The Lamda Loudspeaker

A subwoofer for the Magnepan MC1.

Lamda is a dipole loudspeaker consisting of a Magnepan MC1 loudspeaker and an open baffle cabinet with the Peerless 830452 XLS woofer (**Photos 1** and **2**). Each unit is driven through the Lamda active crossover by its own power amplifier. The Lamda active crossover contains a fourth-order Linkwitz-Riley crossover at 240Hz and several equalizers for the loudspeaker units. It covers the spectrum down to about 50Hz. You should use a subwoofer below this frequency.

THE MAGNEPAN MC1 LOUDSPEAKER

The Magnepan MC1 loudspeaker is a dipole speaker consisting of two vertically oriented drivers—one planar magnetostatic driver for the low frequencies

> In this article, we've let stand the author's unconventional (perhaps phonetic) spelling of the eleventh letter of the Greek alphabet referring to his speaker system. —Eds.

PHOTO 1: The LAMDA loudspeaker.

PHOTO 2: Another view of the LAMDA loudspeaker.

and a quasi-ribbon driver for the high frequencies. The speaker is rather small considering its dipole nature, and is not capable of reproducing the full spectrum.

According to the manufacturer, the frequency response of the MC1 when attached on the sidewall of the listening room is from 80Hz to 20kHz, ±3dB. Of course, the response is quite different when you remove the MC1 from the sidewall. Although in the Lamda loudspeaker the MC1 operates only at frequencies above 240Hz, electronic equalization is applied by the Lamda active crossover to compensate the dipole loss to the frequencies below 1kHz.

CABINET DESIGN

The MC1 is a dipole source, and its ideal companion for the lower frequencies would also be a dipole source such as an open baffle woofer. When considering a woofer for an open baffle, the most important parameters are the large effective piston area, the large linear excursion, and the low distortion.

My choice was the Peerless 830452 XLS woofer. According to the manufacturer, it has an effective piston area of 352cm^2 and a 12.5mm peak excursion. Additionally, it has low distortion and high power handling capability. The woofer will cover the lower part of the spectrum down to the frequency of 51Hz. Below this frequency you should use a subwoofer.

You'll find a very good analysis for the design of an open baffle speaker at the site of S. Linkwitz (www.linkwitzlab.com). The main factor for the design of the open baffle cabinet is the distance that separates the positive and the negative sides of the woofer radiation. There are several different shapes that you can use as open baffle speakers.

The purpose of all of them is to increase the distance between the two opposite sides of the woofer radiation in such a way that the total size of the cabinet remains as compact as possible. One of the simplest shapes to perform this task is the H-frame.

Place the woofer on a baffle that extends its sides both in the front and in the back. The result is that the distance between the positive and negative sides of the woofer radiation becomes larger, while the total size of the loudspeaker remains acceptable. Assuming that the near field response of the dipole loudspeaker is absolutely flat, the far field frequency response of a dipole loudspeaker in the free field is shown in **Fig. 1**. The frequency Fpk where the first peak occurs is given by:

$$F_{pk} = (0.5^*c)/D$$

where c is the sound velocity and D is the distance between the two dipole sources.

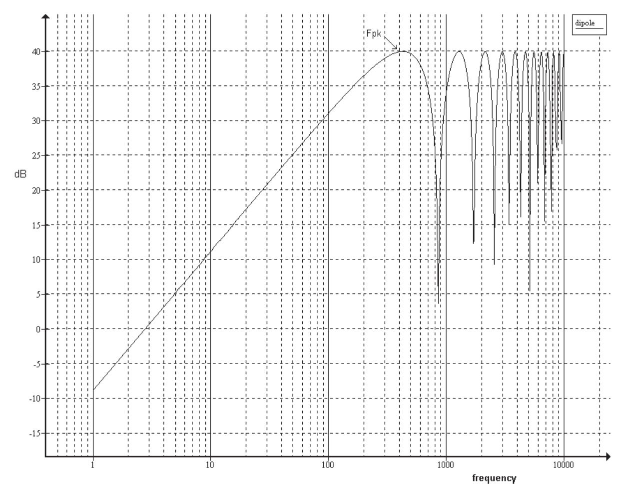

FIGURE 1: The far field frequency response of a dipole loudspeaker in the free field.

This peak in frequency response results when the negative polarity source after the 180° of phase shift due to the distance D adds to the positive source, and the resulting pressure is twice that of a single source (+6dB). Above the peak frequency there are also many other peaks and notches for the same reason.

Below the peak frequency Fpk, the sound pressure falls with 6dB/octave. This is due to the front-back cancellation of the sound. At the low frequencies the distance D is small compared to the length of the sound, so it cannot provide any isolation between the positive and negative sources. The distance D for my cabinet including the front and back covering is about 270mm, thus the Fpk will be about 640Hz.

The frequency at which the open baffle speaker has the same level output with a single similar monopole (for example, a closed box woofer) is given by: Feq = (0.17*c)/D = 220Hz.

Above this frequency the open baffle speaker has more output than a single monopole, and below this frequency it has less output that falls with -6dB/octave, where the single monopole has a flat response.

There is another peak in the frequency response of the open baffle cabinet, due to the cavity resonance which exists in the front and back of the woofer. This peak should be equalized with a notch filter so that the near field response of the baffle will be flat. Additionally, the far field low-frequency rolloff will be equalized with a circuit that boosts the low frequencies with -6dB/octave in order to flatten the frequency response.

The directivity of the open baffle subwoofer is maintained at the lowest frequencies. The response at all frequencies drops –3dB when the listening point is at an angle of 45° with the dipole axis and –6dB when it is at 60°.

