Subwoofer placement In Non-Rectangular Rooms

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Introduction

Subwoofer placement is already a well-debated topic. Chances are, that you have read (and experienced) quite a lot about golden rules and ratios, about corner placement, about exciting room modes and SPL modeling in rectangular rooms. In doing so, you may have noticed, that the great majority of publications stop short of tackling non-rectangular rooms[2]? Indeed, even quite an abundance of computer software modeling SPL in rectangular rooms, does not go beyond this simple geometry. Image method is employed most of the time for this purpose, being recognized for simplicity of implementation[3]. So, what if your listening room (or space, I should say) is not conforming to this simplification ?. Well, if this is your problem or the area of your interests, perhaps you may find something here for you.

The simplest configuration of subwoofer system consists of a single subwoofer and two wide range loudspeakers. The subwoofer is typically positioned in the "widely recommended" corner location and the two wide range loudspeakers are placed suitably, to re-create acoustic stage image for the listener. Which corner you may ask ?. Well, not ALL corners are equal, as you will see. This paper attempts to examine corner locations of subwoofers and some pros and cons of single-subwoofer vs. dual-subwoofer systems for a given placement within the listening room. In my previous articles on loudspeaker placement[4][5][6][11], I emphasized the importance of understanding the location of the room's nodal lines and pressure maximum. Now I have been able to extend the analysis and actually generate the "room contribution" curves for a non-rectangular room. Here, I am talking about SPL of an "ideal" speaker with a flat frequency response from 0-200Hz. Two of such subwoofers are placed in the room and the resulting SPL is plotted up to 200Hz. Showing only the room contributions, offers better clarity for visualizing the room modal response, as it is not obscured by the subwoofers' own irregular SPL.

The Basics You Know

As we know, all rooms (a cavity volume enclosed by walls) have resonant frequencies at which the SPL generated by a source can be quite large. The frequencies at which resonances occur (called **modes**), depend on the geometry of the room. At a resonance frequency the pressure pattern inside the room will consist of **antinodes**, where the pressure is maximum, and **nodes**, where the pressure is zero. In a room with hard (eg. reflective) walls, the pressure will always be maximum at the wall or in a corner when the room is excited at any of its modal frequencies. If the source is located at an antinode for a given mode, the room response will be greatest. If the source is located at a pressure node for a given mode, the room will not respond regardless how powerful the source is. Some of us (myself including) take advantage of our listening room's acoustic behavior to improve the performance of our systems. Placing a loudspeaker or subwoofer against a wall or in the corner of a room allows the low frequency modes of the room to enhance the low frequency performance of the loudspeakers.

When the source is placed at a node for that frequency standing wave pattern, the maximum room response drops to zero at that frequency. Moving the speaker some distance away from the node restores back (at least partially) the room's response. Modal patterns only occur when the room is being driven at a modal frequency. At any other frequency, the pressure waves radiating outwards from the source reflect from the walls, but do not combine to produce a modal pressure pattern. As a result, there is no nodes and antinodes and the pressure can actually fall to zero at a wall. You will see these irregular patterns on Figure 6 – Figure 10.

A Leap Beyond the Rectangular Room

If I was to model a low frequency loudspeaker generated pressure patterns in a simple, 6-wall room, I could simply employ a closed form equations based on summation of images. However, in a more general case, the room will not be a simple 6-wall cavity[11]. In this case, I would resort to the Finite Element Method (FEM) to take advantage of its accuracy at low frequencies and its excellent handling of complex geometrical shapes[1]. Figure 1 shows a floor plan of an "L-shaped" room with Subwoofer 1 (Sw1), Subwoofer 2 (Sw2) and Listener (L1) located at nodes "186", "188" and "0" respectively.

