Three-way Crossovers for *fEARful*™ 12/6/1 and 15/6/1 Cabinets

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The standard ***fEARful*** is a 2-way (woofer and midrange) musical-instrument speaker cabinet originally intended for use with bass, drums, and keyboard instruments, although it has found wider application than that. The high-frequency response is determined by the midrange driver and rolls off rapidly above about 5 kHz.

As an option, the frequency response may be extended by adding a horn-loaded tweeter and a high-pass crossover network. The natural upper rolloff of the midrange driver functions as the low-pass characteristic of the midrange/tweeter crossover. This approach works well for most MI backline (musical instruments on stage) applications and provides a voicing that is not masked easily.

The standard crossovers are designed for good performance with a minimal parts count. The 3-way crossovers described here have a different design goal: high-quality reproduction of general program material. The designs have been developed using hand-guided computer optimization and listening tests involving a wide variety of source material. Driver measurements were made with drivers installed in the cabinets so that cabinet-related effects like baffle step and edge diffraction could be taken into account. Care has been taken to minimize the effects of driver and horn resonances that compromise sound quality. Steep crossover filter slopes keep the crossover regions narrow and reduce the audibility of the off-axis nulls that are characteristic of multi-driver systems. The system impedance is 7 ohms or greater for frequencies above 200 Hz. The midrange level switching options and adjustable tweeter controls of the standard ***fEARful*** crossovers have been retained.

Component counts have been kept to the minimum consistent with the performance goals, but the 3-way networks are inevitably more complex than the standard networks. They occupy more real-estate and are more difficult to assemble, but should be manageable for anyone who can assemble the standard networks.

Crossover frequencies are approximately 850 Hz and 3 kHz. Below 1.5 kHz the response is essentially the same as the response with the stock crossover. Above 3k Hz the voicing obviously deviates from that of the stock crossovers. With the tweeter control at its nominal setting the on-axis response is flat within a few dB to around 15 kHz. With the tweeter turned all the way down the response falls sharply above 2.5 kHz and is reminiscent of some 15-inch drivers.

The wide variety of compression driver and horn combinations in common use leads to some complications. Each combination has its own characteristics and there is enough variation between them that each requires its own customized crossover network. A modular approach is used to manage the potential complexity of mixing and matching components. The tweeter modules are designed to be compatible with both the **12/6** and **15/6** base systems. The section on each module includes a schematic and a parts list. Finally, there are some notes about the parts lists and crossover construction.

A supplement to this work is available that addresses a three-way crossover for the **1515/66** and a response-bending mod for the **15sub**, also a tweeter protection supplement is contemplated.

Compatibility Matrix

The following table shows the compatibility of the tweeter modules with the base systems operating both stand-alone and with the matching sub. The tweeter modules include the four combinations of the Eminence ASD1001S and Selenium D220Ti-8 (8 ohm version) compression drivers with the JBL PT-B99HF-1 and Dayton H07E waveguides in addition to the 18-Sound XD125 driver/waveguide and the Eminence APT-80.

The two values in each cell are the L-pad settings for a nominally flat frequency response. The first value is for the base system operating alone and the second value is for the base system with its matching sub. "NA" means "not applicable" and indicates configurations that are not feasible. Where possible, the tweeter crossovers include fixed pads that set the maximum output level (with the adjustable L-pad set fully clockwise) to match the level from an 18-Sound midrange driver operating with no padding. This accounts for the duplication of L-pad settings.

System (+sub)	*ASD - JBL*	*ASD - H07E*	*D220 - JBL*	*D220 - H07E*	*XD125*	*APT-80*
12/6 (+12sub)	8 / NA	3 / 10	3 / 10	3 / 10	NA	NA
12/6cube (+12sub)	8 / NA	3 / 10	3 / 10	3 / 10	3 / 10	NA
15/6 (+15sub)	NA	7 / 10	7 / 10	7 / 10	7 / 10	NA
15/6/1tube	NA	NA	NA	NA	NA	7 / 10

The D220Ti-8 is about 3 dB more sensitive than the ASD1001S, sounds a little smoother and has slightly higher power handling. It is also 2 lbs heavier and is a little more expensive.

The JBL waveguide is more difficult to obtain than the Dayton waveguide. It has to be ordered from the JBL Professional Service Center and reports vary about its availability. For this reason it is no longer recommended on the ***fEARful*** web site, but it is a useful alternative to the Dayton waveguide. It is more difficult to tame than the Dayton, so the crossover networks are more complex, but its dispersion is noticeably wider and its high-frequency response holds up better off-axis.

