24 dB/Octave 2/3-Way Linkwitz-Riley Electronic Crossover

Rod Elliott - ESP

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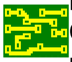


Please Note: PCBs are available for this project. Click the image for details.
Click here to see a photo of the board in 12dB/Octave format (See Project 81 for details of this modification).

Introduction

The Linkwitz-Riley filter featured here has (almost) perfect phase-coherency, with no peaks or dips at the crossover frequency. The design is adaptable to 2-way or 3-way (or even 4-way) operation, and all formulas are provided below (or use the ESP-LR component calculator program).

The photo shows the standard P09 circuit board, but wired for 12dB/octave operation as described in Project 81.

Please note that the PCB version of the P09 crossover is a stereo 2-way design, and has input buffers, filters and output buffers for each channel. Each output buffer is configured for variable gain to allow your system to be set up correctly. The suggested power supply is the P05 Rev-A, which also has an auxiliary output suitable for operating muting relays (see below for reasons you may want to include muting).

2-Way Linkwitz Riley Crossover

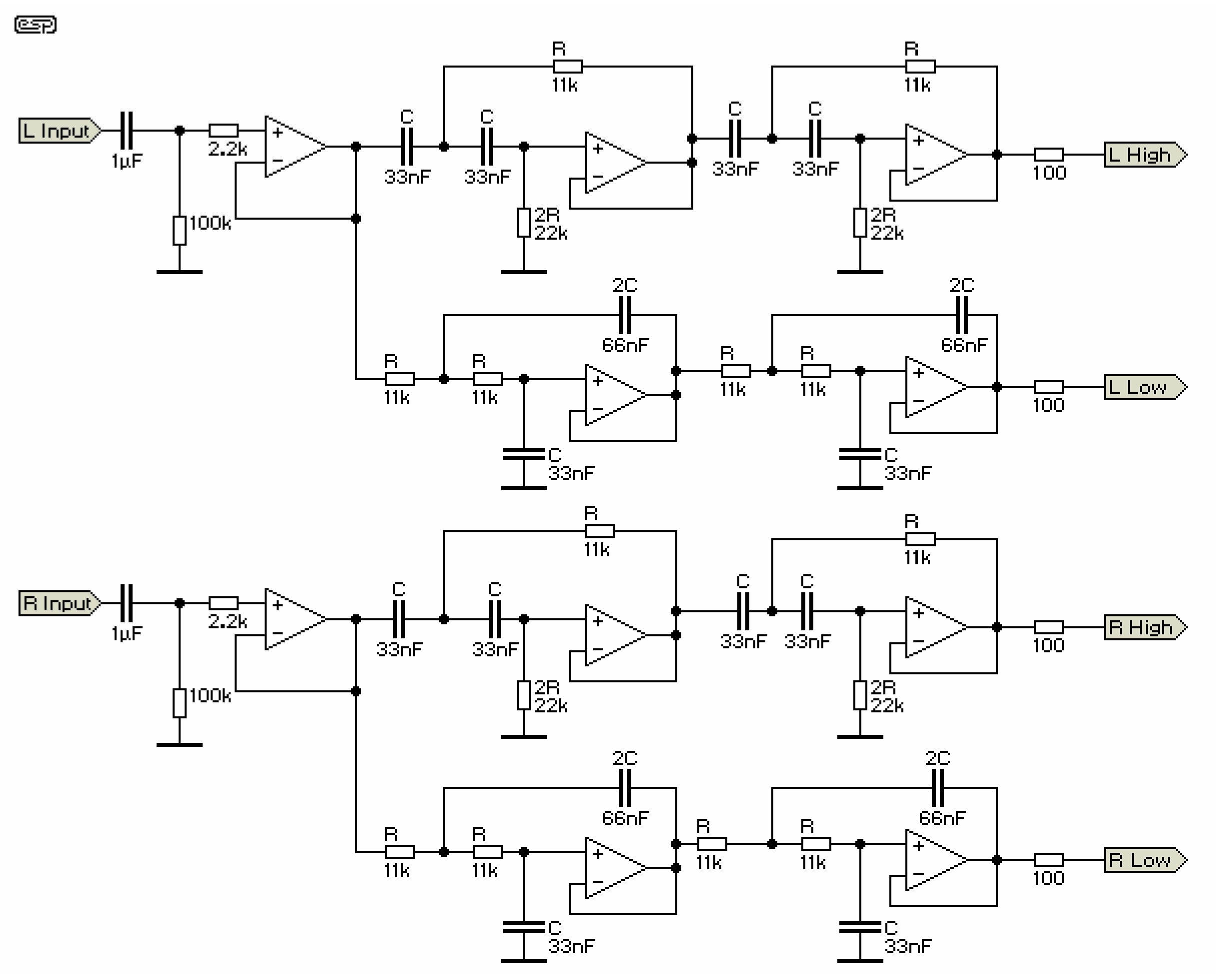


Figure 1A - Stereo Version of a 2-Way LR Crossover

Figure 1A shows a full stereo version, with two identical filter sections. With the component values shown, these have a crossover frequency of 310Hz (refer to the article on Bi-Amping to see the reason for my choice of frequency). This unit will provide a completely flat frequency response across the crossover frequency, with the signal from both filters remaining in phase at all times.

The 2-Way unit is separated into 3 sections per channel ...

- **Input Buffer** - ensures that all filters are driven from a low impedance source, to prevent frequency and phase shifts
- **High Pass** - as shown, frequency is approx. 310Hz
- **Low Pass** - as shown, frequency is approx. 310Hz

It is important with both versions that the filters are properly matched, both within the individual filters, and between channels. While small variations between channels will not be audible, if the high and low pass sections are not accurately matched, then phase and amplitude errors will result.

3-Way Linkwitz Riley Crossover

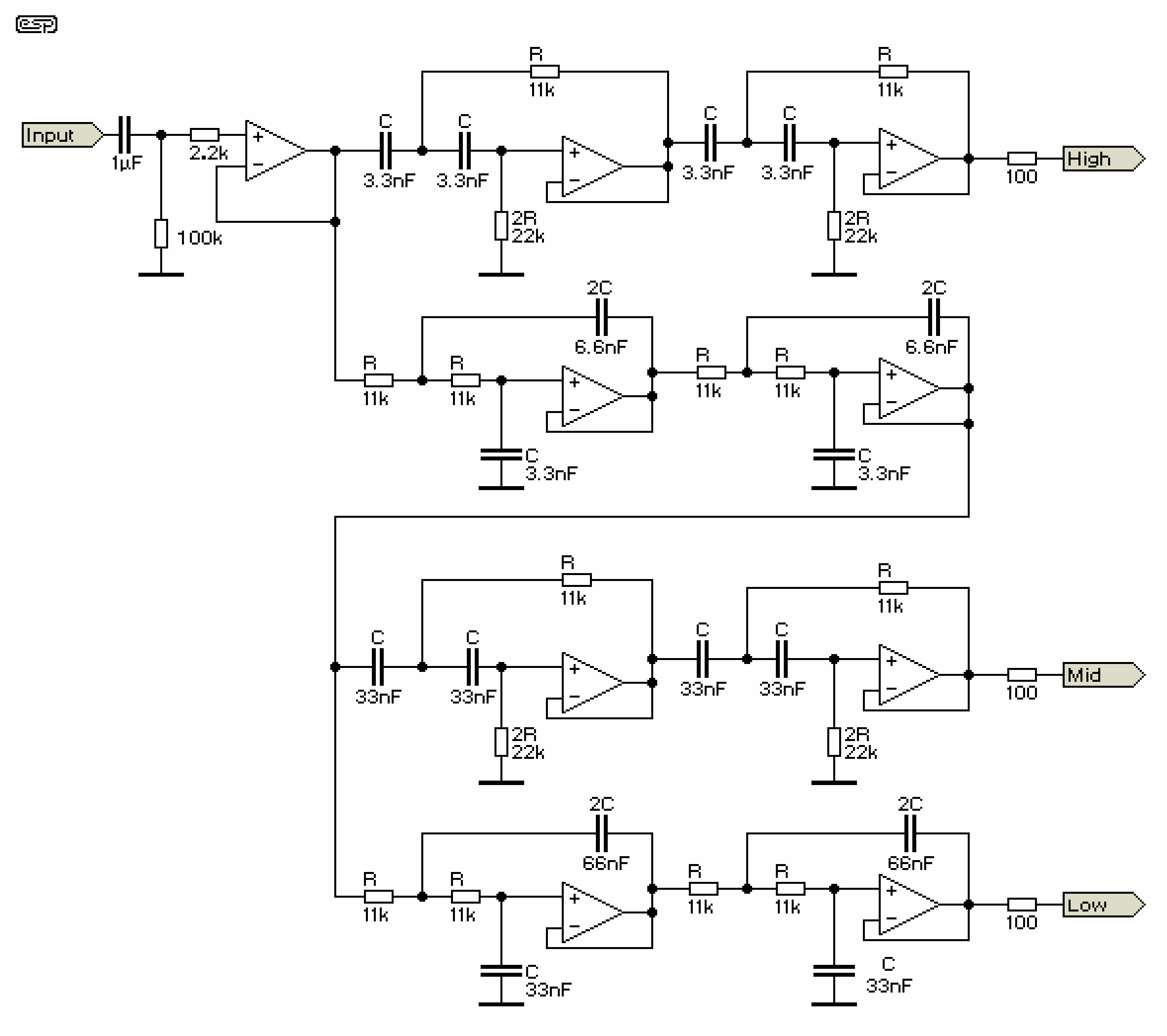
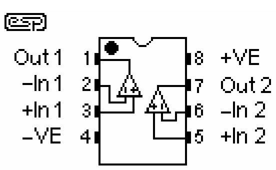


