The Decibel System

by Malcolm Chisholm

While there are two formulae given for decibels, they say the same thing. The only reason for using two is to give direct figures for either power or voltage, rather than converting one to the other.

The purpose of the system is to state ratios. How much more or how much less than a given standard is present in the system. The ratios are usually given in even numbers, as 2x, 200x, 2000x, etc, and are not exact. That is, a ratio of 789x is not presented as such, but rounded off to 800. Further, the actual ratio for a given dB figure is generally not exact. In the above example, for instance, the dB figure for a ratio of 800 would be given as 58 decibels even, but the exact ratio for 58 dB is 794.3282347.

The rounding off process has to do with stating dB in even numbers. For a ratio of 789, the exact dB figure is 57.941, but would be stated as 58dB.

The next even number down, 57dB, is a ratio of about 708 and the next up, 59dB, about 891.

ONE DECIBEL JUMPS THE RATIO BY 10% TO 26%! PRECISION AIN'T POSSIBLE.

The system, in short, is sloppy. It gives pretty close approximations, but not precise statements as to how much more or less than a standard figure is present in the equipment.

There are three good reasons and one excuse for this. First, the normal human tendency to make things neat. An engineer designing a unit which requires a gain or loss of between 180 (45.106dB) and 240 (47.6dB), will bring it out at 199.52 (46dB even) every time as 46dB is a short, tidy number. Easy to read, easy to convert to ratio. A figure like 45.106dB is neither, and defeats one of the purposes of the dB system, which is to present gain/loss/level information in a simple, instantly understandable form.

The second reason has to do with electronic components, the most exact of which have tolerances of plus or minus 5% and a gap of 10% from one value to the next. It is no coincidence at all that real world units, built with real world components have a gain/loss variation of plus or minus 1/2 dB, identical to component tolerances. Testing units are an exception, but have calibration controls, and cost more. Several times more.

Reason three is that decibels are a real world system, used in meters to read audio levels. Meters reading signals bounce, and trying to read a signal level closer than one dB is an exercise in futility.

The excuse is a bunch of research indicating that the human ear, under the best of conditions, can't detect a level change of less than one decibel. That may well be true of normal folk and steady tones, but as competent music mixers commonly strike and hold music balances to 1/2 dB or less, it is at best irrelevant to working audio types.

The reasons are valid, however, and make the decibel system poorly suited to making precise statements. It is very good, however, at making simple, instantly understandable statements about relative levels, with as much accuracy as can be used in real time work.

The simplicity, readability, and relative imprecision of the system are the result of a mathematical trick called logarithms. And away we go.

Logarithms sound hard. They're not hard. They're just unfamiliar. Logs have been used for several centuries to avoid the drudgery and "slippery error" involved in the multiplication and division of long numbers, as they allow one to do those things by simple addition and subtraction.

They are, in fact, as good a way to cheat at arithmetic as a pocket calculator, but much older.

The way logs work is fairly simple.

Step 1: Take a number, any number. Write 1 above it. That's the base.

Step 2: Multiply the base number by itself. Write 2 above it.

Step 3: Multiply the second number by the base. Call it 3.

Step 4: Keep doing step 3 until you've got big enough numbers to work with.

Example; Base two log system, numbers below, logs above.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 2 4 8 16 32 64 128 256 512 1024 2048 4096 8192 16384 32768 65536 131072 etc.

The LOGS increase one number at a time, the NUMBERS they represent double.

ONE LOG NUMBER UP OR DOWN MULTIPLIES OR DIVIDES THE REPRESENTED NUMBERS BY THE BASE NUMBER.

In this case, two. 64 is 2LOG 6. 32 is 2LOG 5, half. 128 is 2LOG 7, double.

Up a 2LOG, double the real number. Down a 2LOG, half the real number. For a base 7, you'd multiply or divide by 7 with each 7LOG, if 10, by 10.

Now for the fun part. 262,144 divided by 256 is 1,024. Not an especially hard problem, but it takes a little time, and it's pretty easy to make the odd mistake in the process. 18 minus 8 is third grade stuff. Easy to do, easy to check.

2LOG 262,144 is 18. 2LOG 256 is 8. 1,024 is 2LOG 10.

Add or subtract the logs of the numbers you want to multiply or divide, look up the number of the result; it's the answer. Quick, easy, mistake proof. Been used nearly forever.

ADD THE LOGS: MULTIPLY. SUBTRACT THE LOGS: DIVIDE. BY THE BASE NUMBER.

