Decibel Decoding by Plane Hell Action

What are decibels - legacies of Alexander Graham Bell and James Watt? Can we get to grips with it at all?

1. Sound Intensity

Firstly, a decibel value is actually a kind of Sound Intensity. Sound Intensity is all about how energy/power affects a given spatial area. Imagine a noise source and how its sound waves pass through space then come into your house through an open window. Once inside the window there is a resulting Sound Intensity that we can measure using a noise meter and see its equivalent decibel value: this decibel (dB) figure represents how the original energy was converted into Sound Intensity with respect to the square area of the window.

Sound Intensity is often known by the symbol $\boldsymbol{I}$.

Sound Intensity is measured in watts/metres^2. Or power per square metre.

A decibel value is not only derived from the Sound Intensity measured at a location, but it also factors in the Sound Intensity of the Threshold of Human Hearing. In fact, a decibel value compares the measured Sound Intensity against this Threshold to standardise the computed result.

The Threshold of Human Hearing is a fantastically small/soft value. In terms of power it can be 'imagined' as spreading 1 watt of power over the entire area of Germany 3 times, and the Intensity of the resulting sound will still be audible to the healthy human ear. The human ear is that sensitive!

The Threshold of Human Hearing has a Sound Intensity that is 1 trillionth of a watt per metre^2.

The Threshold of Human Hearing Sound Intensity is represented by $I_0 = 10^{-12}$watts/m^2.

The full range of human hearing starts with this threshold as a lower bound, $I_0 =$ 0.000000000001 watts/m^2 and has an upper bound of 1 watt/m^2. This upper bound is where pain and damage start to occur.

The range for $\boldsymbol{I}$ = [0.000000000001, 1] watts/m^2.

2. Decibels

Now that we know about the Threshold of Human Hearing, the decibel scale sets:

0 dB = 0.000000000001 watts/m^2 = Threshold of Human Hearing

120 dB = 1 watt/m^2 = Upper tolerance level of Human Hearing

On with the maths! You will often see decibels being described as a 'ratio' or 'relative' value. This ratio is just a part of the formula for decibels, where a Sound Intensity that has been measured at a specific location must be divided (standardised) by I_0.

The ratio is written as $[\ I\ /\ I_0\ ]$.

Now, dividing a figure by 1 trillionth (I_0), as happens in this ratio, will make very, very large numbers with lots of zeros. To make these results more easily represented, such as for charts or in tables, they are expressed by their log to base 10 ($\log_{10}$).

This ‘log base10’ ($\log_{10}$) value means knowing how many 10s we need to times together to get the starting figure back?

As an example, the $\log_{10}$ of 100 is 2. 2 10s are needed as 100 = (10 * 10) = 10^2.

Similarly, the $\log_{10}$ of 1000 is 3, since 3 tens are needed as 1000 = (10 * 10 * 10) = 10^3.

A bit more complicated is something like $\log_{10}$ of 400. Well, we can just use our calculator for that one …. Answer is 2.6!

So by taking $\log_{10}$ we could write 2 instead of 100, or 3 instead of 1000 or 2.6 instead of 400.

So far we have looked at this much of the decibel formula …. ($\log_{10} [I / I_0]$).

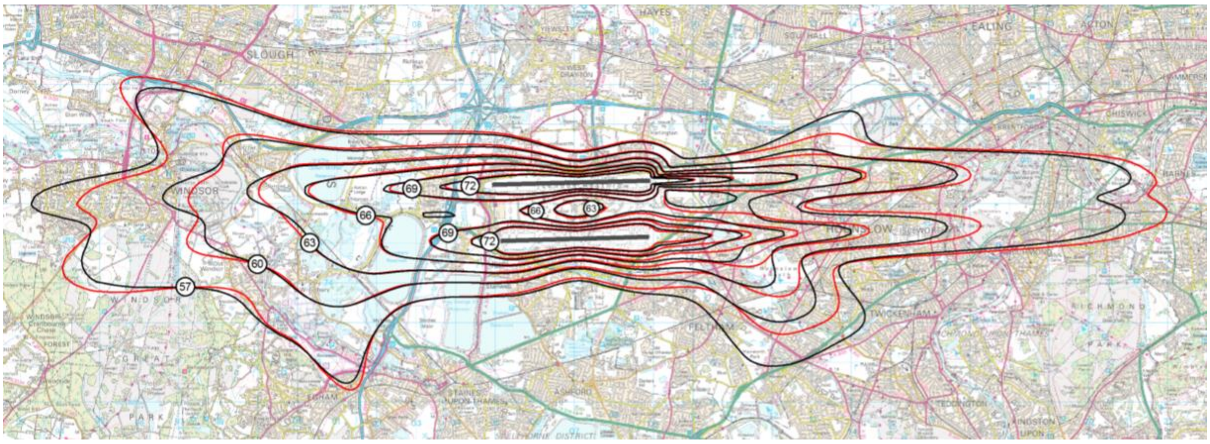
The final piece of maths for giving us our Sound Intensity in decibels is to multiply by 10. With the part of the formula shown so far we have computed a value in Bels, and we need to convert it to decibels by multiplying by 10. Decibels are the number of tenths of a Bel that the measured Sound Intensity represents.

