Number #49: AC METER SCALES:
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While writing a recent ***Heathkit of the Month*** article I spent a little time exploring the meter scale on the Heathkit IM-38 AC Voltmeter. Examining a Hewlett Packard HP-400C I noticed that the meter scale was set up identically, as were the scales on the AV-2 and AV-3 AC VTVMs. These meters all use the same 1 : 3 range step as shown in table I, the Hewlett Packard meter having two additional ranges at the low end.

Each meter also has a decibel scale that starts at -12 dB and extends to +2 dB. This scale starts a bit below 20% of full scale and extends almost to the full-scale point. If the dB scale was continued downward it would quickly become too compressed to read.

A 10-fold increase in voltage is a change of 20 dB and looking at table 1 we see that this is the case with these AC meters: The one-volt range is 0 dB and the ten-volt range adds 20 dB; also the three-volt range adds 10 dB and the 30 volt range adds 30 dB. However, this implies that 10 dB should be an increase of 3 which is not quite accurate. Let's calculate what 10 dB as a voltage ratio really is:

From the ARRL Handbook we know:

$$10\text{ dB} = 20 \log (V2 / V1)$$

$$0.5\text{ dB} = \log (V2 / V1)$$

but we want to solve for (V2 / V1) so we need to know the relationship:

$$A = \log (B) \qquad \text{so:} \qquad B = 10^{A}$$

Substituting, we get:

$$(V2 / V1) = 10^{0.5\text{ dB}}$$

$$= \sqrt{10} \text{ [square root of ten]}$$

$$= 3.162$$

Figure 1: Heathkit AV-3 Meter Scale

Look again at the meter scale of Figure 1. Notice that the two scales do not stop at the same place. If the 0 - 3 scale were extended to 0 - 3.162, it would stop inline with the 10 on the 0 - 10 scale. Multiplying 3.0 by 3.162 yields 9.49 which is where 3 aligns to on the 0 - 10 scale. The meter scales are thus in reality 0 - 10 and 0 - √10 [the square root of ten].

Range	Decibels	HP-400C	IM-38*
1.0 mV	– 60 dB	√	–
3.0 mV	– 50 dB	√	–
10 mV	– 40 dB	√	√
30 mV	– 30 dB	√	√
100 mV	– 20 dB	√	√
300 mV	– 10 dB	√	√
1.0 V	0 dB	√	√
3.0 V	+ 10 dB	√	√
10 V	+ 20 dB	√	√
30 V	+ 30 dB	√	√
100 V	+ 40 dB	√	√
300 V	+ 50 dB	√	√
* Also Heathkit AV-2, AV-3 and IM-21			

Since the decibel is a ratio, there has to be a reference that corresponds to zero dB. Probably the most common one used in audio measurements today is the dBm, which is one milliwatt into 600 ohms. The reference is almost always disclosed on the instrument, often right on the meter scale, as in the the case of Figure 1.

Using Ohm's power law, the AC voltage is calculated for the 1 milliwatt 600 ohm standard as:

$$V = \sqrt{(W \times R)}$$
$$= \sqrt{(0.001 \times 600)}$$
$$= \sqrt{(0.6)}$$
$$= 0.775 \text{ volts}$$

Again, looking at Figure 1, notice that the 0 dB mark corresponds with 7.75 on the 0 - 10 scale. Don't let the decimal point confuse you. In table I the 0 dB range uses the 0 - 10 scale for 0 - 1 volt range.

Besides the 1 mW 600Ω standard, many other dB standards exist; hams might be familiar with the ones relating to RF energy or antennas. Two other popular audio standards exist. The first is the volume unit[1] (VU) used in recording levels. It is 1.228 volts 600 ohms (2.512 mW) and is 4 dB higher than the 1 mW 600Ω standard. The second standard was used for many years by the telephone company. It is 6 mW 500Ω (1.732 [√3] volts), and is 7.78 dB greater than the 1 mW 600Ω standard.

Reading a different dB standard on an AC meter is simple. You only need to add or subtract a given dB value corresponding to that standard. For instance, to use the IM-38 to measure an AC voltage in dB at the 6 mW 500Ω standard using the 1 mW 600Ω standard, you first make the measurement in dB and then subtract 7.78 dB to convert. The original Heathkit V-1 VTVM voltmeter, the second kit Heathkit produced, used the 6 mW 500Ω standard. It was not until the V-6 that Heathkit switched to the 1 mW 600Ω standard.

Heathkit's Standard VTVM AC Scales:

After examining the meter scales on AC VTVMs, I assumed that the same held true for the many regular DC-AC-Ohms VTVMs that Heathkit also produced over the years.

