The Reflection Loudspeaker

PHOTO 1: The Reflection loudspeaker.

I needed two small loudspeakers for the rear channels of my multichannel system. I had available several Audax AP130Z0 woofers and Audax TM025F1 tweeters from my previous projects, so I decided to design a new compact loudspeaker with these units. The "Reflection" loudspeaker is the result of this effort (**Photo 1**).

The AP130Z0 (**Photo 2**) is a 130mm shielded woofer for audio/video use with Aero gel cone and rubber surround, while the TM025F1 (**Photo 3**) is a 25mm dome tweeter with ferrofluid and a shielded neodymium magnet for audio/video use.

Table 1

Parameter	Audax 1	Audax 2	Audax 3	Audax 4
Fs (Hz)	64.6	61.3	63.9	69.4
Qt	0.54	0.51	0.51	0.53
Vas (liters)	9.5	10.5	10.6	8.3

The passive crossover consists of an acoustic fourth-order Linkwitz-Riley low-pass filter and an acoustic fourth-order Linkwitz-Riley high-pass filter with the crossover frequency set at 2500Hz.

THE BOX

According to the data provided by the manufacturer, the AP130Z0 woofer has the following Thiele/Small parameters:
Fs = 57.6Hz
Qt = 0.41
Vas = 10.85 liters

I measured the Thiele/Small parameters on four of the units that I had available[1]. **Table 1** shows the results. The averages of these measurements are as follows:
Fs = 64.8Hz (about 12% higher than the manufacturer value)
Qt = 0.52 (about 27% higher than the manufacturer value)
Vas = 9.72 liters (about 10% less than the manufacturer value)

With these parameters in mind, I chose a box with a net internal volume of 4.5 liters, which gave a resonance frequency at 115Hz with Q = 0.75. I constructed the box (**Fig. 1**) with 12mm MDF and covered it with a wood imitation varnish. I also loosely fitted it with fiberglass.

CROSSOVER DESIGN

Selecting the crossover frequency is an important decision for the design of every loudspeaker. Choose the crossover frequency as low as possible to push the unavoidable rolloff in the power response to the higher frequencies[2]. I chose a fourth-order Linkwitz-Riley filter with the crossover frequency set at 2500Hz. The 24dB/octave slope will give

PHOTO 2: The Audax AP130Z0 woofer.

PHOTO 3: The Audax TM025F1 tweeter.

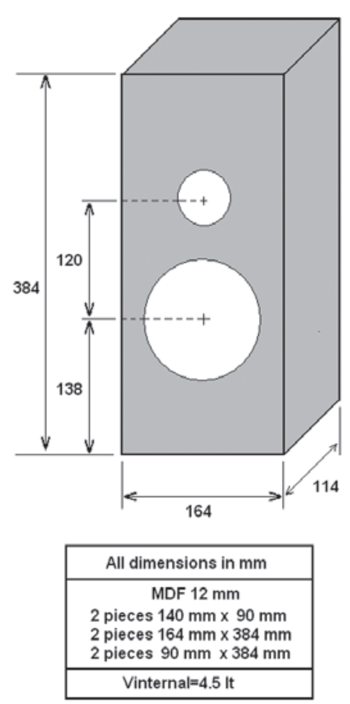

FIGURE 1: The box dimensions of the Reflection loudspeaker.

sufficient attenuation to the woofer resonance which exists in the region of 5 to 6kHz and will protect the tweeter from high excursions at the lower frequencies. The crossover frequency is a little higher than I prefer, but, unfortunately, the TM025F1 tweeter is not able to provide enough volume capacity for the lower frequencies due to the limited volume displacement.

For the design of the crossover, I used the ORCAD 15.7 demo version (www.cadence.com/products/orcad/index.aspx). The program includes a version of a PSPICE simulation program for electronic circuits. But before I proceed with the analysis of the crossover circuit, I need to determine the following:

a) the topology of the network
b) an electrical network that will simulate the impedance of the woofer and the tweeter
c) a measurement of the frequency response of the woofer and the tweeter when they are installed in the box.

