The Decibel Scale

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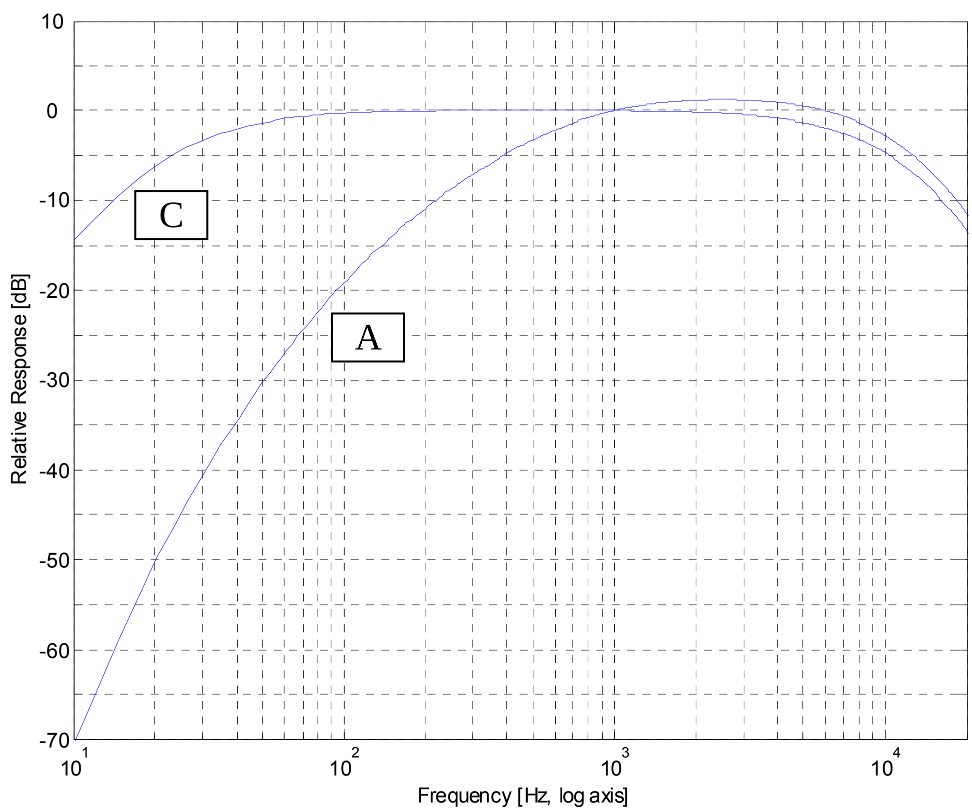
The characteristics of audio signals and noise are often specified in decibels (dB). The bel is defined to be the base ten logarithm of a power ratio. The logarithm compresses the numerical range of its argument, and this is often a convenient feature when one must deal with numbers differing over several orders of magnitude.

dB measurements may be made using a frequency weighting filter, sometimes called a weighting *network*, to make the measurement depend on the frequency distribution of the signal's spectrum. The input signal is passed through the weighting filter prior to the signal level determination.

Several weighting filters have been standardized. Two standard weighting filters, arbitrarily designated A and C, are the most common. The A-weighting filter corresponds roughly to the average sensitivity of the human ear at low to moderate sound levels, while the C-weighting filter approximates the ear's sensitivity at high sound levels. Note that the A-weighting filter tends to emphasize spectral components in the 2 to 5 kHz range while reducing the contribution from lower and higher frequencies. The C-weighting filter has a flatter response over much of the audio frequency band.



Weighting filter response: C-weighting and A-weighting

It is important to understand the influence of the weighting network because noise levels and signal levels in audio systems are sometimes specified in this manner.

Detailed Background

It is often convenient to compare two quantities in an audio system using a proportionality ratio. For example, if a linear amplifier produces 2 volts (V) output amplitude when its input amplitude is 100 millivolts (mV), the *voltage gain* is expressed as the ratio of output/input: 2V/100mV = 20. As long as the two quantities being compared have the same units--*volts* in this case--the proportionality ratio is dimensionless.

