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DECIBEL PROBLEMS

xplanation of a subject which often puzzles

UNDERSTANDING the various uses of the decibel is not at all difficult, even though the beginner is often nonplussed at the extremely complicated formulae generally used in expressing ratios of sound. These same formulae may be expressed in simple everyday terms so that even the non-technical reader may grasp a working knowledge of them.

First, we all know what sound *is*. From the moment of birth we were conscious of sound and its pleasant effects upon us. Later, in school we learned that tone is the difference between music and noise; pitch is the difference between various keys in the musical scale; and an octave is a *multiple* or *sub-multiple* of a certain pitch.

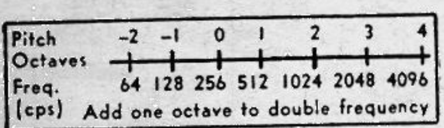

Fig. 1—Octaves express pitch in logarithms.

This means that in order to go an octave *above* any pitch, the frequency of the original pitch must be *doubled;* to *drop* the pitch one octave, the frequency must be *divided* by *two.* Thus 4000 cycles (per second) is one octave *above* 2000 cycles, and 400 cycles is one octave *below* 800 cycles.

The pitch scale is shown in Fig. 1. In this diagram, figures above the vertical lines represent octaves of the physical pitch of C, and the figures below are the corresponding frequencies.

THE DECIBEL SCALE

With the advent of the telephone, and later radio and its numerous applications, came the necessity of measuring accurately the levels and various power ratios of sound energy. Since the human ear is much more sensitive to changes in sound at *low* than at *high* levels, all means of expressing sound changes and ratios electrically must be made in the same manner. A standard unit called the Bel was introduced by sound transmission engineers for these measurements. The Bel, however, proved to be rather unwieldy for small ratios of sound and so a more suitable unit, the *Decibel* (one-tenth Bel) was adopted. Since one Bel (10 Db) indicates an amplification by 10, two Bels (20 Db) mean an amplification by 100 and three Bels (30 Db) mean amplification by 1000.

The decibel scale shown in Fig. 2 is similar to the pitch scale except that its major steps represent changes by a factor of 10 instead of 2 and its basis is power in watts instead of frequency in cycles. To go up the scale by 10 Db, the power must be multiplied by 10; to go 10 Db further, the power is again multiplied by 10. We now have gone up the scale 20 Db and the power is 10 x 10 or 100 times what we started with. To go down 10 Db the power is divided by 10.

Another convenient step found on the Db scale is 3 Db. To go up 3 Db means to *double* the power; to go down 3 Db the power is divided by 2.

The clue to the rest of the scale is found in the definition: The Bel is equal to an amplification by 10. One Db, then, is a step which, taken 10 times, will multiply the original power by 10. This requirement sets the value of 1 Db as a power ratio of 1.26. In other words, the addition of 1 Db multiplies the original power by 1.26. This ratio can be proved as follows: Start with 1 watt, for example, and increase this power by 1 Db or 1 x 1.26 = 1.26 watts. Increasing again by 1 Db, 1.26 x 1.26 = 1.588 watts. Increasing the third time by 1 Db, 1.26 x 1.588 = 2.0 watts. (Note that we have made 3 one-Db steps and have doubled the power). Increase by three more one-Db steps, a total of 6 Db, and we have 2 x 2 = 4 watts. Again increase by 3 Db, a total of 9 Db, and we have 2 x 4 = 8 watts. Now increase by 1 Db to make the total increase 10 Db and we have 1.26 x 8 = 10 watts, or 10 times the original power.

There we have the decibel unit, and that's about all there is to it. The Db is a unit for expressing a change in *power*. This it does on a *relative* basis

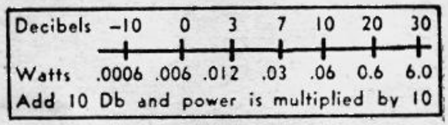

Fig. 2—Watts versus decibels. Not to scale.

so that a 1 Db change is always a change of approximately 26% regardless of the power we start with. A tenth of a watt is a big change if we had only .1 watt to start with, but .1 watt added to 25 watts would be hardly worth bothering with. A change of 1 Db, however, is the same *relative* size change for any value of power, 26% for .1 watt or 26% for 25 watts.

If you have been interested only in knowing what the decibel is, stop here! For a review of the uses and rules for applying this unit, the following should serve for the practical man. For the mathematician who likes these things served up rich in complicated formulae, study of some of the classical treatises on the subject is suggested, such treatment being beyond the purposes of this paper.

IMPORTANCE OF RATIOS

The ratio of one number to another is the *first* number divided by the *second* number, as, for example, the ratio of 10 to 5 is 10/5 = 2. The ratio of 5 to 10 is 5/10 = .5, and the ratio of W_2 to W_1 is W_2/W_1.

The ratio of the output voltage of an amplifier to the input voltage is constant. For instance, in a certain amplifier an input of one volt becomes 5.6 volts at the output. Two volts input would result in 11.2 volts output, and 10 volts in would appear as 56 volts out. These ratios of output to input are 5.6/1 = 11.2/2 = 56/10. The output of an amplifier bears a *constant ratio* to the input.

