Subwoofer Camp

…needed for good sound, or not? [i]

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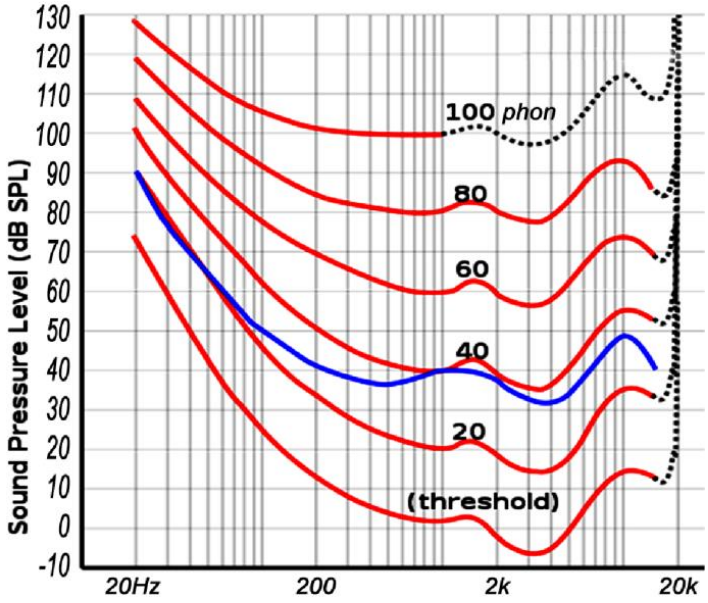
Even with age, we all can still enjoy rich low bass. We'll be unlikely to lose sensitivity to low frequencies (LF) 20~200Hz, the lowest third of the 10 octaves of hearing, 20~20,000Hz. However hearing LF fully and lifelike is not likely using bookshelf-size or even typical "tower" speakers alone. Even if we think we do, what LF we hear may only be distortion! Whether for music in 2-speaker stereo or movie effects in 5.1, actually hearing fundamentals of music extending below 30Hz, or thunder-like effects to 20Hz, very likely requires one or more subwoofers (SW).



Equal Loudness Contours of standard ISO:226 2003 show how hearing perception compresses bass frequencies, requiring higher SPLs to match loudness. The **blue** 40phon curve of Fletcher & Munson 1933 exemplifies the 2003 update, and inverted is approximated by the A-weighting curve used for noise measurements.

Can we know what we need when we haven't heard it?

The Equal Loudness Curves above provide insight into the subwoofer range from 20Hz to 63, 80,100, or 120Hz. Follow the "threshold" curve (the softest most can perceive) until it intersects a 30Hz tone (to cover the lowest Bb of a piano or the open B of 5-string bass) at 60dB sound pressure level (SPL). If heard live just below a moderate 70SPL, it should be mildly audible. But if reproduced over a loudspeaker advertised as having a "frequency range to 30Hz" (–10dB), it plays shy of 60SPL, so it will be *inaudible*. At double and triple the 30Hz, harmonics including distortion may sound louder than the pure tone. And may cause us only to *think* we hear low fundamentals for any audio content when we don't. *Many audiophiles cannot know they have not fully heard low bass!*

Our brains lie to us when we *perceive un-hearable* fundamentals by virtue of higher harmonics that *are heard.* How? Due to diminishing LF sensitivity more than speaker limitations, we may not be able to hear 30Hz up to nearly 60SPL (still below zero phon). But at the same near 60SPL, we are able to hear a 2nd harmonic at 60Hz at louder than 20phon, along with a 3rd harmonic at 90Hz approaching 40phon, that together "imply" a unique fundamental at 30Hz, which our brain *fills in* (perceives). Even an octave higher, we perceive utility frequency "hum" over a 3-inch smart-speaker just from the hum's 120 (or 100) and 180 (or 150) Hertz 2nd & 3rd harmonic components, although the 60 (or 50)Hz fundamental is not heard. Manufacturers and recordists count on this phenomenon for music to sound OK on bass-deficient boom boxes or desktop speakers. Would it require unusual listening acuity to reveal this illusion of common perception, playing a recording with low bass while slowly fading out or a decrescendo, to hear that the low bass is actually dropping off faster?