The full formula for computing decibels from a measured Sound Intensity is

Intensity as Decibels (dB) = $10 * (\log_{10} [I / I_0])$.

3. Increase in Decibels

We are often told that an increase of 3 dB is observed. In fact, when we look at the Noise Contours produced by an airport such as Heathrow, we see that the contours decrease by 3dB as they move further out. Why is 3 dB being used in this way?



What does a change such as 3dB mean as far as Sound Intensity or even Loudness is concerned?

To answer this we need to do some maths, so consider that this increase of 3dB gives us a new Sound Intensity measurement of I_B.

And if we say that the original Sound Intensity is I_A then we can do some substituting into the decibels formula and work out what the difference of 3dB shows. So first we write that 3dB is the difference between the new and the original decibels readings:.

$3dB = 10 (\log_{10} I_B) - 10 (\log_{10} I_A)$

$\Rightarrow 3 = 10 (\log_{10} I_B - \log_{10} I_A)$

$\Rightarrow 0.3 = \log_{10} (I_B / I_A)$ …. this step uses log arithmetic

$\Rightarrow 10^{0.3} = I_B / I_A$

And since $10^{0.3}$ is approximately 1.995,

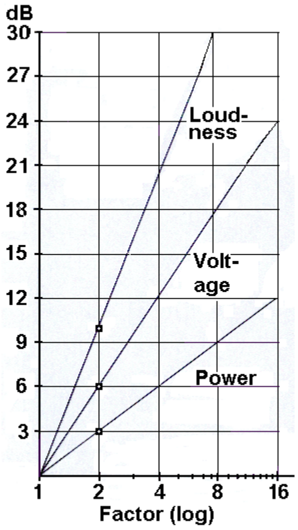
$1.995 * I_A = I_B$

So maybe that's why airport noise contours are using 3dB to distinguish enclosed areas – because it means a doubling of intensity..

4. Loudness

Loudness is related to, but is not equal to, Sound Intensity. Loudness is how strongly the **ear** perceives sound. It is a psycho-physical sensation, belonging to the science of psychoacoustics. Technically, Loudness is not measured in decibels, but in **Phons**. The Phon Scale accounts for the design and physiology of the human ear.

The Phon takes account of the 'frequency' of the sound. For example, with 1000 Hz as the standard frequency against which measurements are made, then a sound with an intensity that results in 50dB at 1000 Hz has a loudness of 50 Phons.



For a sound to be **twice as loud**, its Sound Intensity must increase by a **factor of 10**.

We know from the maths that we did in the previous section, that a

3dB increase = 2 times the original Sound Intensity.

We can do the same maths and find that a

10dB increase = 10 times the original Sound Intensity.