Figure 1B - 3-Way Mono LR Crossover (2 Needed for Stereo)

Figure 1B shows the way to connect a 3-Way crossover. This unit will produce excellent results, with good phase coherency and a flat response across the entire frequency band.

I know the circuits look complicated, but each is basically repetition of a common circuit block - the filter section. Since the opamps are all used as unity gain buffers, the use of premium devices is not really essential, so the TL072 type would be quite serviceable in this role. Needless to say, if you want to use better devices (even discrete opamps) you can easily do so. Make sure that any device used is stable for unity gain - this is not always the case with some devices, especially when external compensation is used. In this case, use the manufacturer's recommended value of stability cap for unity gain operation.



Power supply connections (and bypass capacitors) have not been shown, but the diagram shows the standard connections for a dual opamp. The IC is viewed from the top. The +/-15V power supply described (see [Project 05 - Power Supply For Preamps](#)) is suitable for this crossover as well. For dual opamps, power is connected to Pin 4 (-ve) and Pin 8 (+ve).

NOTE: Only one channel is shown for the 3-Way - for a stereo setup, two identical filter circuits are required.

As can be seen, the 3-Way unit is separated into 4 sections ...

- **Input Buffer** - ensures that all filters are driven from a low impedance source, to prevent frequency and phase shifts
- **High Pass** - as shown, frequency is approx. 3100Hz
- **Band Pass** - as shown, frequencies used are high pass at 310Hz and low pass at 3100Hz
- **Low Pass** - as shown, frequency is approx. 310Hz

In 3-Way mode, the bandpass section must have a highpass section whose frequency is exactly equal to that of the main low pass (bass) filter, and a low pass section whose frequency is equal to the main highpass (treble) filter. (No, this isn't confusing, it just looks that way.) See the chart above for clarification if this doesn't seem to make sense.

If it helps, I have added a block diagram that may make things clearer. This is shown below, and has all the sections for a 3-way crossover network. Again, this is mono, so two complete blocks are used for a stereo system.