The first meter I looked at was an IM-13. Unlike the AC VTVMs the IM-13 AC ranges go from 0 - 1.5 VAC to 0 - 1,500 VAC on 0 - 15 and 0 - 50 scales; see Figure 2. If the scales are designed to be 10 dB steps then the 15 should be aligned just under halfway between 47 and 48 on the 0–50 scale; which it is.

$$Scale_{50} = Scale_{15} * \sqrt{10}$$

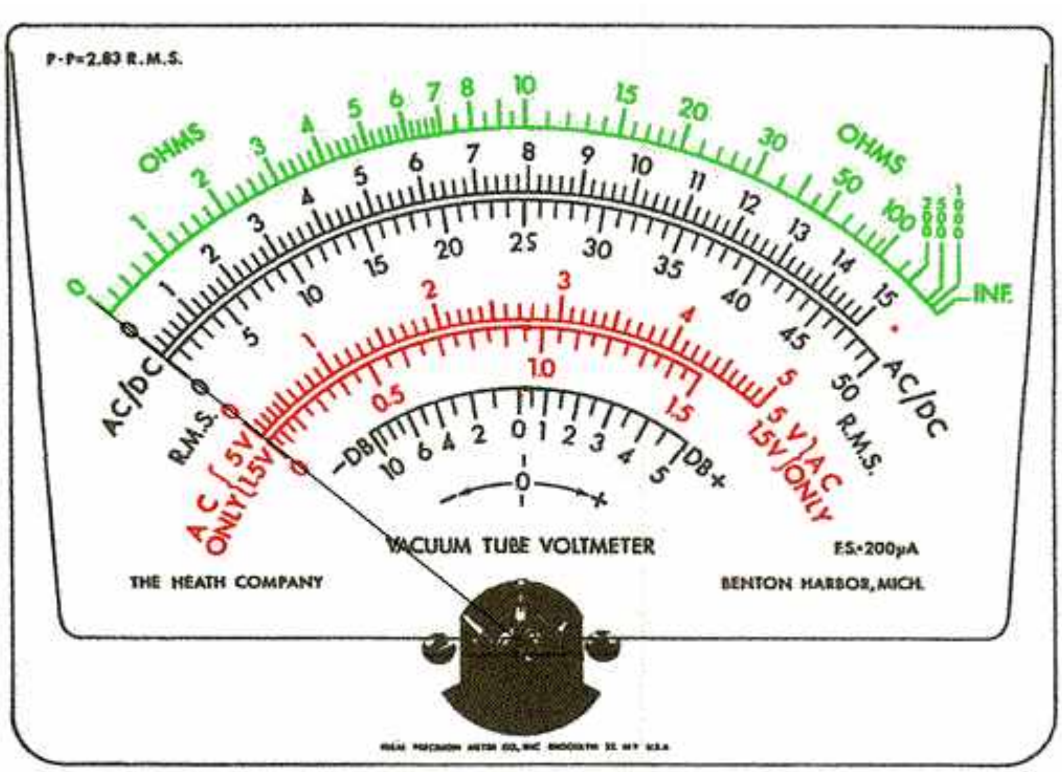

Figure 2: Heathkit IM-13 VTVM Meter Scale

$$\begin{aligned} Scale_{50} &= 15 * 3.162 \\ &= 47.43 \end{aligned}$$

While typical AC only VTVMs rectify the AC after amplification, eliminating the nonlinearity problems of rectifying low AC voltages, standard voltmeters rectify AC signals before amplification. Thus, separate scales are provided for the 0 - 1.5 VAC and 0 - 5 VAC ranges. Unfortunately this creates errors when using the dB scale. This error is stated in the manual:

Due to the special calibration used on the 1.5 V and 5 V AC scales, slight inaccuracies will be introduced into the db reading when making decibel measurements with the Range switch in the 1.5 V and 5 V positions.

Other Heathkit DC - AC - Ohm VTVMs:
When I examined an IM-11 VTVM, I was surprised to see that the meter scales had a 1 : 3 ratio and the 0 - 5 and 0 - 15 scales ended in alignment; see Figure 3. The dB errors are not discussed in the manual. However the manual discusses how to make comparative dB measurements. There is also no correction for rectification errors on the lower AC ranges. The dB errors are small, getting larger as the reading approaches full-scale. However they are within the range of accuracy specified.

Looking through Chapter 20, the VTVM chapter, of ***Heathkit Test Equipment Products*** by Chuck Penson - WA7ZZE[1] I noticed that the Heathkit VTVMs that are in the "Service Class" with their larger 6" meters, all have the true 10 dB ratio between meter scales. These include the IM-10, IM-13, IM-28, IM-32 and IM-5228. With the exception of the IM-10 and IM-32, these are all "bench" style meters with a large meter to the left and controls to the right. The IM-10 and IM-32 are upright meters with the controls below the meter, but due to the large 6" meter they are wider than the general purpose upright VTVMs.

