The Double-Dipole Subwoofer

This author from Greece shares with us his design of an open-baffle subwoofer which works well in a corner placement.

By George Danavaras

Open-baffle loudspeakers offer many benefits for the reproduction of the audio spectrum. Complete freedom from internal box reflections and bipolar radiation are the most important of them. These have, as a result, openness and neutrality to the reproduction of the music that no other loudspeaker can offer.

My previous loudspeakers were full-range open-baffle speakers; each one used a 12† woofer for the bass reproduction and a large custom-made electrostatic panel for the frequencies above 600Hz. I listened to this loudspeaker for several years and was very pleased with its sound.

With the arrival of the home cinema and its multichannel sound, it was not possible to put five of these big speakers in my listening room. My first decision was to maintain two systems in my room one with the two open-baffle loudspeakers for the music reproduction and another with five small loudspeakers and a closed box subwoofer for the home cinema.

I bought five small loudspeakers and constructed a closed box subwoofer for the home cinema using two 12† woofers similar to the ones used in the open-baffle speakers. After living for some time with these two separate systems, and with the arrival of the multichannel SACD and DVD-Audio, it was obvious that the only system that could remain was the multichannel one. So I decided (one more time) to change both the loudspeakers and the subwoofer with new ones.

All that time I was thinking about building an open-baffle subwoofer since, with the closed box subwoofer I used for the home cinema system, I missed the clarity and the neutrality of the low range that I had using the open-baffle loudspeakers.

It was about that time I found the S. Linkwitz site (www.linkwitzlab.com), which contains a very good analysis of open-baffle speakers and also presents the construction of an open-baffle subwoofer and design theory for its equalization. The shape of this subwoofer was not suitable for installation in the corner of my listening room, so I designed one that was. Maybe you can install one in your room.

ABOUT THE AUTHOR

George Danavaras graduated from National Technical University of Athens, Greece, in 1986 with a degree in Electronic Engineering. He currently works in the R & D division for a Greek telecommunication company. His hobbies include design and manufacturing of audio crossovers, amplifiers, and loudspeakers.

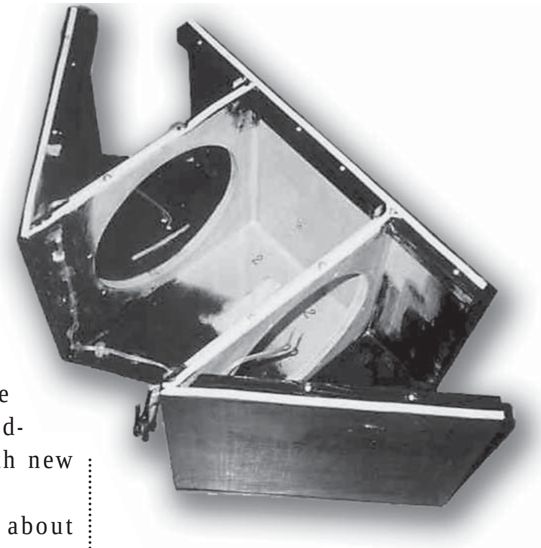

PHOTO 1: W-frame subwoofer cabinet.

REQUIREMENTS

My back projection TV is in the corner of my listening room, with much space behind the box. Normally nothing can be put there, so I thought it was an ideal place for the subwoofer. First, because the corner can boost the low frequencies, and second, because it can hide the huge volume of the subwoofer.

I had four INFINITY KCS-120IB 12† woofers available from previous projects. These woofers are of excellent quality and are designed for open-baffle systems. According to the manufacturer, their features include: IMG injection-molded graphite cone, high temperature Kapton/Nomex voice coil formers, Kapton-laminated copper ribbon voice coil lead wire, and extremely high power capability.

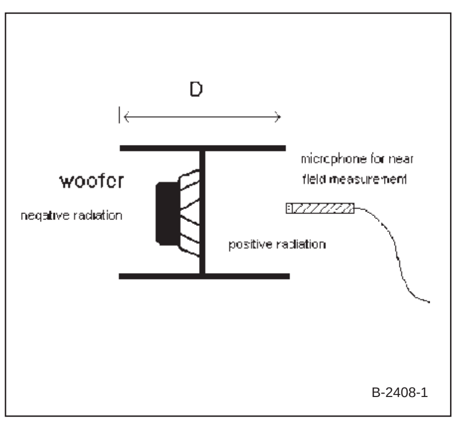

FIGURE 1: The H-frame.