The dimensions of the open baffle cabinet are shown in **Fig. 2**. The front and rear views of the cabinet are shown in **Photos 3** and **4**. I used plywood for the construction of the sides of the cabinet and MDF for the internal baffle that holds the Peerless woofer.

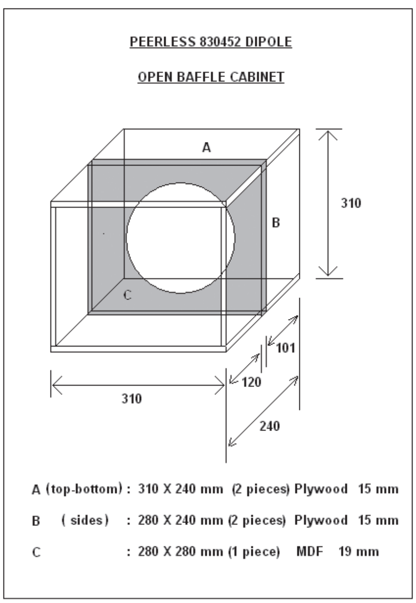

FIGURE 2: The dimensions of the open baffle cabinet.

PHOTO 3: Front view of the Peerless woofer.

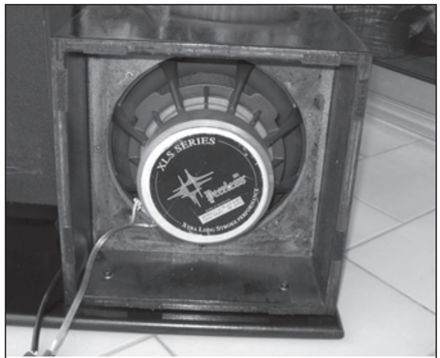

PHOTO 4: Rear view of the Peerless woofer.

The open baffle cabinet is also used to support the MC1. A wooden rod is screwed on the side of the open baffle. On the rod, the two supporting hinged brackets that are provided by the Magnepan are installed and support the MC1.

The MC1 is not vertical to the floor and has a slope of about 5° (**Photo 5**). This helps the center of the axis of the MC1 speaker to point directly to the listening position, which is assumed to be ideally at a distance of 2.6m and at a height of 1.1m above the floor.

CROSSOVER DESIGN

The Lamda active crossover includes the filters and the equalizers for the MC1 and the Peerless dipole. The selection of the crossover frequency is one of the most important decisions for the design of a loudspeaker so you should choose the frequency very carefully. It cannot be too high because of the woofer open baffle resonance and not too low because the MC1 will be overdriven.

My decision was made easier when I measured the near field response of the low-frequency driver of the MC1. The MC1 is a panel speaker with a very light diaphragm and boosts the low frequencies by using the resonance of the diaphragm. Actually, the diaphragm is divided into several areas and each one resonates at a different frequency. To evaluate this, I put the microphone very close to the diaphragm to measure three near field responses—at the bottom, at the middle, and at the top of the MC1 low-frequencies panel. The results are shown in **Fig. 3**.

The fundamental resonance of the bottom part of the panel is at 92Hz, while the fundamental resonance of the top part of the panel is at 180Hz. Two other resonances exist at 135Hz and 235Hz.

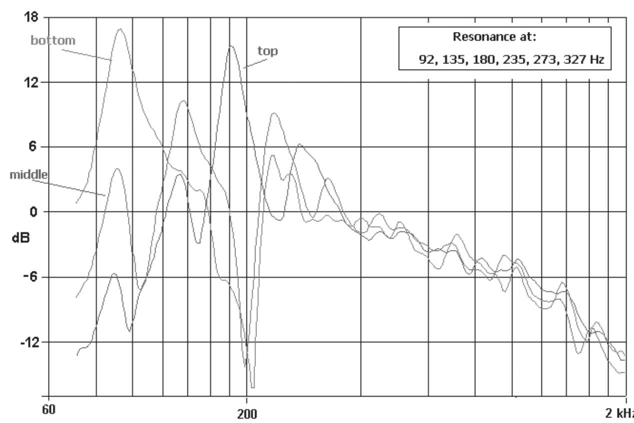

FIGURE 3: Near field responses taken at the bottom, at the middle, and at the top of the MC1 midrange panel.

It seems that the MC1 should be ideally operated above 400Hz. I chose not to operate the Peerless woofer at such a high frequency, so a good compromise for the crossover frequency was 240Hz. The crossover topology is a fourth-order Linkwitz-Riley. The full electronic diagram of the lamda active crossover is shown in **Fig. 4**.

The input signal passes through a simple first-order low-pass and high-pass filter (R1, R2, C1, and C21) before it goes to the IC1A, which buffers the signal and applies equalization with a gain of about +2dB for the frequencies above 1kHz. At the output of the IC1A, the crossover is divided into three main parts:

a) The Magnepan MC1 part consisting of two second-order high-pass filters in series to form a fourth-order Linkwitz-Riley crossover at 240Hz, an equalizer of the MC1 response, and two stages of delay circuits.
b) The Peerless part consisting of two second-order low-pass filters in series to form a fourth-order Linkwitz-Riley crossover at 240Hz, a second-order high-pass filter at 51Hz, a buffer-inverter, a Linkwitz transform circuit to equalize the woofer low Q value, a notch filter to equalize the λ/4 resonance of the cavity, a low-frequency equalizer, and, finally, an equalizer for the compensation of the dipole loss.
c) The subwoofer part consisting of two second-order low-pass filters in series to form a fourth-order Linkwitz-Riley crossover at 51Hz.