If the proportionality ratios of interest end up being very large or very small, such as $2x10^5$ and $2.5x10^{-4}$, manipulating and interpreting the results can become rather unwieldy. In this situation it can be helpful to compress the numerical range by taking the *logarithm* of the ratio. It is customary to use a base-10 logarithm for this purpose. For example,

$$\log_{10}(2x10^5) = 5.301$$

and

$$\log_{10}(2.5x10^{-4}) = -3.602$$

If the quantities being compared have the units of power (watts), or intensity (watts/m^2), the base-10 logarithm $\log_{10}(P_1/P_0)$ is expressed with the unit *bel* (symbol: *B*), in honor of Alexander Graham Bell (1847 -1922).

The decibel is a unit representing one tenth (deci-) of a bel. The expression for a proportionality ratio expressed in decibel units (symbol dB) is:

$$10 \log_{10}(P_1/P_0),$$

where P_1 and P_2 must have the same units, again either power or intensity.

Intensity Level = IL = 10 log10(I/I_{ref}), expressed as dB re I_{ref}

Common Usage

The power dissipated in a resistance *R* ohms can be expressed as V^2/R, where *V* is the voltage across the resistor. If we compare two power levels specified with the *same* resistance R, we can express the dB ratio as

$$10 \log_{10}((V_2^2/R)/(V_1^2/R)) = 10 \log_{10}((V_2/V_1)^2) = 20 \log_{10}(V_2/V_1)$$

Also, for a plane or spherical wave the acoustic intensity is proportional to the square of the acoustic pressure, leading again to an expression

$10 \log_{10}((P_2^2/\rho_0 c)/(P_1^2/\rho_0 c)) = 20 \log_{10}(P_2/P_1)$,

where $\rho_0 c$ is the specific acoustic impedance.

These results have led to the casual definition of dB as 20 $\log_{10}()$ of the ratio of any two voltages or two pressures, even when the electrical or acoustical impedance, respectively, are not actually the same. In this case it is most common to use an explicit reference level in the denominator of the ratio, and then to specify the reference explicitly.

Sound Pressure Level (SPL):

- $L_P = 20 \log_{10}(P/P_{ref})$, expressed as dB re P_{ref}

The reference pressure, P_{ref}, is 20 μPa (20 micropascal, or $2x10^{-5}$ pascal) for most hearing-related measurements in air, although sometimes SPL measurements are expressed relative to 1 μbar (1 μbar = 0.1 Pa).

Expressing sound levels in decibels is also appropriate because human loudness perception tends to be logarithmic: a 10dB increase in SPL for a pure tone corresponds roughly to a doubling of perceived loudness.

Voltage:

$20 \log_{10}(V/V_{ref})$, expressed as dB*x*, such as

- dBV when V_{ref} = 1 V RMS (root-mean-square)
- dBu (or dBv) when V_{ref} = 0.775 V RMS

Note that 0.775 volts is the voltage necessary to dissipate 1mW (milliwatt) in a 600 ohm load, a common standard in the telecommunications industry.

Power:

$10\log_{10}(P/P_{ref})$, expressed as dB*x*, such as

- dBm when P_{ref} = 1 mW
- dBW when P_{ref} = 1 W

References

- IEC 61672-1:2002: Electroacoustics-Sound Level Meters, IEC, Geneva, for A- and C-weighting filters.
- Beranek, Leo L., Acoustical Measurements, Acoustical Society of America, 1988.
- Eargle, John M., Handbook of Recording Engineering, 4th ed., Kluwer Academic Publishers, 2002.
- Kinsler, Lawrence E., Frey, Austin R., Coppens, Alan B., and Sanders, James V., Fundamentals of Acoustics, 4th ed., Wiley & Sons, 1999.
- MATLAB functions for weighting filters: ftp://ftp.mathworks.com/pub/contrib/v5/signal/octave/