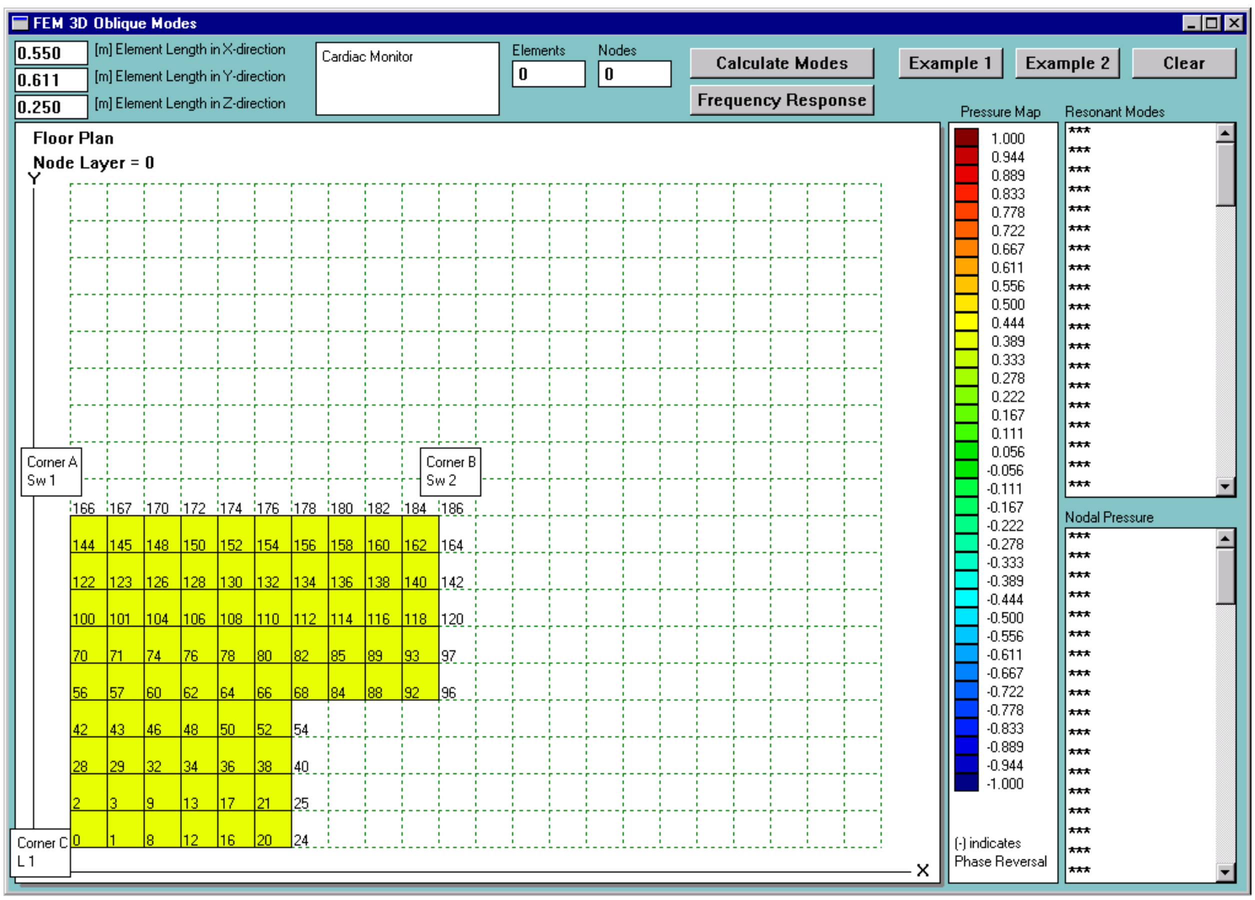

Figure 1. "L-shaped" listening room floor plan

I have also used "brick" elements to approximate my listening room internal geometry for the purpose of creating the FEM mesh. The "brick" element has the following dimensions: X=0.50m, Y=0.611cm and Z=0.25cm. With the above dimensions in mind, I will get 20 elements per 20Hz acoustic wave and only 2 elements to approximate 200Hz wave. It is obvious, that accuracy of my model deteriorates as the frequency increases. I could have chosen smaller elements and readily improve the accuracy at 200Hz. This would be great, but the penalty would be increased calculation time and RAM usage.

It is probably worth to mention, that although my analysis covers the frequency range up to 200Hz, I am mostly interested in frequencies below 100Hz. These would be easier to discriminate from the SPL modal plots and have more defined pressure patterns. Additionally, the low-end modes are spaced more widely, therefore easier to deal with without affecting the immediately adjacent modes.

As a starting point, I have determined room modes. Some of the results are shown on Figure 2 – Figure 5. You can easily observe, that generally, modal (minimum pressure, deep green colour) lines are not straight. They curve within the room and their location would not be immediately obvious without the FEM analysis. As I mentioned before, knowing your room nodal lines will help you to determine where you should NOT place your subwoofers.

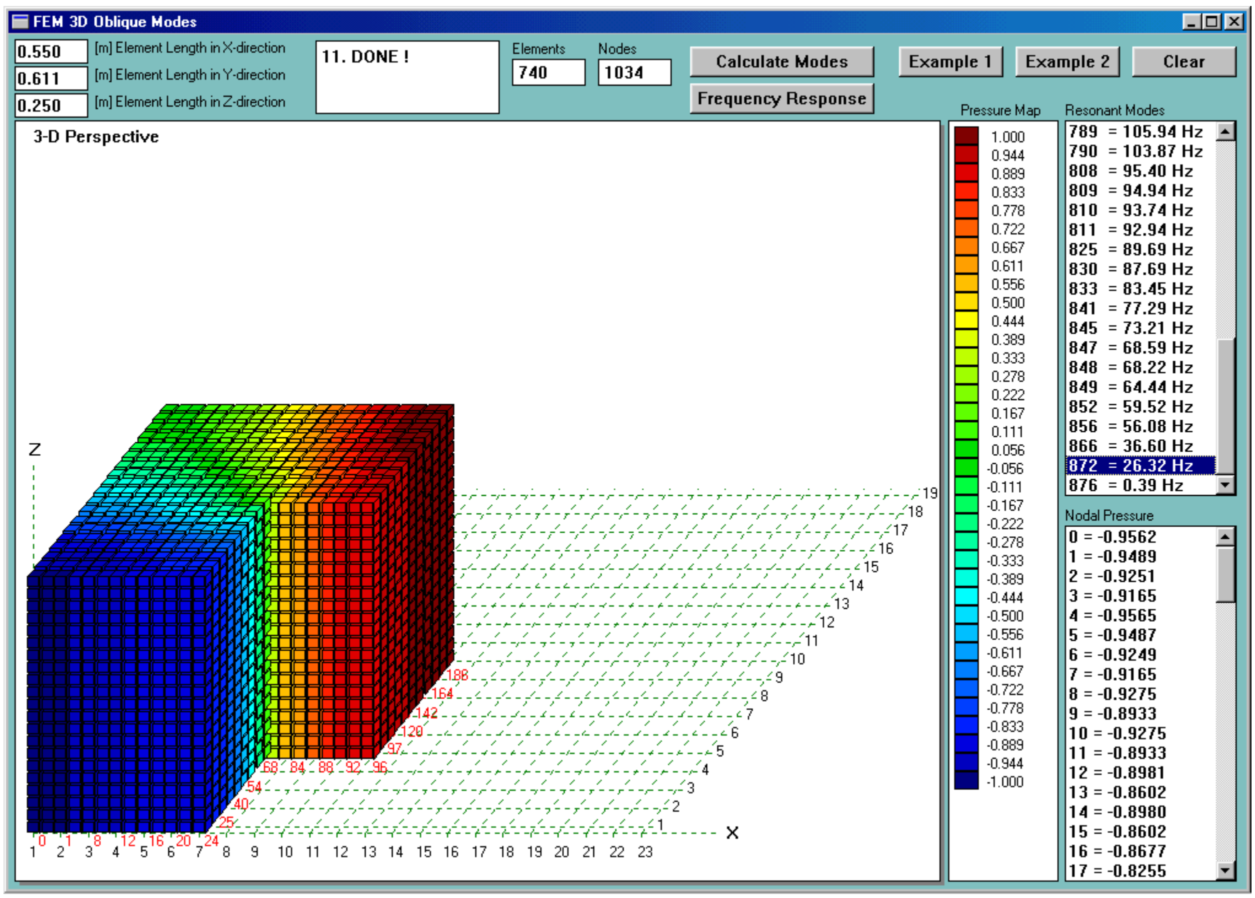

Figure 2. First mode at 26.32Hz

Modal analysis revealed that the lowest modes are: F1=27Hz, F2=36Hz, F3=54Hz, F4=57Hz, F5=64Hz and F6=73Hz. There are many more modes below 100 Hz, but for the sake of clarity of this presentation, I will only focus on those ones I mentioned. It is easy to observe, that areas of maximum pressure (antinodes - deep red colour for positive pressure or deep blue colour for negative pressure) are always located near the walls or corners. Accordingly to what I have just said, you would be tempted to locate your single subwoofer in one of those corners. You would do this, because you want to take maximum advantage of the "room gain" effect. You may have also convinced yourself, that you should place your subwoofer this way, to allow the speaker to excite maximum number of room modes, and preferably ALL room modes. This way, the smoothest (although still quite irregular) overall frequency response could be achieved. Here the "golden ratios" of room dimensions come into focus. The idea is to position room modes evenly across the low-end frequency range, and you can do this by affecting room geometry.

