A Decibel Primer

Dallas Hodgson
RockIsland@iname.com
www.dallashodgson.info

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In all the world of audio, there is no measurement that is so key, yet so difficult to understand, than the decibel (dB.) They're so commonly used both in live sound and recording that we often take them for granted without understanding they really mean or worse, understanding them *incorrectly.* And it's very easy to understand them incorrectly, because there are many flavors of dB (which we'll get to in a moment) and without the proper frame of reference, are as meaningless as they are convenient. But audio convenience *is* at the heart of all this, because the decibel scale would not exist were it not for Alexander Graham Bell, inventor of the telephone (which it was named after.)

Part of the reason for the decibel scale, which is derived from logarithms, is to compress the extreme range of loudness perceivable by the human ear into something more compact.

(threshold of hearing/pain chart derived from http://ohioline.osu.edu/cd-fact/0190.html, Dave Moulton and myself)

Safe Range	**(dB SPL)**	**Sound Pressure Ratio over 0 dB (times)**
Threshold of Hearing (.0002 dynes/cm^2)	0 dB	1 x
(convenient reference)	6.02 dB	2 x
(convenient reference)	10 dB	3.16 x
Stream flow, rustling leaves	15 dB	5.62 x
Watch ticking	20 dB	10 x
Soft whisper	30 dB	32 x
Quiet street noises	40 dB	100 x
Conversation, quiet room	45 dB	178 x
Conversation, crowded room	60 dB	1,000 x
Normal city or freeway traffic	70 dB	3,162 x
Vacuum cleaner	75 dB	5,623 x
Hair dryer	80 dB	10,000 x
Motorcycle, electric shaver	85 dB	17,783 x
Lawn mower, heavy equipment	90 dB	31,623 x
Garbage truck	100 dB	100,000 x
Screaming baby	115 dB	562,341 x

Injury Range	**(dB SPL)**	**Sound Pressure Ratio over 0 dB (times)**
Jack hammer 3 feet / Jet airplane takeoff from 120 feet / Threshold of discomfort	120 dB	1,000,000 x
Air begins to distort	125 dB	1,778,279 x
Race car, loud thunder, rock band	120-130 dB	1,000,000 x - 3,162,278 x
Sensation of eardrums moving ("tickle")	130 dB	3,162,278 x
"Horrific" Pain	140 dB	10,000,000 x
Rocket launch from 150 feet	180 dB	1,000,000,000 x
Theoretical maximum at 1 atmosphere	194 dB	5,011,872,336 x

Some interesting things from this table – you can see that the human ear has a *very* wide dynamic range, with the loudest common sounds (120dB SPL) being one *million* times louder in intensity (pressure) than the quietest sound we can hear. In fact, it is generally considered that for something to sound *twice* as loud to our ears its SPL must increase 20dB, a sound pressure increase of *ten* times. You can begin to see why faders on mixing boards are calibrated in dB, not sound pressure or volts; it would take a huge fader to go all the way from 0 to a million, and at low volumes you'd be moving the fader in impossibly small steps whereas at high volumes the hand motions required would be huge.

Looked at another way, you can see what orchestras are so large: It takes 10 musicians to sound twice as loud as one!

<u>Some Interesting Sound Facts:</u>

1) The ear is so sensitive, that if the Threshold of Hearing were much lower we'd be hearing the Brownian noise of air-molecules as they randomly bump into each other all day long.
2) I've also read the Threshold Of Hearing being described as .0002 microbars, 20 micropascals (μPa = 1×10^-6 Pa), 10^-12 W/m^2 (watts per square meter), and roughly the sound of a mosquito flying 3 meters away!
3) Only a few sounds in Nature (like lightning) are so loud that that *the air itself distorts* like a guitar amp. When a speaker moves forward, it creates air pressure; and when it moves backward, a partial vacuum. Now imagine a sound so large that the partial vacuum actually becomes *total,* and simply can't get any larger – that's what happens at 194dB, and you'll probably be dead - earplugs or not.
4) SPL stands for "Sound Pressure Level" which is relative to the threshold of hearing. There are many other possible thresholds, such as dbFS, dbM, dbU, dbV and dbW which we'll get into later but for now, just remember that they're all different beasts and often can't be compared directly, like apples and oranges.
5) A 1 dB change in gain is about the smallest we can notice *in isolation.* In the context of a mix though, .3dB-.5dB changes in gain are common for me. Professional recording engineer Roger Nichols has been known to make tweaks as small as .1dB!