Base Systems

There is a large enough difference between the midrange driver responses on the **12/6** and **15/6** baffles to justify a separate crossover design for each cabinet. Each woofer network uses the same inductor as the standard ***fEARful*** crossover, which saves some cost if an existing cabinet is modified. In the U.S. the 18-Sound 6NM410 is more readily available than the 6ND410. The 6NM410 is essentially a 6ND410 with different connector locations and slightly reduced sensitivity. For practical purposes the two can be regarded as equivalent.

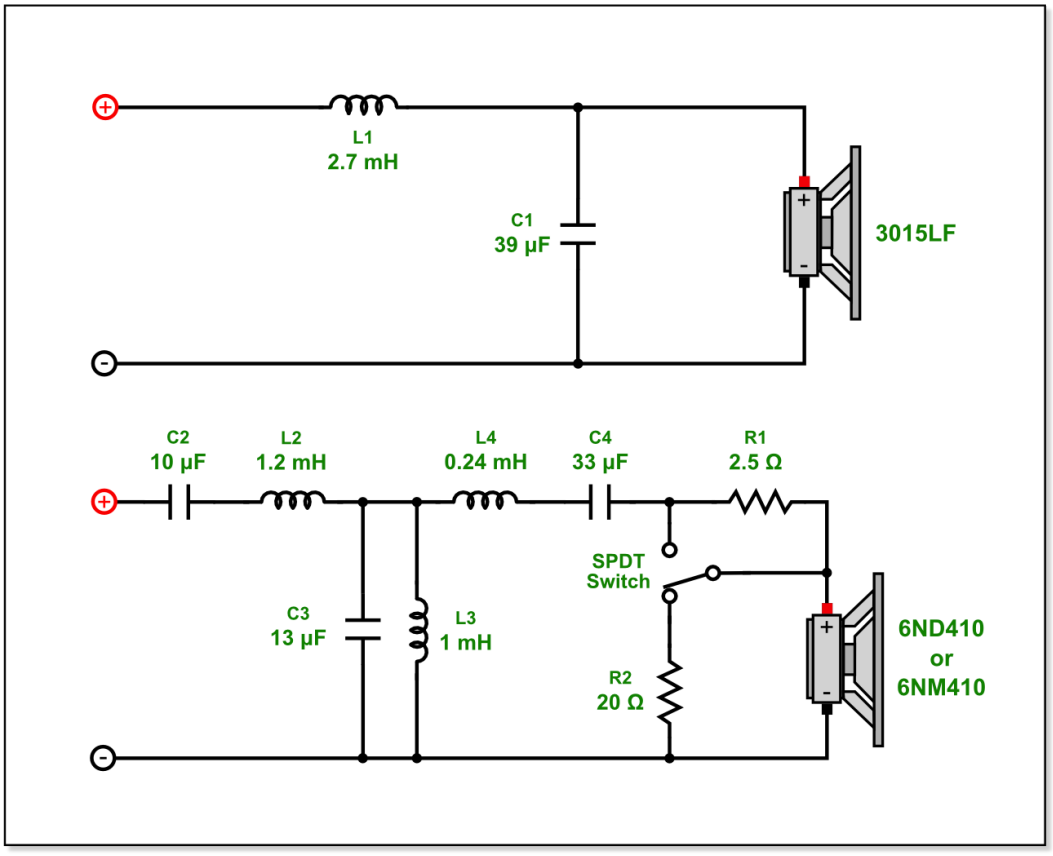
The **12/6** and **15/6** designs both include an L-pad that can be switched out of circuit to increase the output from the midrange driver when the cabinet is used with a sub. The L-pad may be permanently wired in circuit and the switch omitted if the cab is not to be used with a sub.

The **15/6/1tube** should use the **15/6** woofer network, the **12/6** midrange network with the padding resistors from the **15/6** midrange network (2.5 and 20 ohms) and the APT-80 tweeter module.

No design has yet been formulated or tested for the **1212/6**. If one wishes to attempt this we suggest using the standard woofer low pass for that module (1.5mH inductor + 68µF capacitor into the dual 3012LFs), the **15/6** midrange network described below, and one of the tweeter modules that is suitable for the **15/6/1 + 15sub**. The midrange pad and level switch could be retained to provide two voicing options, or simply removed.

