Computerized Loudspeaker Placement II

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In the article (see SB 1/98) to which this is the sequel, I described the calculation of a room's resonant frequencies and their corresponding sound pressure distributions within that space. Knowing the room modes is the essential first step in understanding the acoustical properties of your listening environment. As before, the Finite Element Method (FEM) facilitates modeling the sound field of a complex-shape space.

In this sequel article, I would like to focus on altering the placement in the room of a sound source that radiates at non-resonant frequencies and also room modes. I have kept the shape of the room the same as that in Part I in order to highlight the application of the FEM to the problem at hand.

Theoretical basics

In order to model harmonic acoustic behavior of an enclosed space with a sound source, the following equation is sufficient:

$$(K[][] - k^2 M[][] + j\omega C[][])p[] = j\rho_0 \omega v[]$$

$$\omega = 2\pi f$$

$$k = \frac{\omega}{c}$$

$$j = \sqrt{-1}$$

Where: K[][] is called acoustic stiffness matrix, M[][] is the acoustic mass matrix, C[][] is the damping of the system, p[] is the sound pressure vector, v[] is the excitation vector in qubic meters per second, f is the test frequency and c is the speed of sound. Assuming C[][]=0, that is no damping in the system, the above equation simplifies to:

$$(K[][] - k^2 M[][])p[] = j\omega v[]$$

For the source of the sound I assume a "point source", which is convenient, as it can be located in any of the mesh nodes. Larger sources would have to be accounted for as a part of the room boundary. Mathematically, the problem now reduces to assembly of the K[][] and M[][] matrixes and inverting the expression in the brackets. This way, vector p[] can be found for any frequency and location of the sound source represented by excitation vector v[]. For room modes, the expression in the brackets:

$$(K[][] - k^2 M[][]) = 0$$

In Part I , I used many “brick” (8-node) elements to approximate the volume of the listening room and the functions describing the pressure distribution between the nodes are linear. This is important, because if you know the pressure at the nodes, you can calculate pressure at any distance between them.

One of the limitations of the above approach is that FEM cannot model the “close field” sound pressure very accurately. It would take much more dense (finer) mesh to do this job properly. I am not however concerned with this limitation, because the job at hand is to look at the whole room. To illustrate the application of the FEM method I selected a listening room shape indicated on Figure 1. This is an L-shaped room with wall A-B slightly longer than D-E wall. This deliberate lack of symmetry will make the analysis perhaps more difficult, but will emphasize the usefulness of the FEM.