First, I measured the impedance of the woofer and the tweeter[1] and developed equivalent electrical circuits that simulate with high accuracy the impedances of the woofer and of the tweeter. These circuits are shown in **Fig. 2** for the woofer and **Fig. 3** for the tweeter. Then I measured the frequency response of the woofer and the tweeter when they are mounted on the box. These frequency

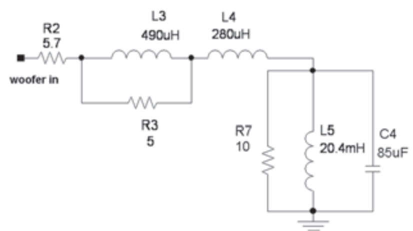

FIGURE 2: The network for the simulation of the woofer impedance.

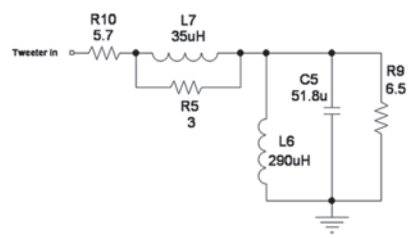

FIGURE 3: The network for the simulation of the tweeter impedance.

responses will be used for the computation of the crossover network.

I took all the measurements in my listening room and this implies some limitations. I placed the loudspeaker on a height 1.5m above the floor and at least 1.5m from the sidewalls. The microphone was about 1.5m from the speaker and its height was about 1.4m above the floor. In all the measurements the microphone was pointed directly at the center of the tweeter. I took several measurements of the woofer in different places in an effort to eliminate the room influence in the low frequencies.

The final frequency response measurement of the woofer, which is an average measurement, is shown in **Fig. 4**, and for the tweeter in **Fig. 5**. Now I am ready to proceed with the design of the crossover network.

I entered the topology of the circuit on the ORCAD Capture Demo editor and, using the special EFREQ device, I also entered the measured frequency response of the AP130Z0 woofer and the TM025F1 tweeter. The circuit as used in the ORCAD simulation program is shown in **Fig. 6**.

The components L1, R_L1, C3, R24, R_L2, and L2 form the low-pass filter of the crossover. The components R2, L3, R3, L4, R7, L5, and C4 form the impedance circuit of the AP130Z0 woofer.

The E2 component simulates the woofer's frequency response, which is entered in discrete frequencies as indicated in **Fig. 7**. For example, the response is entered for 100, 150, 200, 300, 400Hz, and so on, up to 20kHz. Next to the frequency is indicated the amplitude and the phase. Additionally, for the woofer I entered a delay of 60μs in the E2 component, because the acoustic center of the woofer is not in the same plane with the tweeter.

Components G1 and G2 are Laplace functions of the simulation program and compute the theoretical response of a Linkwitz-Riley fourth-order low-pass filter at 2500Hz. The response at the output of these components is compared with the response at the output of the E2 function, which simulates the acoustic response of the AP130Z0 with the crossover. The target of the analysis is to match the two responses as closely as possible.

A similar procedure is followed for

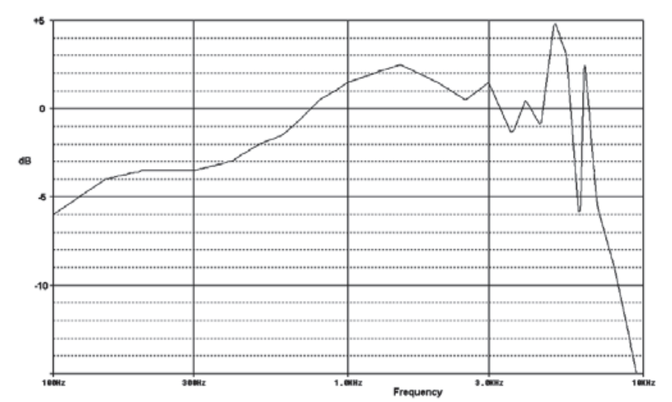

FIGURE 4: The frequency response of the AP130Z0.