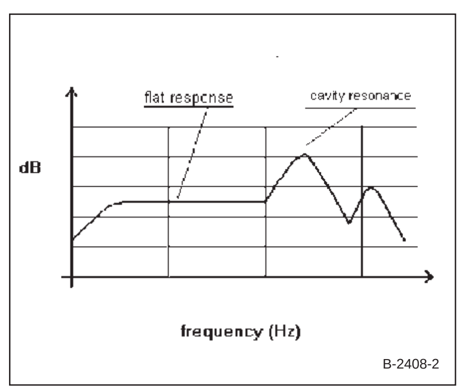

FIGURE 2: Near-field frequency response of the H-frame.

The Thiele/Small parameters of the woofers I measured were:

PARAMETER	WOOFER #1	WOOFER #2	WOOFER #3	WOOFER #4
Q_{ES}	0.735	0.712	0.808	0.72
Q_{MS}	11.23	10.14	11.72	10.23
Q_{TS}	0.69	0.66	0.75	0.67
Fs (Hz)	34	31.5	32.7	30.7
Rdc (Ohm)	3.79	3.85	3.94	4.03
Sd (square meters)	0.053	0.053	0.053	0.053
Xpeak (mm)	6.75	6.75	6.75	6.75
(According to manufacturer)				

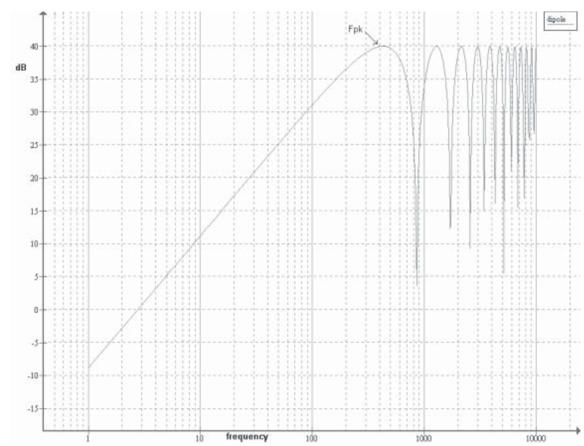

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FIGURE 3: Far-field frequency response of the H-frame.

THE OPEN-BAFFLE THEORY

One of the most important factors in the design of the open-baffle subwoofer is the distance that separates the positive and the negative sides of the woofer radiation. There are

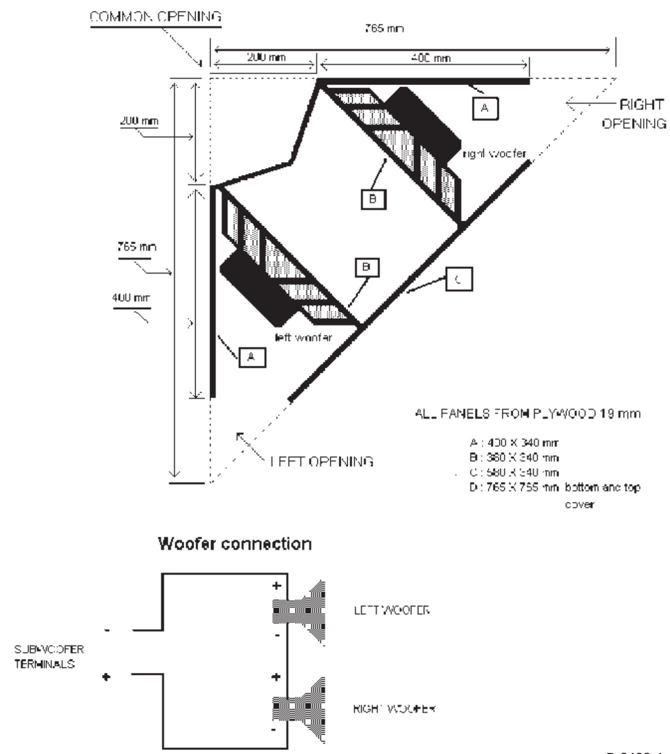

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FIGURE 4: W-frame double dipole woofer.