The fact that the ear gets less sensitive to sounds as they get louder is by design. Internally, a physical mechanism actually "turns the volume down" on the ear like a compressor, but unfortunately this mechanism is not instantaneous. One of the worst things you can do to your ears is to expose them to the sound of brief, impulsive noises such as explosions or gunfire. It may only last a fraction of a second, but an unexpected blast of 140dB SPL could render you deaf *permanently.* How about rock concerts? Well, at least our ears are somewhat prepared for that; but as OSHA's Table G-16 (below) shows, we can't listen to loud sounds forever without sustaining some damage: (from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9736)

A-weighted SPL (slow response)	Max Recommended Exposure
80dB	32 hrs
85dB	16 hrs
90dB	8 hrs
95dB	4 hrs
100dB	2 hrs
105dB	1 hrs
110dB	30 min
115dB	15 min
120dB	8 min
125dB	3.78 min
130dB	1.8 min

(Another Factoid: “A-weighting” refers to one of two common methods of measuring sound with a sound level meter, the other being “C”-weighting. “A”-weighting is less sensitive to low frequencies, while the more accurate “C” weighting is fairly flat. For reasons that are unclear and probably have to do with lobbyists, “A”-weighting is the preferred weighting in laws regarding noise pollution.)

Note that 8 min is not a very long time to spend at a 120dB rock concert! When you leave the show, if you ears are ringing you have received some (possibly permanent) nerve damage which may degrade your ability to mix. So what level *should* one mix at? 85dB is most often cited as the ideal level. For one thing, your ears can tolerate a full day of it and secondly, the ear’s Fletcher-Munson frequency response (see http://en.wikipedia.org/wiki/Fletcher-Munson_contours) flattens out nicely giving you a more accurate read on your mix. Much louder than that? Wear earplugs! There are some good ones out there aimed at audiophiles and musicians that sound much better than what you’re probably used to, and they’re a very cheap investment for protecting your ears: See http://www.etymotic.com/ephp/er20.aspx

This Is Where It Gets Tricky

So what makes understanding dB’s so confusing? Part of it is that it’s not intuitive to think in terms of exponentials and logarithms. For example, when I say that in order to *sound* twice as loud it takes *10 times* the sound pressure, expressed as an increase of *20dB,* that’s just weird. So what do you get if you merely *double* the sound pressure? Only a 6.02dB increase, as it turns out. 6.02dB is one of those magic numbers that’s worth memorizing (along with 20dB) because it comes up again and again in digital audio. Try this test:

1) Open up a project in SONAR, find a guitar track somewhere, and solo it. What’s the highest peak reported by the output bus meter? Let’s say it’s –10dB.
2) Clone that guitar track, solo it, and play both tracks at the same time. What’s the highest peak reported by the output bus meter now?

I don’t even have to look to know – it’s around –4dB, which is ~6dB louder than what you got by playing the single track alone. Why? Because you’ve just doubled the sound intensity by playing two identical guitars at the same time. OK, now you should be able to figure this out – what if you wanted to make a single guitar *sound* twice as loud? You’d make 8 more copies (for a total of 10) and play’em all at once – this yields a 20dB increase, but be careful at this point because your output meters will be clipping severely! Why? Because –10dB + 20dB = 10dB, which is 10dB over the digital mixing maximum of 0dBFS. (We’ll explain the ‘dBFS’ part in a moment, but at this point it’s worthwhile to note that to avoid the clipping problem at this point you should either be reducing the output bus level by 0dB, or reducing *all* of the 10 tracks feeding the Output Bus by 10dB apiece, which has the same effect.)

