LOUDNESS
vs.
INTENSITY

A primer by

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What’s the big deal?

(why do I yammer on about loudness vs. intensity, anyhow?)

- Language exists to communicate.
- If we don’t use the same meanings to the words (leaving out philosophical issues for now), communication is difficult.

- Hence, a few definitions and words to help us in the discussions.
- This understanding will also help explain some of the reasons why different compression sounds so different.

Intensity – What is it?

- Intensity is the EXTERNAL MEASURED LEVEL OF A SOUND.
- There are many measures of intensity. For now, we will use the common psychoacoustic (not mechanical engineering) definition of SPL, or "sound pressure level".
  - There are assumptions built into SPL. Let's keep it simple for now and forget them.
  - SPL, usually measured in dB, is a measure of acoustic energy in the atmosphere.

Ok, now how about electronics?

- In electronics, it’s still the same, except that we do not know the meaning of 0dB in acoustic terms. Therefore:
  - dBm, dBv, and other defined reference levels provide a way to understand what the intensity of the analog of a signal is.
  - There are assumptions (constant impedance, for instance) built into these level measures as well. Again, let us keep it simple for now.

What is Loudness?

- Loudness is the INTERNAL, SUBJECTIVE EXPERIENCE OF HOW LOUD A SIGNAL IS.
- The term loudness dates back at least to Fletcher, if not beyond.
- Loudness is not intensity
- Loudness and intensity can be mostly related by a complex calculation, however:
  - Every listener is a bit different
  - Hearing injuries affect loudness in many ways
  - Intensity does NOT equal loudness. The relationship is complex, and could constitute an entire tutorial in and of itself.
  - In the worst cases, intensity is a very poor substitute for loudness, and vice versa.

When do we use Intensity?

- Intensity is an OBJECTIVE measure. It measures the actual fluctuations in air pressure in the atmosphere that constitute sound.
  – We use intensity when that is what we need to know.
  – We do NOT use intensity when we want to know how loud a sound is to a listener.

When do we use Loudness

- When we are trying to describe the experience that the listener has.
- When we are trying to estimate psychoacoustic parameters.
- When we want to know why somebody is shouting “turn that **** thing down!” and the level (intensity) isn’t that high.
- When we want to know why somebody is shouting “TURN UP THE SOUND” when the intensity is already excessive.
- When we want to match loudness, NOT level, across audio selections, either full-bandwidth or from remotes/phones.

What can we say about Loudness vs. Intensity in the course of 10 minutes?

- When the spectrum (frequency content) of a signal is unchanged, loudness is approximately (sometimes very approximately for some special signals) proportional to the 1/3.5 power of the signal power, or the 1/1.75 power of amplitude.

What else?

- The ear is understood to have “critical bands” or “ERB’s”.
  - These relate to a mechanical filtering system in the ear that does frequency analysis.
- Signals in the same “band” convert intensity to loudness approximately with the power law relationship given in the last slide.
- Signals in different bands ADD linearly in loudness.

REMEMBER – All of these relationships are approximate!

Yes, and?

- This means that two signals at frequencies reasonably removed from each other, each of which has ½ the energy of the original, will have 2*(1/2)^(1/3.5) or 1.64 of the loudness of one of the signals presented at energy 1.
- If I double the energy of a signal without changing the spectrum, the loudness will increase by a factor of about 1.21
- If I double the energy of the signal by adding as much energy in at a frequency where energy was not present, the loudness doubles.

What did I just say, anyhow?

- If we double the energy of a sine wave (to use a simple example), its loudness rises by approximately 2^(1/3.5).
- If we add another, second sine wave at a frequency removed (in terms of critical bands) from the first, the loudness doubles.
- The difference in loudness ratio for these two signals with the same energy is 1.21 vs. 2.

And that can be worse.

