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Microphone Talk

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By George A. Pender

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Decibel

The decibel is widely misunderstood. The definition came from acoustic studies in the early 1900's and has been widely adopted by many disciplines, most notably electronics.

In the very beginning was the Bel (named in honor of Alexander Graham Bell; not sure where the second L went). To grossly oversimplify for the moment:

Bel was first defined in terms of acoustic power, but it can be generalized as the logarithm of the ratio of two quantities with the same units.

$$\text{Bel} = \log_{10} \frac{x}{nx}$$

e.g. x could be the number of dogs with fleas
nx could be the total number of dogs

Since logarithms are extraordinary compressors (being the inverse of exponentiation), the magnitude of the Bel was deemed inconvenient for typical acoustic calculations so the Bel was subdivided into 10 (deci) parts, or decibels, and abbreviated dB.

So by definition,

$$\text{decibel (or dB)} = 10 \log_{10} \frac{x}{nx}$$

That's it. That's all there is. Very arbitrary, but also very handy for comparing quantities.

In acoustic research, the power level of sound was defined as:

$$\text{Sound } \underline{\text{Power}} \text{ Level (in dB)} = 10 \log_{10} \frac{\text{measured sound power}}{\text{reference sound power}}$$

Because it is more convenient to measure sound pressure than sound power, the pressure level of sound was defined as

$$\text{Sound } \underline{\text{Pressure}} \text{ Level (in dB)} = 10 \log_{10} \frac{(\text{measured sound pressure})^2}{(\text{reference sound pressure})^2}$$

which follows from the equation for sound power

$$\text{Sound Power} = \frac{p^2 \times A}{\rho\, c}$$

where p is rms pressure
ρ is density of the medium
c is velocity of sound in the medium
A is a unit area normal to the incident direction

Since $\log_{10} (N)^2 = 2 \log_{10} N$, the Sound Pressure Level can be rewritten as

$$\text{Sound } \underline{\text{Pressure}} \text{ Level (in dB)} = 20 \log_{10} \frac{\text{measured sound pressure}}{\text{reference sound pressure}}$$

This would seem to be an unfortunate definition, because now everyone has to remember whether to use 10 times the $\log_{10}$, or 20 times the $\log_{10}$ when calculating common dB values.

Hint: For acoustic and electrical power, use 10; for acoustic pressure and electrical voltage, use 20.

To further differentiate Sound Power Level from Sound Pressure Level, the Sound Pressure Level is usually abbreviated as dB SPL. And since the reference sound pressure is defined as the threshold of hearing,

$$\text{db SPL} = 20 \log_{10} \frac{\text{measured sound pressure}}{\text{threshold of hearing}}$$

So db SPL simply relates the measured sound pressure to the "threshold of hearing".

The "threshold of hearing" is an experimentally derived number. Teenagers with good hearing were tested in the 1930's and were found, on average, to detect sound waves at 1000 Hz when the acoustic pressure was 0.00002 N/m^2 rms (20μPa). This level has been designated as the "threshold of hearing" and is used as the dB SPL reference (ANSI S1.1-1994). Frequency dependence of the threshold was ignored. Unfortunately the designation of dB SPL for Sound Pressure Level is often shortened to just "SPL" in the literature which could easily be confused with an abbreviation for Sound Power Level.

For example, if you measure a sound pressure of 0.002 N/m^2 rms = 0.002 Pa rms, the

$$\text{db SPL} = 20 \log_{10} \frac{0.002}{0.00002} = 40$$

or if you measure this same pressure in psi (rms of course) – see table below for conversions from Pascal units into psi

$$\text{db SPL} = 20 \log_{10} \frac{2.90 \times 10^{-7}}{2.90 \times 10^{-9}} = 40$$

In a medium other than air, e.g. in underwater sound, the reference level for that medium must be used in the db SPL calculations.

The table below lists some typical sound pressures, and was based on 0.00002 Pa = 2.90×10^{-9} psi. If the dB SPL value is known, sound pressure is $10^n \times 2.9 \times 10^{-9}$ for psi and $10^n \times 2 \times 10^{-5}$ for Pa , where $n = \frac{\text{dB SPL}}{20}$

