LX-mini Analog Crossover

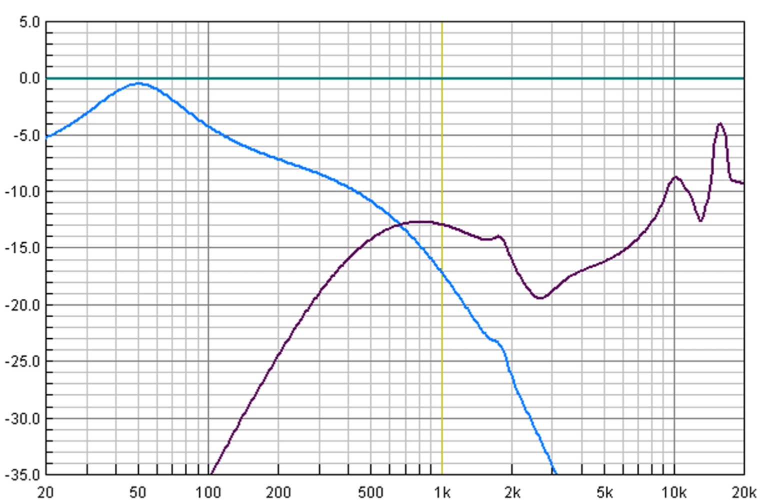
Many of you are already familiar with Siegfried Linkwitz. I first met him in person at a Burning Amp Festival years ago, and I was able to spend more time with him after I moved to Sea Ranch, where he has a house at the far end of the beach. We have spent many afternoons on his deck in the sun, talking about audio and snacking on the treats provided by his wife Eike.

Among his numerous loudspeaker designs is the LX-mini, and there is a demo pair installed in his living room. It's a remarkable loudspeaker, biamped with a DSP based crossover from MiniDSP with filter parameters designated by Siegfried. It would be difficult to make it work with a passive crossover.

I will not recapitulate the design of the Lxmini here, rather I will send you to his web site www.linkwitzlab.com and another site https://oplug-support.org/ where there are complete discussions about his philosophy and loudspeaker designs.

One fine day over melon and cookies he asked if I might have an interest in working up an analog version of the crossover, as he had some interest from his users. I took a look at the DSP filter curves, and said "I dunno, Siegfried, these are some pretty complicated curves you got here. It's gonna take a lot of op amps and stuff, and you know me – I only do the simple stuff."

Persevering, he later offered up a copy of the 2011 edition of Douglas Self's "The Design of Active Crossovers", offering 570+ pages of late night reading, and more than you might want to know about crossover filters. To appreciate the difficulty of replicating his DSP curve, you might want to look at it:

