MICROPHONE TALK

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In his early studies of speech, hearing, and sound, Alexander Graham Bell encountered a tremendous range of acoustical power, e.g.,

1.22×10^{-4} ergs/sec for threshold of hearing at 1 meter
1.22×10^{8} ergs/sec for threshold of pain at 1 meter

Thus, we can say the human threshold of pain occurs at 10^{12} times greater sound power than the threshold of hearing. This tremendous dynamic range of hearing prompted Dr. Bell to search for an alternative to a linear amplitude scale to express values of sound power.

If we compared these two sound powers logarithmically, we would have

$$\log_{10} \frac{1.22 \times 10^{8}}{1.22 \times 10^{-4}} = 12$$

Now, you'll notice that 12 is a much more convenient number to use in describing the (painless) sound power range of the average human ear. Dr. Bell's staff also noticed this convenience and coined a new term, the BEL, in tribute to their boss. The BEL utilized the threshold of human hearing as the reference. So 12 BEL indicated a sound power 10^{12} above the threshold of hearing, and -12 BEL (if measurable) would indicate a sound power of 10^{-12} below the threshold of hearing.

Now that was a nice straightforward relationship but the workers weren't content to leave it alone; they decided the BEL was too large and that the BEL should be subdivided into 10 (deci) parts or decibels, abbreviated dB, and

$$\log_{10} \frac{1.22 \times 10^{8}}{1.22 \times 10^{-4}} = 12 \text{ BEL} = 120 \text{ dB}$$

The acoustic workers then coined the term SOUND POWER LEVEL (PWL) and equated it to this very specific logarithmic ratio:

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

or

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

Because it is more convenient to measure sound pressure than sound power, we can define

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

which comes about because sound power is proportional to the sound pressure squared. e.g., for a point source

$$\text{Sound Power} = \frac{4\pi r^2 \, p^2}{\rho c} \times \frac{1}{100}$$

where r is distance from source in cm
p is rms pressure in newtons/m^2
ρ is density of medium in grams/cm^3
c is velocity of sound in meters/sec. (in that medium)

Now, as you hopefully recall,

$$\log_{10} (N)^2 = 2 \log_{10} N.$$

So we can rewrite the Sound Pressure Level (affectionately abbreviated to SPL) as

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

Since the reference sound pressure is defined as the threshold of hearing,

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

If a different reference is used, as in underwater sound, the reference level must be stated or understood from the technology involved.

Now, just to see if you've got this straight so far, see if the table below makes sense.

SOUND POWER RATIO	SOUND PRESSURE RATIO	PWL in BEL	SPL in dB
1	1	0	0
10^4	10^2	4	40
10^8	10^4	8	80
10^{12}	10^6	12	120

The most commonly used measurement of sound pressure level is the dB SPL The SPL simply relates the measured sound pressure to the "threshold of human hearing."

At this point we should assign a physical value to the threshold of hearing which is, in fact, a statistical value. A group of teenagers with good hearing were tested in the 1930s and found, on the average, to perceive presence of sound at 1000 Hz when the acoustic disturbance was 0.00002 N/m^2 rms (expressed in different units in the past, such as 0.0002 dynes/cm^2 or 0.0002 microbar). This level is used as the SPL reference and is commonly called the "threshold of hearing". Frequency dependence of the threshold is ignored. If you measure a sound pressure of 0.0002 newtons/m^2 (N/m^2) rms,

$$\text{Sound Pressure Level} = 20 \log_{10} \frac{0.002}{0.00002} = 40 \text{ dB SPL}$$

or if you measure the same pressure in psi (rms, of course) units,

$$\text{Sound Pressure Level} = 20 \log_{10} \frac{2.90 \times 10^{-7}}{2.90 \times 10^{-9}} \text{ dB SPL} = 40 \text{ dB SPL}$$

For comparison purposes, the Table below relates some commonly experienced sound pressures and the resulting SPL.

What it is	Sound Pressure (N/m^2)	Sound Pressure (psi)	SPL=Sound Pressure Level (dB SPL)
Threshold of Human Hearing	0.00002	2.90×10^{-9}	0
Electric Clock	0.0002	2.90×10^{-8}	20
Inside a Library	0.002	2.90×10^{-7}	40
Conversational Speech at 3 ft	0.02	2.90×10^{-6}	60
Your Office	0.2	2.90×10^{-5}	80
Lathe at 3 ft	2	2.90×10^{-4}	100
Threshold of Pain (=Acid Rock)	20	2.90×10^{-3}	120
Jet Engine at 50 ft	200	2.90×10^{-2}	140

Note that increasing (or decreasing) sound pressure by a factor of 10 increases (or decreases) SPL by 20 dB (this is a truth that runs at large: take it, it's yours, free of charge). Other relationships readily recalled are 1 dB (1.11 x), 6 dB (2 x), 10 dB (approx 3 x) and the coincident 30 dB (approx 30 x).

The only other fascinating thing about these relationships is that the SPL, at the threshold of hearing, is 0. It's 0 because all SPL's are referenced to the threshold of hearing and $\log_{10} 1 = 0$.