THE MAGNEPAN MC1 PART

The first step in the design of the crossover is the measurement of the MC1 frequency response. This frequency response is taken as the reference response for the computation of the crossover and the equalizer. It is obvious that you should take this measurement very carefully.

I took all the measurements in my listening room, given some limitations. I placed the MC1 on the floor and at least 0.5m away from the sidewalls. The microphone was always at a distance of about 2.6m from the speaker, and the height of the microphone was about 1.1m above the floor. In all measurements the microphone was pointed directly to the center of the MC1.

I took several measurements by moving the speaker and the microphone in different places to eliminate room influence as much as possible. This proved to be a very complex and time-consuming procedure.

The average frequency response is shown in **Fig. 5**. It is not much different from the response that was given in my previous article for the MC1 ("Analog Bass Control for Magnepans," *audioXpress* 8/07), although the measurement conditions were not the same.

The average response is very flat (within ±1.5dB) from about 1kHz up to 10kHz. Below 800Hz the response is falling due to the front to back cancellation, and above 10kHz there is a broad peak of more than +6dB at about 12 to 14kHz. For the design of the crossover, I used the Orcad 15.7 demo version. This is a free version of an excellent simulation program for electronic circuits, offering many capabilities.

I entered the topology of the circuit on the Orcad Capture Demo editor, and I also entered the measured frequency response of the MC1 using the special device EFREQ. I computed the initial values of the components using the relevant theory for the design of the Linkwitz-Riley filters and of the equalizers.

Then I modified the values of the components until the total response of the fourth-order filter and the equalizer was as close as possible to the reference output which was produced by a theoretical fourth-order filter using the special device GLAPLACE. The final values of the components for the MC1 Linkwitz-Riley crossover are shown in **Fig. 4** around the IC2A and IC3A. As expected, they are different from the nominal values.

The components around IC4A equalize the MC1 response by amplifying the frequencies below 1kHz for several dBs. The circuits around IC5A and IC6A form delay circuits that compensate for the difference in the phase response between the Peerless woofer and the MC1 at the crossover frequency. This is due to the different physical distances for the MC1 and the Peerless, to the drivers and to the filters.

I performed the compensation as

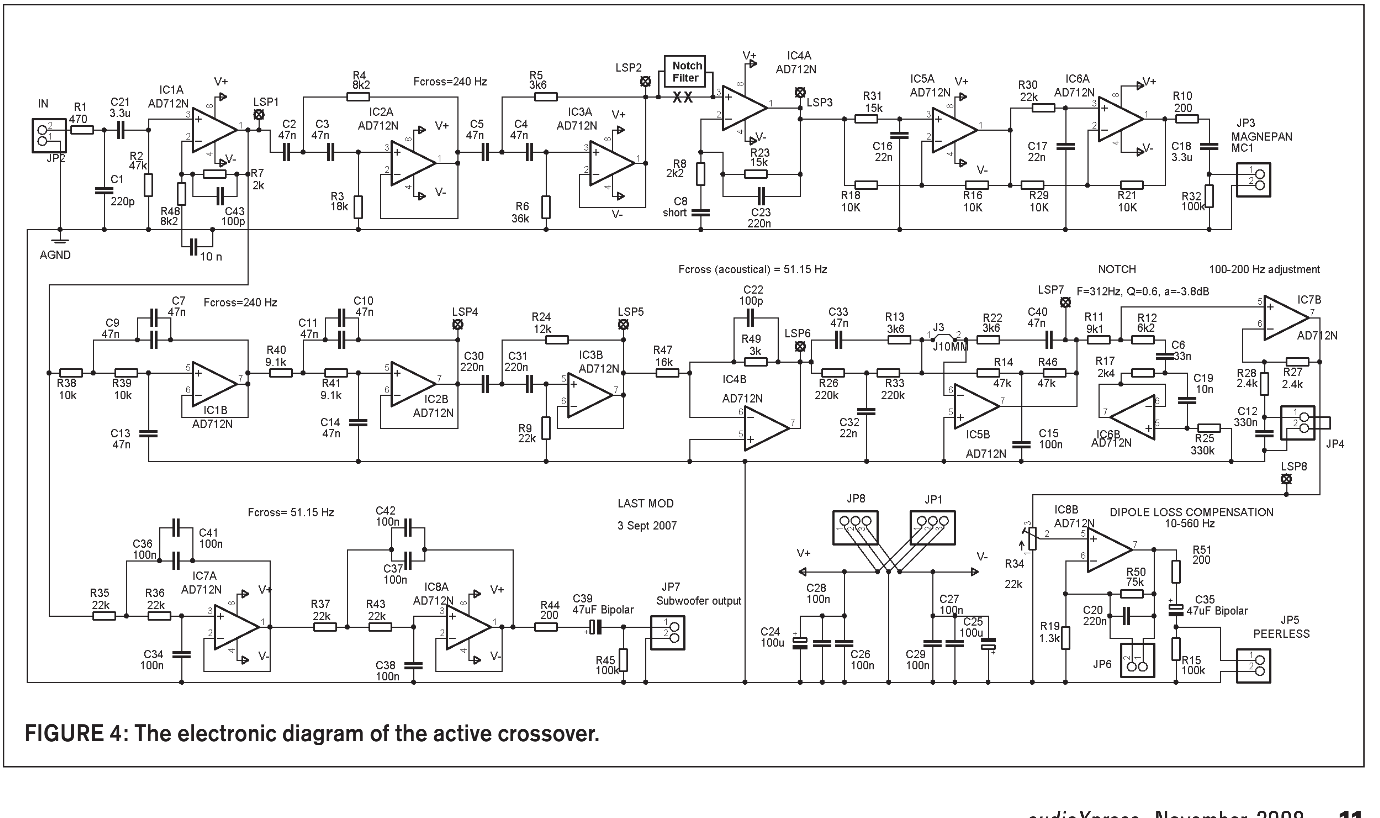

FIGURE 4: The electronic diagram of the active crossover.