Ramifications For Digital Audio

Remember how I said that cloning an instrument (thereby doubling its intensity, or sound pressure) raises things by 6.02dB? Well, we like to double things in the digital world; it happens every time we add an extra bit of precision. How many times have you bought a CD and read the little liner note thingy explaining how great CD’s are? (“The high resolution of this Compact disc may reveal limitations in the master tape, including noise and other distortions.”) Well, that’s because being 16-bit, Compact discs have a dynamic range of 16*6.02dB = 96.32dBFS which is well beyond the 60 dB or so of dynamic range that LP records were capable of. Dynamic Range is the difference between the loudest sound playable to the softest, and for anybody who caught my “Preserve Your Bits” article on Guitar School that’s *65,536* times louder. So is this enough? Most certainly not; the ear has a good 120dB dynamic range (up to the “threshold of pain”) so while the dynamic range of the compact disc is not perfect, CD’s are much better than any consumer format we had prior.

So what kind of wordlength should CD’s have been given in order to supply to 120dB’ worth of dynamic range? The answer is 120dB / 6.02dB, or 19.93 bits. Looks like those 20-bit ADAT decks from the 90’s were good enough! That’s not something that consumers ever saw, however the 24-bit consumer “audiophile” standard today is better still (and more than good enough.) In the old days those “limitations in the master tape and other distortions" were always there – we just couldn't hear them, because they were lost among all the noise and turntable rumble!

<u>"SPL" and "dBFS" Explained, Along With All The Rest</u>

Up until this point, we've avoided giving a formal definition of what a decibel is. This is where I'm going to step aside and let Ken Pohlmann's classic "Principles Of Digital Audio (5^{th} ed.) do it for me:

Specifically, the decibel is defined to be 10 times the logarithm of a ***power ratio:***

Intensity level = 10 log(P1/P2) dB

where P1 and P2 are values of acoustical or electrical ***power.***

If the denominator is set to a reference value, standard measurements can be made. In acoustic measurements, an intensity level (IL) can be measured in decibels by setting the reference intensity to the threshold of hearing, which is 10^-12 W/m^2 (watts per square meter). Thus the intensity level of a rock band producing sound power of 10W/m^2 can be calculated:

Intensity level = 10 log(P1/P2) dB = 10 log(10^1/10^-12) = 130dB SPL

(DJ's Math Refresher: The (base-10) log of a number is simply the number you'd have to raise 10 to the power of in order to get the desired number. In other words, the log of 1000 (i.e., 10^3) is 3. The Antilog of 3 is 10^3, or 1000. It helps to open up the Windows Calculator in Scientific Mode and play around with these formulas a bit until they feel comfortable.

Note that when ratios of currents, voltages or sound pressures are used (quantities whose square is proportional to power), the above decibel formulas must be ***multiplied by 2,*** *which we'll talk about in a sec.)*

I know I've probably lost everybody at this point, but what Ken is trying to say is that dB's don't exist in a vacuum; they're always *relative to something* and that relationship is always expressed as a ratio of *powers.* What is power? In physics, Power is the ability to do *Work.* And what is work? Imagine a river that feeds a hydroelectric plant, like Niagra Falls. What kind of river can generate the most electricity (work)? One that has a lot of water (current) moving at a high rate of speed (pressure). Multiplying these two figures gives you the river's power, which might be expressed in terms of something like gallons per minute (GPM). In electricity, the analogy is the same, only Power is expressed in Watts, and Watts = current (there's that word again) * voltage (pressure).

When the Bel scale was invented it was originally used for measuring signal power loss over telephone lines, hence its standardization around "power" measurements. Much of the audio world, however, involves measuring *pressure* or *intensity,* not power. However, power is proportional to intensity, and you can perform "pressure to power" conversions on the fly simply by squaring the pressure. (To understand this fully, consider that in Ohm's Law, in a circuit with a resistance of 1 ohm voltage and current are always identical – and therefore, the formula of Watts (power) = Volts * Amps is equivalent to Volts or Amps squared.) Incidentally, a deciBel is simply a Bel measurement multiplied by 10, which figures into the formulas above and below. This gives us an extra digit of precision when quoting measurements, as saying things like "the human ear has 12.0 Bel of dynamic range" seemed a little *too* coarse back when the scale was invented.