Within the mid-frequency decade 500~5kHz, the progressively louder contours, in dB-phon, hover roughly flat at their respective physical sound pressures, in dB-SPL. Vertically up the 1kHz line, 1dBSPL≈1dBphon, the 100phon range shown equating to the 100SPL range. At the frequency extremes, the sensation of loudness weakens, requiring ~14dB stronger SPLs at 10kHz; but below 500Hz, the contours become compressed into greater and greater SPLs. Interpolating for a SW range of 25Hz~100Hz, the equivalent filter slopes are 20dB/octave at a quiet 25phon, but only about half that, ~10dB/oct, at a loud 85phon. At 20Hz, where only 55dBSPL (73~128) spans the full 100phon range, 1dBSPL≈2dBphon.

Where at mid-frequencies a sound level change of ~10dB is perceived as a doubling or halving of loudness, *in the SW range doubling or halving loudness happens with only ~5dB change.* So 10dB lower in low bass is perceived as half loudness and half again, or only a quarter as loud. As we are doubly sensitive to SW-range level changes, we ought to consider LF speakers and their adjustments doubly critical. Be doubly attentive to avoid sound that seems "thin" (weak in all bass), tubby (over-emphasizing bass), or muffled (bass overpowering higher frequency sounds). Prepare to allocate budget for low frequency acoustic treatment. And be aware positioning SWs adjacent to a wall, wall+floor, wall+floor+wall that each added plane doubles SPL by 6dB. [Cf. www.filmaker.com/papers.htm "Physiological and content considerations for a second low frequency channel for bass management, subwoofers, and LFE" re positioning SWs]

But isn't this just how we hear LF live? Yes, but to preserve lifelike or produced recordings, reproduction must be flat in frequency response and equal to live in SPL. The disparity is illustrated by music perceived as *normal* when performed and mixed averaging 85SPL. But as typically replayed lower by 10dB or more, LF at 75SPL have a perceived deficit of 6dB at 30Hz – less than half its originally perceived loudness – needing *Loudness Compensation* of 6dB (up to 20dB if played as background).

Louder than normal low bass – even risking ear damage such as at a deafening rock concert, or prolonged exposure at chest thumping dance clubs – may induce endorphin-like pleasure, aid in sleep & meditation with binaural beating, and even treat fibromyalgia pain by exposing patients to 40Hz for 23min. But having too much low bass is not the usual condition.

Harmonic distortion (HD) & inter-modulation distortion (IMD)

Distortion is where loudspeakers have the hardest job in high-fidelity, especially with subwoofers tasked to deliver very low frequencies at very high SPL. Referring again to the loudness contours, a 30Hz fundamental that is just audible at 60SPL *will be equaled in loudness by its own* 2nd

Continued overleaf…

harmonic when weaker by 25dB. At only 5% of the fundamental's level, the 2nd harmonic equates to 100% distortion! More than enough to skew a double bass way too bright. And as odd harmonics prevail with speakers at very LF, a bass viol will take on the tone color of a contra-bass clarinet.

Now consider this quandary in a good consumer SW typically having 5% harmonic distortion. 5% at 30Hz might be perceived the same as a very poor amplifier at mid-range producing 100% HD! To achieve 1% distortion (the definition of a high-fidelity component), the SW would need to measure 0.05%! In the SW range, published percentages of distortion regarded as "normal" for higher frequency sounds mean tone color is falsified much more than expected. Less distorting than home speakers, the best studio-quality subwoofers measure 0.5% or so distortion, which at 30Hz sounds like 10%, and still alters tone color. Whether for studio or home, the need for very low distortion is critical for subwoofers. But our exploration thus far describes only harmonic distortion (HD)…