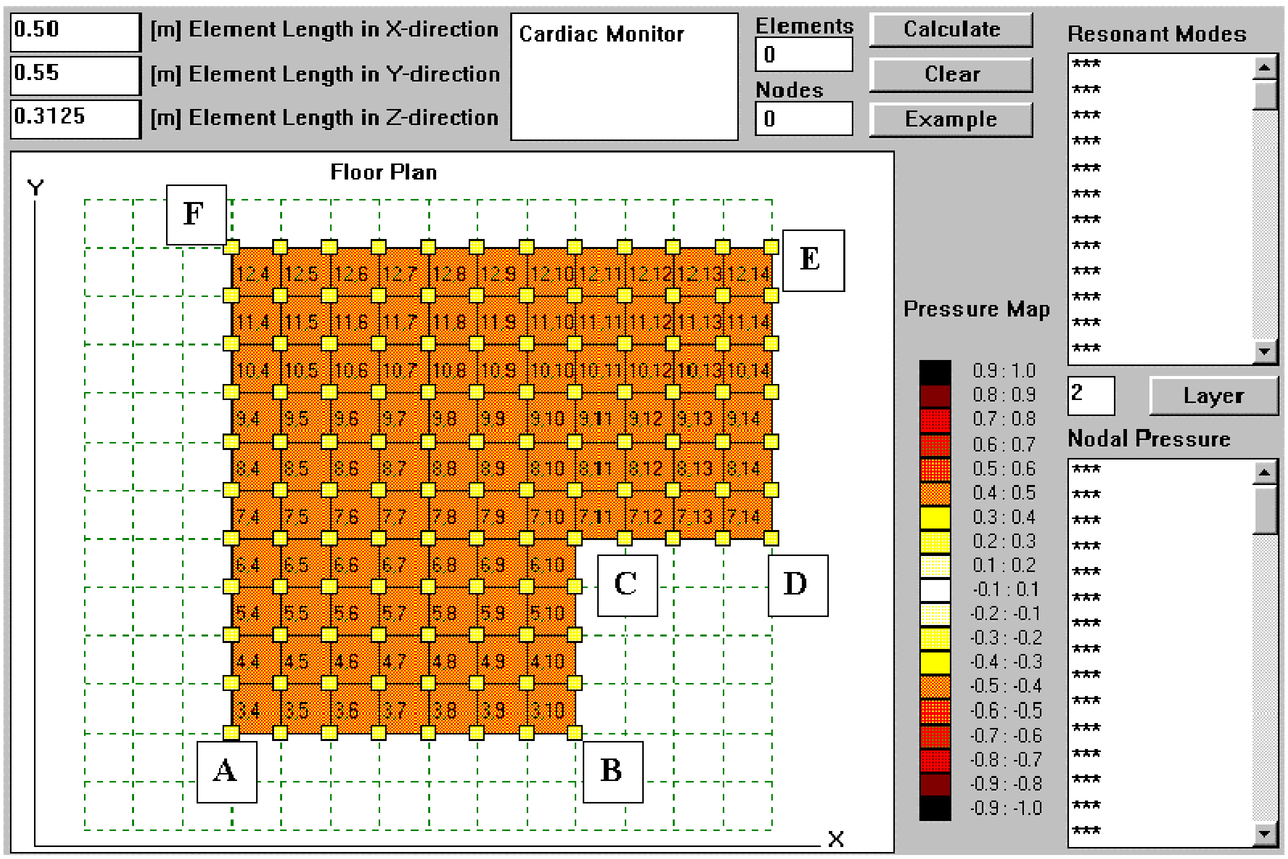

Figure 1. L-shaped room

Introducing a source of sound

Think about the following sequence: If the “point source” radiates in free space, it would produce some sound pressure, which you consider to be at 0.0dB level. When you place this source in front of a hard wall the sound pressure is reinforced by the reflections from the wall and a +3dBincrease in the Power Level (PWL) will occur. If in addition, you move the source to the wall/floor junction, the resulting PWL is further reinforced . And finally, if you move source of the sound into the corner of the room, the Power Level increases by some 9-10dB.