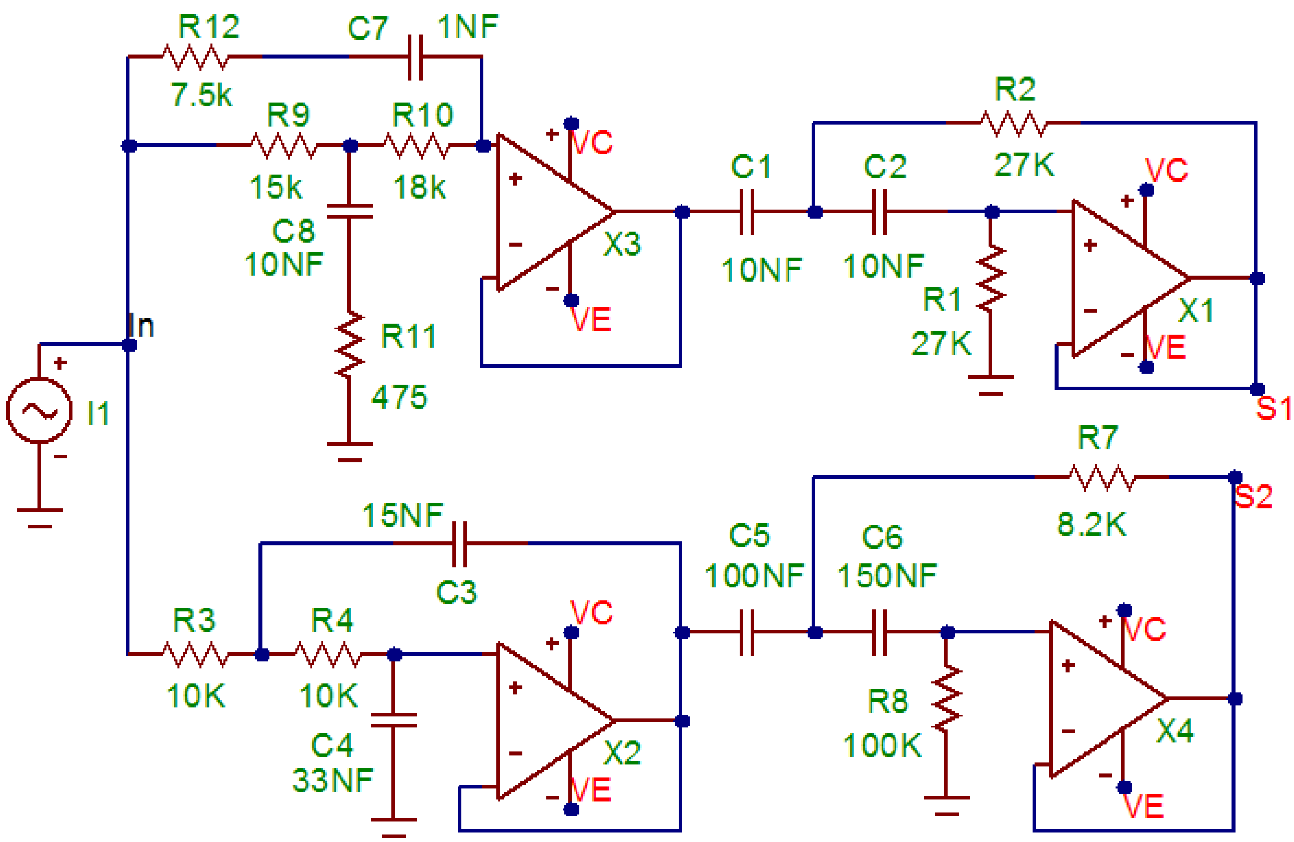


DSP CROSSOVER CURVE

It's got lots of little bumps, peaks and dips, each correcting for the curve that Siegfried obtained when he put a microphone in front of the speaker and measured the response.

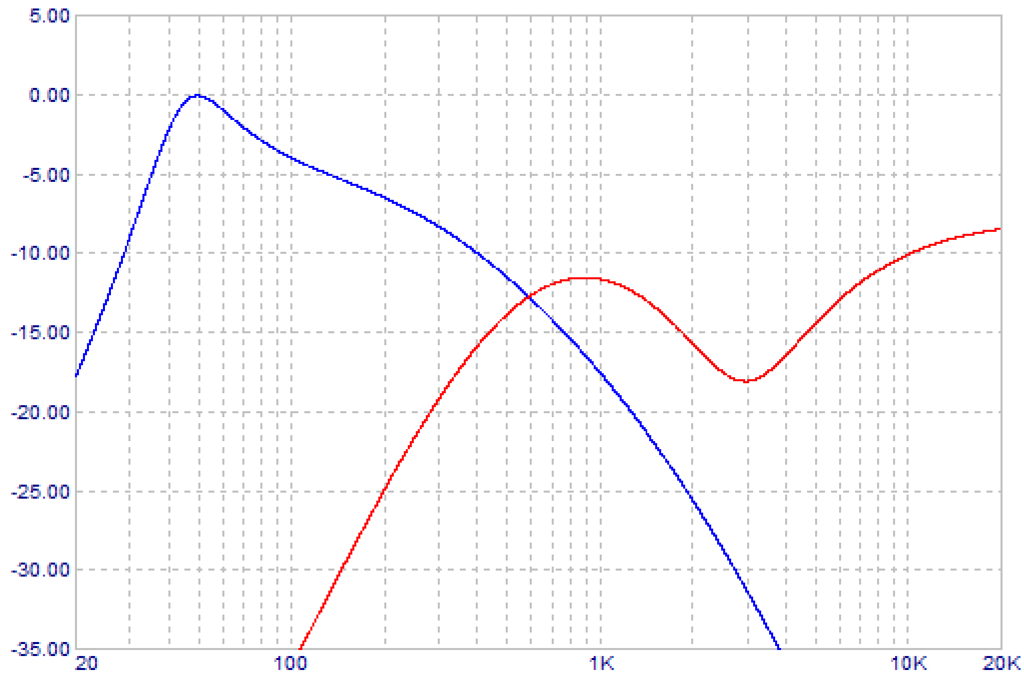
“I'm not going to chase that stuff,” I said, but after a couple of weeks I decided that it would be interesting to do something with broad strokes and see how it worked out. After some time with Micro-Cap™ I had a decent looking simulation, so I laid out a circuit board with Jfet buffers and gave Siegfried a working copy to play with. He came back with some suggestions for curve modifications based on his listening, and later measured the response in comparison with the DSP based crossover.

Here is the circuit we ended up with, as seen by the simulator. X1 through X4 are op amp based buffers representing the simple Jfet buffers. At the top we see the equalization and then the high pass filter for the mid/high driver, and below that is the low pass filter and then bass equalization for the low/mid driver.



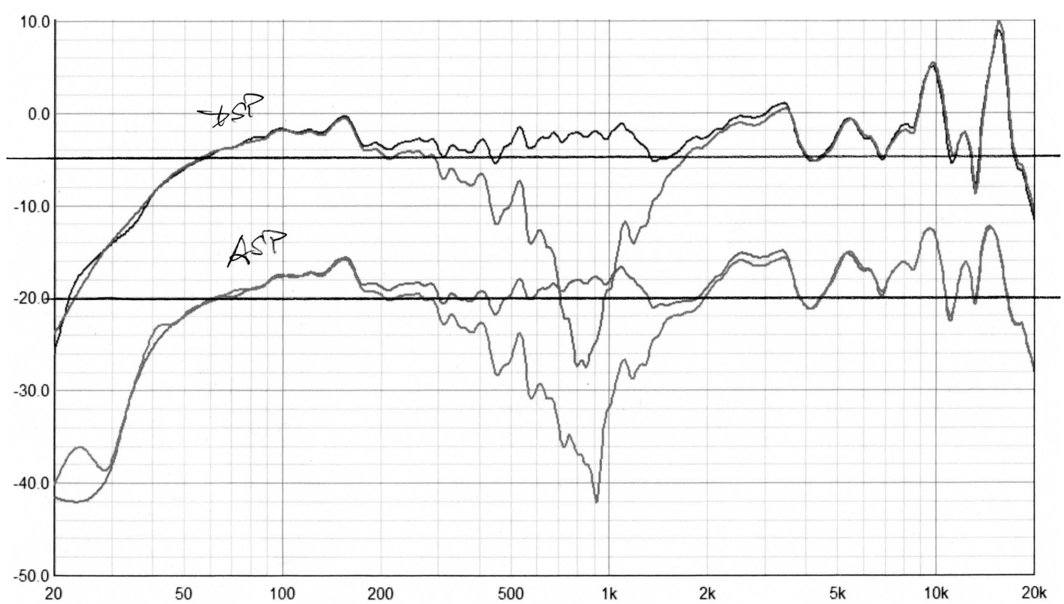
Interestingly, the filter topology is remarkably close the First Watt B5 crossover, which caters to full range drivers and woofers in open baffle enclosures.