Anyway, armed with all this common knowledge, I continue with my modal analysis. Looking at Figure 2, you may find it at first quite contradictory to what I just said. Why ? – well, I have just said, that pressure maximums are located at room's corners. And here, on Figure 2, we have corner "A", with the 26.32Hz nodal line (minimum pressure) sitting right at it. This is exactly the OPPOSITE to my previous statement. Or is it ?.

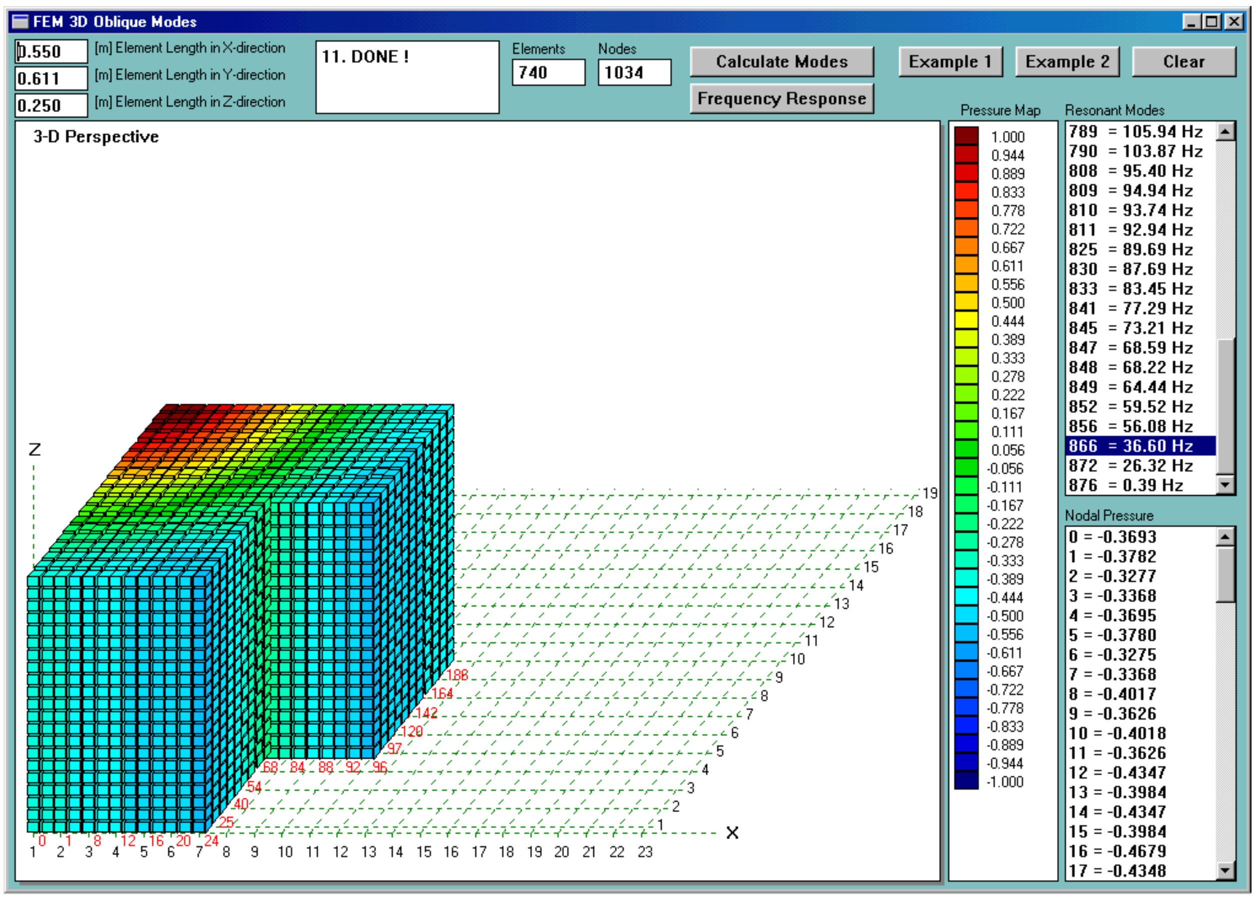

Figure 3. Second mode at 36.60Hz

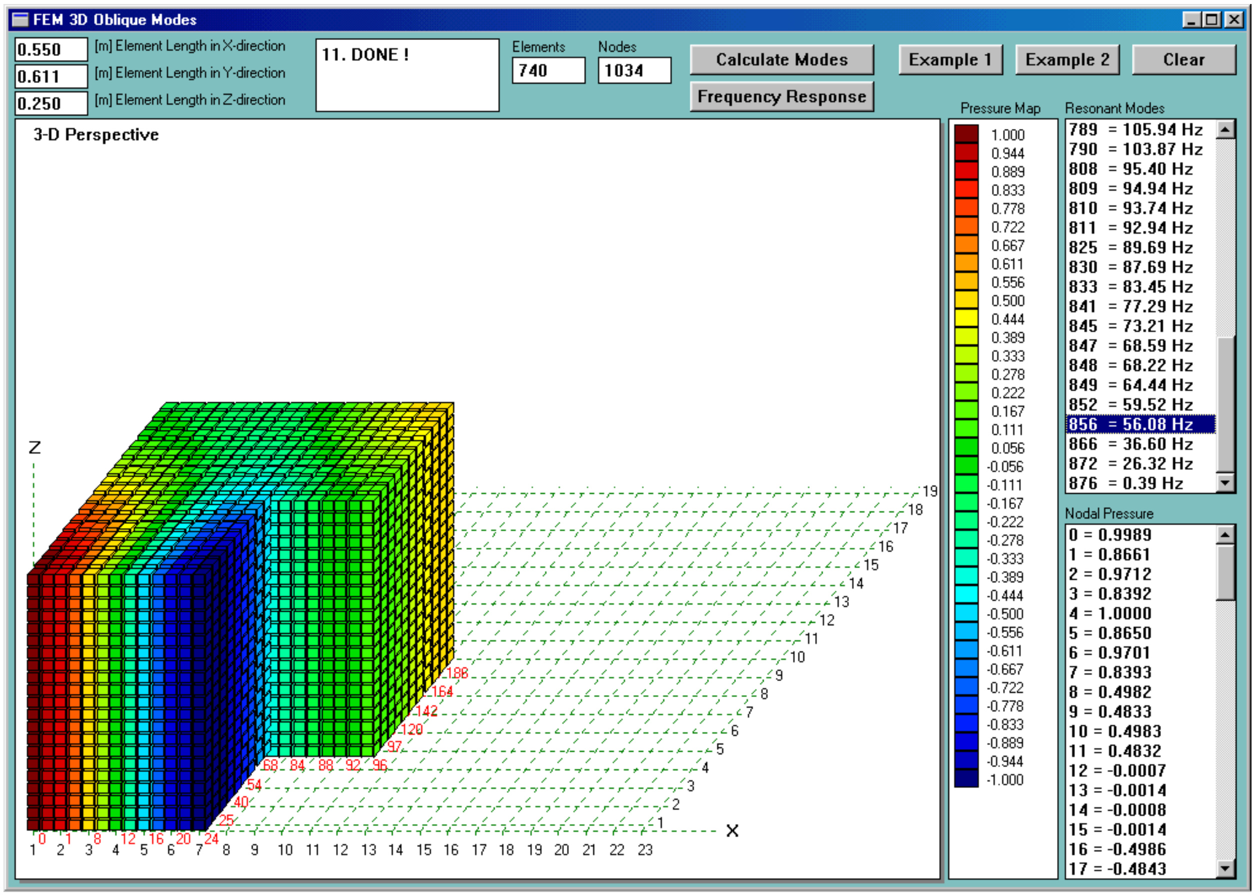

Figure 4. Example of mode at 56.08Hz

Before I go any further, let me point out here the advantage of FEM employed for this analysis. Of course, FEM is complex, but it allows you see and model things, that would not be readily possible without it. Now, back to solving our problem.

The answer lies in the room “L-shape” geometry. The corner “A” is located almost exactly half way between corners “B” and “C”. As you can see on Figure 2, the 26.32Hz mode would develop between