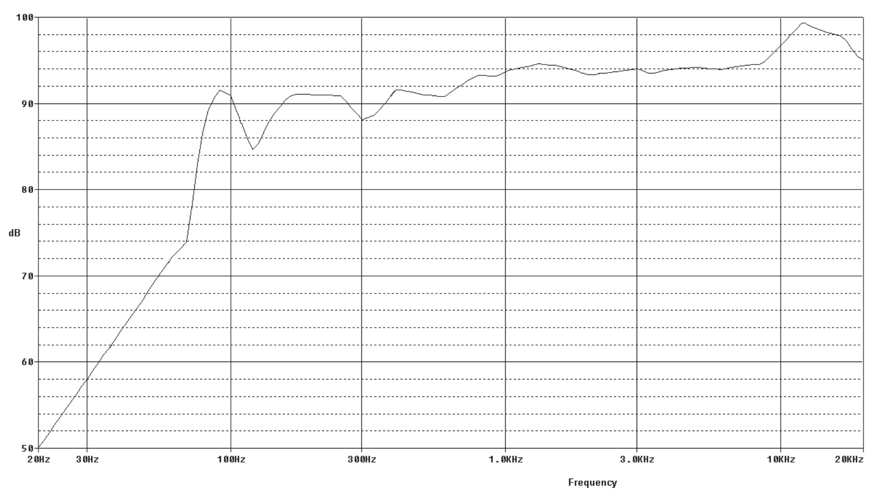

FIGURE 5: The average frequency response of the MC1.

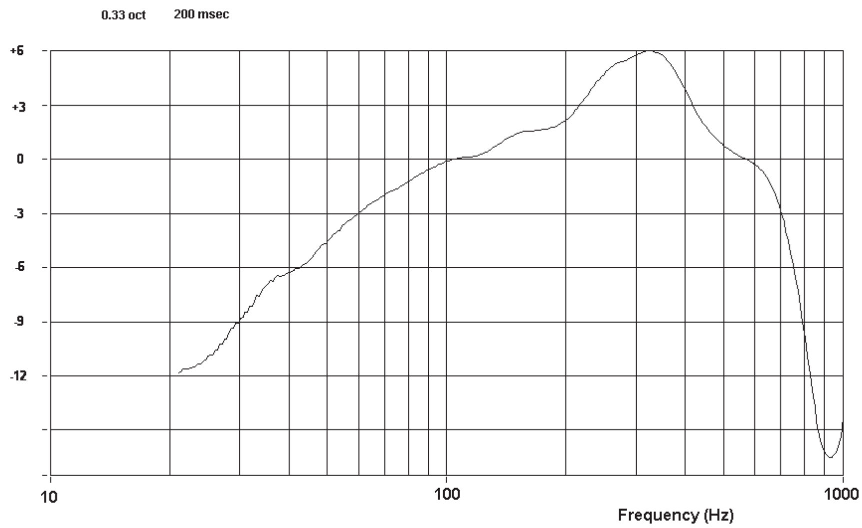

FIGURE 6: The near field response of the open baffle loudspeaker.

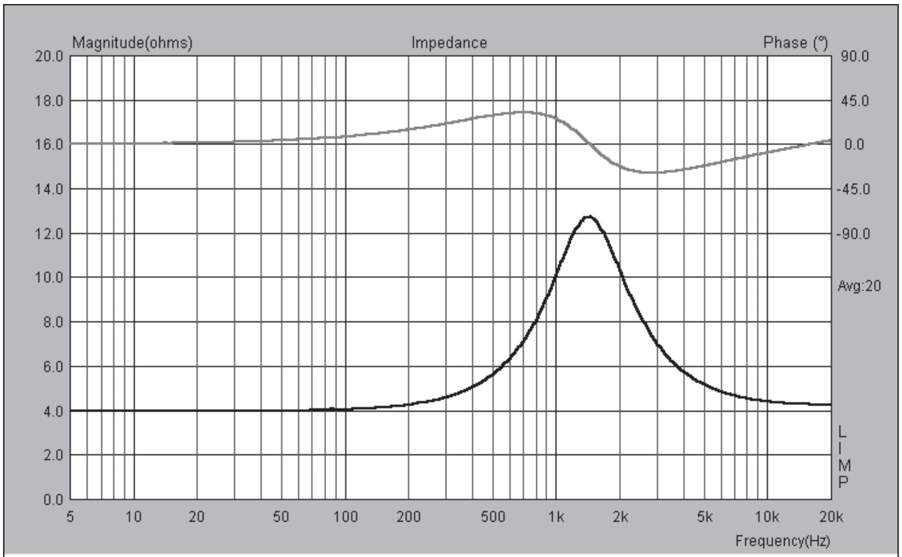

FIGURE 7: The impedance of the Magnepan MC1.

follows: I connected the MC1 and the Peerless to their power amplifiers through their active crossovers, but connected the MC1 out-of-phase in reference to the Peerless woofer. Then I changed the values of R30, R31, C16, and C17 and successively took frequency response measurements until the notch at the crossover frequency of 240Hz became as sharp and deep as possible. This means that the Peerless and the MC1 are in phase at the crossover frequency.