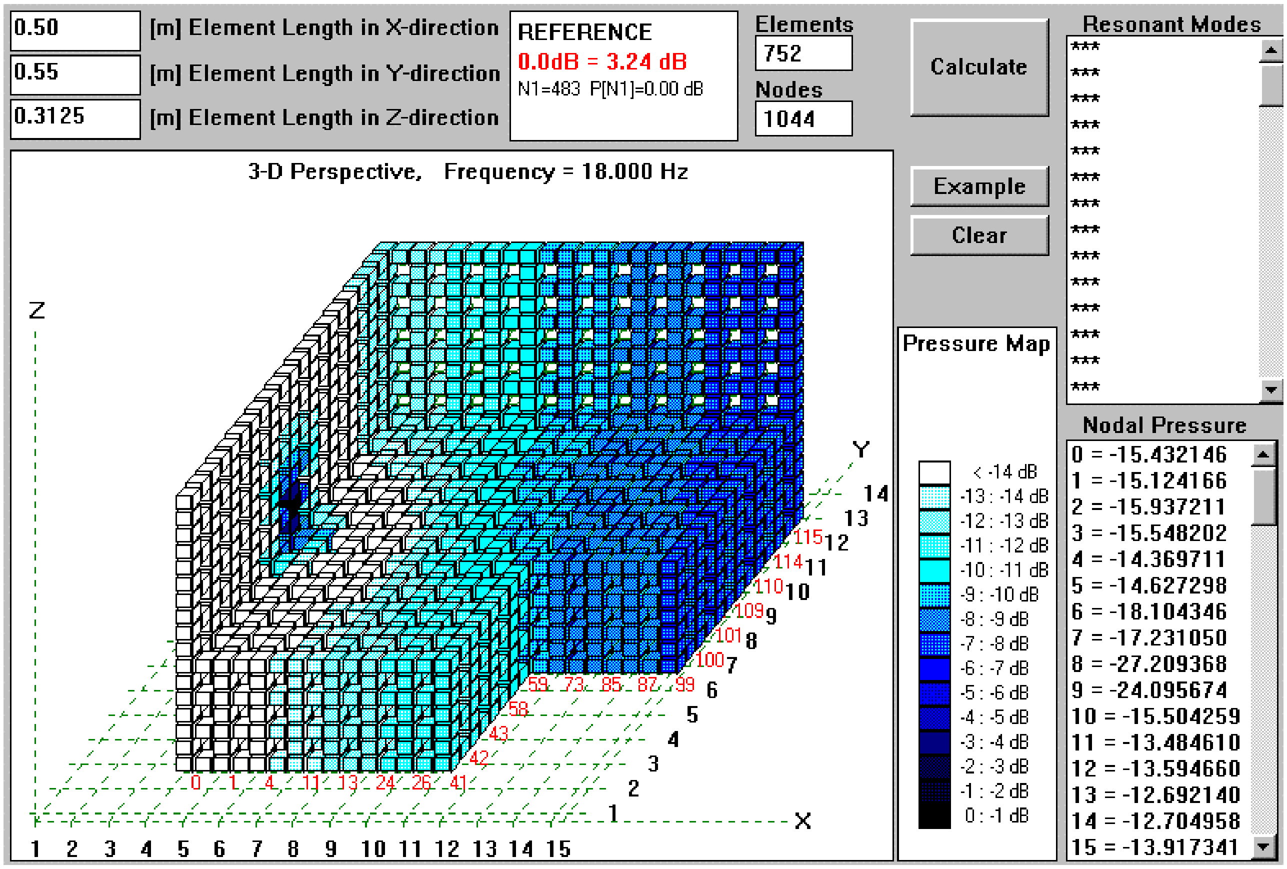

Figure 2. Source placed in front of a hard wall.

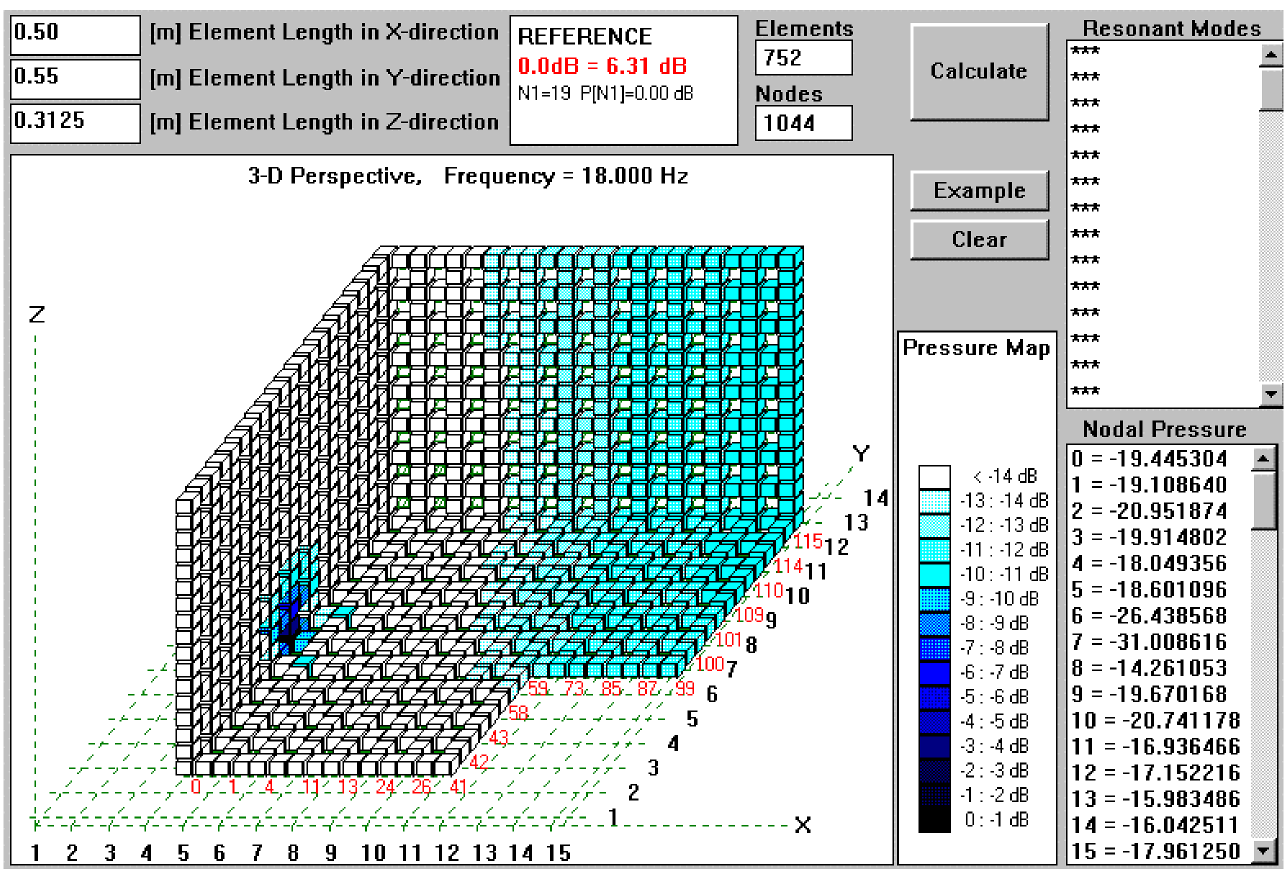

Figure 3 Source placed at wall-floor junction.