Therefore

10 * Sound Intensity = 2 * Loudness = 10 dB increase

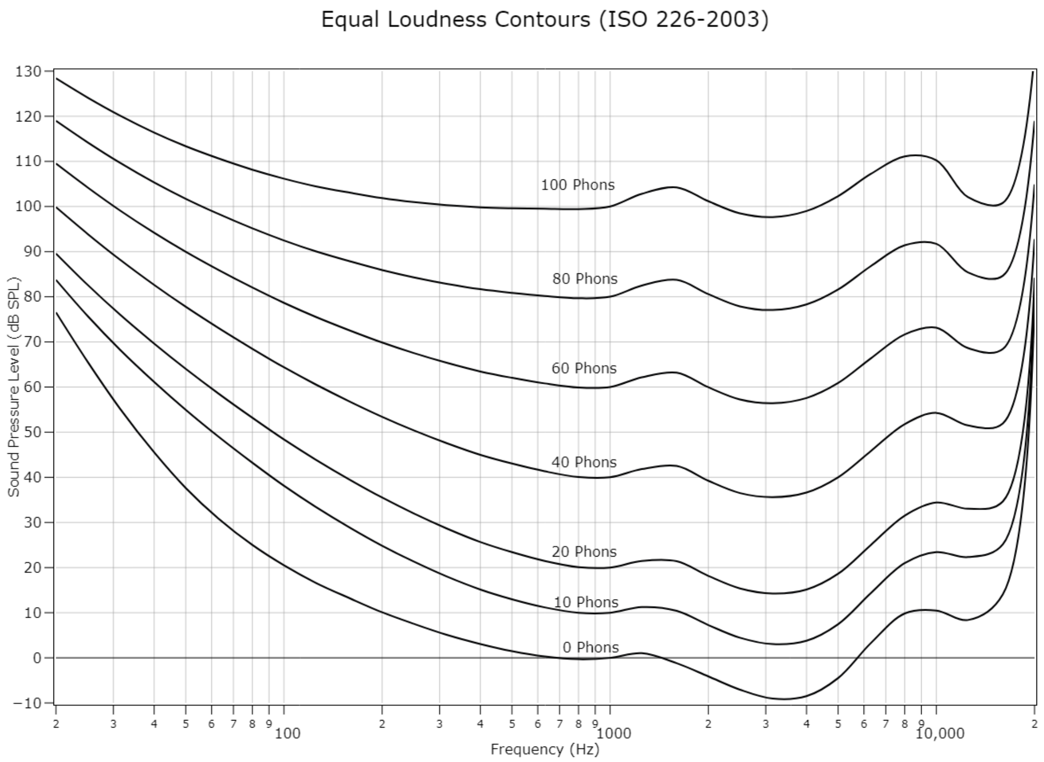
With Loudness, for these equalities to be true, we must be considering the same type of sound, but it is generally accepted that

- for a sound to be twice as loud requires its Sound Intensity to be 10 times greater.
- each doubling in loudness requires a ten-fold increase in Sound Intensity or an additional 10 dB.

Some results claim that if the original sound has a higher decibel value, perhaps 60dB, then it more rapidly becomes twice as loud provided the nature of the sound does not change.

The Phon unit is complicated by the fact that a sound will sound louder or softer if it is replayed at different frequencies. So if a sound is played at a given frequency (Hertz, Hz) it will have a particular decibel value at that frequency and by changing the frequency of the sound, its decibel value will change. This is famously known and represented by the Equal Loudness Contours using a formally tested and plotted contour diagram. Yes we have our lovely contours again!

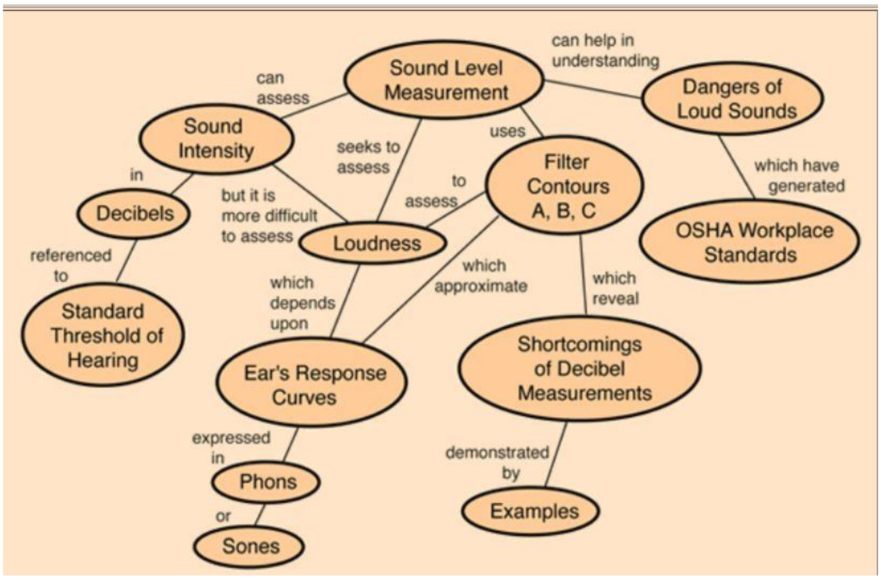
The contour plot below is the published ISO 226-2003 standard: https://plot.ly/~mrlyule/16.embed



For example, the plot shows that at a frequency of 1000 Hz, a 60 Phons sound has about 60 dB, but that the same 60 Phons sound will register higher decibel values when played at much lower or much larger frequencies.

The curves also show for the 1000 Hz frequency that 20 Phons is twice as loud as 10 Phons and there is a 10 dB difference. Comparing 40 Phons with 20 Phons (a doubling of loudness) we see that there is a 20 dB difference. And so on.

References



Hyperphysics at http://hyperphysics.phy-astr.gsu.edu/hbase/Sound/loud.html#c1

Tontechnik-Rechner at http://www.sengpielaudio.com/calculator-levelchange.htm