15/6

A 3 dB pad is used to reduce the output level of the 6ND410/6NM410 to match the 3015LF. Bypassing the pad raises the midrange level by 3 dB. This is not enough to match the 6 dB level increase obtained at lower frequencies when a **15/6** is augmented with a **15sub**, but it partially closes the gap and the result (a response that drops by 3 dB above about 800 Hz) may be acceptable or even desirable. The **15subby-sub** described elsewhere provides another voicing option by lowering the shelving frequency to around 500 Hz.



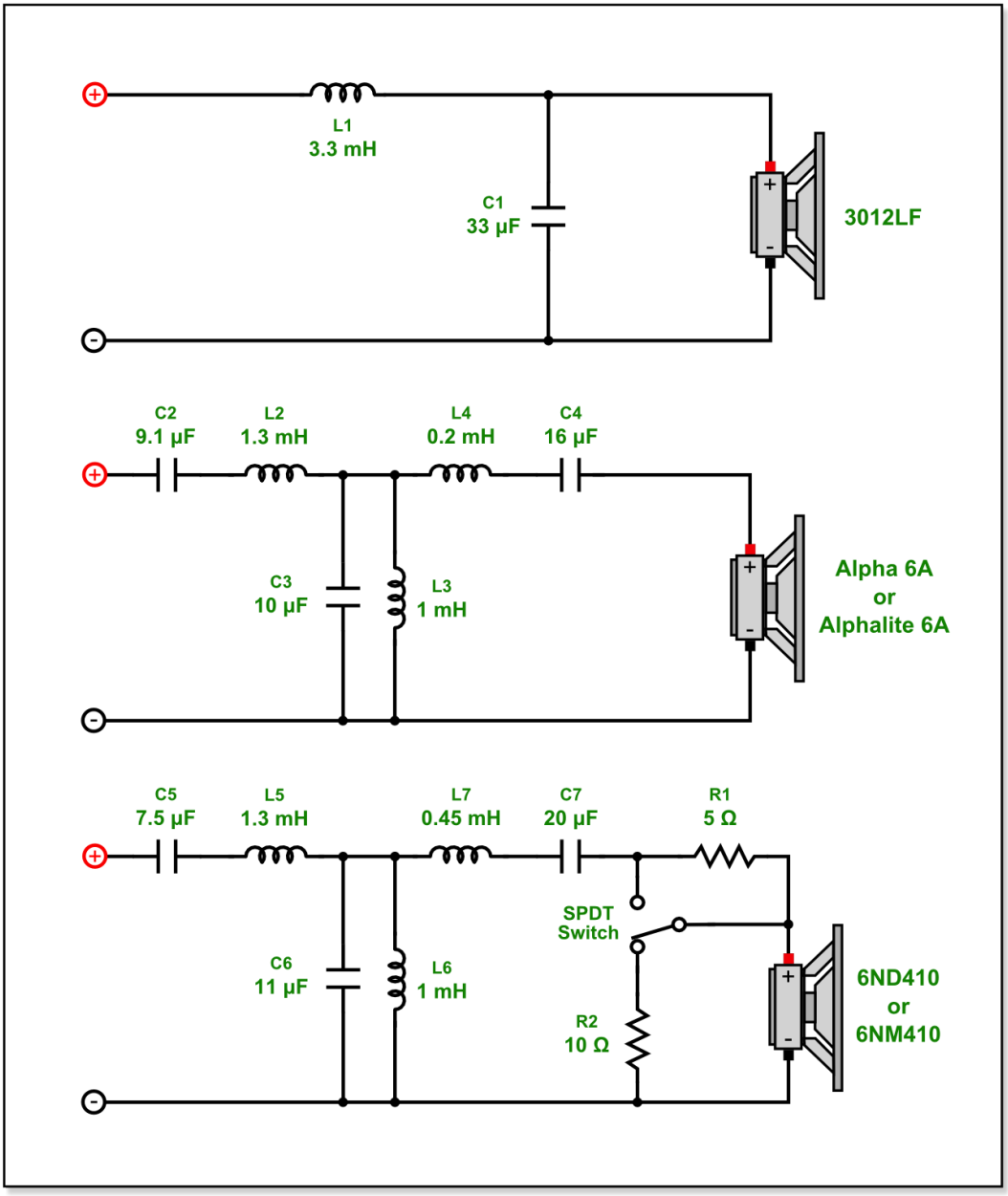
Component		*Qty*	*Erse P/N*	*Cost*
L1	2.7 mH, 0.17 Ω*	1	ESQ55-16-2700	16.58
C1	39 µF 9.1 µF || 30 µF*	1	MET25-05-39.0/PB MPX25-03-39.0 MET25-05-9.10/PB	6.21 10.47 1.44
C2	10 µF	1	MET25-05-10.0/PB MPX25-03-10.0	2.65 4.11
L2	1.2 mH, 0.53 Ω†	1	EAC33-18-1200	7.93
C3	13 µF	1	MPX25-03-13.0	4.61
L3	1 mH, 0.31 Ω	1	EAC34-16-1000	8.73
L4	0.25 mH, 0.30 Ω 0.24 mH, 0.14 Ω	1	EAC15-20-250 EAC32-16-240	2.53 4.14
C4	33 µF 18 µF || 15 µF*	1	MET25-05-33.0/PB MPX25-03-33.0 MPX25-03-18.0	5.46 9.17 5.63
R1	7.5 Ω, 25 W*	3	EWR25-05-7.5/PB	1.80
R2	40 Ω, 25 W*	2	EWR25-05-40.0/PB	1.20
	SPDT switch*	1		