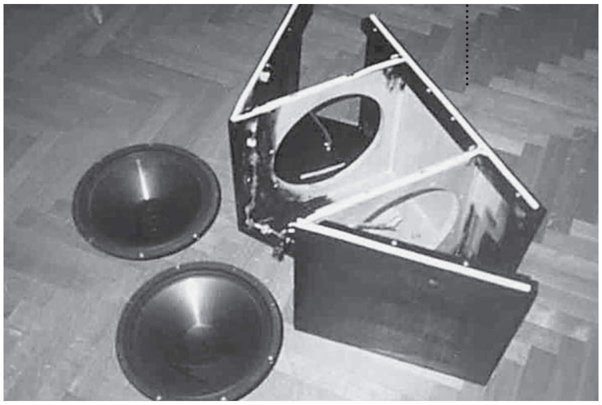

PHOTO 2: W-frame subwoofer cabinet with the two woofers.

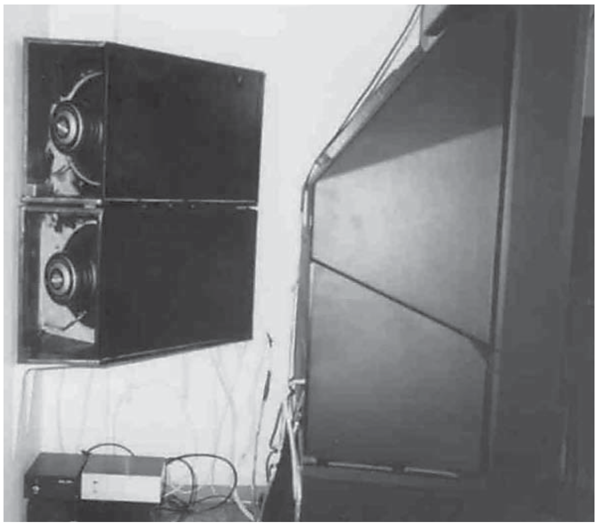

PHOTO 3: Subwoofer installed on the corner of the listening room with the equalizer and the power amplifier below.

several different shapes that can be used as open-baffle subwoofers. The purpose of all of them is to increase the distance between the opposite sides of woofer radiation in such a way that the total size of the subwoofer remains as compact as possible.

One of the simplest shapes to perform this task is the H-frame (*Fig. 1*). The woofer is on a baffle that has extended 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 subwoofer is not much bigger.

The near-field response (with the microphone placed in front of the one opening as indicated in *Fig. 1*) is shown in *Fig. 2*. The peak in the response is caused by the 1/4 resonance of the cavity that is produced in front of (and similar behind) the woofer. In the near-field measurement, the negative side radiation of the woofer does not come into place and so the frequency response below the cavity resonance frequency remains flat down to the woofer resonance frequency.

The far-field response is shown in *Fig. 3*. The frequency Fpk where the first peak occurs is given by:

$$F_{pk} = (0.5 \cdot c)/D$$

where c is the sound velocity and D is the distance between the openings.

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; 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 at 6dB/octave due to the cancellation of the sound that comes from the negative side. 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 frequency at which the open-baffle

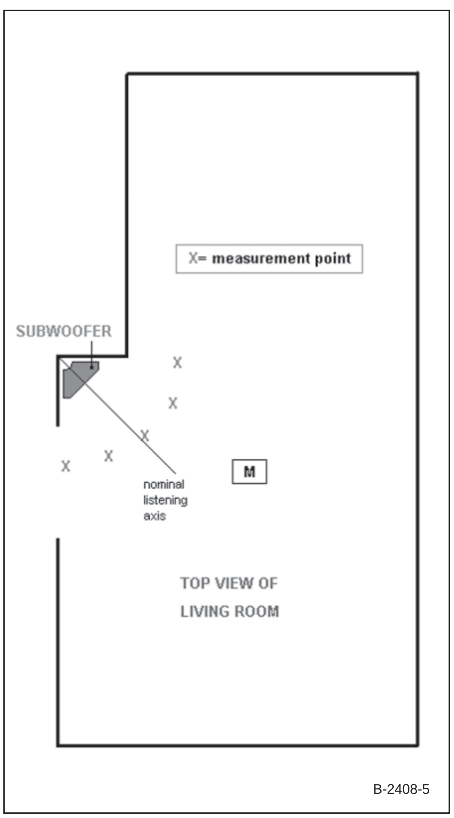

FIGURE 5: Double dipole directivity measurement.