Figure 7 shows the impedance of the MC1 as measured with the demo version of another excellent program that can be used for loudspeaker measurement, the ARTA software (www.fesb.hr/~mateljan/arta/). The minimum value of the impedance is 4Ω, while the maximum value is about 13Ω at about 1500Hz. The phase has a minimum value of –40° and a maximum value of +40°.

THE PEERLESS 830452 PART

The Peerless crossover part is much more complicated than the MC1 part.

The components around IC1B form a second-order low-pass filter at 240Hz, while the components around IC2B form a second-order low-pass filter at 263Hz. Both filters with the acoustic response of the Peerless form an acoustic fourth-order low-pass filter at 240Hz.

The components around IC3B form the first part of the fourth-order high-pass filter at 51.5Hz. The IC4B is an inverter which is needed because the next circuit also inverts the signal. The circuit around IC5B is a Linkwitz transform circuit, whose operation I will explain later.

First, look at the near field frequency response of the open baffle with the microphone placed in the front opening as shown in **Fig. 6**. The peak in the response at 312Hz is caused by the λ/4 resonance of the cavity which is produced in front (and similarly behind) of the woofer. In the near field measurement, the negative side radiation of the woofer does not come into play. The loss in the frequencies below this peak is due to the low Qts value of the loudspeaker.

The response (excluding the peak) can be approximated by a second-order high-pass filter with Fo = 22Hz and Q = 0.34. This response is corrected by a Linkwitz transform circuit. The circuit removes the above pole and introduces a new pole at Fo = 51.5Hz with Q = 0.7 to form the second part of the fourth-order high-pass filter at 51.5Hz.

The components R11, R12, R17, R25, C6, and C19 around IC6B form a notch filter which removes the λ/4 resonance peak of the cavity of the open cabinet. The notch has its center frequency at 312Hz with Q = 0.6 and an attenuation of -3.8dB.

The next circuit around IC7B is an optional equalizer for the 100-200Hz range and is not used in the Lamda loudspeaker. The jumper JP4 is short circuit. The trimmer R34 is used to adjust the level of the Peerless woofer relative to the MC1.

Finally, the circuit around IC8B is the dipole loss correction circuit. It starts to boost the low frequencies with a 6dB/octave slope from the frequency of 560Hz down to the frequency of 10Hz. Resistor R51 buffers the output of the crossover and capacitor blocks any DC component from the signal.

In **Fig. 8** the impedance of the Peerless open baffle woofer is shown. I measured the impedance with the ARTA software. The minimum value is 5Ω/-7.7° at 127Hz, while the maximum value is about 56.7Ω/0.7° at 19.3Hz. The phase has a minimum value of –58° and a maximum value of +58°.

THE SUBWOOFER PART

As I mentioned before, the Lamda loudspeaker is used down to the frequency of 51Hz. Below this frequency you should use a subwoofer. For this reason, I included a standard low-pass fourth-order Linkwitz-Riley filter in the PCB. The filter is composed of two second-order low-pass filters around op amps IC7A and IC8A.

THE PCB OF THE LAMDA CROSSOVER

The construction of the Lamda active crossover is very complicated. For this reason, I designed a PCB using the demo version of the Eagle Layout editor. You can download the program for free from Cadsoft (www.cadsoftusa.com). The demo version is fully operational, except for a limitation on the maximum dimensions of the PCB. As a result, the dimensions of the PCB are 90mm × 120mm. The placement of the components on the PCB is shown in **Fig. 9**.

I used pin headers for the connection of the input and output cables. I placed the trimmer that is used for the level adjustment on the PCB, but you can use a potentiometer of similar value if you need to have this adjustment externally. I placed all the op amps on gold-plated sockets.

As with every filter construction, I strongly recommend measuring the values of the resistors with an ohmmeter and the values of the capacitors with a capacitance meter, at least for the components that are used for the filters and the equalizer. A tolerance of less than 1% for the capacitors will guarantee that the response of the filter will be very close to the theoretical response, which is very important. I usually buy a larger quantity of the capacitors than I need. Then I measure the value of each capacitor and choose the components with

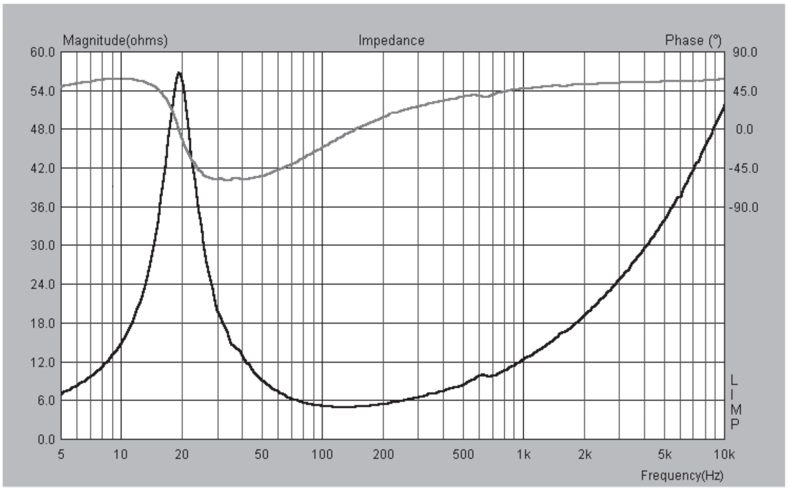

FIGURE 8: The impedance of the Peerless open baffle.