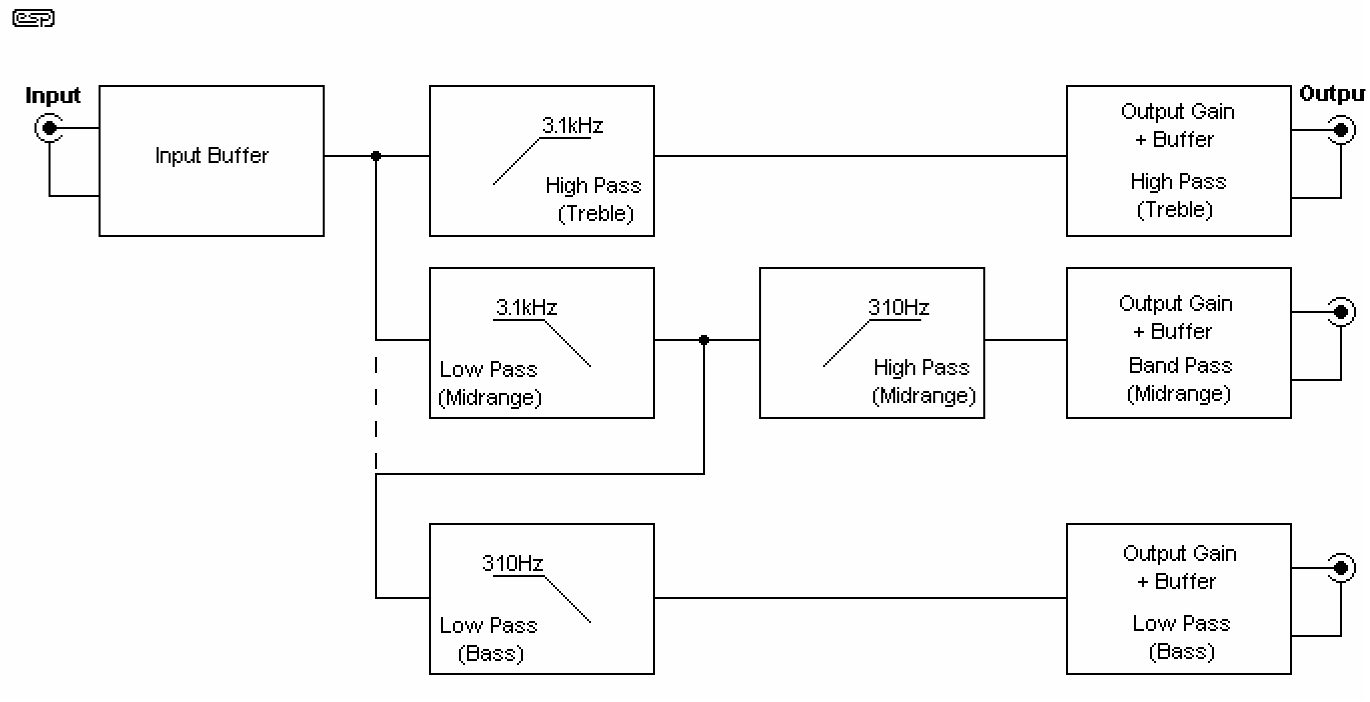


Figure 1C - Block Diagram of 3-Way Crossover

Frequencies shown are for reference only, and are the same as described above. Naturally, these may need to be changed to suit your application.

The frequency responses of each section are shown below, note that the crossover frequency is at the -6dB point, and not at the traditional -3dB frequency. This is an important difference between a Butterworth and Linkwitz-Riley filter, and allows the signals to be in phase across the audio band, regardless of which filter section they are being passed by. The summed output of this filter is flat, there are no peaks or dips, and no phase reversals are produced (unlike Butterworth filters).

A simple test with any electronic crossover is to connect a 10k resistor to each output, and join the other ends together. Run a frequency sweep from an audio oscillator into the input, and observe the output level at the output of the resistor summing network. Most crossovers exhibit a 3dB increase at the xover frequency, and drop back to the reference level about an octave or so each side. This is a less than ideal situation, since in most cases a similar effect will occur from the speaker's summed acoustical output - assuming that the drivers are "time aligned" so the output of each is in phase (acoustically speaking) at the crossover frequency. If time alignment is not done, and the physical distance difference between speaker voice coils is large (more than 0.1 wavelength of the frequency concerned), then other acoustical differences caused by phase will tend to overshadow any anomaly in the crossover network.