Decibels are a 10LOG system, but the original unit, the Bel, named after Alexander Graham Bell, was too large. A Bel is the power increase needed to make a sound twice as loud, as perceived by a listener. That power increase is ten times, and anything less would have been point something, making the system unwieldy. Rather like measuring everything in feet instead of using inches for the short stuff. So the Bel was divided by ten to allow whole number statements for small changes in power. Deci means 1/10th. 1 Decibel equals 1/10 Bel.

The 10 log system looks like this:

1 2 3 4 5 6 7 8 10 100 1000 10,000 100,000 1,000,000 10,000,000 100,000,000

The 10log is the number of zeros after the 1. Each 10LOG multiplies or divides by ten. A familiar system, and the basis of scientific notation, as in 1.2 X10 to the fifth, or 1.2 with 5 zeros, 120,000.

The Power dB formula being "dB=10x10LOG ratio", a ratio of 1000 would be 10LOG 1000=3, 3x10=30: 30dB=ratio 1000.

10dB=10, 20dB=100, 40dB=10,000 and so forth. Obvious for even 10s, but tricky for ratios other than 10. So we use a trick.

10dB IS TEN TO ONE.....3DB IS TWO TO ONE. Using 3s and 10s you can get to any number you want. For examples, 5: 5x3=15, 20-15=5. or 1: 3x3=9, 10-9=1

ADD DB, MULTIPLY THE RATIO. 15 is 3+3+3+3+3=15 Ratios are 2x2x2x2x2=32. So 15dB=32 to 1. 20dB is 10dB+10dB, ratios are 10x10, 100 to 1. SUBTRACT DB, DIVIDE THE RATIO. 20-15=100/32.

Five decibels must be 3.125. Since the system is inherently sloppy, call it three. Second example, 10dB-9dB, 10/8=1.25. One dB is 125% Nothing to it.

Nothing to calculating decibels, but the all the above refers to the Power formula, which is the base formula for decibels, and there is no simple way to measure power and show it on a meter.

The reason for this is that power equals volts times amps, but at any voltage, the amps vary with resistance. Three variables and one result.

A real power meter, therefore, would have to simultaneously measure the volts, the amps, and the resistance of the thing being metered in order to figure the power. In short, three measuring devices and a built-in calculator. It can be done, but it ain't cheap. So we don't do it.

The way we don't do it is pretty straightforward. The resistance, which for audio is generally impedance, is made standard for anything we might want to meter.

THE STANDARD IMPEDANCE IS 600 OHMS. That eliminates one variable, leaving only volts and amps, with a nice direct relationship, in that more volts yield more amps.

Now we build voltmeters which assume 600 ohms of impedance/resistance, measure the voltage, and calibrate the meter face to show either power or voltage.

DECIBEL METERS ARE CALIBRATED FOR 600 OHM LINES. POWER WILL BE FLAT OUT WRONG AT ANY OTHER VALUE. The voltage will be O.K., but the power reading will be correct ONLY for 600 ohms.

Example: .775 volts at 600 ohms equals one milliwatt. This is standard "zero" voltage for decibel meters, and shows as 0dB on any proper unit.

.775 volts at 150 ohms, on the other hand, while showing as zero on a dB meter, just over four milliwatts, four times the other's energy, and if the 150 ohm line were transformered up to 600, would read as double .775, or 1.55 volts. So a dB meter calibrated to read in power decibels MUST look at a 600 ohm line to be accurate.

Most dB meters, on the other hand, are calibrated to read voltage. They're call VU (Volume Unit) meters, and are found on virtually all professional audio equipment. The Volume Unit, in passing, appears to be one of those terms invented by a standards committee to justify it's existence, and is generally ignored by the working types. One calls it a VU meter, but all readings are referred to as dB or dBm. The m stands for milliwatt, as in 600 ohms, one milliwatt, the standard line level.

The formula and scale for voltage are different than the formula and scale for power. They have to be, because while power equals volts times amps, an increase in volts yields an increase in amps, and squares the increase in power.

Triple the volts, triple the amps. Multiply the two, nine times the power. Square law.This is a nuisance, but power dB convert to voltage dB and vice versa with no great amount of effort.

Formulae are POWER DB=10 X 10LOG of RATIO. VOLTAGE DB=20 X 10LOG of RATIO. 3dB POWER is twice the power, but only 1.414 times the voltage. Square root of two. 6dB POWER is four times power, twice the voltage. Square root again.

10 dB VOLTAGE is 3.162 times the voltage. The square of 3.162 is 10, and that, of course, is the increase in power.

THERE IS ONLY ONE DECIBEL SYSTEM. There are two ways to express the values, but the conversions are easy.