What it is	Sound pressure (Pa)	Sound pressure (psi)	Sound pressure Threshold	dB SPL
Threshold human hearing	0.00002	2.90×10^{-9}	10^0 or 1	0
Electric clock	0.0002	2.90×10^{-8}	10^1 or 10	20
Inside a library	0.002	2.90×10^{-7}	10^2 or 100	40
Conversational speech	0.02	2.90×10^{-6}	10^3 or 1000	60
Your office	0.2	2.90×10^{-5}	10^4 or 10 000	80
Lathe at 3 feet	2	2.90×10^{-4}	10^5 or 100 000	100
Threshold of pain	20	2.90×10^{-3}	10^6 or 1 000 000	120
Jet engine at 50 ft.	200	2.90×10^{-2}	10^7 or 10 000 000	140
In-car stereo blaster	2000	2.90×10^{-1}	10^8 or 100 000 000	160
Krakatoa at 100 miles	20 000	2.90×10^{0}	10^9 or 1 000 000 000	180

Note db SPL, at the threshold of hearing, is 0. It is 0 because all dB SPL's are referenced to the threshold of hearing and $\log_{10} 1 = 0$.

It is obvious from the table above that a 20 dB change is equal to a factor of 10 (1 order of magnitude). This is simply a result of the definition of dB SPL as 20 times the $\log_{10}$. If dB SPL had been defined as 43 $\log_{10}$ X, then a difference of 43 dB would equate to a factor of 10. So for work in acoustic pressure or electrical volts, just remember that 20 times the $\log_{10}$ is used for the calculation, and the definition of a logarithm to the base 10 ($\log_{10}$) tells you that a difference of 20 dB will be a factor of 10. If a logarithm to base 3 ($\log_3$) was used, the difference of 20 dB would correspond to a factor of 3.

Microphone sensitivity

Fortunately, stating the sensitivity of microphones in V/Pa (volts/pascal) is gaining popularity. Since the output of any type microphone is linear with pressure, the units of V/Pa fall out naturally. As an indication of the confusion still prevalent in defining microphone sensitivity, the Endevco model 2510 piezoelectric microphone has the following numbers and units listed for sensitivity (the electrical output from piezoelectric microphones is commonly expressed in picocoulombs [pC], rather than volts):

31	**pC rms @ 140 dB SPL**
1069	**pC rms/psi**
0.155	**pC rms/N/m²**
-36.2	**dB re 1 pC rms @ 1 µbar rms**
44	**pC pk @ 140 dB SPL**

Although sensitivity units of V/Pa (or pC/µbar in the case of piezoelectric microphones) are commonly used now, the other equivalent units are still in use, and microphone sensitivity is often expressed in dB as

$$20 \log_{10} \frac{\text{Output in Vrms @ 1 Pa}}{\text{1 Vrms @ 1 Pa}}$$

which simply references the output of the microphone to a theoretical microphone which can pump out 1 V rms for 1 Pa of rms pressure. Since no one (to my knowledge) has yet marketed a microphone with such a high output, microphone sensitivities in dB are negative, something like -60 dB re 1V/Pa.

Conversions

In the equations below, let S_1 be the known value, S_2 be the unknown value of sensitivity.

To convert from S_1 dB (re 1V/Pa) into S_2 V/Pa:

$$S_1 \text{ dB (re 1v/Pa)} = 20 \log_{10} S_2 \text{ (V/Pa)}$$

$$\log_{10} S_2 \text{ (V/Pa)} = \frac{S_1 \text{ dB (re 1v/Pa)}}{20}$$

$$S_2 \text{ (V/Pa)} = 10^R$$

$$\text{where } R = \frac{S_1 \text{ dB (re 1v/Pa)}}{20}$$

To convert from S_1 dB (re 1V/Pa) into S_2 mV/psi:

$$S_2 \text{ (V/Pa)} = \frac{10^R \times 1000}{14.5 \times 10^{-5}}$$

$$\text{where } R = \frac{S_1 \text{ dB (re 1v/Pa)}}{20}$$

To convert from linear sensitivity S_1 volts/Pa into S_2 dB (re 1V/Pa) - excepting piezoelectric microphones:

1) Convert electrical output units into volts
2) Convert pressure units into pascal (Pa)
3) Calculate S_1 in volts/Pa
4) S_2 dB (re 1V/Pa) = $20 \log_{10} S_1$

To convert from linear sensitivity S_1 pC/µbar into S_2 dB (re 1pC/µbar) for piezoelectric microphones:

1) **Convert electrical output units into picocoulombs (pC)**
2) **Convert pressure units into µbar**
3) **Calculate S_1 in pC/µbar**
4) **S_2 dB (re 1pC/µbar) = $20 \log_{10} S_1$**

Dynamic range/resolution

Resolution (or threshold) defines the lower limit of the dynamic range. Electrical noise in the transducer and signal conditioning is the primary limiter.