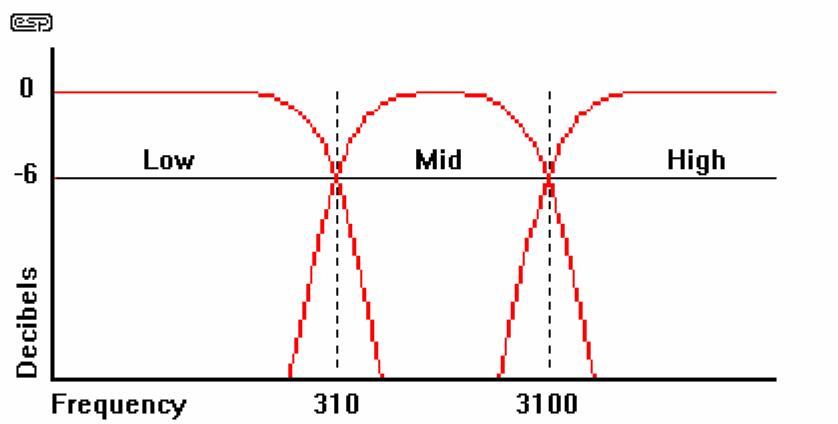


Figure 2 - Frequency Response of 3-Way Linkwitz-Riley Crossover Network

When the original graphs were produced, frequency response ranged from 10Hz to 50kHz, and the influence of the 1uF capacitor in the input is negligible (the -3dB point is 1.59Hz). Insertion loss is 0dB, since there is no gain or loss introduced by the filters in their pass-band.

Output Buffers (and ....)

If you are going to use the crossover, you will need some way of equalising the levels from each output to match the power amp sensitivity and speaker efficiency. I have had several requests for this, so the circuit for a suitable buffer is shown in Figure 3. There is nothing special about it, but it is designed to give a gain of 2 to allow maximum flexibility, and ensures that the impedance of the pots does not cause any high frequency loss with long interconnects.

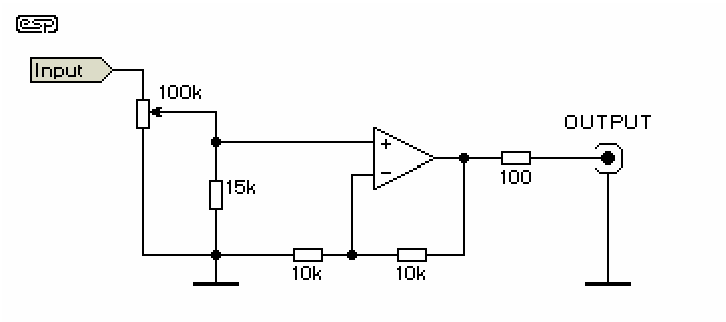


Figure 3 - Buffer Stage. One Per Output Needed

These buffers should use high quality opamps, and can be mounted on a separate board if desired. Construction is not critical, but proper bypassing must be used to ensure stability.

Several people (including me) have found that the crossover unit has a short 'chirp' or 'snap' (depending on the opamp characteristics) as power is removed, and this may be accompanied by some DC swing. If you use the new version of the P05 preamp power supply, the auxiliary output can be used to activate a 6-pole relay (or as many smaller relays as needed) to short all outputs to earth when there is no power. The normally closed contacts simply short the outputs to ground, and when power is applied the short is removed. P05 (Rev-A) boards use a loss of AC detector that will mute the crossover almost immediately when power is turned off.

Because all common opamps have short circuit protection, this will not cause any damage, and current is limited further by the 100 ohm output resistors.

Variable Frequency Crossover

As you can see from the main circuit diagram, a 4th order Linkwitz-Riley would be difficult to make into a variable network, due to the large number of resistors which need to change. Use of multi-ganged potentiometers is discouraged, because of the matching requirements. Sufficiently accurate 8-gang pots are unlikely to be readily available!

One possibility is to build modules, containing the tuning components. These may be plugged into suitable sockets on a printed circuit board, which otherwise contains the rest of the circuitry. The modules could be made quite small. A possibility for this option is shown in Figure 3, showing the connections which need to be made for each unit. It would not be possible to make these "hot-pluggable" (i.e. with power on), since the opamps will be deprived of their biasing resistors, and will swing to the +ve or -ve rail. Power amplifiers and speakers are not expected to enjoy the experience!