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Obtained Radiotelephone First Class License in 1941 and joined WRR, Dallas as transmitter and maintenance engineer. Later joined KFJZ, Ft. Worth, as transmitter-studio engineer and in 1942 assumed present duties of studio-field-recording engineer with WKRC, Cincinnati.

Hobbies—Amateur radio, crossword puzzles, writing. Associate member I. R. E., member ARRL. Present ambition is to stop spare-time work on aircraft radio and B. C. receivers long enough to build a .5-Kw 10-6-2-meter portable-mobile rig.

Let us say that another amplifier has a voltage ratio of 1.6. Then the combination of this amplifier with the one mentioned above would result in a ratio of 1.6 x 5.6, or the *ratio* of an amplification system is the *product* of the *ratios* of its components.

The ratio is encountered in every phase of our work—even after the sound has emerged from the speakers and we listen to it. If we start with 1 microwatt (one-millionth watt) at the ear and increase it to 2 microwatts, we notice a small increase in loudness. Increase from 2 to 4, from 4 to 8, 8 to 16, etc., and the steps of loudness will be approximately the same. In these cases

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the ratio of change is 2 to 1. So, it may be said that the successive *increase* of acoustic power by a *constant ratio* results in increases of loudness by approximately *constant* steps.

From the foregoing it is evident that the word "Ratio" is all-important. It is the business of the decibel to express such ratios in a convenient form which tremendously simplifies calculations and the interpretation of the results.

DECIBELS AND LOGARITHMS

The subject of decibels could easily be handled without once using the word "logarithm." This has been seriously contemplated, since many seem to be afraid of the word. But it is so great a help that it just isn't fair to pass it up. We could walk twenty miles on foot, but we prefer to drive a very complicated automobile. "Logs" have certain complicated aspects (which do not enter into Db work), but we need only to know what logarithms are and how to use them—a very simple matter. Now, if necessary, forget all you know about logs and study the relation between the columns in the following tabulations.

Power Ratio	W_2/W_1	Logarithms	Bels	Decibels
10	$= 10^1$	1	1	10
100	$= 10^2$	2	2	20
1000	$= 10^3$	3	3	30
10000	$= 10^4$	4	4	40

Proceeding downward from 10 we have zero and negative exponents, as may be seen in the next table. Note that a power ratio of 1:1 is expressed by 10^0, a rather strange-looking expression, but one justified by its position in the scale.

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Power Ratio	W_2/W_1	Logarithms	Bels	Decibels
10	$= 10^1$	1	1	10
1	$= 10^0$	0	0	0
.1	$= 10^{-1}$	–1	–1	–10
.01	$= 10^{-2}$	–2	–2	–20
.001	$= 10^{-3}$	–3	–3	–30
.0001	$= 10^{-4}$	–4	–4	–40
.00001	$= 10^{-5}$	–5	–5	–50

First the power ratio is re-written as 10 raised to some exponent, the exponent being the number of zeros to the right of the 1 and preceding the decimal point (for numbers *less* than 1 the zeros are to the left, so the exponents are negative). This exponent of 10 is called the *logarithm* of the ratio.

We already have enough to define the common logarithm; the log of a number is the *power* (exponent) to which 10 must be raised to equal the number. In other words, if 10^n equals a certain number, then "n" is the log of the number. *That's all there is to the logarithm.*

Bels are logs provided we start, not with just any number, but with a ratio of two values of power (watts) since Bels, to avoid confusion, apply only to power ratios. Decibels, as the prefix Deci- implies, are 10 x the *number* of Bels or 10 x the log of a power ratio. In other words, Db power change = 10 x the logarithm of the final power divided by the original power. This formula may be stated:

Db power change $= 10 \log W^2/W^1$, or Db $= 10 \log P^2/P^1$.

We have taken easy cases in the above tables—exact powers of 10. Finding the logs of other numbers requires the use of log tables since it is not so easy to find the exponent to which 10 must be raised to produce, say, 5.

LOG AND DECIBEL RULES

(Refer to logarithm tables)

When the ratio is more than 1, the log and Db value will be positive. If less than 1, they are negative. When the ratio is exactly 1 they are zero.

For a ratio between 1 and 10, the log is somewhere between 0 and 1 (a fraction or decimal) and the Db value is between 0 and 10. For a ratio between 10 and 100, the log is between 1 and 2 and the Db value is between 10 and 20, etc.

When ratios are to be *multiplied* together, their logs or Db equivalents must be *added* together. This may be illustrated by the example—100 x 1000 = 100,000. Expressing this in exponential form, $10^2 \times 10^3 = 10^{(2+3)} = 10^5$. The log of 100 is 2, the log of 1000 is 3, and the log of 100,000 is 5, since 2+3 = 5. The preceding operation may be written: log 100 + log 1000 = log 100,-000. By decibels, a power ratio of 100 is 20 Db, of 1000 is 30 Db, and of 100,-000 is 50 Db. Hence 20 Db + 30 Db = 50 Db is another way of writing 100 x 1000 = 100,000.

A second article on this subject will appear in an early issue. In it, Mr. Ledbetter will discuss voltage and power levels, and describe how decibel tables are made.