Now, if the sound-source frequency happens to be one of the room-resonant modes, the sound pressure at the source is dramatically magnified by the resonant effect and lack of dumping (assuming, that matrix C[][]=0).The display is arranged such a way, that nodal pressure is normalized to the maximum pressure within the room. This maximum pressure is marked “0.0dB”, so all other nodes will exhibit negative pressure values, as shown on the colour coded pressure map on each screen dump. The actual level of the “REFERENCE 0.0dB=” is displayed in red colour, and its value is relative to sound pressure radiated from a “point source” in free space. Generally, if the REFERENCE is above10dB mark, you would be approaching a resonant mode. When the REFERENCE exceeds 20dB you hit the mode. Levels below 10dB relate to various locations of the source at non-modal frequencies. In general, sound field of a complex-shape enclosure can be modeled for any location of the source or sources of the sound. For the non-modal frequencies, the resulting sound field at low frequencies typically exhibits variations in the near-field and a gradual increase in intensity toward opposite wall.

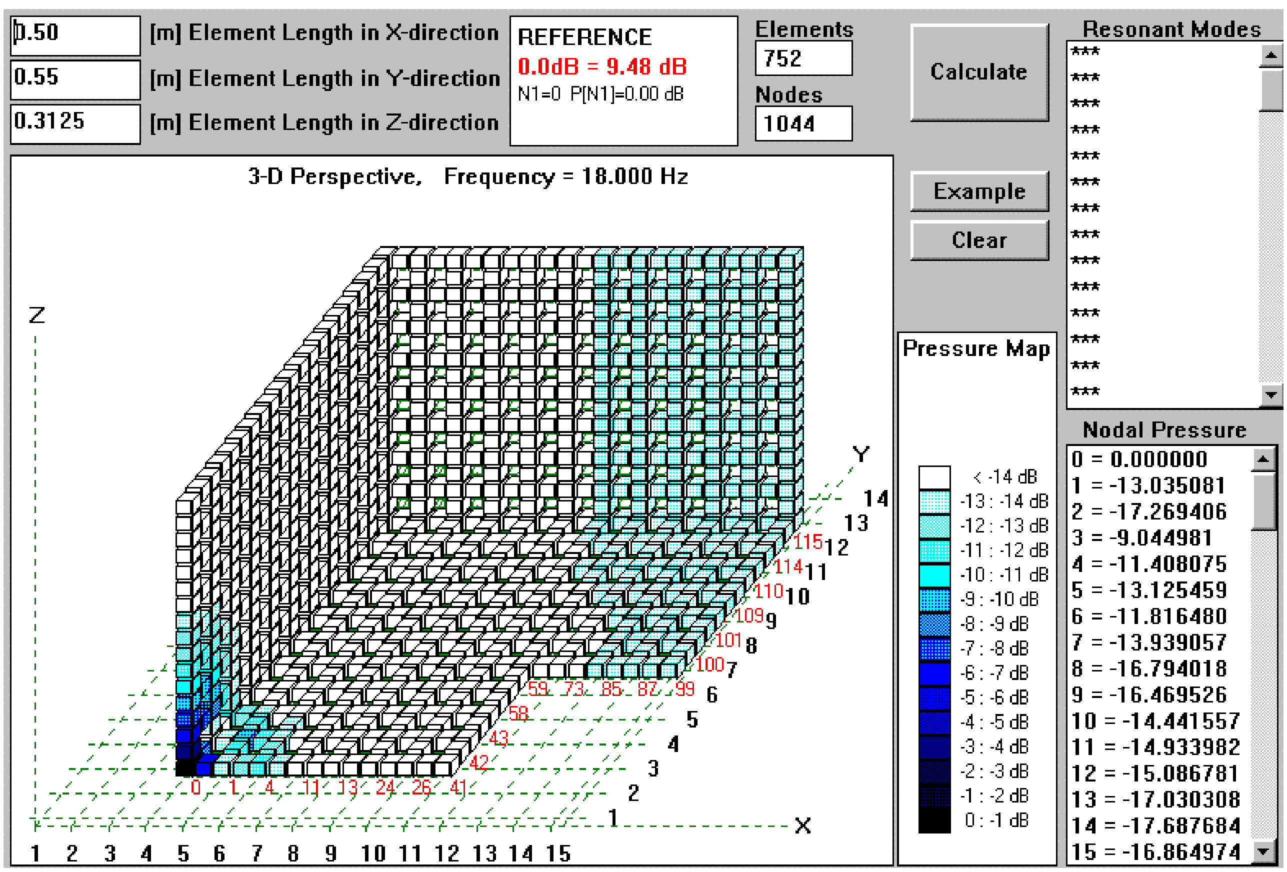

Figure 4. Source placed at the corner.