So when computing dB values based on pressure or intensity, (which would include almost everything that wasn't a Watt or pre-squared in some other fashion) the decibel formula needs to be written like so:

Intensity level = 20 log(p1/p2) dB

*where p1 and p2 are values of acoustical of electrical pressure***.** (Changing the "10" to "20" before the log is equivalent to squaring p1 and p2 in the formula above, only easier – such is the power of logarithms.)

In this example, we'll compute the maximum dBFS (FS=Full Scale) of a 16-bit word as used in a compact disc. The maximum value would be 65536, and the minimum value would be one. The dynamic range of a compact disc is, therefore:

Intensity level = 20 log(p1/p2) dB = 20 log(65536/1) = ~96.32 dBFS

Going in the reverse (antilog) direction is even easier:

16-Bits Full Scale = antilog(96.32 dbFS/20) = 10^(96.32/20) = ~65,536 (x 1)

How about the 130dB SPL rock concert mentioned above? As you can see, the ratio is quite large:

Sound Pressure Ratio = antilog(130dB SPL/20) = 10^(130/20) = 3162277 (x 0dB SPL)

Doing Decibels In Your Head (taken from Dave Moulton's "Total Recording")

Doing all this in your head is fairly easy, believe it or not. Keep in mind the following basic equivalents:

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FOR POWER                      FOR PRESSURE
3 dB = 2 x power               6 dB = 2 x pressure
-3dB = .5 x power              -6 dB = .5 x pressure
6 dB = 4 x power               10 dB = 3.16 x pressure
-6 dB = .25 x power            -10dB = .316 x pressure
7 dB = 5 x power               12 dB = 4 x pressure
9 dB = 8 x power               -12 dB = .25 x pressure
10 dB = 10 x power             14 dB = 5 x pressure
-20 dB = .01 x power           18 dB = 8 x pressure
13 dB = 20 x power             20 dB = 10 x pressure
17 dB = 50 x power             -40dB = .01 x pressure
20 dB = 100 x power            26 dB = 40 x pressure
30 dB = 1,000 x power, etc.    34 dB = 50 x pressure
                               40 dB = 100 x pressure
                               60 dB = 1,000 x pressure, etc.
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Using these, you can work out just about anything you want. For instance, 33dB is a *power* ratio of 2000 (3 dB over 1000), or a *pressure* ratio of a little less than 50. A little practice and you'll have it in no time.

How Much Louder Is That New Guitar Amp? (Calculating volume relationships from amp wattage)

We've already mentioned that it takes an increase of 20dB SPL (10x pressure) in order to sound twice as loud. But when comparing guitar amplifiers, we're comparing Watts, which are a unit of *power.* For a guitar amp to wound twice as loud therefore requires an increase of 10dBW, or *10X the watts.*

So. A 50W amp is only twice as loud as a 5W amp, and it takes *500 Watts* to sound twice as loud as a 50W amp. (Historical Note: Tom Scholz's custom designed amps for Boston were possibly the biggest stage amps ever, and they were 500W. But still, only twice as loud as a 50W Marshall!)

Which leads us to this formula:

Amp Volume Ratio = 2^log10(Amp Wattage 1/Amp Wattage 2)

So, to prove that a 50W amp is only twice as loud as a 5W amp , we plug in the numbers:

$2^{\log_{10}(50W/5W)} = 2^{\log_{10}(10)} = 2^1 = 2.$

Here's a common one. How much louder is a 100W Marshall than a 50W one?

$2^{\log_{10}(100W/50W)} = 2^{\log_{10}(2)} = 2^{.30102999\ldots} = 1.23$. (Just 23%!)

Decibel References (also taken from Dave Moulton's "Total Recording")

As I've mentioned, decibels are simply alternative numbers that represent ratios of power (and, indirectly, pressure). Naturally, there are many occasions when we want to know the ratio, expressed in decibels, between some value and a known, standardized reference. As a result of this need, an array of decibel references have evolved over the years. Below are several such references that are in common use today for audio, along with some discussion of their applications.

0 dBSPL = .0002 microbars = .0002 dynes/cm^2 = .00002 Pascals

This reference is for the threshold of hearing. It is an acoustic expression of pressure (all calculations should use the pressure multiplier, 20) that represents the pressure level of the softest 1KHz sound that average humans can detect. Any expression of acoustical amplitude using dB is usually derived from this value.