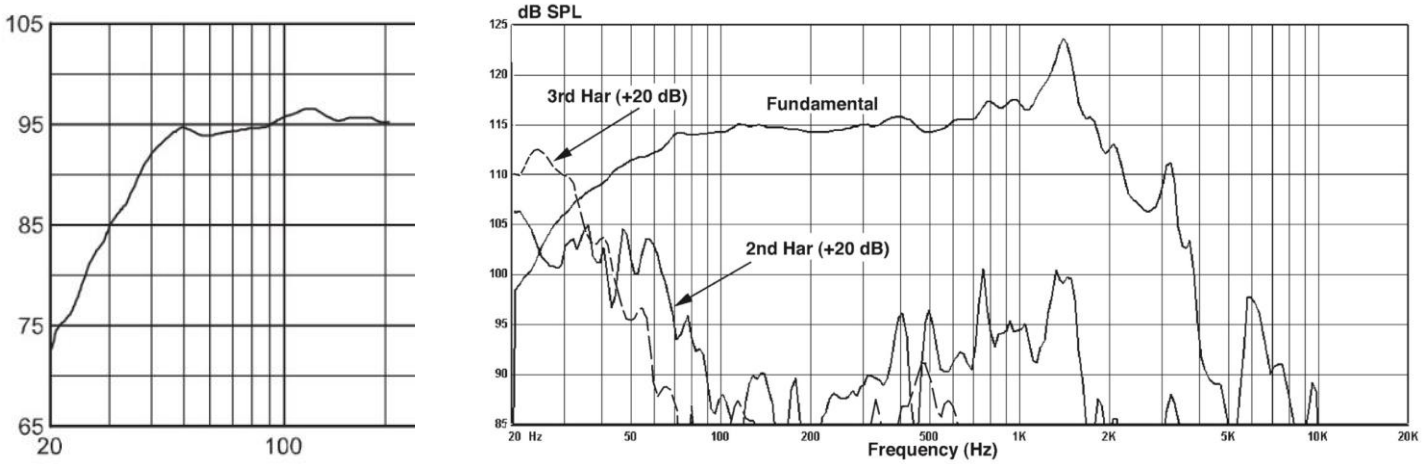
Another common form of distortion is *inter-modulation* (IMD) by which two pure tones produce sum & difference frequencies. These artifacts are not harmonically related, so are not musical, but are alien "clang" or "burr" sounds accompanying any two tones, *even if one or both are not audible!* Where there's HD, there's a likely similar percentage of IMD. Take two C-extended double bass viols playing low D1 with heavy vibratos modulating randomly to 35 & 38Hz. These fundamentals may not be audible, but IM adds a random 73Hz, which is audible. You may think a saving grace is that for music there is typically only one bass note playing at a time. But combinations of that note's harmonics or HD artifacts add spurious IMD products: e.g. summing to low & mid bass tones at 108Hz, 111, 143, 146, 149, 181, 184, 219Hz, etc., plus many difference-producing combinations. Bogus sounds above the SW's crossover frequency can call attention to the SW. The solution is the lowest distortion subwoofer within budget.

Conclusion & what's next…

Low bass is difficult to hear, and to convey with purest tone color, the holy grail of high fidelity. Because perception is tricky, many audiophiles are not aware they haven't heard authentic low bass, therefore can't know whether they need to augment their main speakers with a subwoofer(s). A dilemma for producers & recordists is: "Do we use consumer-grade subwoofers in order to anticipate our recordings' sound at home?" The same question caused studios to install cheap monitors to anticipate playback quality. Then research by Harman found the average of many cheap consumer speakers was an excellent speaker! So savvy engineers began using only their best monitors to make the greatest number of consumers happy. It remains whether this history repeats itself re SWs.

For as much as loudspeakers have improved in frequency response and distortion since the advent of hi-fi in the 1950s, they remain the audio components with the furthest to go. Very low-distortion SWs are needed. Even so, the most satisfying listening normally calls for using subwoofers.

Preparing to test a pair of commercial 18in subwoofers with very good frequency response and distortion data, below. When operated below their design maxima, most SWs exhibit distortion falling much faster than SPL. [Filmaker Technology]



Left: Frequency response of subwoofers above, given a boost in low bass by ducted port enclosures, at 95SPL down 3dB at 40Hz before equalization, so deemed flat. Right: Even at a very loud 115SPL, they exhibit low 2nd & 3rd harmonic distortion (raised 20dB), showing at 70Hz less than 1% of the more musical 2nd harmonic and <0.2% of the less musical 3rd harmonic. At more moderate home entertainment levels, distortion drops greatly to 0.1% and lower. [data courtesy JBL Professional.]

The Peabody-winning filmmaker ***Robin Miller*** is an internationally recognized audio & video engineer, and who has presented his work to the Audio Engineering Society, Society of Motion Picture & Television Engineers, Acoustical Society of America, Canadian Acoustical Assn, and German Tonmeisters VDT. His company, Filmaker Technology, engages in applied research, systems design & integration, and has a Patent for a system of full-sphere 3D recording & reproduction. He has written two books: a memoir "American Radio Then & Now," and for vinyl hobbyists to professional archivists "The Better Sound of the Phonograph."

[i] "White Papers" are short educational, semi-technical surveys on practical topics. Scientific research papers, updates, and books by the author are at www.filmaker.com/papers.htm.