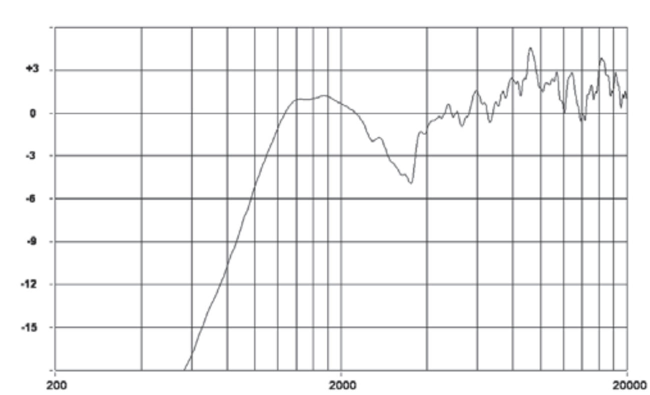

FIGURE 5: The frequency response of the tweeter TM025F1.

the tweeter part of the crossover. Components R23, C1, L8, R_L8, C8, and C6 form the high-pass filter of the crossover. Components R10, L7, R8, L6, R9, and C5 form the impedance circuit of the tweeter. The E1 component simulates the frequency response of the tweeter as was measured.

As with the low-pass filter, components G3 and G4 are Laplace functions of the simulation program and compute the theoretical response of a Linkwitz-Riley fourth-order high-pass filter at 2500Hz. The response at the output of these components is compared with the response at the output of the E1 function, which simulates the acoustic response of the tweeter with the crossover. Again, the target of the analysis is to match the two responses as closely as possible.

I computed the initial values of the components using the relevant theory for the design of the Linkwitz-Riley filters. Then I modified the values of the components until the response of the theoretical filters were as close as possible with the acoustic outputs of the woofer and the tweeter. The function ESUM is used to add the acoustic outputs of the woofer and the tweeter to simulate the total acoustic output of the loudspeaker.

You can also use the simulation program to analyze the input impedance of the loudspeaker by changing the voltage source V1 to a current source of 1A. Then the voltage as measured at the input of the crossover (junction R23 and L1) is the impedance of the loudspeaker. This input impedance simulation is shown in **Fig. 8**, which is very close to the real impedance of the loudspeaker as measured in **Fig. 14**.