0 dbW = 1 Watt

This reference is a power reference tied to Watts, generally used with power amplifiers.

0 dBM = 1 milliWatt

This reference has become a little ambiguous. In its original form, it unequivocally referred to 1 milliWatt of power, for use in telephone and other audio transmission lines.

At that time, power management was a critical issue, and so transmission systems used matched impedance systems for the most efficient transfer of power between elements in a system. In telephone practice, the standard source and input impedance of all devices was 600 ohms. Given that impedance, the voltage level needed to generate 1 milliWatt of power is .775 volts. As a result, 0 dBM has, over the years, come to refer informally to .775 volts in common practice, regardless of the load. (If the load is not 600 ohms, then .775 volts will not generate 1 milliWatt of power.)

So, the literal usage of 0dbM is as a power reference of 1 milliWatt, while the sloppier common-practice usage is as a voltage reference of .775 volts. When you run across the dBM reference in specs and advertising for modern audio gear, it almost always is the common-practice reference. We simply aren't concerned about the power issue at line levels anymore.

For the more literal-minded and anal-retentive among us, there is a more formal voltage reference to use:

0 dBu = .775 Volts

This reference is unequivocal. It is the voltage reference that is equivalent to 0dBM when a 600-ohm load is present. It is a standard audio reference. (Dallas' note: +4dbU (1.23Vrms) is the standard signal level for balanced professional audio gear)

0 dBV = 1 Volt

This reference is an obvious and convenient one. It is unfortunate that it is only 2.2 dB from 0dBu,which causes the two to get tangled up a lot. The confusion is magnified by the casual practice of some engineers to refer to 1 Volt with a capital "V" and to .775 volts with a lower-case "v". So, the bad news is that this particular specification is a bit of a minefield, and you've got to proceed with a little caution. The good news is that if you get it wrong, you're only off by 2dB!

If I were king, I'd abolish the .775 volt reference now, and have a single line-level voltage of 0 dBV = 1 Volt. (Dallas's note: -10dbV (.316Vrms) is the standard signal level for unbalanced consumer audio gear)

0 dBFS = Digital Audio Level at the top of the Most Significant Bit

dBFS (Full Scale) is a digital audio reference. It equals the maximum level on a meter used to measure a digital audio sine wave signal, and typically in digital audio, it refers to the level of a sine wave at the top of all bits, or the maximum capacity of the digital word used to represent the audio information. The practical consequence of this is that 0 dBFS represents the peak level the system can handle without overloading.

There are numerous other decibel references. The principle is the same: a symbol following the term dB refers to some standard value that will be 0dB for that reference system. All you've got to do is find out what the reference is!

Actually, you can even have fun with this and make up your own decibel references. For instance, as a teaching example I created the Nugent, or dBN, where 0dbN = the sound pressure level of Ted Nugent playing a power chord at full level. Question: How many Ted Nugents playing a single power chord all at once does it take to generate a sound pressure level of 40 dbN? Answer, 10,000! It's enough to make you think carefully about this business!

Finally, as you work with decibels, you've got to stay aware of exactly when you're working with decibels as ratios and when as decibel references. Any decibel value tied to a reference (say, -21 dBu) is a fixed value, while 21dB is just a ratio. If, for example, you say, "I'd like a 3dB pay increase," you are saying you'd like to double your salary! This is quite a bit different than saying "I'd like to earn 3 dB$."

(dB$ is an obscure capitalist reference, where 0dB$ = $1. In the example, you are asking for $2!)

Dallas' Wrap Up

That's it for this tutorial, and believe me it was a very difficult one to write. Decibels were on my mind this week and there's no better way to test one's degree of understanding in a concept then by trying to explain it to someone else. For more info, (a *lot* more) check out David Moulton's "Total Recording" and Ken Pohlmann's "Principles Of Digital Audio', now in its fifth edition. This little write-up represents what I find most useful in thinking about dB's, and as wordy as it is I felt like I couldn't make it any shorter with leaving something important out!

Happy recording,

-djh