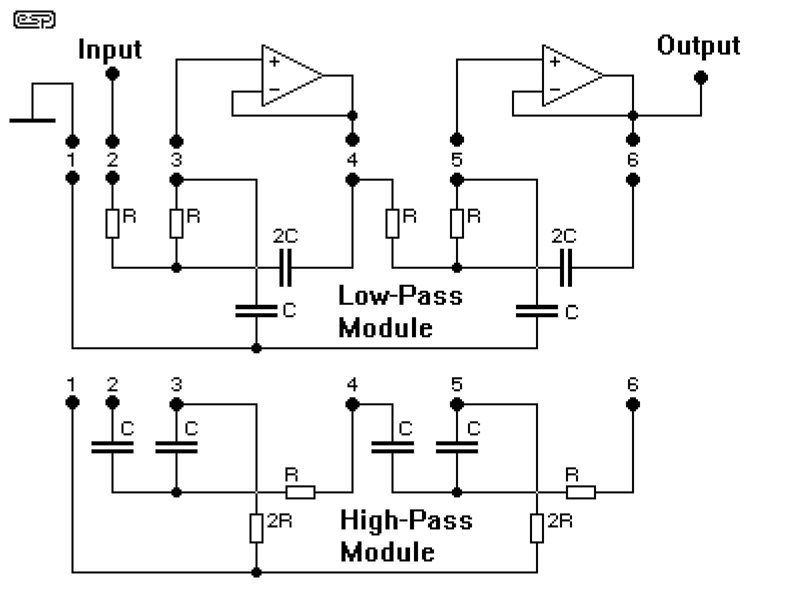


Figure 4 - Modular Connections for L-R Crossover

With this arrangement, the main PCB will simply contain a whole bunch of opamps (and their power supply bypass components), and some suitable sockets for the tuning modules. Each plug/socket combination needs 6 pins (as shown), with one for the earth (ground) connection, and the others for connection to the opamps. The plugs and sockets should be of high quality (preferably gold plated) to ensure reliability. The standard 0.1" pitch PCB pins (often used for IDC connectors) would make a good choice - they are quite cheap and reliable. Sockets are also available, but you might have to search for them - I have not seen them in any of the local retail electronics shops in Australia.

It might be an idea to use a 10M Ohm resistor (which will have virtually no effect on the tuning resistance) from the opamp's +ve input terminal to earth, just to ensure that bias cannot be lost. This will cause some offset, but it will be a lot less than 15V.

Tuning Formula If you absolutely insist on performing the calculations yourself, the formulae are ...

(1) $R = 1 / (2 * \pi * 1.414 * f * C)$

(2) $C = 1 / (2 * \pi * 1.414 * f * R)$

(3) $f = 1 / (2 * \pi * 1.414 * R * C)$

Where R = resistance in Ohms, $\pi = 3.14159$, 1.414 is $\sqrt{2}$, f = frequency in Hertz and C = capacitance in Farads

(1) This assumes that you have selected the capacitance first, which is the most sensible, since they are available in fewer different values in each decade than resistors. Capacitors follow the "E12" series, which has 12 values per decade, so:

1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2, 10

These are multiplied by 10, 100 (etc), to obtain all the values from 1nF - 10nF, 10nF - 100nF, and 100nF - 1uF. Values above 1uF and below 100pF are generally not as readily available in all values, and should be avoided for this design, since very large or very small values will create impedances which are too difficult to handle. Very low values of capacitance mean that even small amounts of stray capacitance on PCB tracks or in wiring will create errors. Large values of capacitance will imply low impedances, which opamps may not be able to drive without excessive distortion or clipping.

(2) Is the least useful, since the range of capacitor values is only half that of 1% resistors. Really strange values can be assured, which will require parallel combinations of smaller caps - messy.

(3) Is useful to check that the components selected will give you the frequency that you first thought of, or something reasonably close after standard component values have been substituted for the theoretical values you will get with the calculation.

The calculator program is far easier and more fun, too. (Of course I like it - I wrote it!)

Capacitor values need to be accurate - the standard offering is +/-10%, which is not really good enough. If you have (or can get access to) a capacitance meter, simply buy more than you need (they are inexpensive), and select the values to be within 2% or better if possible. My experience is that the tolerance of most MKT and MKP caps is actually better than that quoted, but you do need to check!

The easiest way to get the "2C" value is to use two capacitors in parallel, each of value "C".

Resistor values also need to be accurate, and 1% metal film resistors are perfectly acceptable. These are generally available in the E24 series (24 values per decade), allowing a much wider choice of values. Both the E12 and E24 series values are available in the Component Calculator (Help-Preferred Values) for reference. In some shops (oh, really?) you might even be able to get resistors in the E48 or E96 range - these offer an almost limitless range of possibilities (48 or 96 values per decade - awesome!), just don't count on it.

General Notes ...