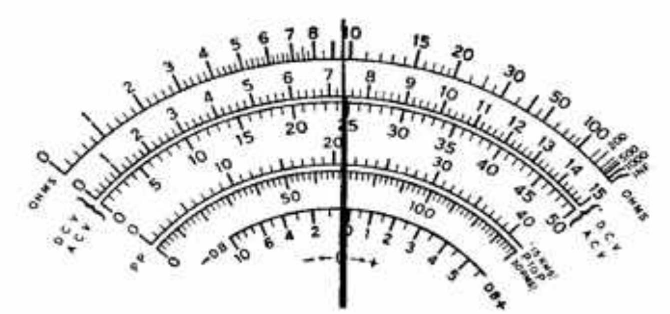

Figure 3: Heathkit IM-11 Meter Scale

All the general upright VTVMs use the lower accuracy 1 : 3 ratio between AC scales. They include the V-6, V-7, V-7A, IM-11, IM-18 and IM-5218. Also included in this group are the V-1 through V-5A, although they vary in ranges and scales from the later meters. All these meters use 4-1/2" or smaller meters.

What About VOMs?
I looked at a Simpson 260 series VOM scale (series 7F). Many VOMs, such as the Simpson, use copper oxide rectifiers to convert AC voltages into DC, causing nonlinearity at the lower AC ranges. This nonlinearity is corrected for voltage by using two separate scales for the AC ranges. This VOM has five AC ranges: 0 - 2.5V, 0 - 10V, 0 - 50V, 0 - 250V and 0 - 500V. The 0-2.5 VAC range has its own scale while the remaining three scales share a scale separate from the DC scale. A table on the meter face gives correction data for the ranges: 10V add 12 dB, 50V add 26 dB, 250V add 40 dB and 500V add 46 dB. The nonlinearity of the meter affects correlation between meter scales and the dB accuracy, while the AC voltage reading remain accurate.

Figure 4: Simpson 260-7F VOM Meter Scale

Summary:

When making dB measurements, you might first want to consider using an AC VTVM. Every one I've covered has a true 10 dB change between scales, and, since the rectification occurs after the amplifiers, it is not prone to errors at lower voltages. When making measurements with standard VTVMs and VOMs, go ahead and read the dB from the scale, but if you desire more accuracy you can also do the calculations using the equation:

$$dB = 20 \log (V2 / V1)$$

where V2 is the voltage reading and V1 is a reference voltage depending on the standard you are using.

Since decibels is a ratio, you may use any value for your standard. Say you're measuring hum from an audio amplifier you just built, and with the amplifier gain control set at a specific setting, you measure 2.0 volts RMS[3] of hum. After making some improvements in the circuit layout you take the measurement again at the same gain setting and measure 0.1 volts RMS of hum. Solving the above equation you get:

$$\begin{aligned} dB &= 20 \log (2.0 / 0.1) \\ &= 20 \log (20) \\ &= 20 * 1.30 \\ &= 26 \text{ dB} \end{aligned}$$

You've reduced the hum by 26 dB.

If you're using an AC VTVM (look at Figure 1), when you read 2.0 you can read -1.8 on the dB scale. Since you are on the 0–3 volt range you add +10 dB. Then, when you read the 0.1 volts you read -7.8 on the dB scale, and since you are on the 0–0.3 volt range you add -10 dB. Taking the difference gives:

$$\begin{aligned} dB &= -1.8 + 10 - (-7.8 - 10) \\ &= 8.2 - (-17.8) \\ &= 26 \text{ dB} \end{aligned}$$

Using the scales on the other meters will result is less accurate solutions. I did try this problem using the VTVM and VOM meter scales and came up with different answers; however, they turned out to be surprisingly close as the errors seem to partially cancel when summed up. Usually an error of 1 dB is not considered significant in audio measurements, though in reality it is an error of about 12% in voltage.

Conclusion:

This was not a subject I thought I'd be exploring. However, it turned out to be interesting and provided me with a bit more insight in the measuring of decibels.

As far as ***Bob's Tech Talk*** is concerned, I hope to get back to writing articles on a more frequent schedule sometime in the spring when family matters settle down. I also plan to conclude some of the topics I left hanging in previous articles.

73, from AF6C

NOTES:

[1] Voltage units (VU) also have requirements for the dampening of the meter movement to provide a proper meter response.

[2] ***Heathkit Test Equipment Products*** by Chuck Penson - WA7ZZE is available through Amazon.com for $19.95. It is in its first edition. ISBN 978-0-615-99133-7, April 2014 publication date.

[3] All AC voltages discussed in this article are RMS (Root Mean Square) sine wave voltages. This RMS voltage is 0.707 of the peak voltage.

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