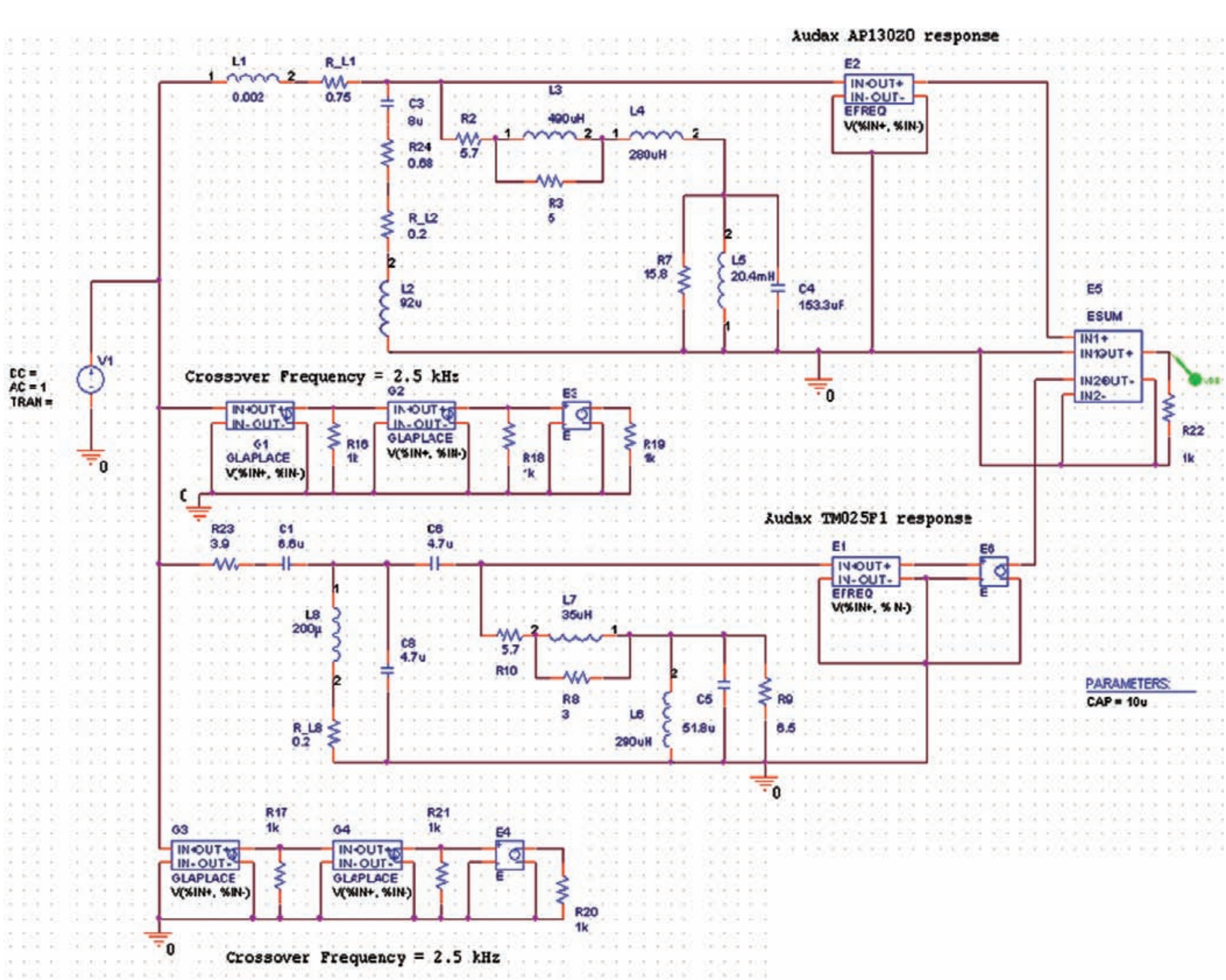

FIGURE 6: The ORCAD simulation network for the Reflection loudspeaker.

```
E_E2      N32214 0 FREQ { V(N105082, 0) } =   (
(100,89,80) (150,91,70)
+  (200,91.5,60) (300,91.5,60) (400,92,45) (500,93,40)
(600,93.5,40)
+  (700,94.5,35) (800,95.5,30) (900,96,30) (1k,96.5,20)
(1.5k,97.5,-25)
+  (2k,96.5,-20) (2.5k,95.5,-25) (3k,96.5,-27) (3.6k,93.5,-25)
(4k,95.5,-22)
+  (4.5k,94,-28) (5k2,100,-35) (5.5k,98,-60) (6.1k,88,-80)
(6.3k,98,-100)
+  (7k,89.5,-100) (8k,86,-100) (9k,82,-100) (10k,78,-105)
(20k,66,-100) )
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FIGURE 7: Simulation of the woofer response as used for the analysis of the crossover in ORCAD.

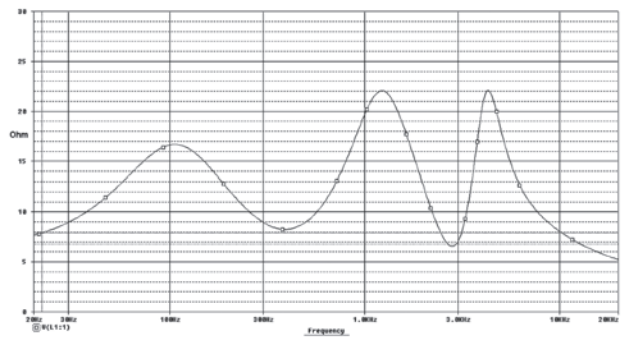

FIGURE 8: PSPICE simulation of the loudspeaker impedance.

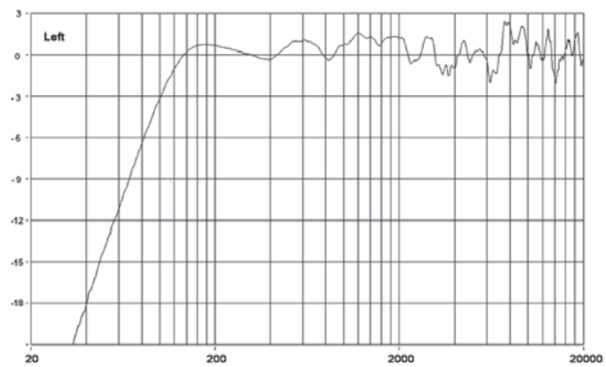

FIGURE 9: The frequency response of the Reflection.

CROSSOVER CONSTRUCTION

The simulation is a very valuable tool, but you need to construct a real circuit in order to confirm the simulation results. So, I quickly assembled the crossover onto a piece of wood and measured the total response of the loudspeaker. I just needed to modify the value of the resistance R23 from 3.9Ω to 5Ω, which reduces the output of the tweeter, to get a flat response. The final crossover of the Reflection loudspeaker is shown in **Fig. 12**.

