the antenna gain relative to a dipole)

ICOM IC-7300 — The receiver has a built-in three-step RF attenuator (6, 12 and 18 dB). This refers to signal voltage levels and means the attenuator can drop the levels by 2, 4 or 8 times.

Kenwood TS-480 — Carrier Suppression is more than 40 dB (SSB). This refers to the suppression of the carrier by 100 times.

Find more references and have a look at the ratios associated with these numbers.

Valves

JJ Thomson, a scientist, discovered in 1897 that electrons flowed from the negative terminal (cathode) to the positive terminal (anode) in a vacuum. The transfer of electrons in the vacuum is termed thermal emissions.

In 1904, the English physicist John Ambrose Fleming built the first practical vacuum tube termed the ‘Fleming valve’, and this is the forerunner of all vacuum tubes, which dominated the electronics industry for 50 years.

Valves go by various names.

- Valves
- Tubes
- Vacuum tubes
- Thermionic valve
- Bottles

The term ‘valve’ is mostly used in British equipment and the term ‘tube’ is mostly used in American equipment.

The basis of the valve is that electrons flow from the heated cathode to the anode, which are separated and placed in a vacuum chamber. This is a diode. Now, if you can control or vary the flow of electrons between the cathode and anode, you have an amplifier. Figure 1.

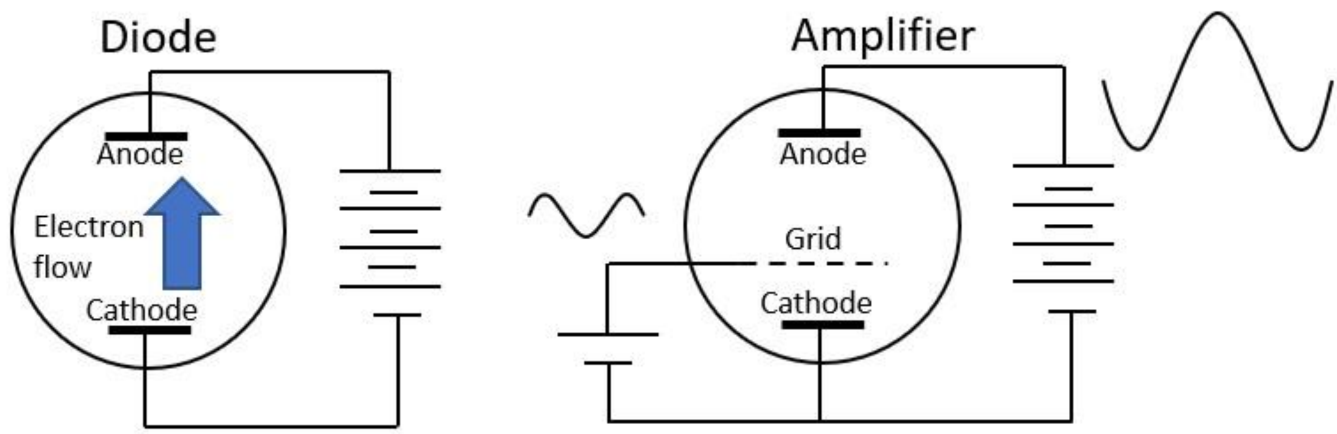

Figure 1: Valve elements.

I pulled three random valves from my old dust covered valve box. Figure 2.

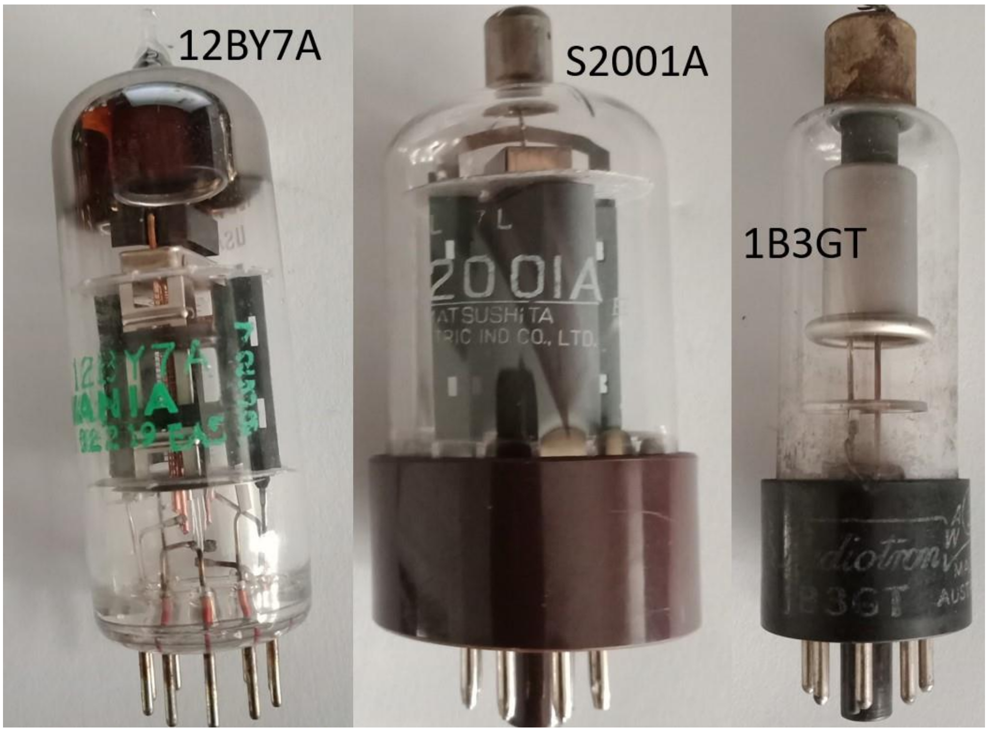

Figure 2: Valves.

