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Low Frequency Control

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Tight and punchy low frequencies with lots of impact are considered by many, one of live sound's most highly acclaimed achievements. Outside this comes naturally, but inside, more often than not, it can be really challenging. This paper features an excerpt of a much longer article which can be found at my website [1]. For this conference, I chose to focus on arguably the most challenging force to reckon with regarding low frequency reproduction which is reverberation in enclosed spaces.

1 The challenge

1.1 Long wavelengths

In the frequency range of interest, we're dealing with wavelengths ranging from a 12-meter long intermodal shipping container to a Mini Cooper of "merely" 3 meters in length (Figure 1).

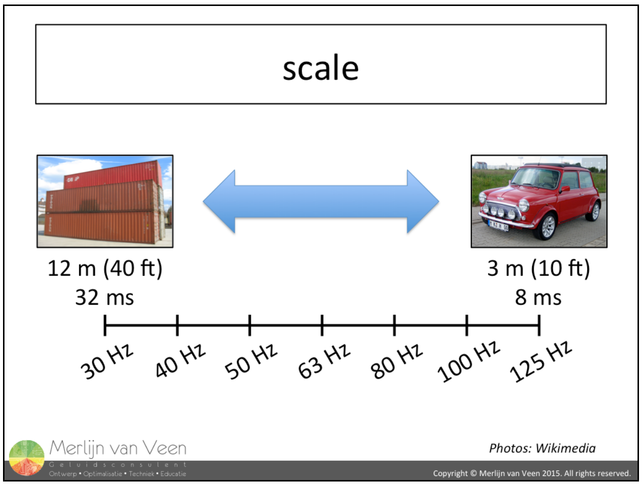

Figure 1: Wavelength

This order of magnitude makes these frequencies both notoriously hard to control and absorb. They abide by the same rules of physics but typical solutions like horns would have to be so big, that we might as well leave the speakers in the truck and drive it onto stage. When left unchecked these frequencies can wreak havoc on an otherwise good mix and ultimately become a separate entity all together.

1.2 No absorption

With the exception of very large membrane absorbers like Flex Acoustics' aQtube™ from Denmark [2], low frequency absorption in general is very challenging (Figure 2).

Figure 2: Flex Acoutstics' aQtube™

1.3 Omnidirectional source

Medium format loudspeakers are typically quite capable of maintaining their nominal coverage pattern from 1 kHz and up. Larger format speakers are capable of extending this control towards the lower end of the audible spectrum by as much as 2 octaves. Line arrays, in the vertical plane, even control the low frequencies by committee. When applied correctly, this control greatly reduces the chances of exciting the room with sound. Unfortunately, conventional subwoofers, for all intends and purposes, are virtually omnidirectional

1.4 Don't wake the beast

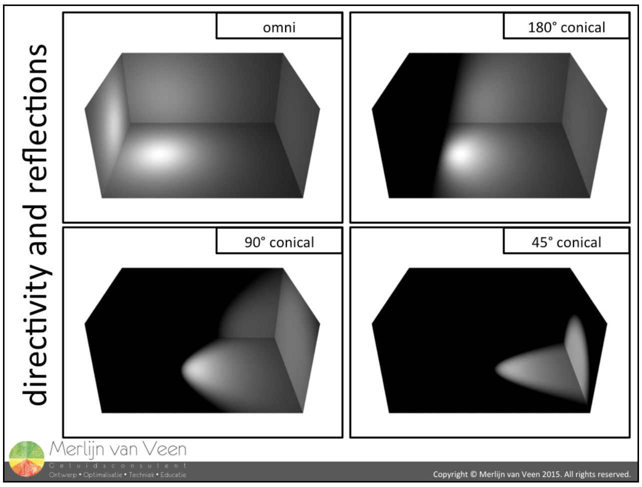

Figure 3: Don't wake the beast

The principal precept in healthcare is: "first do no harm". By not illuminating the walls and ceiling with sound (Figure 3), the perceived intensity (not the decay time) of the reverberation is reduced.

On top of that, absorption by air, a distance related phenomena, attenuates the high frequency reflections even further as they propagate through the venue.

Subwoofers however, due to their inherent lack of directivity, are incapable of avoiding the venue.

1.5 Black light party

If we compare audible sound to visual light, purposely imagining it in a reversed order and stretching its “mere” 1-octave wide range out over 9 octaves (like audible sound). Then the reduction of mid- and high-frequency reverberation by pattern control in concert with absorption and humidity is analogous to attenuating the green to red part of the visual spectrum, leaving us with nothing but ultra violet.

Figure 4: Low frequency “black light” party

A “black light”, low frequency reverberation, party (Figure 4). The well behaved mid- and high-frequency pattern control, effectively emphasizes low frequency reverberation. This reverberant energy, smeared out over time, tramples over the remaining audible spectrum, reducing intelligibility and clarity. Loosing impact.