* This part from the standard crossover may be reused.

† The 1.3mH coil from the standard crossover may be reused by removing 7 turns.

12/6 and 12/6cube

There are two versions of the **12/6**, one using an Eminence Alpha 6A or Alphalite 6A for the midrange driver and the other using an 18-Sound 6ND410 or 6MN410. The Eminence drivers are less expensive and less sensitive than the 18-Sound drivers. They have the same sensitivity as the 3012LF, so they do not require a level-matching pad, but this means they are not sensitive enough to be used with a sub. The crossover for the 18-Sound driver includes a 6 dB pad to match the midrange level to the 3012LF. The pad may be switched out of circuit to obtain a level response when the cabinet is used in conjunction with a **12sub**.



Component		*Qty*	*Erse P/N*	*Cost*
L1	3.3 mH, 0.19 Ω* 3 mH, 0.18 Ω†	1	ESQ55-16-3300 ESQ55-16-3000	17.93
C1	33 µF*	1	MPX25-03-33.0	9.17
C2	9.1 µF	1	MPX40-03-9.10	4.65
L2	1.3 mH, 0.57 Ω‡	1	EAC33-18-1300	7.93
C3	10 µF	1	MET25-05-10.0/PB	2.65
L3	1 mH, 0.31 Ω	1	EAC34-16-1000	8.73
L4	0.2 mH, 0.18 Ω	1	EAC31-18-200	3.24
C4	16 µF 3.9 µF || 12 µF*	1	MET25-05-16.0/PB MPX25-03-3.9	3.71 2.05
C5	7.5 µF	1	MET25-05-6.00/PB || MET25-05-1.50/PB MPX25-03-3.60 || MPX25-03-3.90	2.49 4.10
L5	1.3 mH, 0.57 Ω‡	1	EAC33-18-1300	7.93
C6	11 µF*	1	MPX25-03-11.0	4.32
L6	1 mH, 0.31 Ω	1	EAC34-16-1000	8.73
C7	20 µF	1	MPX25-03-20.0	5.94
L7	0.45 mH, 0.3 Ω	1	EAC32-18-450	4.65
R1	15 Ω, 25 W*	3	EWR25-05-15.0/PB	1.05
R2	20 Ω, 25 W*	2	EWR25-05-20.0/PB	1.20
	SPDT switch*	1		

* This part from the standard crossover may be reused.

† It is OK to use the 3 mH inductor from the standard crossover for the 12/6 with an Alpha.

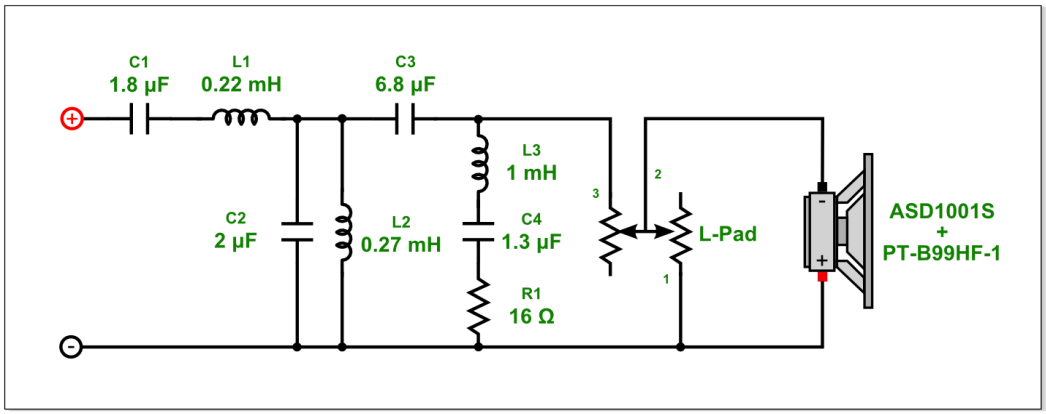
‡ The 1.5mH coil from the standard 6ND410/6NM410 crossover may be reused by removing 13 turns.