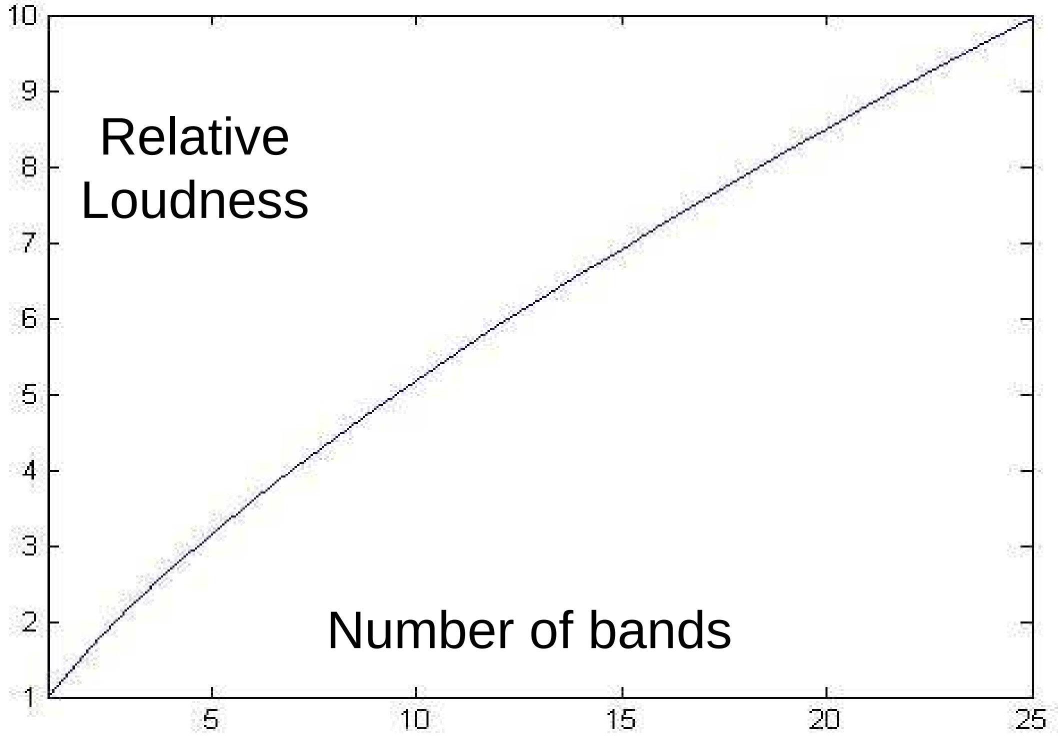
If we take the same amount of energy, and spread it out from a tone across 1, 2, 3, 4, critical bandwidths, the loudness will change (increase) as the energy is spread out, as long as the signal spectrum is somewhat above the absolute threshold of hearing.

A demonstration

- The two files I am about to play have the same energy.
  - In one case the energy is all in one sine wave
  - In the other case, it’s in 3 sine waves an octave apart (each)

(press ESC to cancel the playback)

A graphical example



In this slide, the vertical axis is the relative loudness, with the single-band loudness set to '1' for simplicity. The curve shows the relative loudness when the same amount of ENERGY is split over 'n' bands, from 1 to 25. The numbers for over 15 bands are probably an overestimate, but that is signal dependent.

Two things to recall about that graph

- The range of loudness corresponding to a given signal energy can vary by about a factor of 10.
- The graph is approximate. It is ONLY approximate.
  - Effects due to different listeners will change it
  - Effects regarding absolute threshold will change it
  - It's only an approximation in any case. The power law is quite approximate to start with.
- None the less, the point holds that loudness is not very strongly correlated to intensity.

Loudness vs. dB

- dB SPL is a measure of the INTENSITY of a signal. dB does not measure loudness.
- A doubling of loudness is about 10dB or so.
  - These numbers were established by a set of experiments done by Fletcher, after Bell's original experiments.
  - The work was confirmed by many other experimenters.
  - The level change to double loudness depends on both level and frequency
  - The design of the experiment is a full tutorial topic in itself.

Some other demos

- Another example of narrow vs. broadband signals.
  - Narrowband noise (white noise, 1 critical bw wide)
  - Broadband noise (white noise)
- Two music clips with the same energy
  - N.B. since these are not stationary, the comparison is much harder
  - N.B. these clips not presented due to DRM.

So what's this "loudness" button?

- There is a "loudness" button on my receiver/amplifier/whatever. What is this?
  - Because of the well-known reduced sensitivity of the ear at low frequencies, some manufacturers choose to add a bass boost, sometimes variable, and call it a "loudness" control.
  - It's linear, time-invariant. The ear is neither. It really is much more difficult than a fixed frequency shaping.
  - The best you can say is that it makes the sound louder. It can not fully compensate for changes in sensation level without being signal dependent and time varying.

Why the Loudness Button can't do what it is supposed to do.

FIG. 134.—LOUDNESS LEVEL CONTOURS VERSUS SENSATION LEVEL.