Approaching the resonant mode

With the source located in the corner A (Node 0), you can select a test frequency close to, but not equal to the lowest room mode. Figure 15 depicts the situation for a frequency of 26.0Hz, where the expected sound field is beginning to take shape, but the resonance has not quite yet developed. The REFERENCE parameter just exceeds 10.

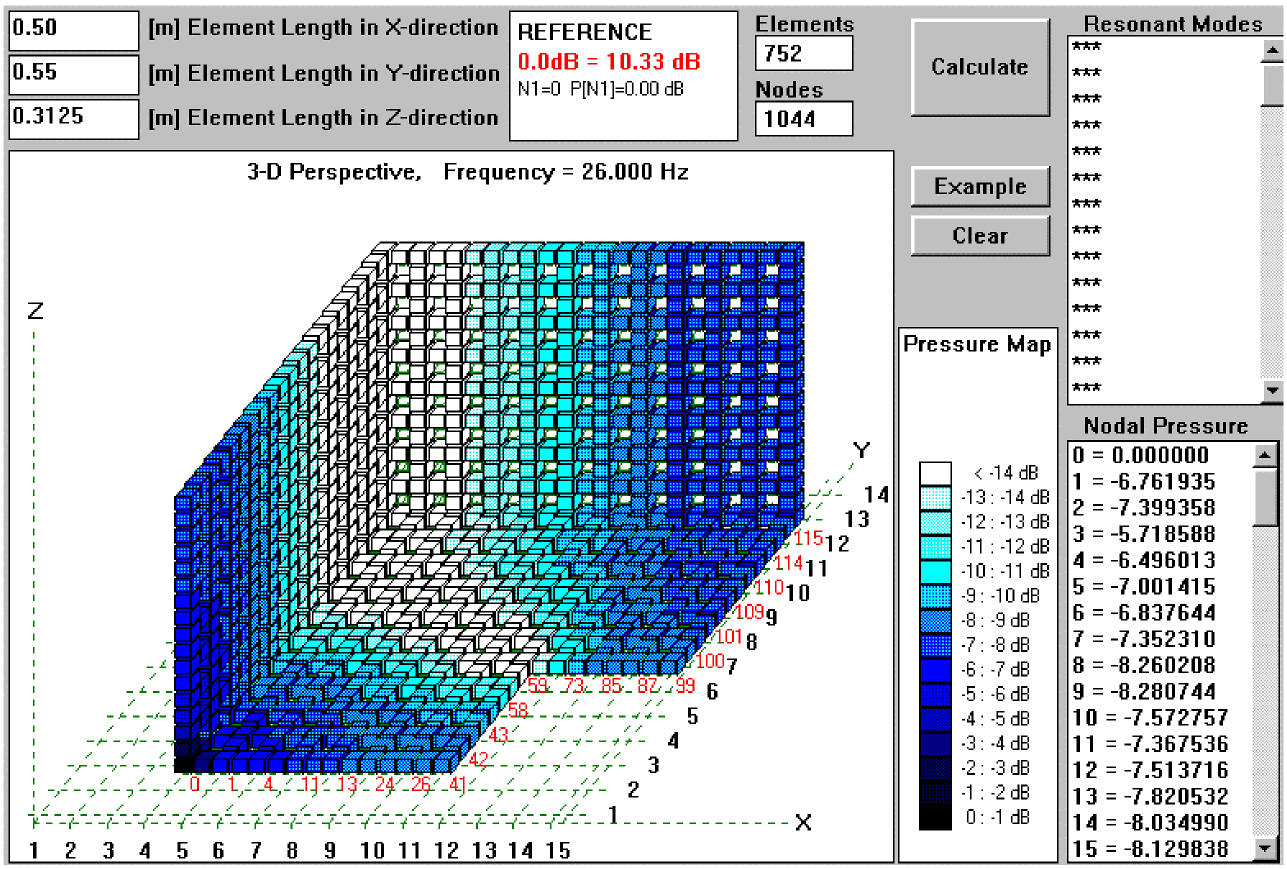

Figure 5. Source in the corner, approaching room mode.