VOLTAGE DECIBELS ARE DOUBLE POWER DECIBELS. 2x power= 3dB. 2x volts=6dB. 10x volts= 20dB, 10x power= 10dB

Therefore; If you know the power dB, double it for voltage. If you know the voltage dB, halve it for power.

Better still, anyone working with professional audio equipment has a voltage dB to ratio converter at hand. It's on the meter.

The standard VU (meter) has two scales, above and below a curved line. For the most part the top scale reads in decibels, the bottom in modulation percentages. There is a reverse scale meter for broadcast with modulation on top, but it is not often seen outside broadcast stations.

Decibels are written at -20, -10, -7, -5, -3, -2, -1, 0, +1, +2, and +3, with short lines at the intermediate values.

Modulation percentages are written as 10% 20% 30% 40% 50% etc. thru 100, with dots marking the exact percentage position on the scale.

These two scales are in very precise alignment, and constitute a Rosetta stone for voltage decibels. Under the -2dB line is a dot for 80%.

Therefore -2dB is a loss of 20% of voltage. Under -3dB, the 70% dot is just a trifle low, because 3dB is half-power, and the square root of .5 is .707

Under -6dB is, of course, 50% or one-half voltage, and under -20, 10% For decibel figures under 6dB the meter conversions work only for minus values, as 50% of something is half, but 150% is not double. For 6dB or more they work for both plus and minus dB. So for odd figure conversions add to just above the designed dB, and subtract the small stuff.
Example:

77 decibels would be worked as 80 minus 3. 80 is 20+20+20+20. The ratio for 20dB is 10, so 10x10x10x10 for an 80dB ratio of 10,000. -3dB has a ratio of .707, so the final 77dB ratio is 10,000 x .707 or 7070. 78dB, 80-2, comes up at 8000, 74dB, 80-6, at 5000, and so forth.

This being a technical paper, the technical figures are herein-under given for the first 6dB, on the off chance they might be useful for something.

+1= 1.222 -1= .891 +3= 1.413 -3= .708 +5= 1.778 -5= .562 +2= 1.256 -2=.794 +4= 1.585 -4= .631 +6= 1.995 -6= .501

Ratios for power are, of course, the squares of the above figures. In the real world, though, the meter will be a VU, reading voltage, and voltage decibels are used for virtually all specifications, measurements and even conversations involving audio. The original power dB system is seldom used except for Sound Pressure Level work, in DB/SPL, in which all the figures used are in power dB and amplifier watts, and conversions are not normally made to voltage decibels or voltages.

It may seem odd that the original power dB system is more or less ignored in audio work, but there are several good reasons. Specifically, it is far easier to measure voltage than power, and the voltage figures are easier to understand; partly because of a longer scale (6dB for double instead of 3) and partly because very little working audio equipment has any practical limitation as to power, making power statements and specifications largely immaterial. More of that later.

Decibels are used to specify what equipment will do, and calculate what needs doing. The two expressions are used as follows.

VOLTAGE DB: GAIN, LOSS, LEVELS, NOISE, LINE EQUIPMENT SPECIFICATIONS.

POWER DB: SOUND PRESSURE LEVELS, POWER AMP & SPEAKER SPECIFICATIONS.

Voltage decibels are used primarily in equipment which picks up sounds, converts them to electrical signals, and transfers them from point A to point B. This is called line equipment, as it outputs at a standard level, usually +4dB, which is refers to 600 ohms, one milliwatt, .775 volts as 0dB or 0dBm. (Plus four is 1.228 volts) Line equipment includes such things as consoles, tape machines, equalizers, limiters, filters, gates, echo chambers, and various toys. (phasers, flangers, delays, etc.)

Power decibels are used for equipment which translates those signals back into sound and presents them to someone's ears.

First, line equipment and voltage dB. Except for microphones, all line equipment is specified for a 600 ohm balanced line output, generally at 4dB over the calibrating level of 0dBm. Mikes are specified for 150 ohms and, if transformer matched to 600 ohms, produce twice (+6dB) the voltage listed in their specs. If not, (transformerless input) not.

Transformers have some good points.

PASSIVE line equipment includes resistive circuits, such as pads, faders, combining networks, and passive equalizers with an insertion loss of about their maximum boost. These things are specified in negative decibels (-18dB) or as loss in dB. (insertion loss, 18dB).

A fader has an insertion loss of 6dB when fully open, and up to infinite loss when all the way down. Since a fader is normally used at 15 to 20dB down so the mixer can get more OR less of signal, the real world insertion loss for a fader is about 26dB, which requires 26 dB of gain somewhere down the line to maintain a signal level at the usual -20 thru the system.