Notes:
Minimum impedance value 5 Ω / -7.5 deg at 127 Hz
Maximum impedance value 56.7 Ω / 0.7 deg at 19.3 Hz
Maximum phase value 58 deg / 14.8 Ω at 10 Hz

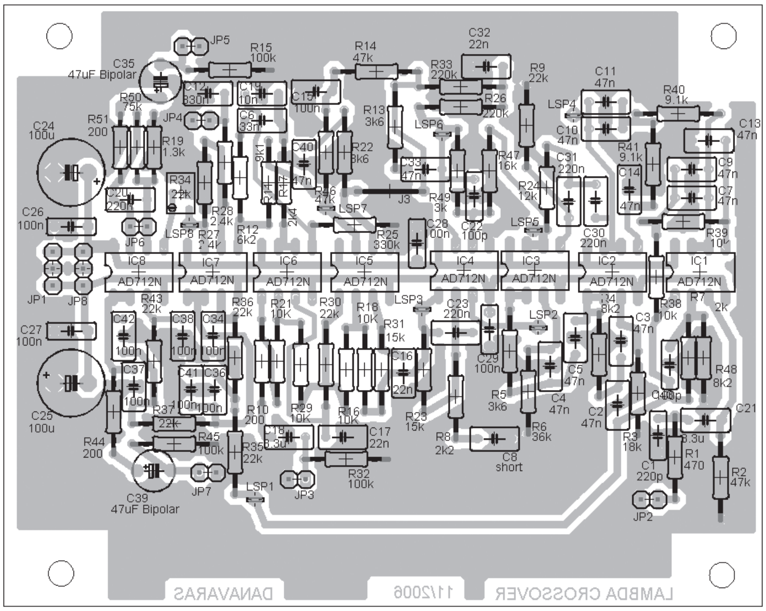

FIGURE 9: The placement of the components on the PCB.

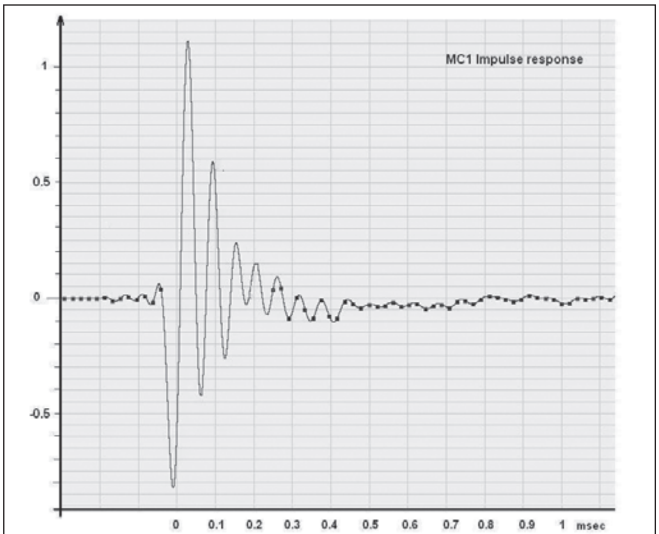

FIGURE 10: The impulse response of the MC1.

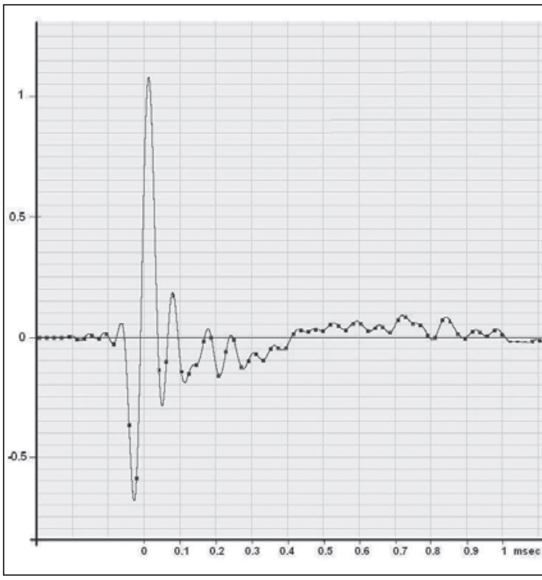

FIGURE 11: The electronic diagram of the notch filter for the MC1.

the closest value to their nominal value. This is a very good method to have high accuracy filters with minimum cost. The assembled PCB of the Lamda crossover is shown in **Photo 6**.

I used a regulated power supply based on the LM317T and LM337T regulators for the supply of the circuit (**Fig. 14**). An output voltage of ±16V at about 200mA is suitable to drive the crossover. You should mount the regulators on small heatsinks.

Place the power supply board on the same box very close to the PCB of the crossover. Note that two PCBs are needed, one for the left and another for the right channel. All the boards and the power supply are on the same box (**Photo 7**).

NOTCH FILTER

Initially I had not intended to equalize the high frequencies peak of the MC1. I thought that no benefit would come from this equalization. But when I looked more carefully at the impulse response of the MC1, I changed my opinion.

The response is shown in **Fig. 10**. After the initial pulse there is a long oscillation which lasts for approximately 0.3-0.4 msec. I decided to design a notch filter to correct the response peak and suppress this oscillation.

After several tries, the best result was with a notch filter with the following parameters:
Notch frequency fs = 16.6kHz
Quality factor Q = 3

Attenuation at the notch frequency a = -8.5dB

The electronic diagram of the notch filter is shown in **Fig. 11**. I designed the notch filter with the method described by S. Linkwitz (www.linkwitzlab.com). The components R5, R4, and C2 around the op amp form an electronic inductor, which resonates with the capacitor C1 to form the notch filter.