those two corners, so the pressure maximum would be located in those corners. It should be easy to envisage, that the nodal line for this particular mode, should fall right in the middle between these two corners. If you could “unfold” the room, (imagine corners “C”, “A” and “B” lined-up) you would find corner “A” sitting in the middle of the long wall marked by corners “C” and “B”.

The problem actually gets worse. If you examine Figure 5, you will find the same issue at 68.22Hz. This is NOT exactly the harmonic of the 26.32Hz mode because the room has shorter walls on one side than the other. Once again, corner “A” has nodal line right across it. You may expect this to happen at higher frequencies as well. I hope the above short explanation of Figure 2 and Figure 5 offers you some indication about the importance of modal analysis, as it offers significant insight into physics of your room acoustics.

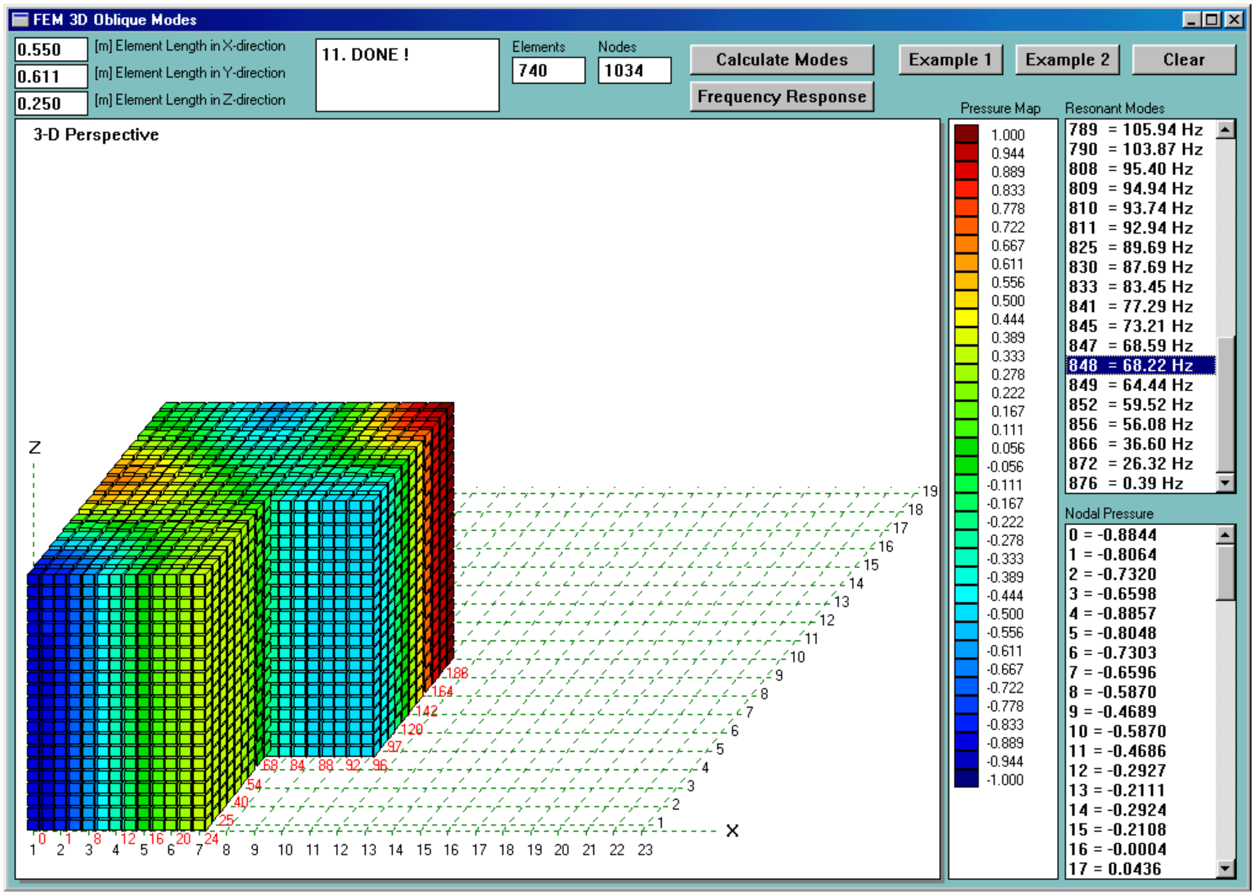

Figure 5. Harmonic mode 68.22Hz with nodal line in the corner.