This circuit produces a curve that looks like this:



ANALOG CROSSOVER CURVE

Initially SL had some concern that we were not completely duplicating the curves of the original, particularly at the top end, where there are high Q peaks and dips. However, he subsequently measured the acoustic response and found that the top end was a bit flatter without those corrections. Here is that result with the DSP on top and analog on the bottom.



ACOUSTIC COMPARISON - DSP / ANALOG

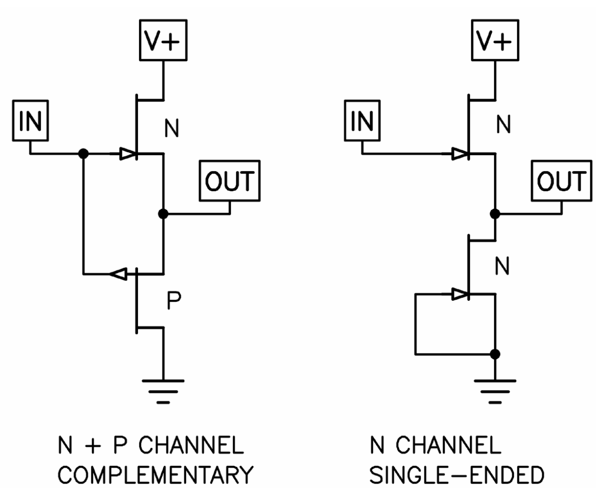
We speculated a bit on why that might be. One possibility was that the anomalies of the high end driver might vary from unit to unit. The other was that at wavelengths of less than an inch, variation of microphone position might account for it.

The above curve also shows the response of both with the speaker drivers wired in-phase, where ideally they should have a deep null at the crossover point, a good indicator that the phases are identical at the frequency in normal use.

This reminds me to mention that there are no phase inversion circuits in this crossover, only unity gain discrete Jfet buffers without feedback. This means that with this crossover you have to invert the phase of the mid-tweeter, probably in the speaker wiring between the amp and the mid-tweeter, otherwise you will be listening to that big deep dip.

At the bottom you can note that the analog crossover drops off faster below 40 Hz, an artifact of generating the 50 Hz equalization peak with a simple buffer. I didn't expect this to please SL, but he didn't complain when we played the Telarc 1812 Overture cannon shots, so I guess it's okay, and the drivers didn't bottom out....

I have mentioned the Jfet buffers, and as there are some interesting aspects to the design, it is worth talking about them. As you may know, a buffer has the same voltage at the output as its input voltage, but it increases the amount of current available. Many types of audio filters can be made with buffers, and I particularly like them because they are very simple with high performance. Here are two favorite Jfet topologies:



JFET BUFFERS

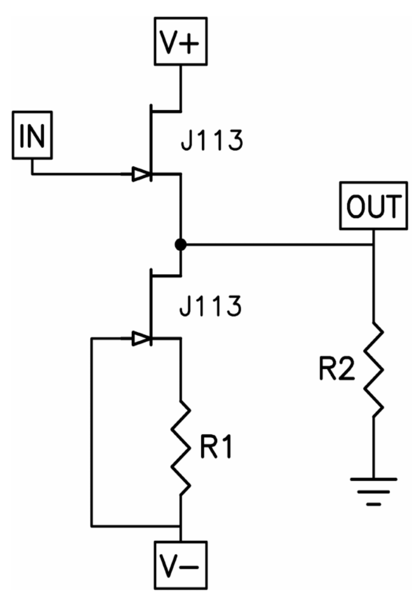
The buffer on the left has two complementary Jfets in Common Drain (follower) mode. On the positive side is an N channel Jfet sharing the input and output with a P channel Jfet in what is known as a push-pull circuit.

On the right are two N channel parts, with the top one acting as the buffer transistor and the bottom one is set up as a constant current source.

Since the 1980's there have been favored parts from Toshiba, the 2SK170 and 2SJ74 Jfets, which work very well in such simple circuits, giving line level distortion numbers in the low 0.00X% region without any special treatment. They have been very popular with DIYers, but were unfortunately discontinued a few years ago. You can still get them, but they are scarce and the price has gone up by as much as a factor of 50. There are good replacements from Linear Systems, but these are also expensive and generally in short supply.