As long as we’re residing in the sole custody of the direct sound, we’re good. But we need to be mindful of critical distance which represents the distance to a source where its direct sound level and reverberation are equally loud.

2 Direct-reverberant ratio

2.1 Hopkins-Stryker equation

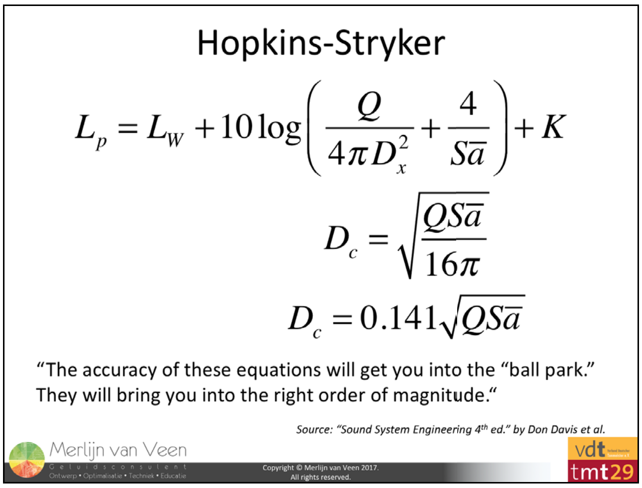

Figure 5

The Hopkins-Stryker equation (Figure 5), among others, allows us to roughly estimate the total sound pressure level (L_p) over distance **for enclosed spaces**, based on the sound power (L_W) and directivity factor (Q) of the source versus surface area (S) and average absorption coefficient ($\bar{a}$) of the venue. This is an example of geometrical acoustics and as such should be treated **with great care**.

The two fractions between parentheses determine the levels of the direct and reverberant sound respectively. Direct sound (first fraction) relies on directivity factor and distance ($1/r^2$ dependency) and the reverberant sound field (second fraction) on surface area and absorption coefficient. Notice, how the latter is **independent from distance**.

2.2 Critical distance

When direct and reverberant levels are equally loud at critical distance, we can estimate its range by rearranging the terms between parentheses (Figure 5). The outcome is highly interesting because it shows the numerical relationship between directivity factor and absorption coefficient which have equal weight. Doubling the directivity factor is equally efficient as doubling the absorption coefficient!

It takes an absorption coefficient of 0,5 to absorb 3 dB per square meter surface area which is very unlikely with typical materials like concrete and metal. The rigidity and stiffness of these materials pretty much rule out help in the way of diaphragmatic action. The walls won't flex and subtract sound power. Fortunately, that also assures us the building won't collapse.

But, if absorption coefficients are expected to be close to zero and the directivity factor for omnidirectional subwoofers is close to 1, then the only parameter left is surface area. We need lots of low absorbent square meters to account for the lack of pattern control.

This gives larger venues under similar circumstances an advantage, but for smaller venues trying to increase the directivity factor of the subwoofer(s) is pretty much the only viable option left.

Normally, I'm not a big fan of critical distance because it changes with frequency proportionally to the directivity of a loudspeaker (Q). Nonetheless, anyone with access to a dual-channel FFT analyzer, can estimate its position for a given frequency quite easily. It's where we measure one part signal and one part noise (the condition at critical distance) with a coherence value of 50%. Noise in this instance, consisting primarily of reverberation.

Regardless, the estimated critical distance for subwoofers can be quite revealing.

2.3 Dead on arrival

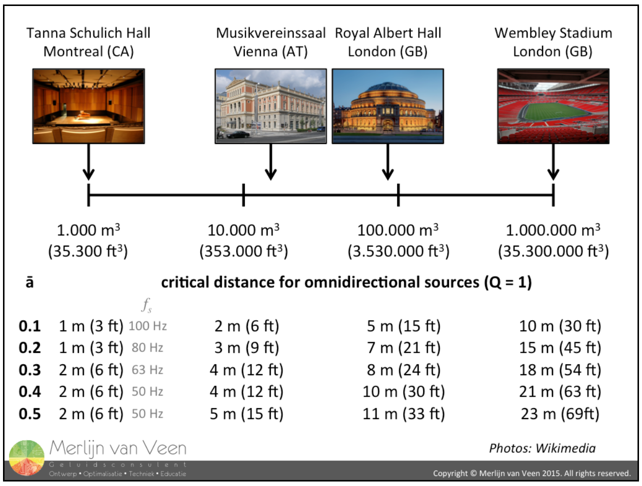

Figure 6: Critical distance

If we look at some very rough estimates for critical distance in various volumes (Figure 6), using a directivity factor of 1 and modest absorption coefficients, the results are depressing. It's readily apparent that a typical subwoofer is pretty much "dead-on-arrival". Within a matter of mere meters, the direct sound is being overtaken by reverberation. Given the typical distances that need to be crossed in order to reach the back of the audience, it doesn't get much better when venue volume goes up.