For the construction, I separated the woofer and tweeter sections and built the crossovers on two small pieces of plywood (**Photo 4**). I glued all the components using hot glue. I placed and glued the woofer crossover at the bottom of the cabinet due to the heavy inductor. I glued the tweeter crossover on the rear of the cabinet behind the tweeter.

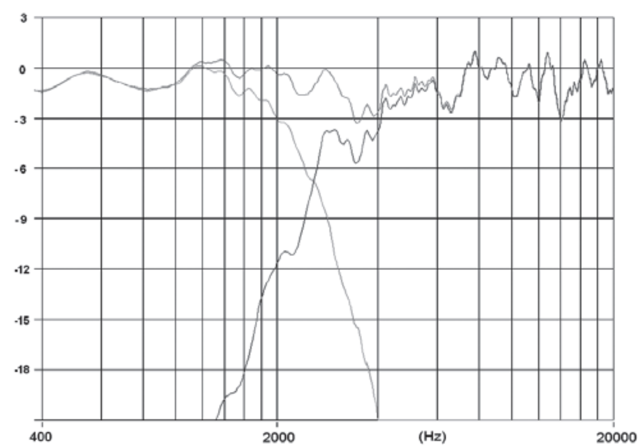

FIGURE 10: The total frequency response with the woofer and the tweeter response.

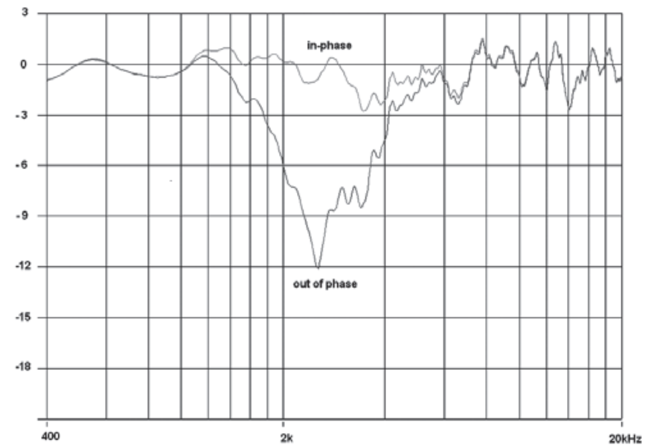

FIGURE 11: The total frequency response with the tweeter in-phase and out-of-phase.

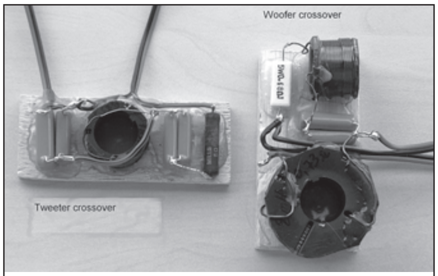

PHOTO 4: The crossover.

MEASUREMENTS

I took the following measurements for the evaluation of the loudspeaker. The total frequency response of the loudspeaker is shown in **Fig. 9**. I performed this response measurement in two passes according to the method described in reference 3. I took the low-frequency response up to about 240Hz using the near-field technique and performed the response above 240Hz using a time selective technique of the far-field measurement. The response is flat within ±1.7dB from about 130Hz to 20kHz.

In **Fig. 10** the individual response of the woofer and tweeter units are shown. The crossover frequency is very close to the theoretical value of 2.5kHz. **Figure 11** compares the total response with the tweeter in-phase and out-of-phase. The notch indicates that the two units are close in-phase at the crossover frequencies, as they should be. In **Fig. 13** the horizontal dispersion of the loudspeaker is shown with measurements taken on the axis of the loudspeaker, at 30° and 60°.