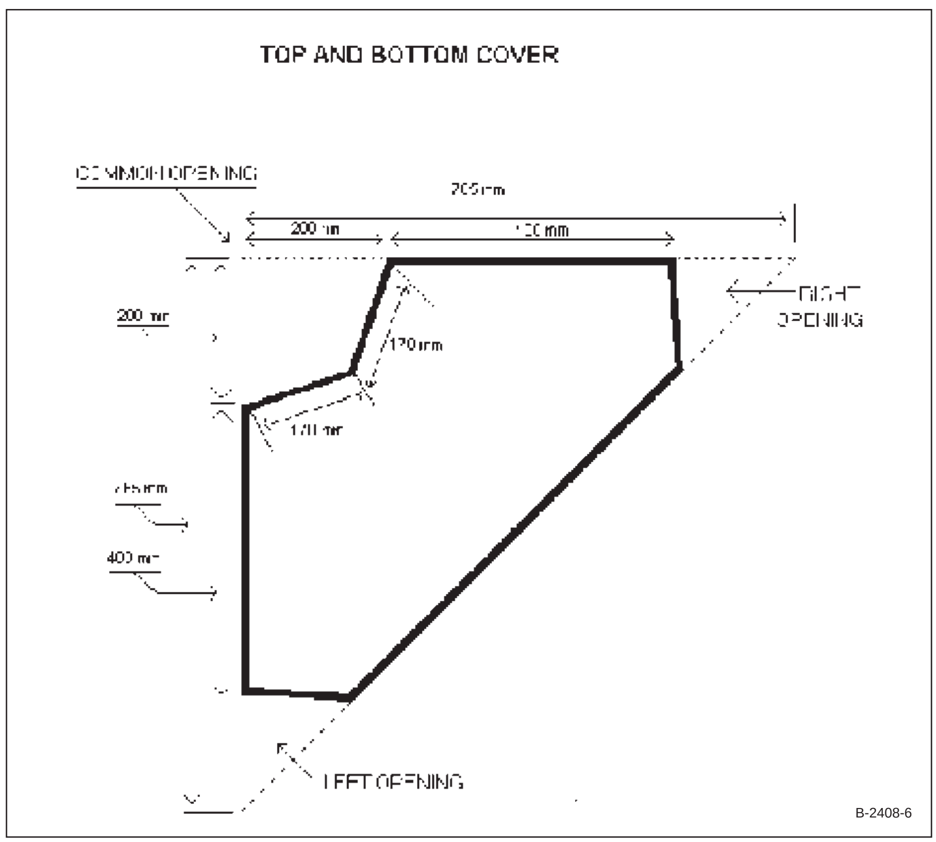

FIGURE 6: Cutout diagram for the panels D.

speaker has the same level output with a single similar monopole (for example, a closed box subwoofer) is given by:

$$Feq = (0.17 \cdot c)/D$$

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

In order for the open-baffle subwoofer to be useful for music reproduction, it is absolutely necessary to equalize first the peak in the frequency response that it is due to the cavity resonance using a notch filter, and second, the far-field low-frequency rolloff. The equalizer should boost the low frequencies with 6dB/octave in order to flatten the frequency response. This boost means that the excursion of the woofer will be increased so the linearity will be worse. That is why you need a lot of drivers in order to get high volumes of sound at the low frequency with an open-baffle enclosure.

The directivity of the open-baffle subwoofer is maintained also at the lowest

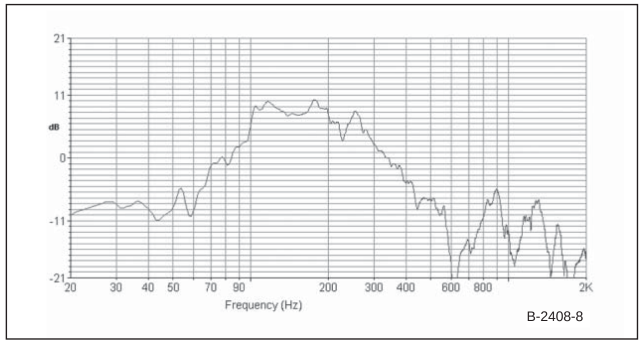

FIGURE 8: Measurement of the dipole subwoofer in the corner of the room and on the floor.