ACTIVE line units contain amplifiers, and include pretty much everything else. Except for levels on tape AS SUCH, active units are specified for GAIN, OVERLOAD point, and NOISE floor. The 600 ohm line is assumed, as all professional equipment is designed to that standard.

GAIN: Easy. How much more comes out than went in. 100X; 40dB. 200X; 46dB, 1000x (rare); 60dB.

Most of the little amps in consoles are set up for 20 to 50dB of gain (46 is popular), and there are several in-line per channel, to compensate insertion losses as they occur. Gain, loss, gain, loss, gain.

This keeps the signals at reasonable levels through the chain, rather than boosting hell out of it and dropping it to the desired level with all the losses.

Hell, in a normal console, would amount to well over 100 watts, which ain't practical.

LOSS: Equally easy, how much less comes out than went in. Except for faders and equalizers (which last will give back most of their loss in boost IF boost is used) loss is generally a fixed value for a given unit.

OUTPUT LEVELS: Maximum undistorted output, used to figure headroom. Since VU meters have a response time of .2 seconds from no signal to 0VU, they do not indicate the real levels of short signals. A piano, as an example, has a short attack level of up to 15 dB more than a meter will read simply because the meter hasn't time to swing.

Because attack and percussion levels are commonly much higher than shown by metering, amplifiers are normally set up to handle anything up to 30 times the metered signal level. That excess capability is called headroom, and is calculated as the difference between maximum undistorted output and standard operating level. Headroom is often built in at 12dB. Not enough.

It should be set (by the input level of the amplifiers) to 20dB or so throughout the signal chain.

For the most part this can be easily done, as amplifiers normally have a maximum undistorted output level of 23 to 26 dB over their required output.

The capability for 20dB headroom is usually present in professional units, but manufacturers are not always aware of how the stuff will be used in a specific installation, so headroom should be checked through the entire signal chain, particularly in cases where outboard processing equipment is in common use.

NOTE: Headroom is where the power dB system becomes unintelligible. 20dB or 10 times the average voltage is an understandable allowance for headroom. In power dB, however, that's 100 to 1, and boggles the mind.

NOISE: Not so easy, specified (Equivalent Input Noise) as hiss level below standard output level, 0dBm. In modern equipment, about -120 dBm for line level amps and about -130 for microphone amplifiers.

Only the noise is specified in professional equipment, on the assumption that the user knows the signal levels involved, and can handle simple subtraction, as in a mike amp at -130 fed by a mike at -70: S/N 60 dB.

It should be noted that the above noise specification is not the only one in use, merely the simplest, and easiest to field test by the user. There are a couple of other systems, noise figure of merit and signal to noise, which are commonly published, but the first involves some pretty complex math, and the second a presumption of input signal level.

In both cases, the figures are difficult to compare when shopping, and have at least occasionally been used for precisely that reason. Noise below 0dBm (EIN) is easy to use, easy to test, and indicates a form of truth in advertising on the part of the manufacturer. Other specifications may well be valid, but the writer has seen several that were deceptive and a few that could not be translated into the real world at all.

On balance, it is probably wise to stick with manufacturers who publish easily corroborated specifications.

STANDARD REFERENCE LEVELS: This is what makes it nearly impossible to learn the decibel system by osmosis. There are several standard levels, all used as zero dB, to which readings or measurements are referred in conversation WITHOUT NAMING THE STANDARD. If you don't know the reference levels, the numbers quoted are garbage, as the context supplies the reference.

You will NEVER hear "Your output is 6dB over 0dBm". Just "You're at plus 6". ("idiot")

The references are:

1. Zero VU or 0dBm, the milliwatt DB. 1 milliwatt/600 ohms, .775 volts. Used for ALL signal levels in a studio. Plus 4 dBm is 1.23 volts, and the usual line level.
2. Tape level, taken from an alignment tape. Ranges from 185 to 250 nanowebers (165 for cassette) and sometimes higher. For 15" or lower speed 200 NW as zero is appropriate as higher levels yield peak saturation on percussive instruments such as piano.
3. Record level, 7cm/second, taken from a calibration record. Most LP's are cut at or just below this standard, and 45's at or just above it.
4. DB SPL, a power system, and how much Sound Pressure is present. Zero is the threshold of hearing, 40 dB a quiet night, 80 dB a raised voice at 18 inches, and 120 dB music pain threshold for normal ears. Control room monitor levels run from 90 to about 118.

Noise pain level is about 90 dB,but noise and music affect the ear very differently, because they are very different things.

Gain/loss decibels are standalone figures, and use no references. They simply state how much more or less level one has at output versus input.

And that's the name of THAT tune