In the beginning, vacuum tubes (valves) were triodes, three element valves. These had a cathode, grid, and anode. Valve improvements added additional elements to make a pentode (five element) valve. There are many variations of valves, and these can be found on the internet. The pentode is common in amateur radio uses.

Not all valves are wired or manufactured the same. The material used for the construction of the valve elements also impacts the efficiency and application of the valve.

The elements of a pentode valve are listed below.

- Anode or Plate is the collection point for electrons flowing through the valve.
- Suppression Grid is added to reduce secondary electron emissions from the anode.
- Screen Grid was added to improve the efficiency of triode valves.
- Control Grid, or Grid, controls the flow of electrons from the cathode to the anode.
- Cathode is the originating source of electrons.
- Heater. The Heater, or Filament, is not included in the element count but is required in most valves.

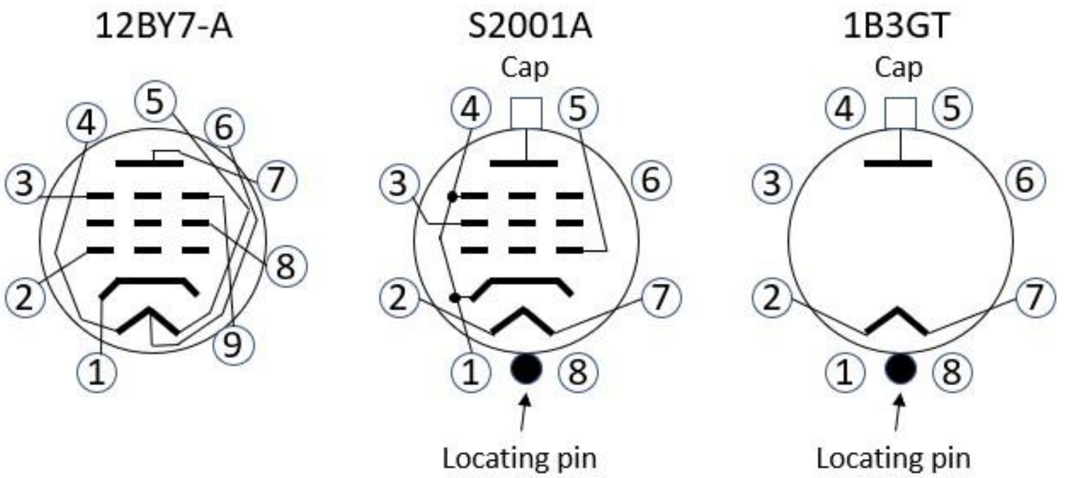

Figure 3: Valve symbols.

12BY7A

This is a medium-low gain pentode valve used in amplifiers and early television receivers. The valve symbol is shown in Figure 3. The 12BY7A doesn't use a base locating pin to orient the valve correctly. This is achieved by the pin spacing on the base.

- Pin 1 Cathode
- Pin 2 Control grid
- Pin 3 Suppression grid
- Pin 4 Heater
- Pin 5 Heater
- Pin 6 Heater tap
- Pin 7 Anode
- Pin 8 Screen grid
- Pin 9 Same as Pin 3

S2001A or 6146B

This is a common power output pentode valve used in older amateur radio transceivers from Yaesu, Kenwood, Collins, et al.

The characteristic of the valve depends on the application so consult a datasheet for more information. The valve symbol is shown in Figure 3.

- Pin 1 Cathode and suppression grid
- Pin 2 Heater
- Pin 3 Screen grid
- Pin 4 Same as Pin 1.
- Pin 5 Control grid
- Pin 6 Same as Pin 1.
- Pin 7 Heater
- Pin 8 Not connected.

1B3GT

This is a high voltage diode used in old black and white televisions and now usually found in museums. The valve symbol is shown in Figure 3. I include this valve to demonstrate these components prior to semiconductors.

The peak inverse voltage for this valve is 30,000 V. The Radio Corporation of America (RCA) datasheet for the 1B3GT dated Nov 1949 states that due to the high voltages involved with this diode, it should be shielded as it can produce "soft x-rays" that are not good for one's health.

Resurgence

The use of the valve has not died out with the introduction of the transistor. Articles suggest a large portion of the current valve production is used in audio and guitar amplifiers. Further details about this can be found at www.effectrode.com/knowledge-base/vacuum-tubes-and-transistors-compared/

Large vacuum tubes are still used in high power amateur and commercial transmitter applications.

Fingers Beware

Caution must be employed when working with vacuum tubes. The cathode is heated to encourage the flow of electrons. Tubes can be hot to touch, 200º C, and the heating elements can be seen to glow. The anode is at a high voltage of around 200 - 700 VDC or higher, and the current flowing though the circuit can be lethal. Capacitors utilised around operating valves can store a charge for a long period. Carefully discharge any exposed anode terminals (on top of the valve) to ground before removing the valve.

Vacuum tubes come in all sizes and shapes and have various names such as vacuum tube, valve, tube and bottle, to name a few. I am sure there are also some derogatory names from people who failed to be careful.

Interesting Note

A neon light is basically a valve diode filled with an inert gas. The colour of the light is determined by the gas used.

Valve Gain

The amplification factor is represented by the Greek letter Mu (μ).

$$\mu = \frac{\Delta E_b}{\Delta E_e}$$

μ = amplification factor
Eb = plate voltage
Ee = grid voltage.

Go to Lesson 8 questions.