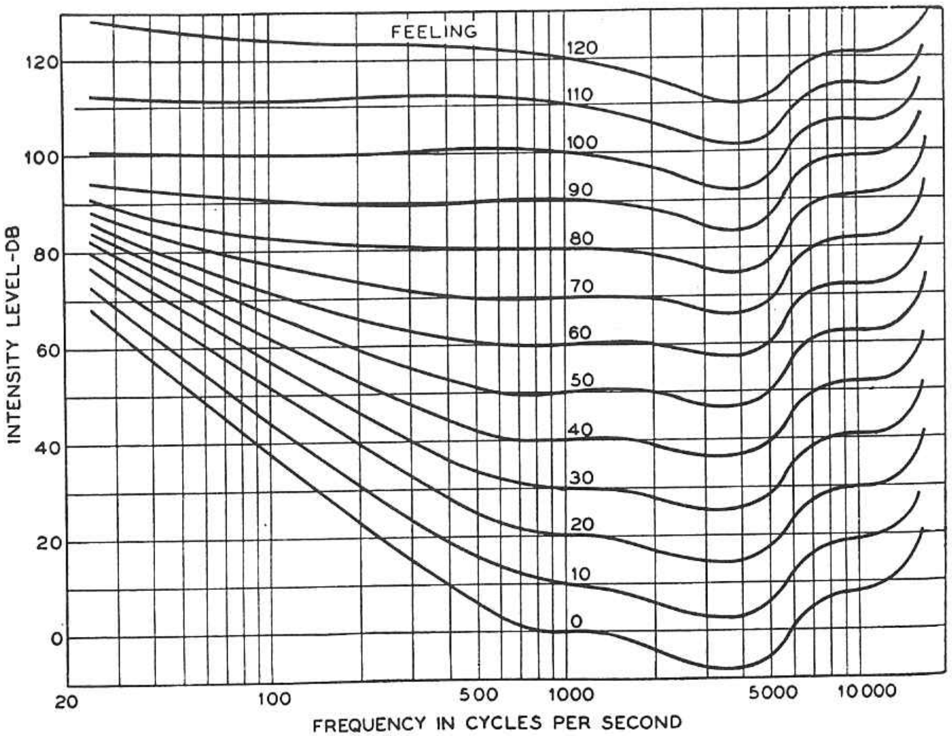


FIG. 135.—LOUDNESS LEVEL CONTOURS VERSUS INTENSITY LEVEL.

A real "loudness restorer" that worked for different intensities of presentation levels would have to be time-varying and signal dependent. It's not that easy.

Moving forward

- We should be careful to use the terms “loudness” and “intensity” properly, and to bear in mind how the two are loosely related.
- When we use nonlinear processing such as level compression that spreads frequency content, we must realize that the loudness may rise faster than expected.

So, does that mean that there is such a thing as “loudness enhancement”?

- Well, leaving aside the metaphysical question of exactly what an enhancement is, yes.
  - If a nonlinearity spreads the spectrum of a signal, it is likely to become louder.

There are some common examples.

- LP distortion grows with level. That means that as level grows, the signal bandwidth (including the distortion) increases.
  - This means that an increase in intensity is over-represented by the increase in loudness.
    - This can create an illusion of “more dynamic range”.
    - It can also be very annoying.
- Tape distortion grows with level. It behaves different than LP’s, but to the same result, at usual saturation levels.

What about “Make it LOUD Sorts of things?

- Oh, yes, they work.
  - It is a bit of an art to make a signal have a peak to RMS ratio similar to that of a sine wave.
  - They spread the spectrum very broadly.
  - You can create your own opinion about how they sound.

So, how would one attempt to measure loudness?

1. Pick a time window (this can vary depending on application and need)
2. Do a frequency analysis in this time window.
3. Group together the energies in each 1/3 ERB of the signal (or so).
4. Spread the data per understanding of cochlear filters.
5. Generate an ERB by ERB power spectrum at 1/3 ERB intervals.
6. Compress that spectrum (using somwhere between 1/3 and ¼ power depending on the signal)
7. Normalize each ERB (i.e. if the spread is 1/3 ERB centers, multiply each by 1/3)
8. Sum up those partial loudnesses to get total loudness for the given block

Could you be a bit more specific?

- Unfortunately, no.
  - At least not in a 1-hour presentation.

Questions?