Enough said about sound power, sound pressure, and Sound Pressure Level (SPL). Let's move on to defining the sensitivity of an acoustic transducer. Similarly to defining sound pressure level in decibel notation, transducer sensitivity is commonly expressed in dB re 1 volt at 1 N/m^2 (i.e., at 94 dB SPL).

$$\text{Transducer Sensitivity} = 20 \log \frac{\text{output (V rms) at 1 N/m}^2}{\text{1 V rms at 1 N/m}^2} \text{ per N/m}^2$$

If a microphone has an output of 1 mV at 1 N/m^2, its sensitivity is commonly expressed as -60 dB re 1 V per N/m^2. Sensitivity of piezoelectric microphones is given in pC or in dB re 1 pC at 1 N/m^2.

The scientific world honors famous scientists by assigning their names to units of measure (e.g., degrees Celsius, Watts of power, Hertz for events/second), so the name of Pascal (Pa) has been assigned to the N/m^2 unit. Reference sound pressure is often written as 20 uPa instead of 20 uN/m^2. And microphone sensitivity is often expressed as dB re 1 V/Pa.

Acoustic Sensitivity

Let's take Endevco's 8550M1 High Intensity Microphone as an example. Its sensitivity (10 V dc excitation) is typically -90 dB re 1 V/Pa. From the foregoing discussion we can list its output at various sound pressure levels.

-90 dB re 1 V at 94 dB SPL
-60 dB re 1 V at 124 dB SPL
1 mV at 124 dB SPL
10 mV at 144 dB SPL
20 mV at 150 dB SPL
60 mV at 160 dB SPL
100 mV at 164 dB SPL

You may wish to use a pressure transducer calibrated in mV/psi. Just note that 1 psi is very nearly 170 dB SPL. Let's use Endevco's 8510-2 as an example. Typical sensitivity is 150 mV/psi. You can mentally convert to output at other levels:

150 mV at 170 dB SPL
15 mV at 150 dB SPL
5 mV at 140 dB SPL
0.5 mV at 120 dB SPL

The 8510-2 is calibrated, statically, at 1 psi. Note that we have used a static pressure value (1 psi) and a static voltage reading (150 mV) to project sensitivity for rms pressure measurements. This is correct because, if the transducer generates 150 mV dc for 1 psi static, it will generate 150 mV rms for 1 psi rms. Similarly, we may substitute other instantaneous voltages and pressure values, e.g., mV pk at 1 psi pk for measuring acoustical shock.

We may ask to how low a sound pressure level the 8510-2 may be used. Its broadband noise level is about 10 uV rms (dc to 50 kHz). If we compute the dB ratio between 10 uV and 150 mV

$$20 \text{ dB} \log \frac{10 \text{ uV}}{150 \times 1000 \text{ uV}} = -83 \text{ dB}$$

we can easily determine that the equivalent noise level is 83 dB below 170 dB SPL, i.e., 87 dB SPL.

The 8510-2 is commonly used to 3 times rated range, or 6 psi, so it can reasonably handle 6 x 0.707 = 3.5 psi rms of sound pressure. This is equivalent to

$$170 + 20 \log \frac{3.5 \text{ psi}}{1 \text{ psi}} = 181 \text{ dB SPL.}$$

So the sound pressure measuring range for the 8510-2 is about 87 or 90 to 180 dB SPL.

Vibration Sensitivity

Vibration sensitivity for pressure transducers is normally expressed as equivalent psi per g. An 8510-2 with a 150 mV/psi sensitivity and an output of 75 uV at 1 g has a vibration sensitivity

$$\frac{75 \text{ uV/g}}{150 \times 1000 \text{ uV/psi}} = 0.0005 \text{ psi/g}$$

For acoustic applications, it is accepted practice (ISA S35.10) to give vibration sensitivity in equivalent SPL at 1 g. For the 8510-2 noted above, use your handy pocket calculator, compute

$$\text{Equivalent SPL} = 170 - 20 \log \frac{0.0005 \text{ psi}}{1 \text{ psi}} = 104 \text{ dB SPL at 1 g}$$

Vibration sensitivity at 10 g would, of course, be 124 dB SPL. These large equivalent SPL values indicate that vibration sensitivity, rather than noise level, may be the limiting factor at the low end of the measuring range.

HANDY CONVERSIONS

1 bar (or saloon) = 14.50377439 psi = 0.98692 atmospheres
1 psi = 68947.57 ubar
1 ubar = 1 dyne/cm^2 (thank God for this one) = 0.1 N/m^2
1 pascal (Pa) = 1 N/m^2 = 10 dyne/cm^2 = 10 ubar
1 pascal (Pa) = 14.50377439 x 10^{-5} psi
1 MPa = 145.0377439 psi
1 atmosphere = 760 torr = 101325 N/m^2 = 14.696 psi
1 mm Hg (at 0°C) = 0.01934 psi
1 in. Hg (at 0°C) = 0.4912 psi
1 in. H_2O (at 4°C) = 0.036127 psi

Conversion Table

RMS PSI	SPL
0.0029	120.0
0.010	130.7
0.020	136.8
0.029	140.0
0.05	144.7
0.10	150.7
0.20	156.8
0.29	160.0
0.50	164.7
1.00	170.7
2.00	176.8
2.90	180.0
5.00	184.7
10.00	190.7
14.696	194.0
20.00	196.8
29.00	200.0
50.00	204.7
100.00	210.7

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