Because the circuit was designed in a later stage, it is not included on the PCB. I assembled it in a small general-purpose PCB that I inserted between the output of the IC3A and the input of IC4A as indicated in **Fig. 4**. The track on the PCB that connects these two points is cut before the circuit is connected. The small general-purpose PCB with the circuit is shown in **Photo 6**.

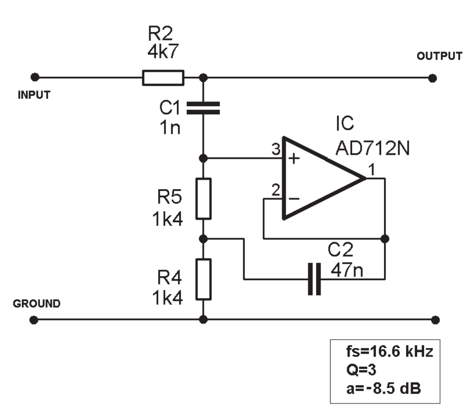

FIGURE 12: The impulse response of the MC1 driven through the Lamda crossover.

The impulse response of the MC1 driven through the Lamda crossover with the notch filter is shown in **Fig. 12**. The oscillation is now well suppressed and the impulse response is much better than without the notch filter.

TESTING THE ACTIVE CROSSOVER

After assembling all the components on the PCB, you should test the crossover to verify its proper operation. For the tests, I used some basic equipment such as a low-distortion audio frequency oscillator, an oscilloscope, and an AC voltage meter.

I attached an oscillator at a frequency of about 240Hz and a level of 1V RMS to the input of the crossover. Then, with the oscilloscope, I checked that the output at the JP3 Magnepan MC1 and at the JP5 Peerless was clean

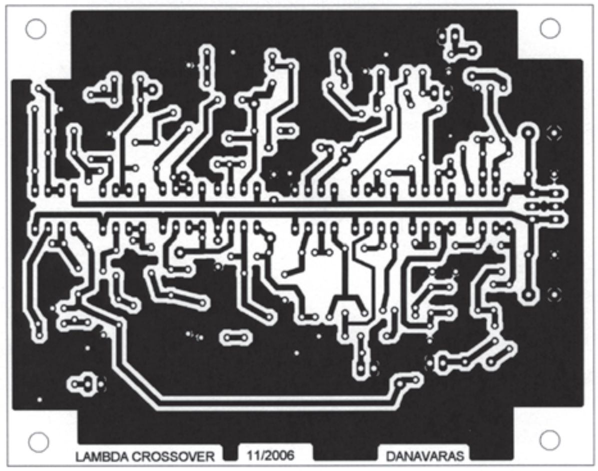

FIGURE 13: The PCB for the Lamda crossover.

PHOTO 5: Side view of the Peerless woofer.

without noise or high-frequency oscillations.

Then I changed the frequency to about 55Hz and connected the oscilloscope at the JP5 Peerless and at the JP7 subwoofer outputs. I again checked that the output signal was clean without noise or high-frequency oscillations.

The next step is to verify that the filters and the equalizer have the correct frequency response. You can do this by measuring the frequency response at specific frequencies as given in **Table 1**. With the oscillator connected to the input of the crossover, measure the values indicated in **Table 1** at the JP3 Magnepan MC1 connector. The 0dB reference is the output signal at 3kHz.

You should follow a similar procedure for the Peerless part of the crossover. Measure the values (**Table 2**) in dB at the JP5 Peerless Out connector with an oscillator connected at the input. The 0dB reference is the output signal at 20Hz. Finally, check the frequency response of the subwoofer channel.

Measure the following values in dB (**Table 3**) at the JP7 subwoofer output connector with the input signal connected at the input of the crossover. The 0dB reference is the output signal

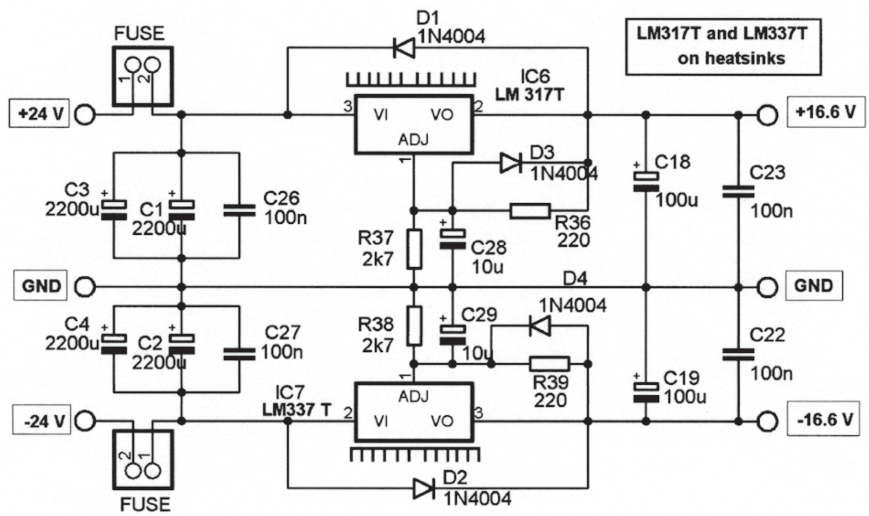

FIGURE 14: The regulated Power Supply for the Lamda crossover.