Analysis of Room Contribution

As a test case, I decided to place my subwoofers as described on Figure 1 before. Now, having performed the modal analysis, I anticipate, that there will be difference between Subwoofer 1 and Subwoofer 2 SPL plots. First, I need a reference “room contribution” coming from BOTH subwoofers. This reference plot is shown on Figure 6. As we discussed before, there will be frequencies, where there are pressure minimums at the Listener location at the wall. The most evident are 32Hz, 136Hz and 184Hz, where the outward radiating pressure waves combined destructively and produced a node at the Listener 1 location. The “notches” due to this, are fortunately quite narrow.

You may notice, that the frequency response horizontal scale is linear, and not logarithmic, as it would be typically used. The “room contribution” is without a doubt, quite irregular in comparison to a typical frequency response of a loudspeaker measured in an anechoic chamber. Figure 6 represents a typical situation you may expect in your home. The room is an enclosed space and it will resonate at its modal frequencies. I have selected a “Medium absorption” scenario for the purpose of this analysis, and this results in a gradual “smoothing” of the “room contribution” curve when moving towards higher frequencies.

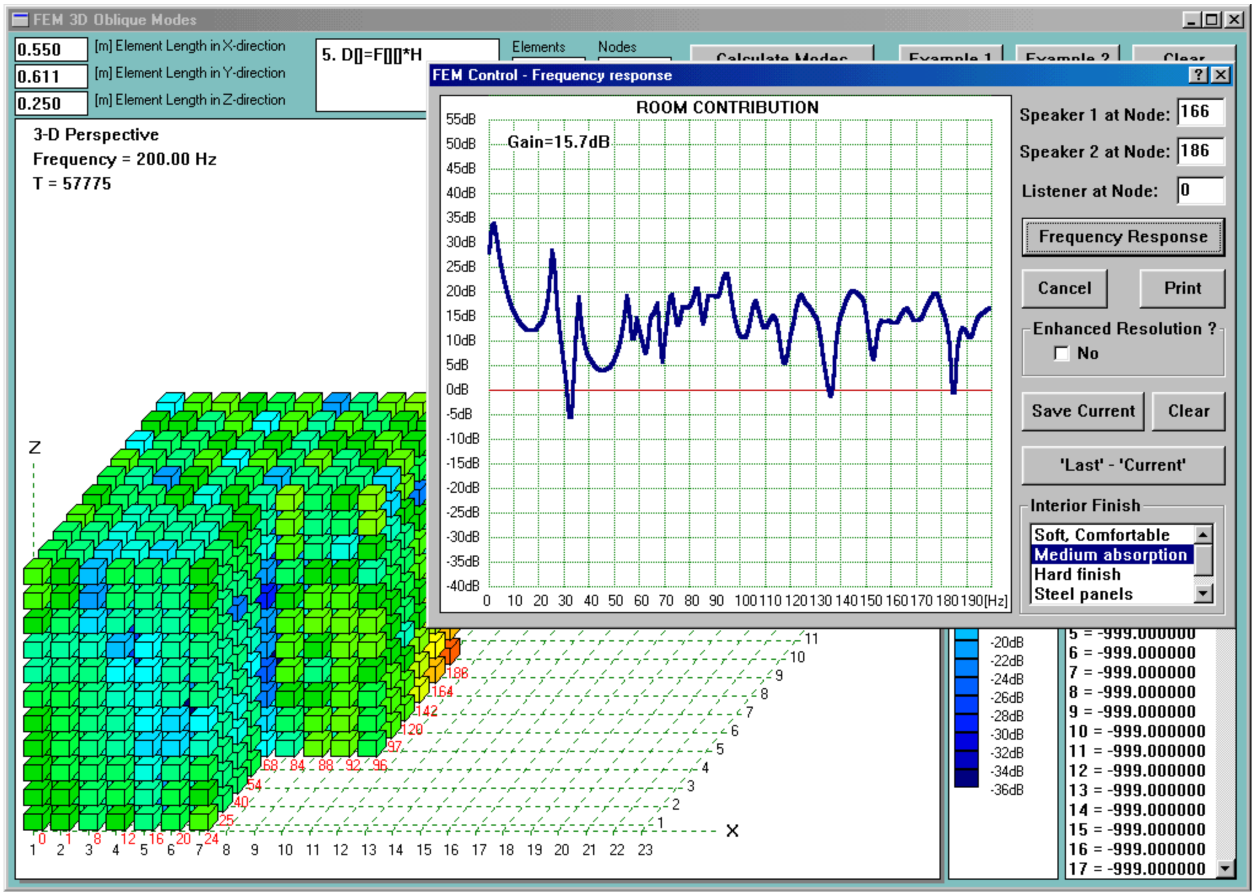

Figure 6. Reference “room contribution” coming from BOTH subwoofers.

If I used lower absorption coefficient in my model, the “room contribution” curve would continue to exhibit sharp peaks and valleys within the whole frequency range of the analysis. I would chose this type of approach for the purpose of better visualizing the pressure patterns, as the analysis progresses through the whole frequency range.

Single subwoofer contributions

The next task to perform in my analysis was to plot “room contribution” due to single subwoofer and for the start, I decided to try subwoofer 2 (Sw 2) only. This speaker is located in corner “B” at the node 186. I plotted the resulting “room contribution” on Figure 7.

It is easy to notice, that this curve is significantly more irregular than Figure 6 (“room contribution” due to both subwoofers). Keep this in mind, as we are trying to understand, if the number of subwoofers makes any positive difference. Frequency bands: 35-50Hz, 110-140Hz, 150-175Hz exhibit 8-12dB lower level.

Also, modes 26.32Hz and 56.08Hz are strongly present in this plot and this can be explained with the help of Figure 2 and Figure 5. In both instances, the subwoofer (Sw 2, node 186) and the listener (L1, node 0) were located at corresponding antinodes for these frequencies.