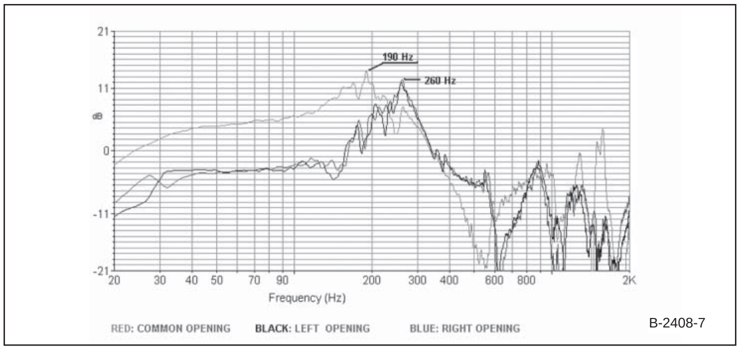

FIGURE 7: Measurement of the dipole subwoofer in the middle of the room.

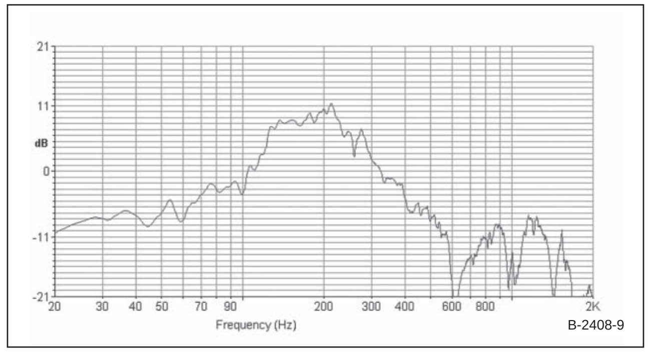

FIGURE 9: Measurement of the subwoofer in the corner of the room and 55cm above the floor. This is the final position.

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 . This directivity means that if you want to have the maximum sound pressure from the open-baffle subwoofer, you should remain in front of its axis.

THE NOVEL VARIATION OF THE W-FRAME

I already mentioned that I intended to install the subwoofer in the corner of my living room. Unfortunately, for this kind of installation the H-frame is not suitable since it requires much free space both to the front and to the back of the cabinet. After several thoughts and tries about which shape would be suitable for installation in the corner, I decided on the cabinet shown (without the cover) in *Photo*