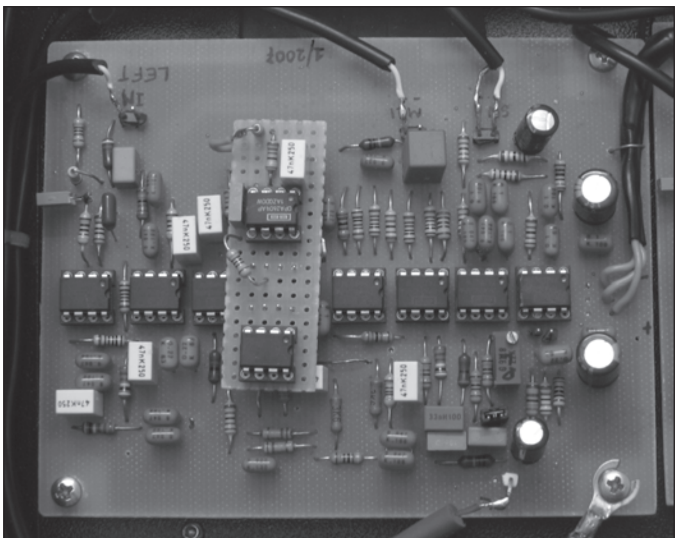

PHOTO 6: The PCB of the Lamda crossover.

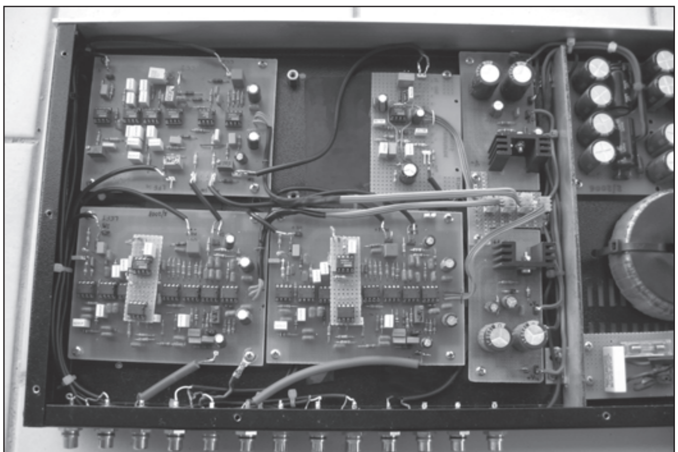

PHOTO 7: Top view of the active crossover box containing two Lamda crossover cards for the left and right channel, one subwoofer management card, one subwoofer equalizer card, and the power supply.

at the JP7 subwoofer output connector at the frequency of 20Hz. If everything is according to these specifications, the testing of the crossover is completed.

ADJUSTMENT

The adjustment procedure for the woofer level of the Lamda loudspeaker is as follows: Connect a generator with a signal of 240Hz to the input of the crossover. Adjust the level of the input signal until the voltage level at the input of the MC1 measures 1.5V. Then adjust the trimmer R34 until the voltage level at the input of the Peerless woofer is 0.21V (-17dB in reference with the MC1 input).

Note that the setting of the woofer level in reference to the MC1 is not an easy decision. This is because the in-room measurement of the frequency response below 300Hz is more a measurement of the room response than a measurement of the loudspeaker response.

The above level works fine for my room. If I move the loudspeakers to a different room—and since the operating range of the Peerless woofer is within the range that has the bigger influence from the room—it is possible that different adjustments of ±2dB or more on the above level will be needed. It is also possible that the level adjustment could be different for the left and right channel.

CONCLUSION

Lamda is a well-balanced loudspeaker. It maintains the huge stereophonic image of the MC1 and combines its transparency at the middle and high frequencies with the robustness of the Peerless woofer in the middle low and low frequencies. *aX*

TABLE 1

Frequency(Hz)	MC1 out (dB)
105	-25
140	-16.3
180	-8.5
240	0.15
350	5.1
420	4.1
850	0.5
1k	0.2
3k	0
10k	-1.2
12k	-2.6
14k	-5.2
16.6k	-8.5
18k	-7.1
20k	-4.8
30k	-0.8

TABLE 2

Freq (Hz)	Peerless out (dB)
20	0
35	8.5
58	11.2
82	9.8
105	8
140	5.1
180	1.4
240	-5.6
350	-17
420	-21.7
850	-44.7

TABLE 3

Freq (Hz)	Subwoofer out (dB)
20	0
35	-1.5
58	-8.3
82	-17.4
105	-25.3
140	-34.9

Lamda Crossover Parts List

Part	Value
C1	220p
C2-5, 7, 9-11, 13, 14, 33, 40	47n
C6	33n
C8	short circuit
C12	330n
C15, 22-9, 34, 36-8, 41, 42	100n
C16, 17, 32	22n
C18, 21	3.3µ, MKT
C19	10n
C20, 23, 30, 31	220n
C22, 43	100p
C24, 25	100µ, 25V
C35, 39	47µF, bipolar
IC1-8	AD712N
J3	Jumper 10mm
JP1, 8	Pinhead, 1 × 3
JP2-7	Pinhead, 1 × 2
All resistors 1% 0.25W	
R1	470
R2, 14, 46	47k
R3	18k
R4, 48	8k2
R5, 13, 22	3k6
R6	36k
R7	2k
R8	2k2
R9, 30, 35-7, 43	22k
R10, 44, 51	200
R11, 40, 41	9k1
R12	6k2
R15, 32, 45	100k
R16, 18, 21, 29, 38, 39	10k
R17, 27, 28	2k4
R19	1.3k
R23, 31	15k
R24	12k
R25	330k
R26, 33	220k
R34	22k, trimmer
R47	16k
R49	3k
R50	75k