- Although not specifically mentioned above, P09 is ideal for subwoofer applications. While the frequency is not adjustable, this is not a major limitation when a full crossover network is used. Most subwoofer 'plate' amplifiers use a variable filter simply because there is only one filter! It is therefore necessary to tweak the crossover frequency and phase to get a smooth integration with the main system. While some plate amps *do* use two filters, only one is adjustable - usually that feeding the sub itself.

  P09 will give a far better result in most cases, because the main system can be rolled off quickly below the selected frequency. This can give a major improvement of intermodulation distortion performance by removing all frequencies that may stress the main speakers. This is especially important when the main speakers are 2-way (including MTM designs).

- As noted above, some opamps create a transient signal upon application or removal of power. Because this will create a loud sound, many builders may want to incorporate a delayed action switch, to ensure that the outputs of the circuit are not connected to the load until the operating conditions have stabilised. One simple solution is described above, and will work perfectly. Alternatively, the P05 Rev-A power supply has an auxiliary output that can be used for muting.

  Although the transients are unlikely to cause damage to any amplifier or loudspeaker, but do not sound very nice. For a system that you build yourself, there is a great satisfaction in having it perform flawlessly, so it is probably worth the small effort to use the P05-A supply's aux output to drive muting relays.

- The crossover as described is phase coherent, in that the phase of each signal applied to each loudspeaker driver is essentially in phase with all other signals that have passed through the crossover. Because filters are used, the crossover is ***not*** phase neutral - there are wide variations in absolute phase as the frequency changes. This is the case with all crossover networks, from the simplest to the most complex, active or passive.

  I mention this because of possible interactions between the main (Left and Right) speakers, and the centre and rear speakers in a surround sound environment. The possibility exists that in some circumstances, the phase interactions between this crossover and other crossovers in a home theatre system may be incompatible with some material. These interactions will always (***always!***) be present unless all speakers in the system have identical crossover networks - not just the same crossover frequencies, but identical networks, drivers and cabinet layouts. This is rarely (if ever) the case in reality.

- If you examine the output waveform, be aware that if your audio generator has more than 0.1% distortion, the high pass output will appear very distorted when you select a frequency more than one octave below the crossover frequency. This is *not* a fault of the crossover. Because the fundamental is attenuated the most, the harmonics are effectively increased by 24dB (for the second harmonic) and about 36dB for the third. This makes the output waveform look very distorted, yet your input signal will appear to be clean on an oscilloscope. It is difficult to see any distortion below 1% on an oscilloscope, but this amount of distortion will make the output look very nasty indeed. Do not despair - all is well.

ESP Linkwitz-Riley Component Calculator

The completed Linkwitz-Riley component calculator is available for you to download. It includes the circuit diagrams for both the high-pass and low-pass sections, and has the following features:

- Calculate resistance from a known frequency and capacitance
- Calculate capacitance from a known frequency and resistance

- Calculate frequency from the resistance and capacitance values (good for checking after standard value components have been selected)
- Includes a chart for the E12 and E24 series. Capacitors generally follow the E12 series, and 1% metal film resistors are always available in the E24 series.
- Calculate the values as a low-pass, then select high-pass. The new values are displayed, along with the circuit.
- Calculates both 12dB/octave and 24dB/octave filters.

This program (ESP-LR12.EXE) is the actual executable file. This is version 1.2 of the program, and is just under 67k, so it is not too big. There are no setup programs or such like, so you simply have to decide where to put it, and create your own shortcut. Feel free to distribute the program to friends, since I have released it as freeware - just don't change the program in any way is all I ask.

The program requires the Microsoft run-time library file VB40032.DLL which can supposedly be obtained from Microsoft's web site (a link to the exact location can be found in the Downloads page) if it is not installed on your machine. Note that the program is 32-bit, so it won't run on pre WIN95 operating systems. The following is a guide as to where the DLL should be installed ...

Windows95/98 - c:\windows\system
WindowsNT - c:\winnt\system32
XP - c:\windows\system32

In all cases, the above assumes that the C: drive is the installation drive. This will usually be the case, but some installations may differ.

Note that although all care has been taken to ensure the file is virus free, ESP cannot absolutely guarantee that this is the case - I don't appear to have any viruses on my machine, but one cannot be too careful. As with all executable downloads, use your own virus scanner to check it before execution.