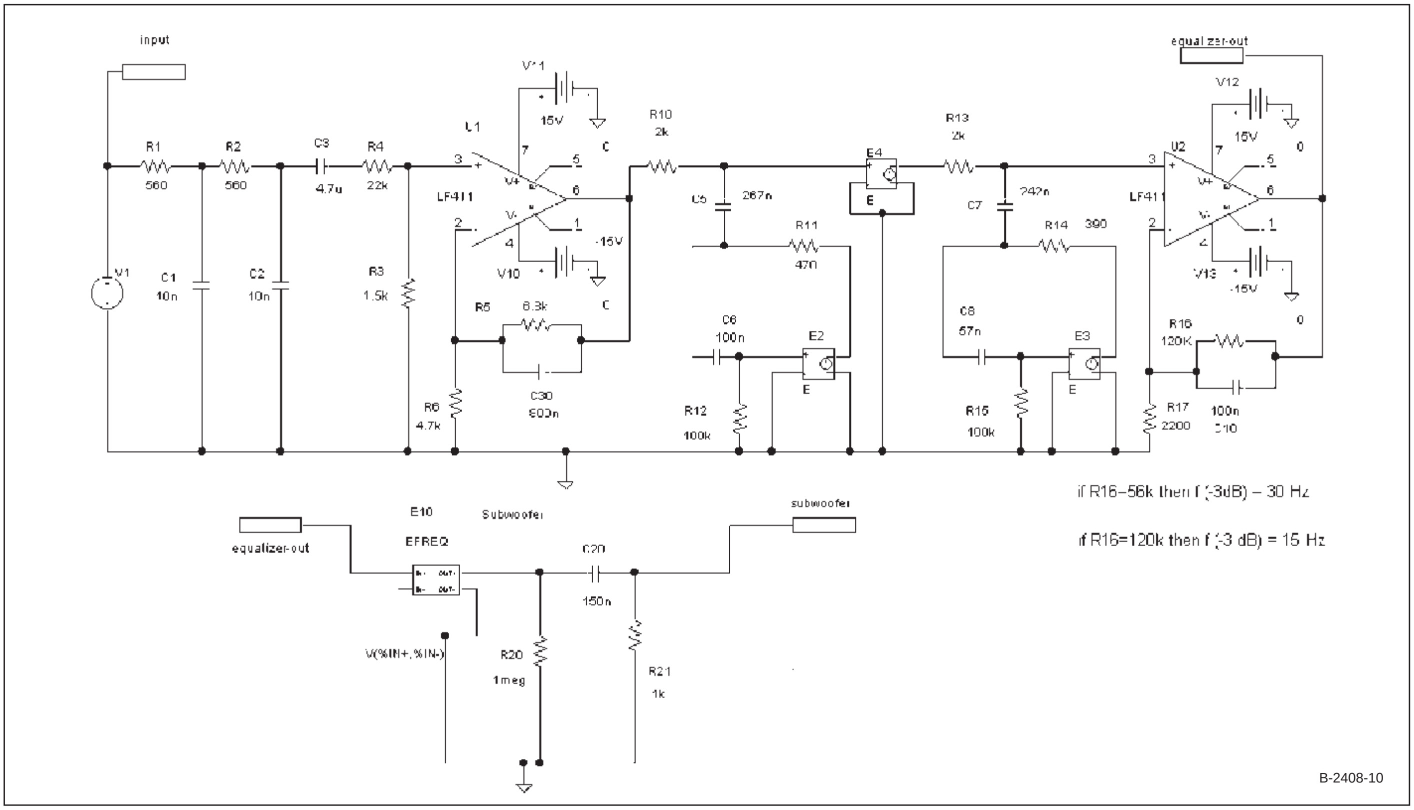

FIGURE 10: Equalizer circuit used for the PSpice analysis.