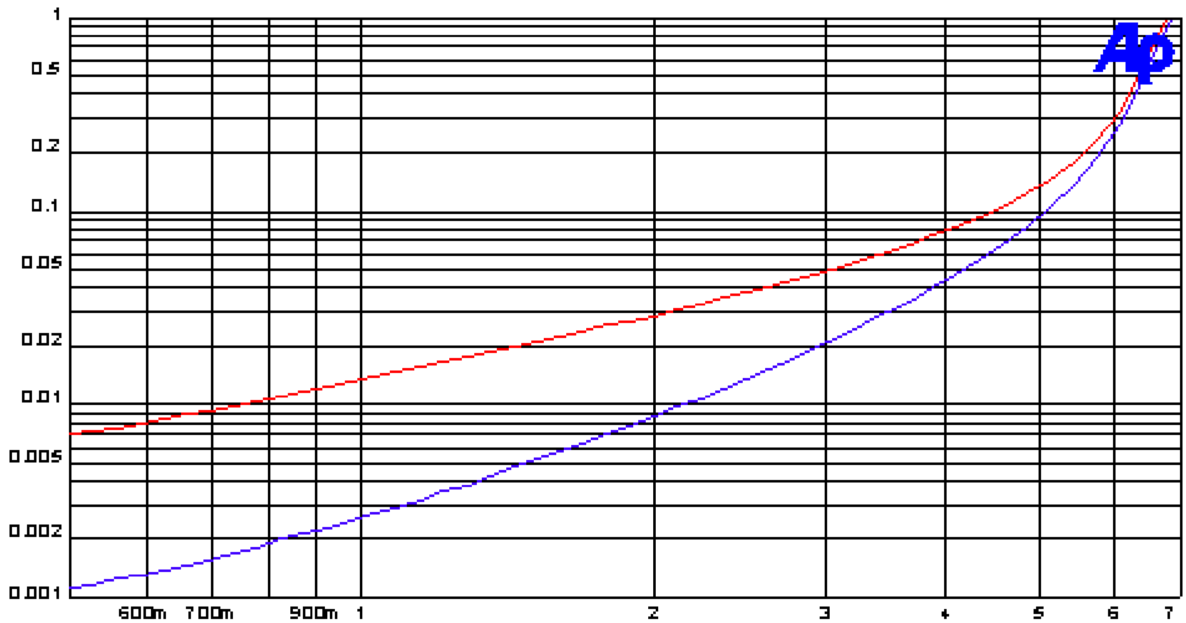
One of Siegfried's goals for the LX-mini was that it would not be very expensive. Many of the parts are available at hardware stores, and the cost for a complete pair is well less than $1,000, including the DSP crossover. I undertook to find an inexpensive Jfet that could be made to give good performance.

I bought samples and played with them, ultimately settling on the Fairchild (OnSemi) J113, which is cheap and available. It can be used in the single-ended circuit above, but without part selection / matching and some additional tweaking it will not give particularly good numbers – distortion figures from about 0.03% to 0.1%. Matching the devices improves that number, but they still fall short of the Toshiba / Linear Systems numbers, although they are very usable.



Above is a schematic showing a pair of J113 Jfets used as a buffer for crossover filters. The two devices have been matched and then a resistor R1 has been used to set the bias current and another resistor to load the output of the buffer at a specific value. Between the characteristics of the Jfets and the values of these two resistors (plus choice of supply voltages) a “sweet spot” can be found which optimizes the circuit for lower distortion. (for lots more discussion of the sweet spot check out http://www.firstwatt.com/pdf/art_sweet_spot.pdf)

Here is an example of a pair of matched J113's treated with values of R1 and R2 for lower distortion. The red curve shows distortion vs output voltage for R1 = 0 and R2 = 1 Megohm. The blue curve shows the distortion for R1 = 100 ohms and R2 = 3 Kohm.