Figure 14 shows the measured impedance of the loudspeaker. The minimum value of the impedance is 7Ω at the region of 250Hz and almost 6Ω at 20kHz. This was one of the design targets, because the length of the cable between the surround loudspeaker and the amplifier usually is very long and this could result in frequency response irregularities, if the impedance of the loudspeaker is low. The maximum impedance value is 21Ω at about 1100Hz. The phase has a minimum value of –40° and a maximum value of +40°.

CONCLUSION

The “Reflection” is a small, low-cost, good-sounding loudspeaker which is very easy to construct. But don’t expect thunderous bass from this speaker with its small woofer. Although it was designed to be used for the surround channels of a multi-channel system, you can also use it as the main loudspeaker of a system by adding the subwoofer. *aX*

REFERENCES

1. Measured with the demo version of the PRAXIS software (www.libinst.com/index.htm).

2. Siegfried Linkwitz, "Which loudspeaker parameters are important to create the illusion of a live performance in the living room?" Convention paper, 113th JAES convention.

3. C. Struck and S. Temme, "Simulated free field measurements," Bruel & Kjaer.

4. Measured with the demo version of ARTA software (www.fesb.hr/~mateljan/arta/).

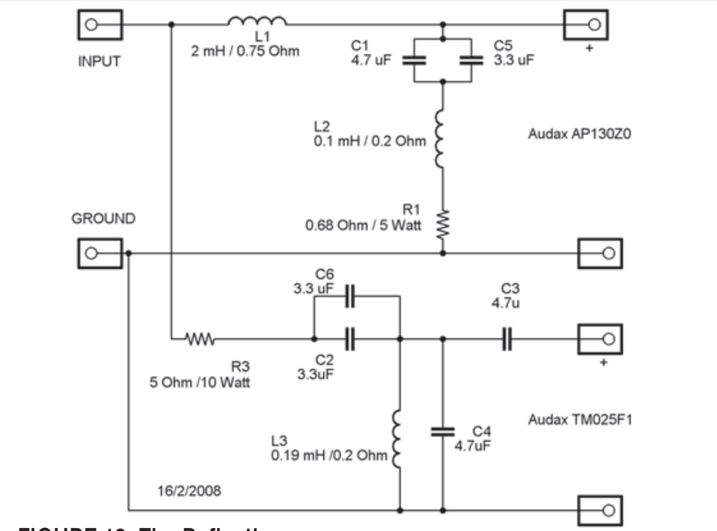

FIGURE 12: The Reflection crossover.

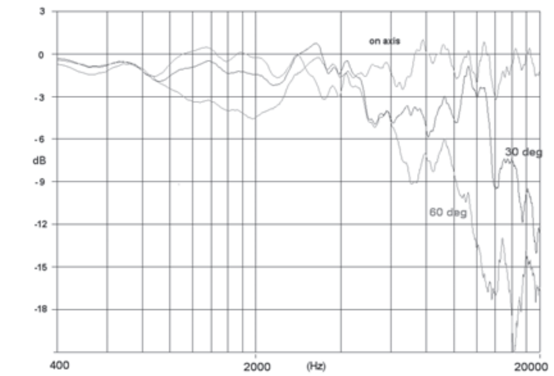

FIGURE 13: The total frequency response measured on-axis, at 30° and 60° horizontal.

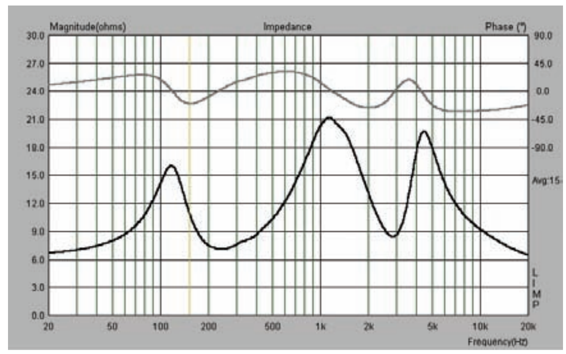

FIGURE 14: The measured impedance of the Reflection.