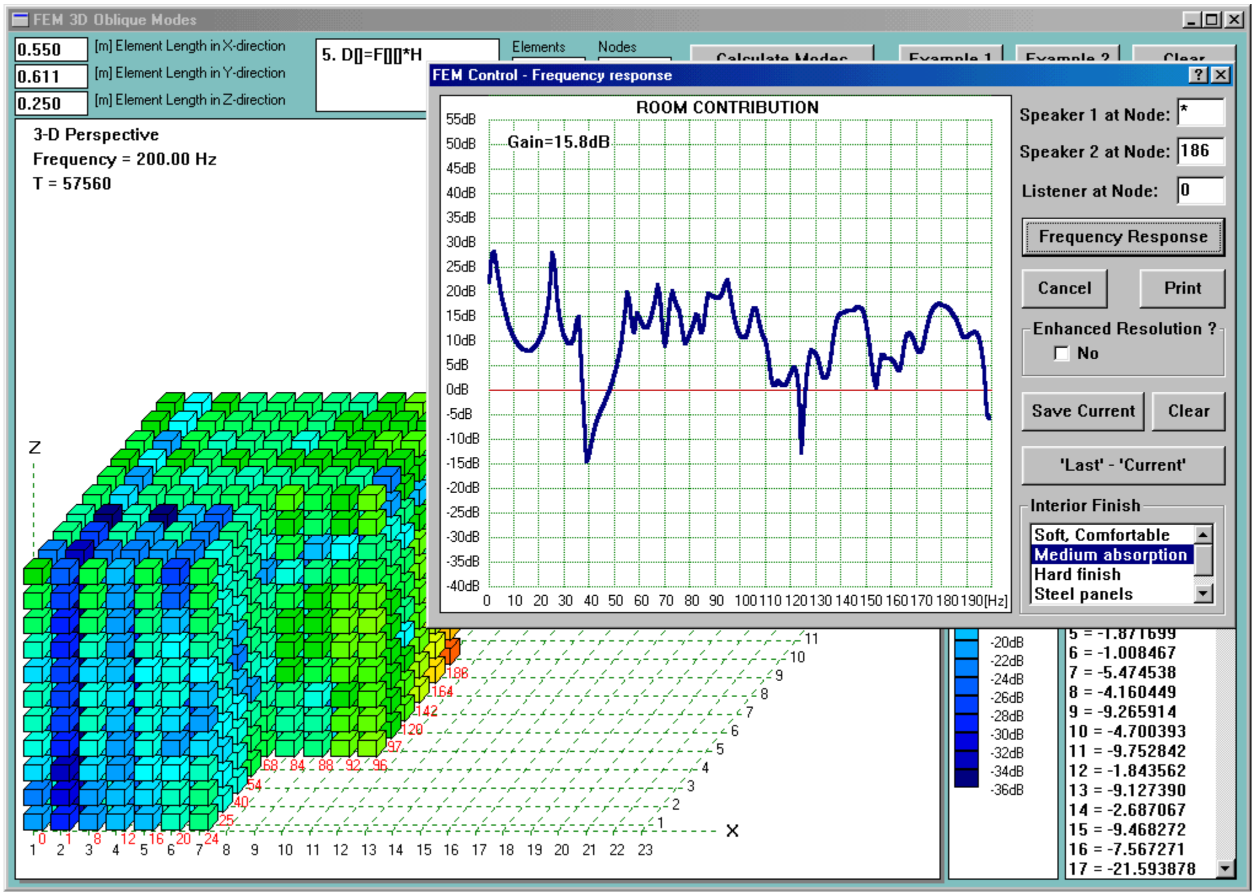

Figure 7. “Room contribution” due to single subwoofer – Sw 2 at node 186.

Finally, poor response in 35-50Hz frequency band is associated with the 36.60Hz mode. Pressure pattern for this mode is shown on Figure 3, and pressure maximum is located at node 166, which is where the missing driver (Sw 1) was located. The source is missing, so the mode will not be fully excited.

Another interesting plot is shown on Figure 8, where the difference between two subwoofers vs. single (Sw 2) is depicted. Everything that lies above the 0dB line indicates the advantage you are getting by using dual subwoofer configuration, as opposed to use only one subwoofer. When the second subwoofer (Sw 1) is switched on, the total radiated power is only 3dB higher. However, inspecting the curve on Figure 8, you may notice, that getting more than 3dB SPL gain in quite a few frequency bands. For instance: below 20Hz, 35-50Hz, 110-135Hz, 155-180Hz.

The “dual-woofer advantage” approaches 6dB for the frequency range below the first mode (below 20Hz). This is quite correct, as the distance related phase difference between two woofers becomes smaller and smaller towards lower frequencies. The outputs from both woofers now add coherently (in-phase) and pressure simply doubles, resulting in 6dB gain. This result is the same as if you put two woofers in twice bigger box and took advantage of mutual coupling between the woofers at lowest frequencies. However, you may find this easier to deal with two smaller subwoofers rather than one box, twice as big[5].