The pattern is familiar and shows characteristic increase in the pressure at the source due to resonant effect developed in the room. The null of the pressure, or cancellation of the sound is marked half-way to the opposite wall. The total pressure increase at the source would include reinforcement due to corner location and additional increase due to sharp resonant effect of the volume of air resonating in the room, giving the REFERENCE level of 32dB. Please note, that computer rounding errors also contribute to the value of REFERENCE at modal frequency and finally, the modal frequencies, as given in the previous article, are calculated and rounded to the second decimal point, as in real life, there is no need for greater accuracy. Source at room nodal line. Now keep the test frequency at the first room mode and move the source to the pressure null line of the first mode. Figure 7 shows this situation and you can easily observe, that – despite radiating the exact room modal frequency - the source fails to energize the room mode.

The sound field fades away quickly around the source and increases slightly in strength toward the opposite walls. The REFERENCE parameter is close to a typical wall/floor value of6dB. The source was located at node 51, which is not exactly at the corner and this is due to the asymmetrical shape of the room. Next, you maintain the location of the source, but switch the test frequency to the second order mode along this wall (Fig 8). Again, as is predictable, the source fully energizes the mode and the REFERENCE parameter shows typical modal value being close to 20.0dB.

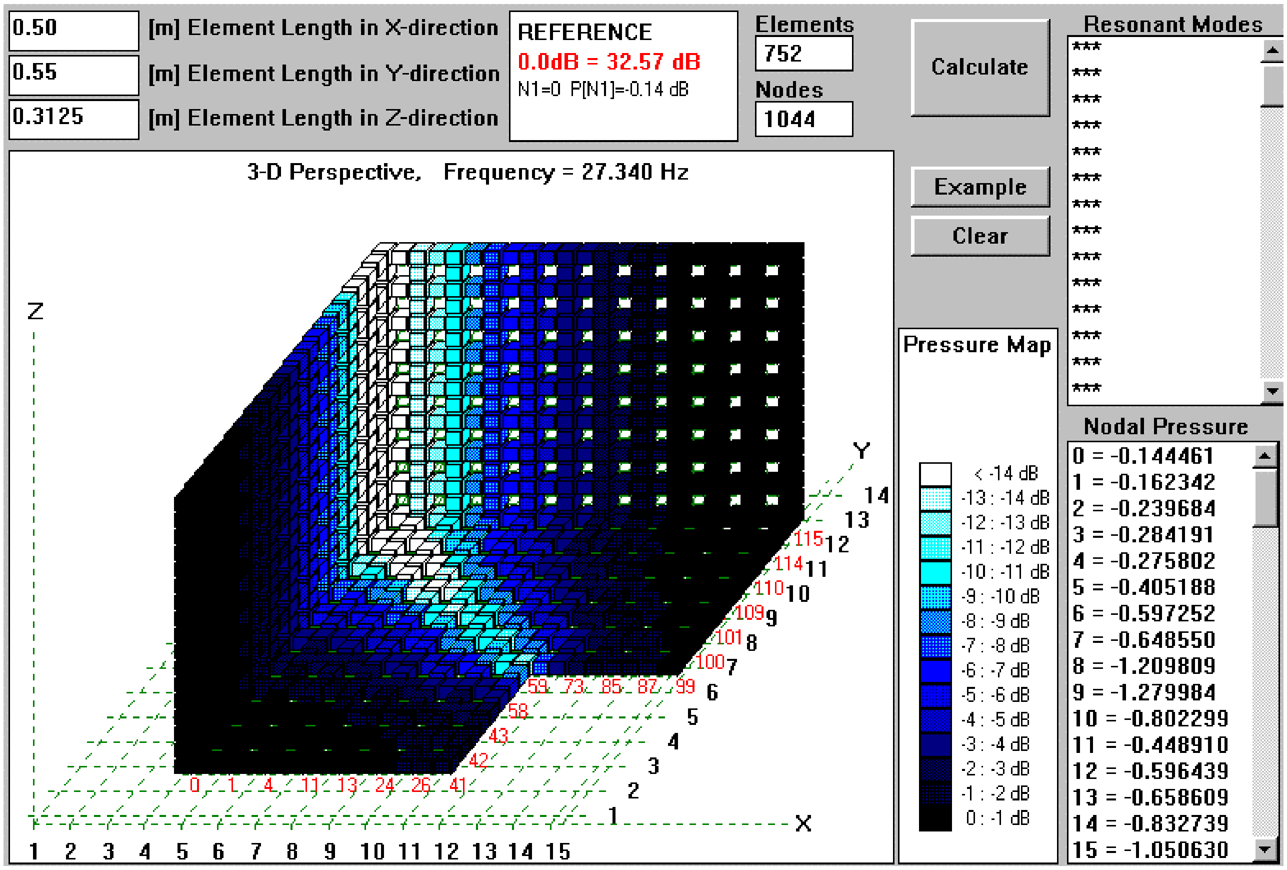

Figure 6. Shows the source radiating at the first room mode.