Tweeter Modules

The tweeter crossovers all include an adjustable L-pad and, where applicable, fixed padding that sets the maximum output level (L-pad fully clockwise) to match a 6ND410 or 6NM410 operating with its pad bypassed. In these cases, the L-pad setting (assuming an Eminence PX-LPAD style pad) to match the padded midrange driver is 3 for a **12/6** and 6.5 for a **15/6**.

Eminence ASD1001S and JBL PT-B99HF-1

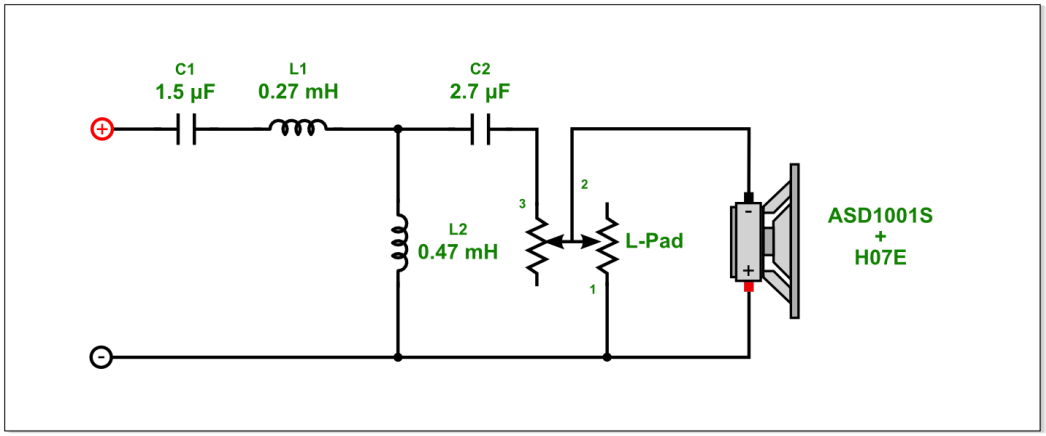
This driver and waveguide combination is limited to use in a **12/6** in stand-alone mode (a **12/6** with an Alpha midrange or an 18-Sound midrange with the 6 dB pad enabled). In this case the nominal L-pad setting is 8. Turning the L-pad fully clockwise provides an extra 2 dB of output, but this is not enough to match a **15/6** and well short of the 6 dB required for a **12/6** with a **12sub**.



Component		*Qty*	*Erse P/N*	*Cost*
C1	1.8 µF	1	MET25-05-1.80 MPX25-03-1.80	0.67 1.36
L1	0.22 mH, 0.32 Ω 0.22 mH, 0.18 Ω	1	EAC15-20-220 EAC31-18-220	2.44 3.36
C2	2.0 µF	1	MET25-05-2.00 MPX25-03-2.00	0.68 1.41
L2	0.27 mH, 0.32 Ω 0.27 mH, 0.22 Ω	1	EAC15-20-270 EAC32-18-270	2.61 3.66
C3	6.8 µF	1	MET25-05-6.80/PB MPX25-03-6.80	1.82 2.78
L3	1 mH, 0.69 Ω	1	EAC14-20-1000	5.50
C4	1.3 µF	1	MPX25-03-1.30	1.22
R1	16 Ω, 10 W	1	EWR10-05-16.0/PB	0.35

Eminence ASD1001S and Dayton H07E

This combination can be used in a **12/6** or a **15/6**. The nominal L-pad settings are 3 for a **12/6**, 7 for a **15/6** and fully-on for a **12/6** + **12sub**.