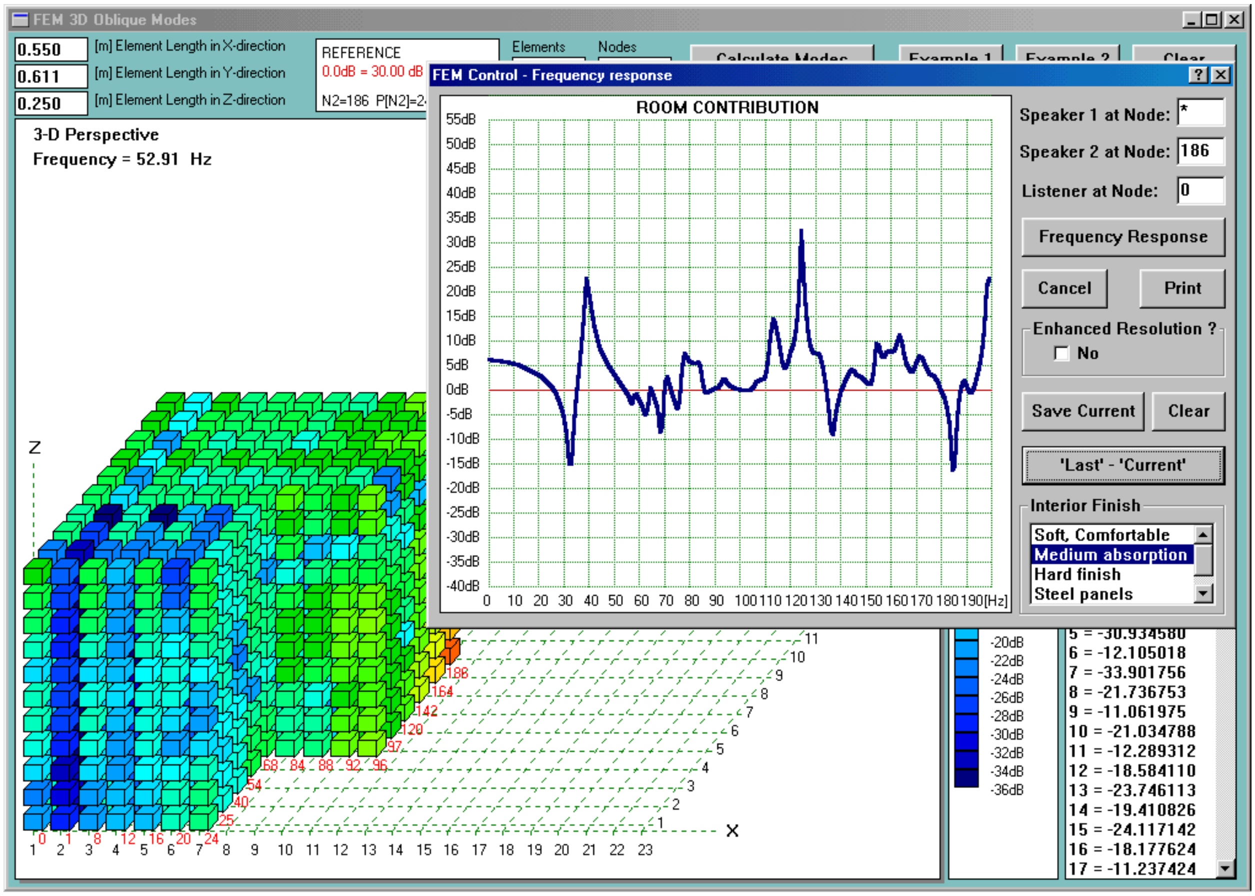

Figure 8. DIFFERENCE between two subwoofers and single (Sw 2) subwoofer.

Next step involves plotting similar set of curves for subwoofer 1 (Sw 1). Figure 9 shows "room contribution" due to single subwoofer – Sw 1 at node 166. Evidently, this SPL curve is poor and even more irregular than the result for single subwoofer, Sw 2. You can immediately notice missing spectrum around 26Hz and 56Hz, as compared to dual-subwoofer operation. I explained this problem when discussing the results of modal analysis. Now, you can finally see what is the effect of placing the loudspeaker on nodal line on the overall SPL curve. It is evident from Figure 9, that subwoofer Sw 1 fails to energize modes 26Hz, 56Hz and so on. Even a simple visual inspection of the Figure 9 is sufficient to say, that corner "A" is not as good location for a subwoofer as corner "B". If you are a happy owner of a single subwoofer system, you may need to do more homework on subwoofer placement, than users of two subwoofer systems. There is a possibility, that corner "A" (node 166) was the choice of many users, simply because of its somewhat central location. Resulting "room contribution" would be poor, as evident on Figure 9 and even more evidently on Figure 10. One option would be to move the subwoofer out of the offending corner. Figure 10 reveals the substantial contribution of subwoofer 2 (corner "B") to the overall SPL. This subwoofer dominates below 30Hz, 40-60Hz, 80-110Hz and more. Summarizing the analysis of my "L-shaped" room I would have to conclude, that:

1. For the chosen example locations, each of the subwoofers alone will not produce SPL as good (level and smoothness) as two subwoofers played simultaneously in their respected locations.

2. For single subwoofer, corner “B” is better location than corner “A”. Further modeling (recommended) is likely to reveal perhaps even better location than “A” or “B”.
3. Placing both subwoofers in corner “A” or in corner “B” will not result in “smoother” SPL response, it will only rise the plots on Figure 7 or Figure 9, respectively.