Concluding remarks

Despite the simplifications noted at the beginning of this discussion, the FEM is quite capable of providing a large amount of useful information about the sound field in your listening room. You can couple your understanding of the room gain and room modes with the predicted distribution of the sound field at non-modal frequencies and use the results of the analysis to improve placement of the loudspeakers and select an optimum listening position. Figures 2, 3 and 4 are typical for frequencies below the first room mode and are indicative of The expected difficulties when you attempt to reproduce low frequencies in a small room.

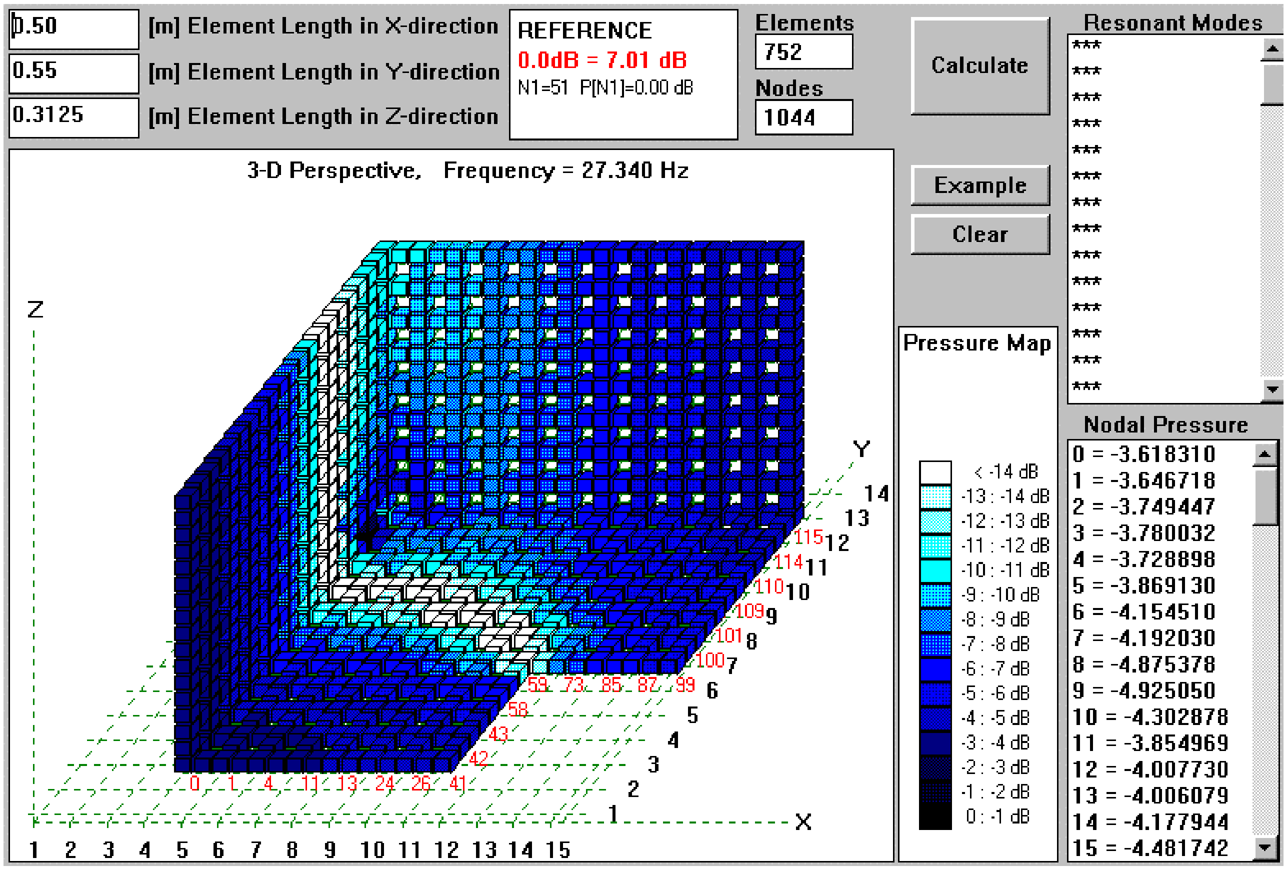

Figure 7. Locating the loudspeaker at node 51 – radiates at first modal frequency.