The grey values in the first column for the 1.000 m^3 (35.300 ft^3) example are the Schroeder frequencies. Below the Schroeder frequency, the venue is predominantly governed by room modes that inherently behave non-statistical and render the Hopkins-Stryker equation useless. I would like to emphasize that these values indicate the approximate range of gradual transition.

2.4 "Up to eleven" won't work

Turning up the level or sound power, won't increase the critical distance. The sound power variable (L_W) in the Hopkins-Stryker equation on the previous page resides outside the term between parentheses.

Raising the level, increases both direct and reverberation levels by equal amounts, without changing their relative offset. After all, the perceived reverberation is the sum of our own efforts (or lack of). A matter of cause and effect. If the former goes up, so does the latter and critical distance remains constant.

If we want to keep LF reverberation low, we should avoid exciting the venue to begin with. This requires high Q values and is more likely to succeed than the alternative which is absorption. Prevention versus treatment. Ideally, we would apply both.

2.5 The arms race

Now that we have a very crude way of estimating critical distance, let's look at the implications. Close to the subwoofer, the direct sound prevails over the reverberant sound which is independent of distance. There's a good direct-to-reverberant ratio which shows up as high coherence on an analyzer. However, as we move away from the subwoofer, reverberation starts gaining market share over the direct sound which drops at a rate of -6 dB per doubling distance. Both D/R and coherence decrease.

In the frequency domain (Figure 7), this progression manifests itself as a gradual increase of frequency response ripple. A metric for interaction.

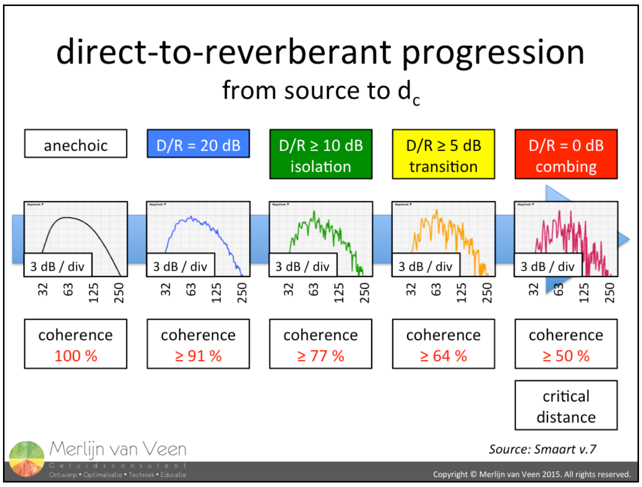

Figure 7: Arms race in the frequency domain

In the time domain (Figure 8), the decrease in D/R manifests itself as time smearing of the impulse response.

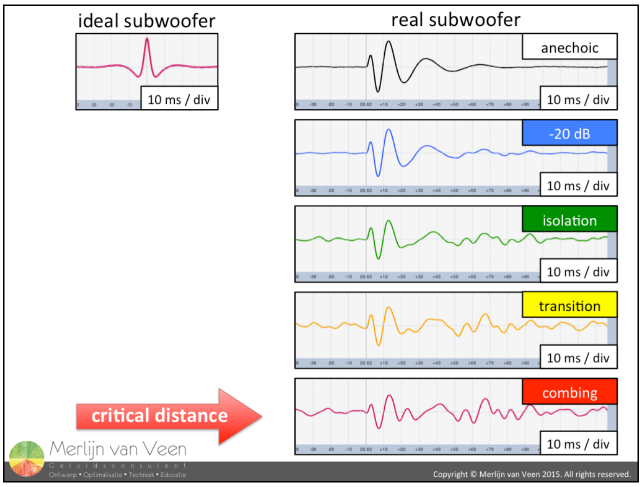

Figure 8: Arms race in the time domain

When we arrive at critical distance, the initial impulse response has grown an apparent 100 ms tail of near identical magnitude! And remember, indoors, this typically occurs after a few meters (Figure 6).

The majority of most indoor audiences, resides well beyond critical distance and listens predominantly to indirect, reverberant sound instead of direct and punchy sound with lots of impact. They get to “enjoy” to the same performance multiple times for the same ticket price.

2.6 A solution

Low frequency control by committee, using multiple arrayed subwoofers in order to increase directivity, is a very viable way of dealing with these issues. But, we’ll save that for another time.

References

[1] https://www.merlijnvanveen.nl

[2] http://flexac.com