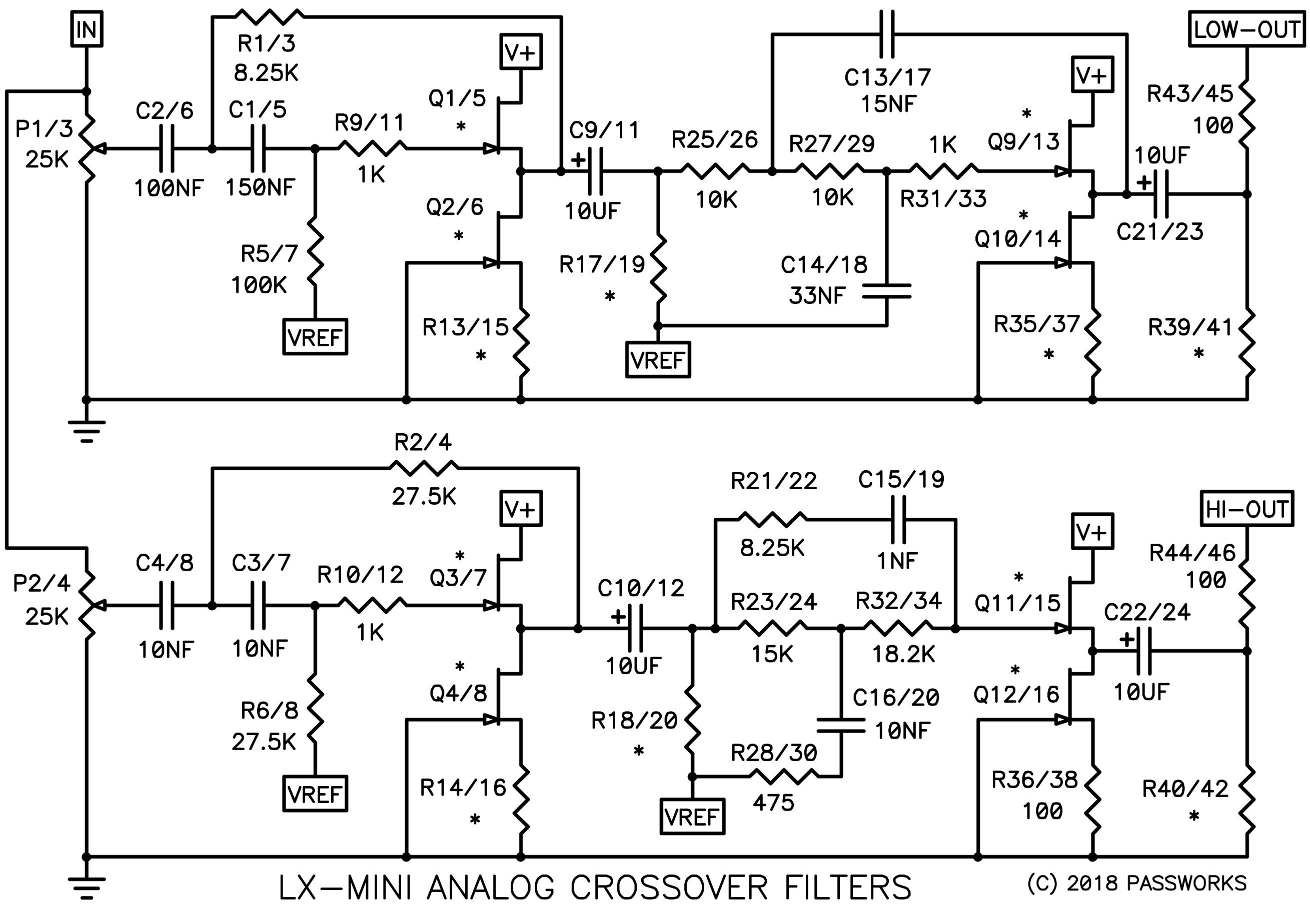


JFET BUFFER DISTORTION BLUE = TRIMMED

In a given circuit, the values for R1 and R2 will depend on the Vp, the pinch-off voltage of the matched Jfets. It is possible to get improvements without matching the parts, but that does not result in the easy consistent approach that we want here. If you have a distortion analyzer (or extraordinarily good ears) you can play with the parts and values yourself to get similar, occasionally even better results.

The base kit of the crossover available from the diyAudio store includes the PC board and 16 matched Jfets as well as 16 resistors chosen to trim the Jfets into the desired load line.

So here's the actual circuit of the analog LX-mini crossover:

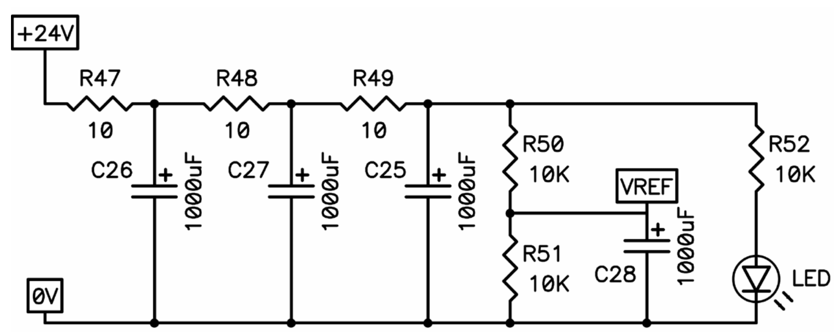


LX—MINI ANALOG CROSSOVER FILTERS

PART NUMBERS: LEFT CH / RIGHT CH   All JFETS SELECTED AND MATCHED

RESISTORS 13 — 20, 35 — 42 VALUE SPECIFIC TO JFET SELECTION

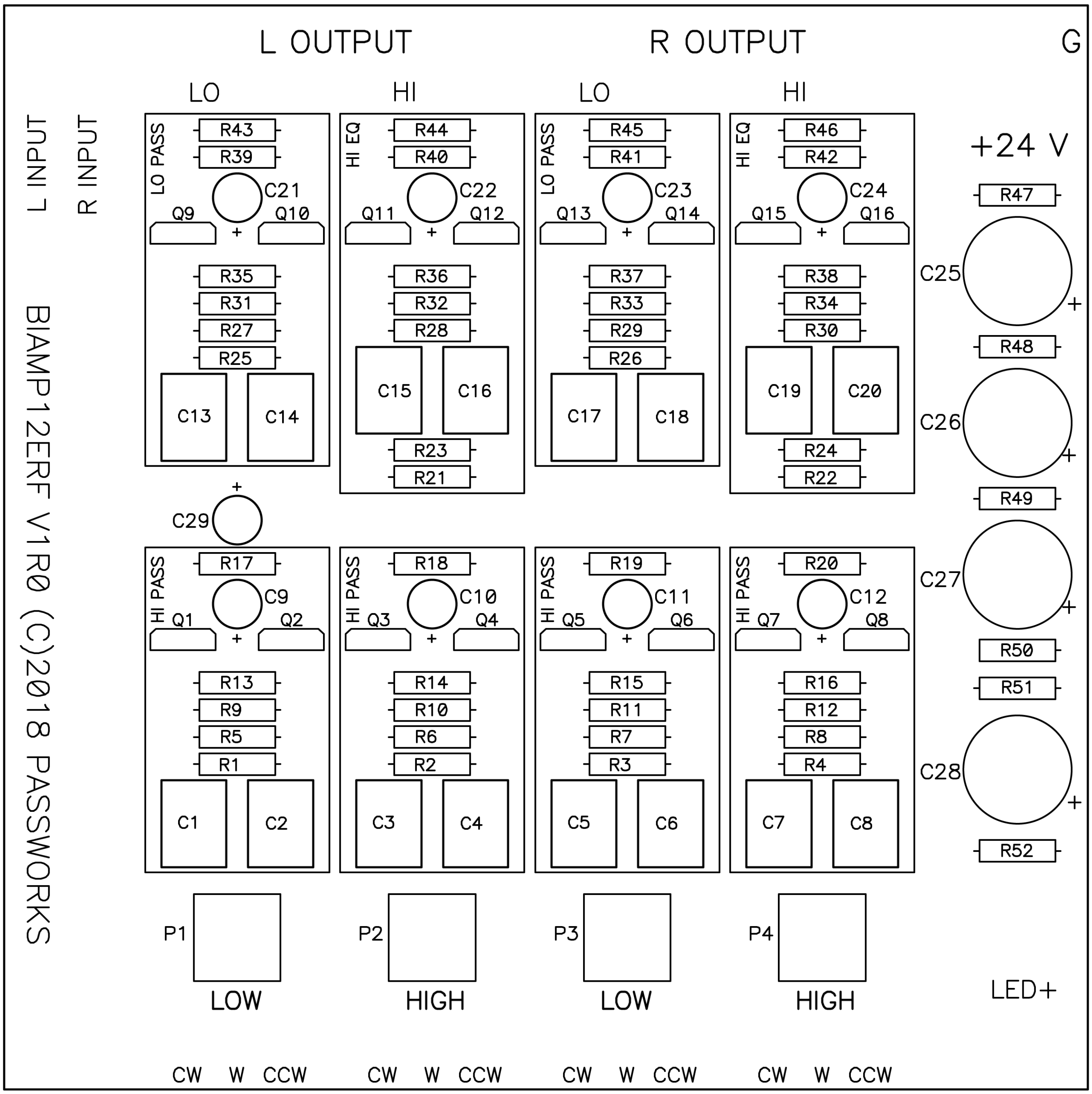
And here is the power supply filtering for the external switching 24 volt power supply. The crossover draws about 75 ma current, and I recommend a quiet wall-wart rated at 500 mA or more. The inexpensive Triad WSU240-0500-13 gives excellent results, but you are free to use something else, including regulated linear supplies.