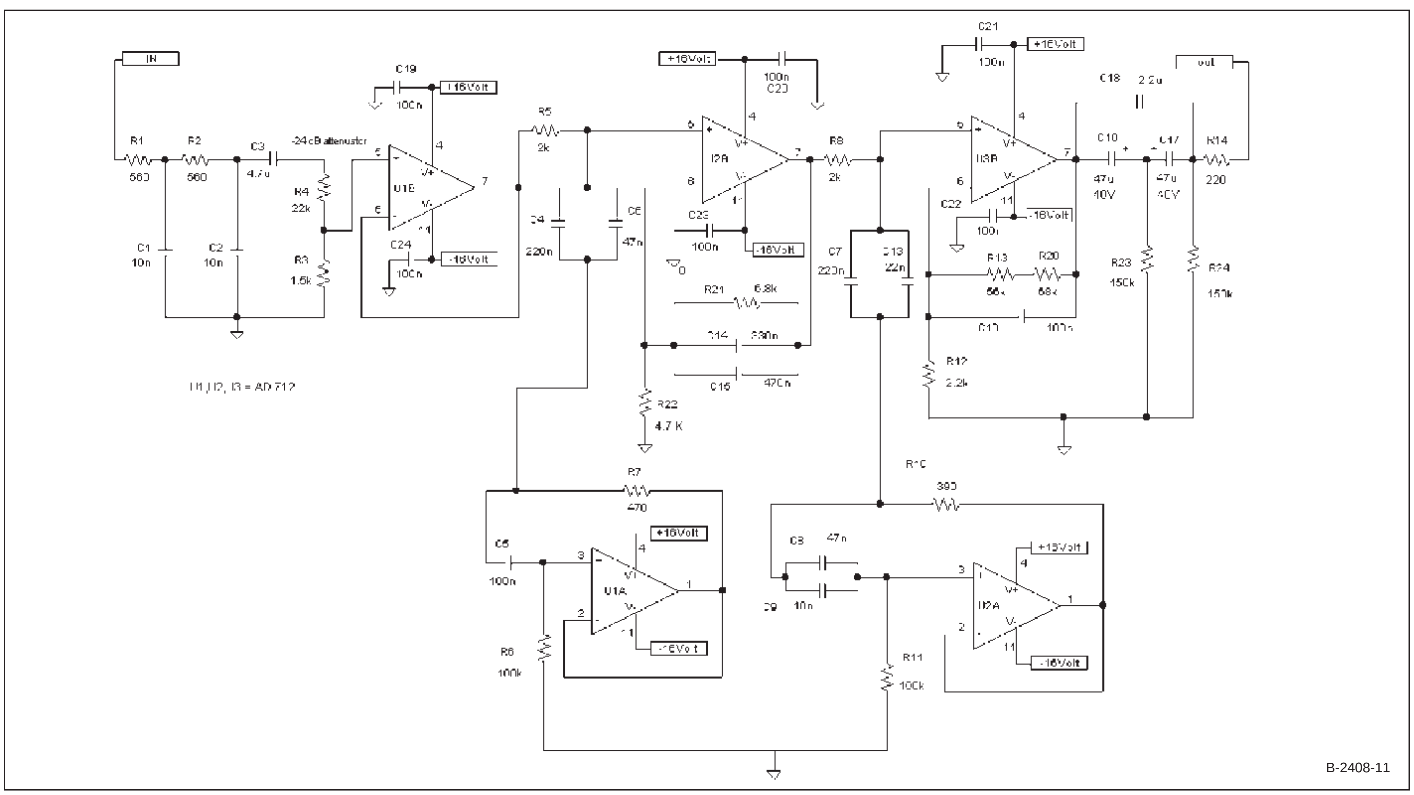

FIGURE 11: As-built electronic circuit diagram of the subwoofer equalizer.

1. This cabinet has three openings: the common, the left, and the right opening. The two drivers face one another.

The common opening of the cabinet is in the corner, while the right and left openings are at the sides of the corner. The positive radiation of the drivers comes out from the left and the right opening, while the negative radiation of both units comes out of the common opening. Mr. Linkwitz characterized this frame (on a personal communication with e-mail) as a "novel variation of the W-frame." In *Fig. 4* a top view of the cabinet is shown with detailed dimensions for construction.

This W-frame can be considered as equivalent to two dipoles at almost right angles with each other. The response at a point P that is in the far field will be equivalent to the sum of the responses of the two dipoles. Since the nominal listening axis will bear an angle with the axis of each dipole, in theory a drop in the amplitude response of the dipole will occur. Of course this is valid when the subwoofer is installed in the free field and not in the corner of a real room.

I verified this by measuring the response of the subwoofer as shown in *Fig. 5*, where the top view of the listening room is shown with the subwoofer installed in the corner. I drove the subwoofer with pink noise, band-filtered in the region between 45 and 85Hz. I used a Radio Shack SPL meter for the measurement. In all five positions where I performed the measurement, the indication was the same. This means that the directivity of the subwoofer when installed in the corner will not be a problem.

Now some important factors for the operation of the subwoofer: the distance between the two openings of opposite phase of the W-frame is not constant; it starts from 40cm and goes up to 48cm. So for the analysis, I took as distance D the mean value of 44cm. According to this theory, the peak frequency can be computed as follows:

$$F_{pk} = 0.5 \cdot 344/(0.44) = 391\text{Hz}$$

The frequency at which this open-baffle subwoofer has the same level output with a single monopole can be computed as follows:

$$F_{eq} = 0.17 \cdot 344/(0.44) = 133\text{Hz}.$$

Another important factor for a subwoofer is the maximum SPL that can be produced with a given frequency. Mr. Linkwitz provides an Excel file (http://www.linkwitzlab.com/spl_max1.xls) with which the excursion limited RMS sound pressure level (SPL) for a driver in an open baffle in half space can be computed.

In my design, I used four woofers, each having Sd = 530cm^2 and Xpk = 6.75mm. I put as effective path difference D = 0.44m. Considering all the preceding, the maximum SPL that can be obtained into half space is as follows:

FREQUENCY (HZ)	MAXIMUM SPL INTO HALF SPACE WITH 4 WOOFERS (DB)
20	87
30	97
40	105
50	111
60	115
70	119
80	123
100	129
150	139

Since the subwoofer will be installed in

TABLE 1
LIST OF COMPONENTS FOR SUBWOOFER EQUALIZER CIRCUIT OF FIG. 11.

RESISTORS	
All resistors ½W, metal film	
R1, R2	560
R3	1.5k
R4	22k
R5, R8	2k
R6, R11	100k
R7	470
R10	390
R12	2.2k
R13	56k
R14	220
R20	68k
R21	6.8k
R22	4.7k
R23, R24	150k
CAPACITORS	
C1, C2	10nF, plastic film
C3	4.7m F, plastic film
C4, C7	220nF, plastic film
C5, C10, C19–24	100nF, plastic film
C6, C8	47nF, plastic film
C9	10nF, plastic film
C13	22nF, plastic film
C14	330nF, plastic film
C15	470nF, plastic film
C16, C17	47m F/40V, electrolytic
C18	2.2m F, plastic film
OP AMPS	
U1-3	AD 712