For example, Endevco model 8510B-1 has a broadband (DC to 50 kHz) noise level of about 5 µv rms, and a typical sensitivity of 200 mV/psi, or an equivalent noise level of 25×10^{-6} psi.

$$\text{dB SPL} = 20 \log_{10} \frac{25 \times 10^{-6}}{2.9 \times 10^{-9}} = 79$$

which sets the low limit of the range
(2.9×10^{-9} is the threshold of hearing in psi units)

Similarly, an upper limit for the dynamic range is based on the maximum pressure where the output is still reasonably linear (3 psi for the 8510B-1)

$$\text{dB SPL} = 20 \log_{10} \frac{3}{2.9 \times 10^{-9}} = 180$$

which sets the high limit of the range.

The lower limit of dynamic range for a microphone may also result from the acceleration ("g") sensitivity. To continue with the model 8510B-1 example, the unit has a vibration sensitivity of 0.00014 psi(rms)/g. Accepted industry practice has been to state vibration sensitivity in equivalent dB SPL @ 1g rms.

$$\text{dB SPL} = 20 \log_{10} \frac{0.00014}{2.9 \times 10^{-9}} = 94$$

For 10g sinusoidal vibration, the output would be 114 dB SPL (a factor of 10 equates to 20 dB). These large equivalent dB SPL values indicate that vibration sensitivity, rather than electrical noise level, may often be the limiting factor at the low end of the range. Since the sensitivity of a microphone diaphragm to vibration goes as the cosine of the angle to the axis of vibration, mounting the unit with the diaphragm at 90° to the vibration input dramatically reduces or eliminates the error. If the microphone diaphragm must be aligned with the principal axis of vibration, shock isolation mounting may be required, e.g. in anechoic chambers, microphones are sometimes suspended by tiny bungee cords to isolate them from vibration inputs. Another alternative is to mount an accelerometer proximate to the microphone and use the measured acceleration to correct the microphone data in post processing. Some microphones, such as Endevco model 2510 have a built in accelerometer to compensate for vibration sensitivity.

Calibration

For units with DC response, such as silicon based microphones, it is possible to perform a static calibration using a precision dead weight tester and directly measure V/Pa and then convert the V/Pa into logarithmic units if required. Since the sensitivity calculations are made in ratios, DC instead of AC (rms) measurements may be substituted in the equations without having to convert from rms to DC levels. Similarly, we may substitute other instantaneous voltages and pressure values, e.g. mV pk at 1 psi pk for measuring acoustic shock.

For units with only AC response, such as piezoelectric or condenser microphones, various methods have been devised for generating a precise acoustic wave, e.g. piston phone, or a step function pressure may be generated using a quick dump valve and a dead weight tester.

Handy conversions

1 pascal (Pa) = 1 N/m^2 = 10 $dyne/cm^2$ = 10 μbar = 1.45039×10^{-4} psi
1 psi = 6894.72 Pa = 68947.2 μbar
1 bar* = 10^5 Pa =14.5039 psi = 0.986928 atmospheres = 10^6 $dyne/cm^2$
1 μbar = 0.1 Pa = 1 $dyne/cm^2$ = 0.1 N/m^2
1 Normal atmosphere = 101325 Pa = 14.6960 psi = 760 torr
1 mmHg (at 0°C) = 133.322 Pa = 0.019337 psi = 1 torr
1 in. Hg (at 0°C) = 3386.39 Pa = 0.491157 psi
1 in. H_20 (at +4°C) = 249.089 Pa = 0.0361275 psi

*Where I come from, we call this a saloon. The "bar" actually has an interesting derivation. The bar is defined as a force of 100 000 Newtons acting on a square meter (N/m^2). It is often confused with standard atmospheric pressure, especially by meteorologists, who commonly specify barometric pressure in millibars.

PSI to dB SPL conversion table

PSI	0.0029	0.010	0.020	0.029	0.05	0.10	0.20	0.29
dB SPL	120	131	137	140	145	151	157	160

PSI	0.50	1.00	2.00	2.90	5.00	10.00		14.696
dB SPL	165	171	177	180	185	191		194

The normal convention is to round off dB SPL numbers to the nearest whole number because the human ear cannot discern differences in dB SPL levels of less than 1 dB.

A dB SPL level of 194 is considered the maximum as it corresponds to 1 atmosphere of pressure, and levels above 194 constitute shock waves.

Notice when the psi levels increase by 10, the dB SPL levels increase by 20 dB, and when the psi levels increase by 100, the dB SPL levels increase by 40 dB.

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