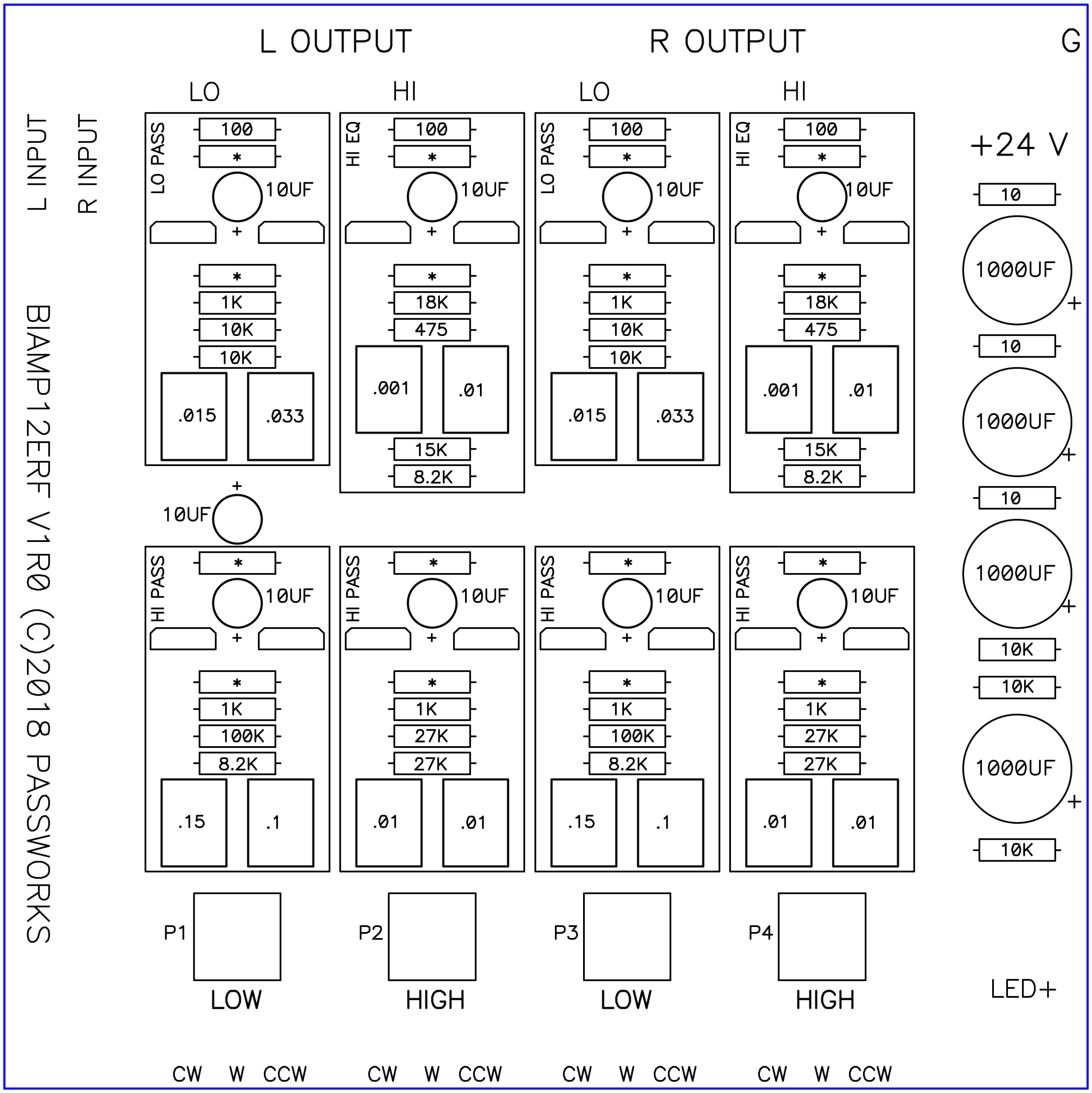
LX—MINI ANALOG CROSSOVER POWER SUPPLY

On the supply, note that 0V from the supply is circuit and chassis ground. VREF is a DC value to set the operating point of the single-ended circuits.