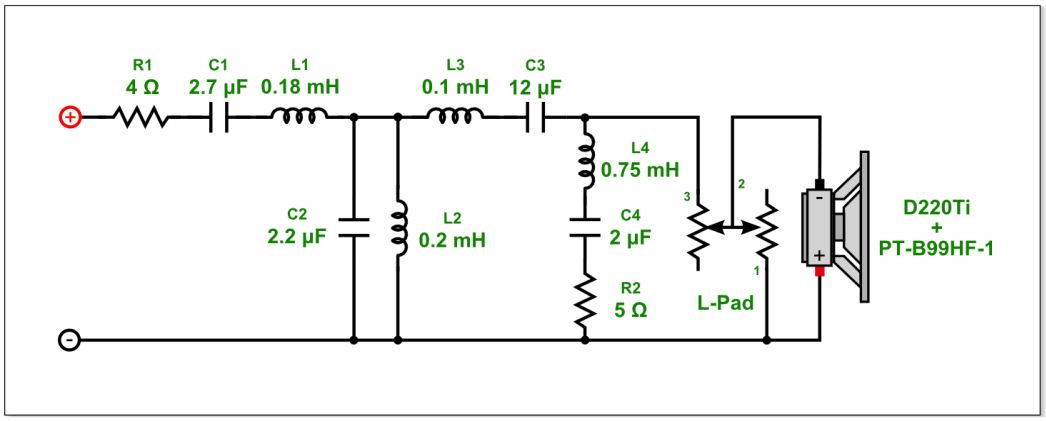


Component		*Qty*	*Erse P/N*	*Cost*
C1	1.5 µF	1	MET25-05-1.50 MPX25-03-1.50	0.58 1.25
L1	0.27 mH, 0.32 Ω 0.27 mH, 0.22 Ω	1	EAC15-20-270 EAC32-18-270	2.61 3.66
L2	0.47 mH, 0.21 Ω 0.47 mH, 0.31 Ω	1	EAC33-16-470 EAC32-18-470	5.73 4.78
C2	2.7 µF*	1	MET25-05-2.70/PB MPX25-03-2.70	0.95 1.79

* This part from the standard tweeter crossover may be reused.

Selenium D220Ti-8 and JBL PT-B99HF-1

This combination can be used in a **12/6** or a **15/6**. The nominal L-pad settings are 3 for a **12/6**, 7 for a **15/6** and fully-on for a **12/6** + **12sub**.



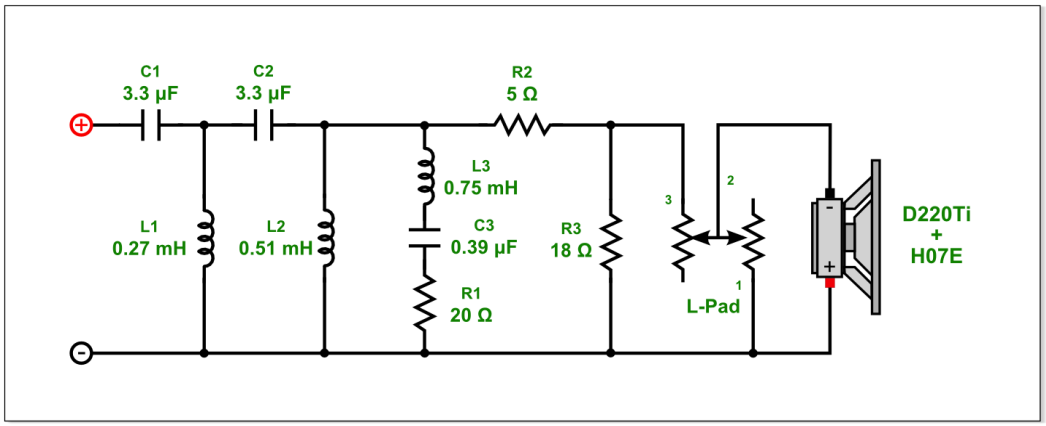
Component		*Qty*	*Erse P/N*	*Cost*
R1	4 Ω, 25 W	1	EWR25-05-4.0	0.60
C1	2.7 µF*	1	MPX25-03-2.70	1.79
L1	0.18 mH, 0.17 Ω*	1	EAC31-18-180	3.08
C2	2.2 µF	1	MPX25-03-2.20	1.63
L2	0.2 mH, 0.13 Ω 0.2 mH, 0.18 Ω	1	EAC32-16-200 EAC31-18-200	3.91 3.24
L3	0.1 mH, 0.12 Ω*	1	EAC31-18-100	2.66
C3	12 µF	1	MPX25-03-12.0	4.57
L4	0.75 mH, 0.27 Ω 0.75 mH, 0.59 Ω	1	EAC34-16-750 EAC14-20-750	4.33 4.08
C4	2 µF	1	MPX25-03-2.0	1.41
R2	5 Ω, 10 W	1	EWR10-05-5.0/PB	0.35

* This part from the standard tweeter crossover may be reused.