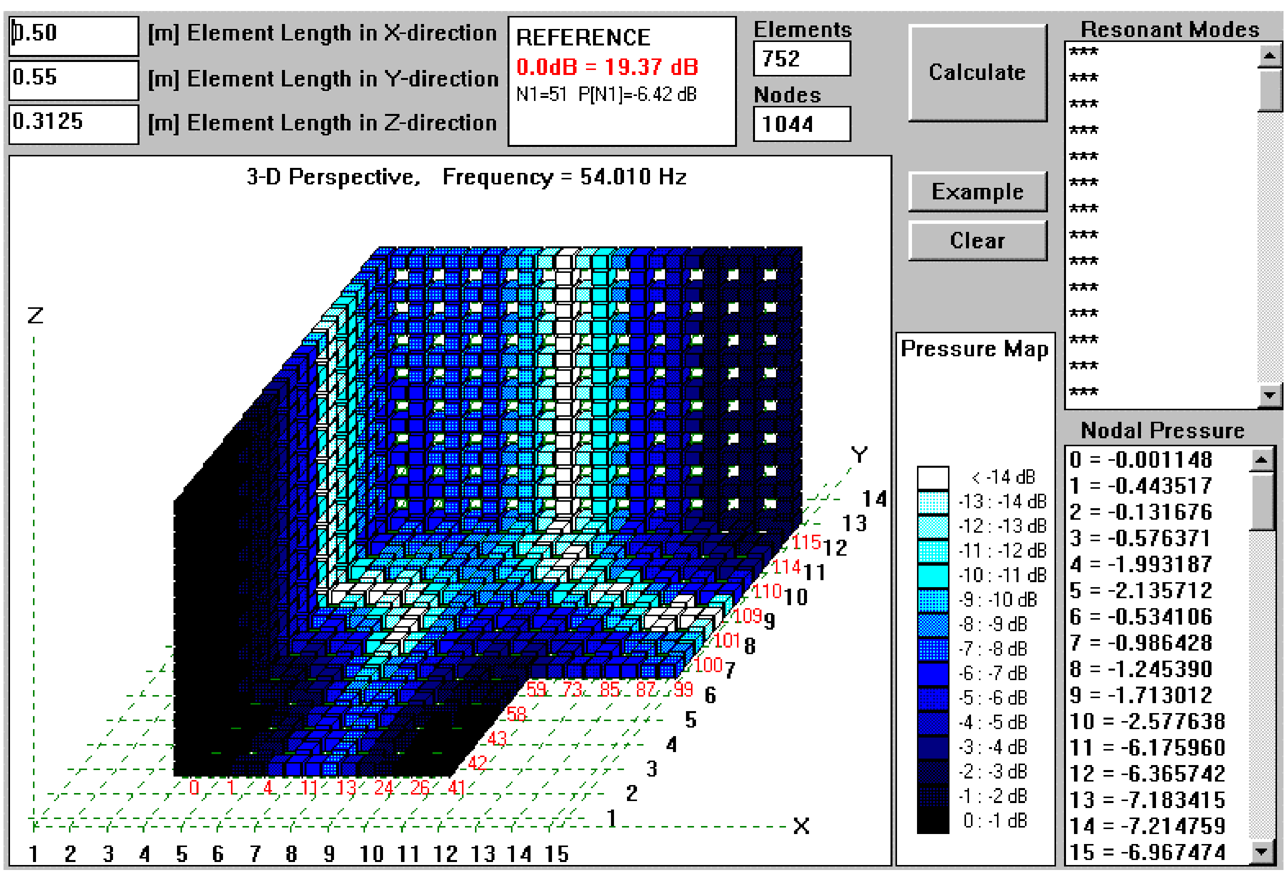

Figure 8. Locating the loudspeaker at node 51 – radiates at second modal frequency.

Locating the loudspeaker at node 51 (Figure 7 and 8), will not fully energize the first room mode, but it will energize the second and this results in 12dB difference in maximum sound pressure in favor of the second mode (54.0 Hz). Also, moving loudspeaker from a corner (Figure 6) location to a null location (Figure 7) reduces the relative SPL from 32dB to 7dB – that is a massive 25dB decrease !. You may not desire this additional sound coloration if your goal is to setup your speakers for maximum sound pressure at the lowest frequencies. If you read Part I, you may notice, that all plots currently presented appear to have "finer" mesh. This is due to pressure distribution functions being linear between the nodes, enabling you to easily calculate and display the pressure at any point between them.

References:

1. SoundEasy V3.0,
2. "A finite element procedure for design of cavity acoustical treatment". Robert J. Bernhard and Seiji Takeo, JASM, 83 June 1988.
3. "Acoustic field in an Enclosure and its Effect on Sound Pressure Responses of a Loudspeaker". Shinichi Sakai, Yukio Kagawa and Tatsuo Yamabuhi, JAES, Loudspeakers Vol 3. 1984- 1991