Here is a picture of the various parts on the circuit board:



For your convenience, here is that same layout picture with values on the parts. Note that parts with a “star” are those which are selected for the Jfets.



At the “front” of the board, note that there are holes marked “CW W CCW” to accommodate front panel pots instead of the ones mounted on the board. If you use them you will likely not want the pc mounted pots, so you can leave them off. There is a spot for a LED if you want one, and it is provided in the additional kit which has the connectors and such.

PC Board Parts List

Q1 – Q16 matched N channel Jfets, Fairchild J113

P1 – P4 25 Kohm trim potentiometers

R1, R3	8.25 Kohms
R2, R4	27.4 Kohms
R5, R7	100 Kohms
R6, R8	27.4 Kohms
R9 - R12	1 Kohm
R13 - R16	* supplied with Jfets – typical value ~ 100 ohms
R17 - R20	* supplied with Jfets – typical value ~ 22 Kohms
R21, R22	8.25 Kohms
R23, R24	15 Kohms
R25, R26	10 Kohms
R27, R29	10 Kohms
R28, R30	475 ohms
R31, R33	1 Kohm
R32, R34	18.2 Kohm
R35 - R38	* supplied with Jfets – typical value ~ 100 ohms
R39, R42	* supplied with Jfets – typical value ~ 22 Kohms
R43 - R46	100 ohms
R47 - R49	10 ohms
R50 - R52	10 Kohms

C1, C5	150 nF polypropylene
C2, C6	100 nF polypropylene
C3, C7	10 nF polypropylene
C4, C8	10 nF polypropylene
C9 - C12	10 uF electrolytic
C13, C17	15 nF polypropylene
C14, C18	33 nF polypropylene
C16, C20	10 nF polypropylene
C15, C19	1 nF polypropylene
C21 – C24	10 uF electrolytic
C25 – C28	1 mF 25V electrolytic
C29	10 uF electrolytic

Assembly Tips:

You will want to own a multi-meter, and a fine tip soldering iron with temperature regulation.

It is most convenient to do the resistors first. All the resistors in this project are to be bent for 0.5 inch spacing as a standard. The colored bands on the resistors can be a little hard to read – you should test each with the multimeter before placing it in the board. Personally, I stuff all the little resistors and then lay the board over, pressing them to the board while I solder them.

I use lead/tin solder, as it works at a lower temperature, and you want to run the iron at the low temperature which still does the job. As this is a plated through board, you should be able to see the solder up on the top side of the board, which shows that it flowed well into the plated through holes.

After the resistors, then the on-board pots and the film capacitors. You have to bend the leads a bit on these after insertion, or they will tend to fall out during soldering.

Then the transistors. As the leads on these are already bent and cut, they can simply be set into the holes with the board on a flat surface and they will stay while you solder one of the pins and then get them neatly aligned. Then you can turn the board over and solder the other pins.

Remember that the electrolytic capacitors are polarized, and it may help you to know that the long lead on them is the + pin.

You will need a chassis and connectors, which are available from the diyAudio store. Probably you don't need me to tell you how they get wired up.

If you do need more information, you will want to check on the threads in the Pass Labs forum at www.diyAudio.com where 6L6 will have undoubtedly posted one of his “how-two” pieces specific to this project. That forum also has helpful people (like ZM) who can answer any sort of question related to this project.

I can't over-emphasize the importance of checking your work after each step and then maybe again when you think you are finished. Much of the time when I assemble something like this, I'm in a bit of a hurry and of course I'm so smart that I don't make mistakes. Then I “fire it up” and with a little luck that's just a phrase. It's totally easy to get something wrong, so check your work.

Testing

Here is where the multi-meter comes in again. After construction it will be time to plug the wall-wart into the AC outlet and see what happens.

Here is a list of resistor numbers and the DC voltages we want to see across them. In the order listed, use the probes of the multi-meter on the two ends of each resistor as found on the placement diagram.

None of these values are critical – if something's wrong they will be way off.

R47, R48, R49 ~ 0.5 V DC this will vary a bit, depending on the Jfets

R50, R51 ~ 11 V DC

R13, R14, R15, R16 ~ 0.7 V to ~1.0 V DC

R35, R36, R37, R38 ~ 0.7 V to ~1.0 V DC

R39, R40, R41, R42 ~ 0.0 V DC

After that we want to measure the DC voltage from a few points referenced to ground. Ground is easily found on the edges of the PC board, and includes the four mounting holes.