Selenium D220Ti-8 and Dayton H07E

This combination can be used in a **12/6** or a **15/6**. The nominal L-pad settings are 3 for a **12/6**, 7 for a **15/6** and fully-on for a **12/6** + **12sub**.

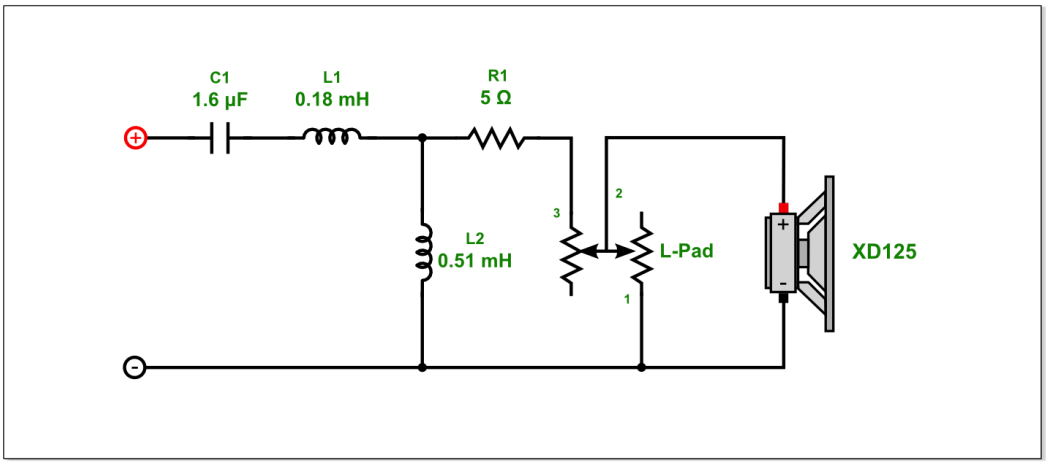
If the fixed L-pad (R2 and R3) is removed, it can also be used in a **1515/66** as an alternative to the D220Ti and Pyle PH612.



Component		*Qty*	*Erse P/N*	*Cost*
C1	3.3 µF	1	MPX25-03-3.30	2.05
L1	0.27 mH, 0.15 Ω	1	EAC32-16-270	4.34
C2	3.3 µF	1	MPX25-03-3.30	2.05
L2	0.51 mH, 0.22 Ω 0.5 mH, 0.32 Ω	1	EAC33-16-510 EAC32-18-500	5.98 4.83
L3	0.75 mH, 0.27 Ω 0.75 mH, 0.59 Ω	1	EAC34-16-750 EAC14-20-750	4.33 4.08
C3	0.39 µF	1	MPX63-03-0.39	1.46
R1	20 Ω, 10 W	1	EWR10-05-20.0/PB	0.35
R2	10 Ω, 25 W	2	EWR25-05-10.0/PB	1.20
R3	43 || 33 Ω, 25W *or* 10 + 8 Ω, 25 W *in series*	1 ea	EWR25-05-43.0/PB EWR25-05-33.0/PB *or* EWR25-05-8.0/PB EWR25-05-10.0/PB	1.20

18 Sound XD125

The XD125 is normally used in a **15/6**. It is too large to fit in a **12/6**, but will fit in a **12/6cube**. Nominal L-pad settings are 3 for a **12/6cube**, 7 for a **15/6** and fully-on for a **12/6cube** + **12sub**.