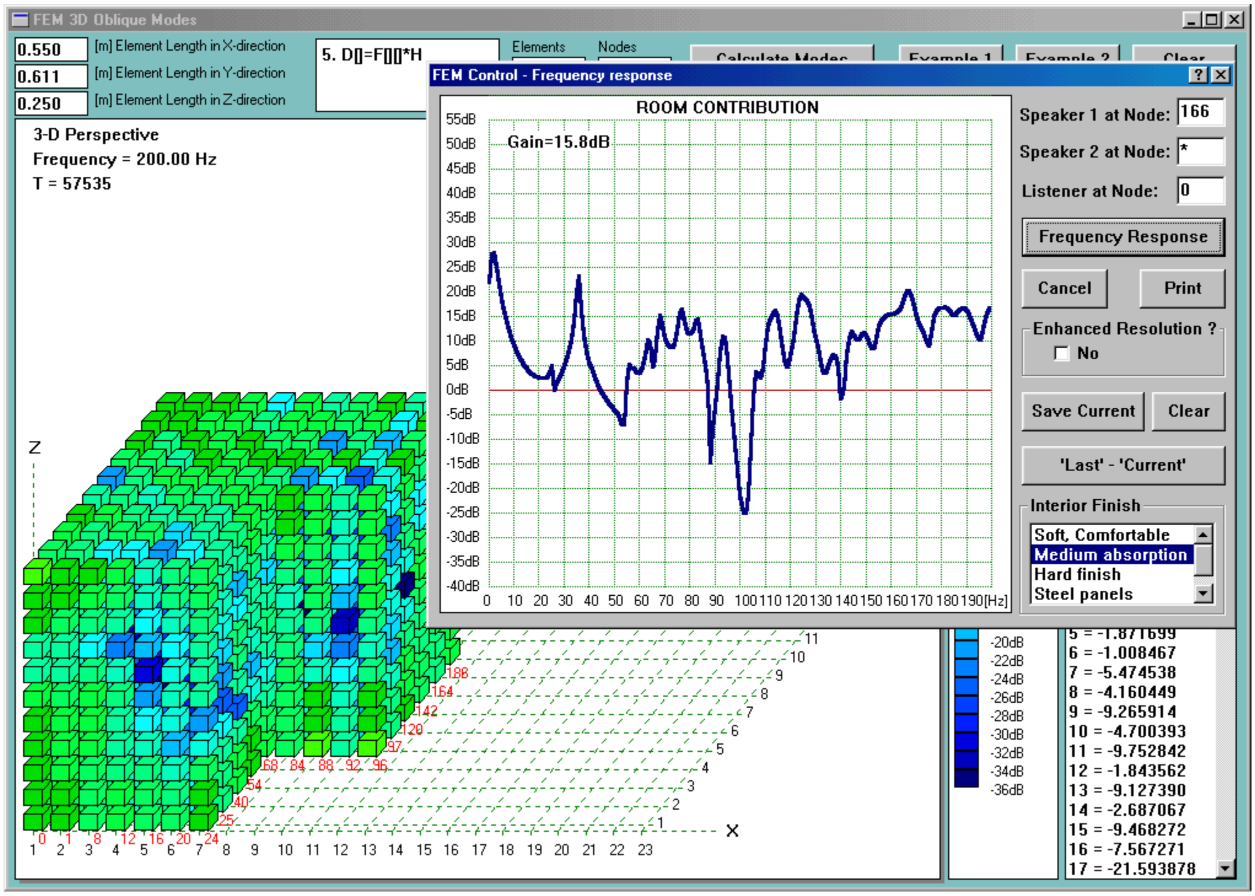

Figure 9. “Room contribution” due to single subwoofer – Sw 1 at node 166.

I have arrived at these conclusions, working through my example and I have accomplished the following:

1. I have determined modal frequencies and pressure patterns for all modes below 200Hz.
2. I have identified an “offending corner” – corner “A”, where the subwoofer would miss some modes.
3. I also generated SPL plot for both subwoofers and listener at chosen locations.
4. Then, I created SPL of individual subwoofers at their locations and finally,
5. I plotted final curves showing the “dual woofer advantage” over the frequency range of interest.

The example I presented here in this paper does not attempt to justify this particular speaker locations and by no means, the location of subwoofers was considered to be optimal.

My goal was to better understand multi-woofer setup and explain the application of the FEM, which is considered to be the most accurate modeling tool for this kind of analysis[3] . Particularly, if the shape of your room can not be handled by simple closed form equations. This would be also true for many of today's contemporary, open plan dwellings[11]. The FEM requires quite a bit of RAM and a lot of megahertz propelling your processor, so be prepared for lengthy analysis. My way around it, was to set up the analysis on my Pentium III (500MHz) processor and then go and do my weekly grocery shopping. 2 hours later, "room contribution" plots was ready. Now, do you still think, that the speaker is the weakest link ?.

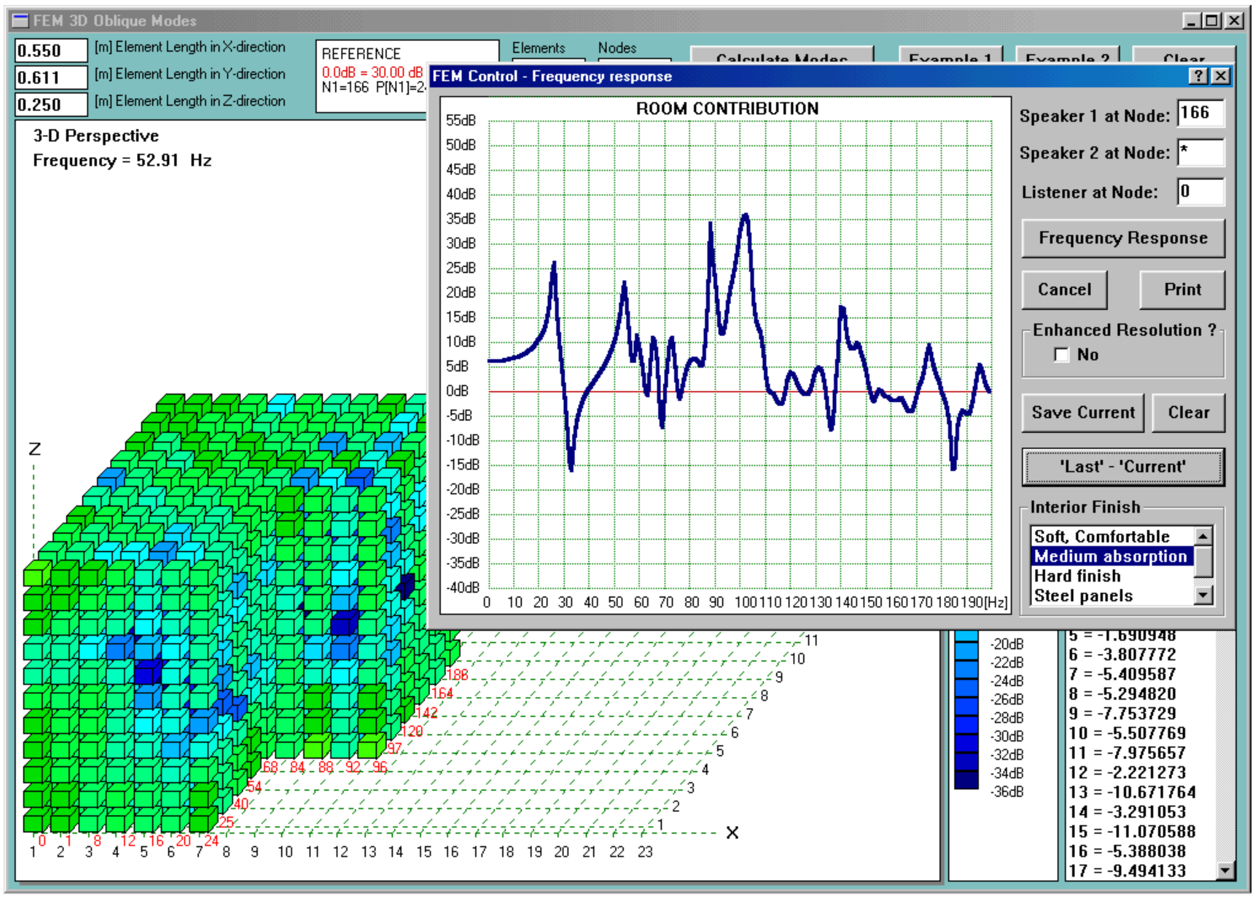

Figure 10. DIFFERENCE between two subwoofers and single (Sw 1) subwoofer.

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