The other (red) probe of multi-meter is used to measure the DC voltage at either end of the following resistors:

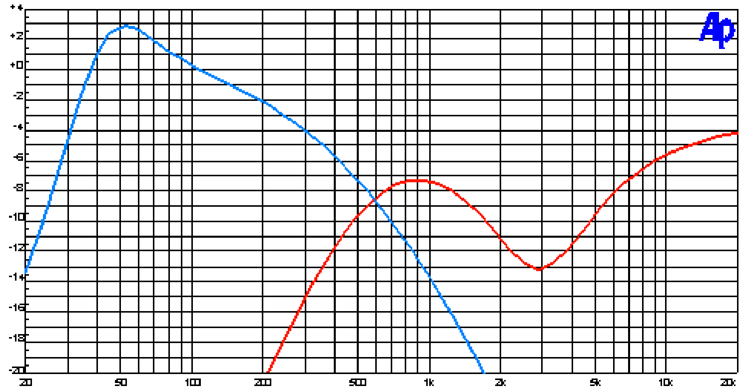
R1, R2, R3, R4 R31, R32 ~ 12 V DC

If you get voltages that are close to these figures, you are probably good, and you should be able to hook it up to your system.

The crossover draws about 1 watt and is designed to be left on continuously.

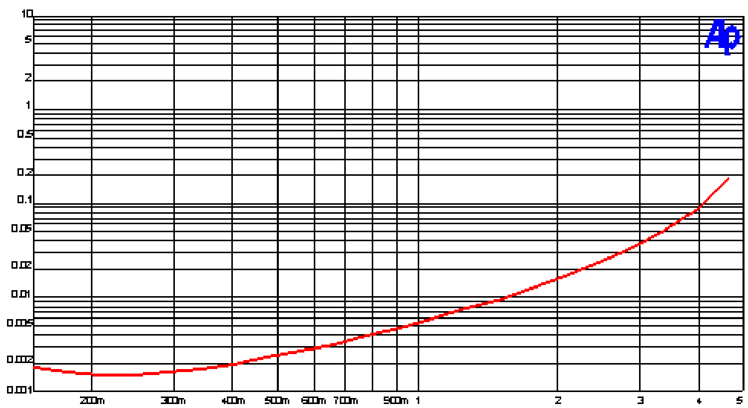
There is a turn-on and turn-off thump associated with these circuits, and if you have powerful amplifiers with lots of gain, you might experience some excitement if you plug or unplug the power while the amps are running. The measured thump is about 0.5V peak at about 0.5 Hz. If you want to lower this amplitude, the four output capacitors C21 through C24 set at 1 uF instead of 10 uF will do it, but my advice is still to simply leave it on all the time.

Previously I have shown response filters as simulated and distortion of single buffers alone. Here are those curves tested in the final crossover:



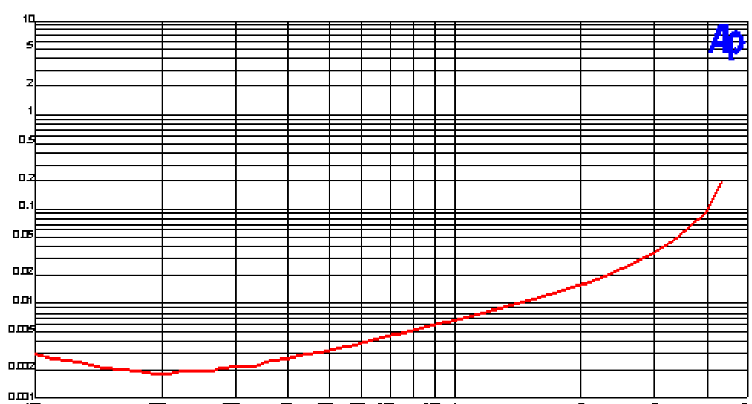
CROSSOVER RESPONSE

Here is the distortion vs output voltage of the woofer filters at 500 Hz:



LOW PASS DISTORTION CURVE

Here is the distortion of the mid/hi filters at 900 Hz:



HIGH PASS DISTORTION CURVE

Final Notes

If you are running amplifiers all with the same gain, as originally set up for DSP, then you can set the level pots on maximum. You are free to adjust the levels from there, but best performance is obtained when either the low pass or high pass are set at maximum and the other adjusted relative to it.

The crossover has a nominal 10 Kohm input impedance, and a nominal 200 ohm output impedance. It is very happy driving loads from 10 Kohm and up.

In listening tests with an oscilloscope and Telarc's 1823 Overture we decided that minimum power rating of the amplifiers is 80 watts on the bottom and 25 the top. Siegfried routinely runs 100 watt amplifiers all around.

There is a PC board version which uses the Toshiba 2SK370, 2SK170, or Linear Systems LSK170 parts in single-ended buffers (different pin-outs on the devices) as well as a version for the complementary Toshiba 2SK170 / 2SJ74 and Linear Systems LSK170 / LSJ74 Jfets. If you have these parts or don't mind spending the money obtaining them, the performance can be improved – they have lower distortion and lower output impedance and less noise, however these improvements may not be very noticeable.

You can use two of these crossovers, one board for each channel, in balanced mode, with XLR connectors on the inputs and outputs if you like. The power supply mentioned will drive two boards. If you do this, be sure that the level potentiometers are set at the same values for the + and – circuits.

For those considering an upgrade to the LX-mini + 2 or LX-mini Studio designs, there will eventually be a three-way version of this crossover.

Lastly, this circuit board, # BIAMP12ERF V1R0, is also functional as a crossover for other loudspeaker designs, for example it will duplicate the function of the First Watt B5, which was intended for full range drivers with woofers in open baffle enclosures, as well as other possibilities (If there are attractive requests for other design variations, they will be seriously considered).

Altering the values of the resistors and capacitors in the circuits shown in the simulator schematic will allow you to play with the filter curves and perhaps give you what you want for another crossover project. I will post a MicroCap template at www.diyAudio.com and at www.firstwatt.com

Nelson Pass