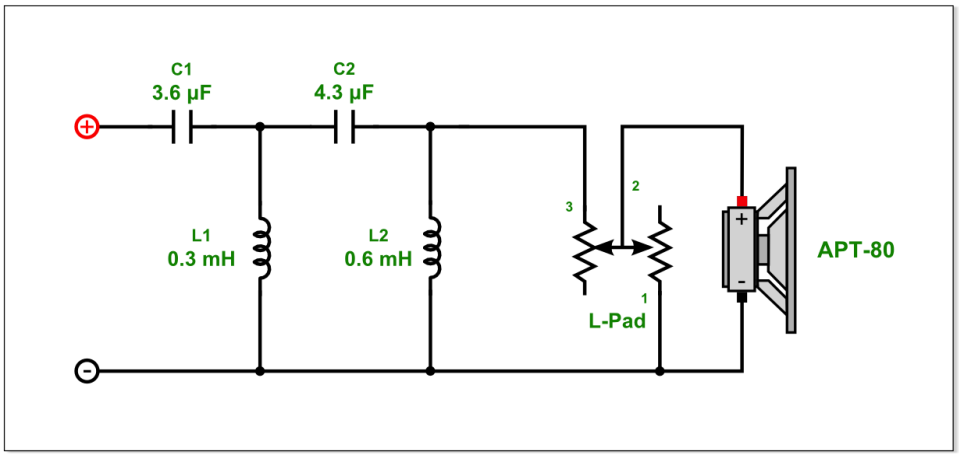


Component		*Qty*	*Erse P/N*	*Cost*
C1	1.6 µF	1	MPX25-03-1.60	1.28
L1	0.18 mH, 0.17 Ω*	1	EAC31-18-180	3.08
L2	0.51 mH, 0.22 Ω 0.5 mH, 0.32 Ω	1	EAC33-16-510 EAC32-18-500	5.98 4.83
R1	10 Ω, 25 W	2	EWR25-05-10.0/PB	1.20

* This part from the standard tweeter crossover may be reused.

Eminence APT-80

This Eminence super-tweeter is used in the **15/6/1tube**.

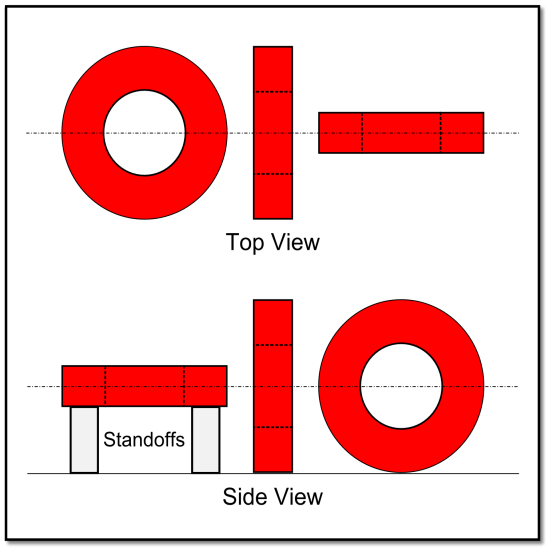


Component		*Qty*	*Erse P/N*	*Cost*
C1	3.6 µF	1	MPX25-03-3.60	2.05
L1	0.3 mH, 0.25 Ω	1	EAC32-18-300	4.21
C2	4.3 µF	1	MPX25-03-4.30	2.45
L2	0.6 mH, 0.36 Ω	1	EAC33-18-600	5.33

Notes

- The parts lists reference Erse components, but this should not necessarily be considered an endorsement of Erse. Similar components from other suppliers should work equally well. Substitute inductors should have resistances similar to those of the Erse inductors.
- Alternative component choices are shown as multiple rows within a single table cell. To keep the component lists short a single PulseX capacitor part number is usually shown, but other PulseX or PEx capacitors of the same value may be substituted.
- Multiple capacitors may be connected in parallel to create values that cannot be obtained as single components. The resulting value is the sum of the individual values (e.g. 1 uF in parallel with 3 uF makes 4 uF). If an existing cabinet is to be modified, some of the existing capacitors might be re-used by parallelling them with new capacitors with appropriate values. Parallel connection is indicated by a symbol comprising two vertical parallel lines: ||
- To obtain sufficient power-handling, the resistors used in fixed pads are typically constructed from several resistors in parallel.

- Some of the components from the standard crossovers may be reused if an existing cabinet is being modified to use 3-way crossovers. These components are marked with asterisks in the parts lists. As indicated in the parts table footnotes, certain coils may be reused after adjusting their inductance by removing a specified number of turns. Turns should be removed from the outside of the coil and new zip-ties should be fitted to keep the coil from unwinding.
- Consult the ***fEARful*** web pages devoted to crossovers for lots of useful information.
- Coils should not be mounted using ferrous (steel) hardware as this can change the inductance value.
- If necessary, coils *can* be mounted close to each other to reduce the space occupied by the crossovers, but care is needed to prevent unwanted coil-to-coil coupling. The following figure shows how to do this. Adjacent coils must be at right angles to each other and their center-lines must be aligned accurately. Coils that are lying flat typically must be raised on standoffs to be aligned with adjacent coils that are mounted on edge. If in doubt, follow the guidelines in the ***fEARful*** crossover web pages and keep coils well separated.



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