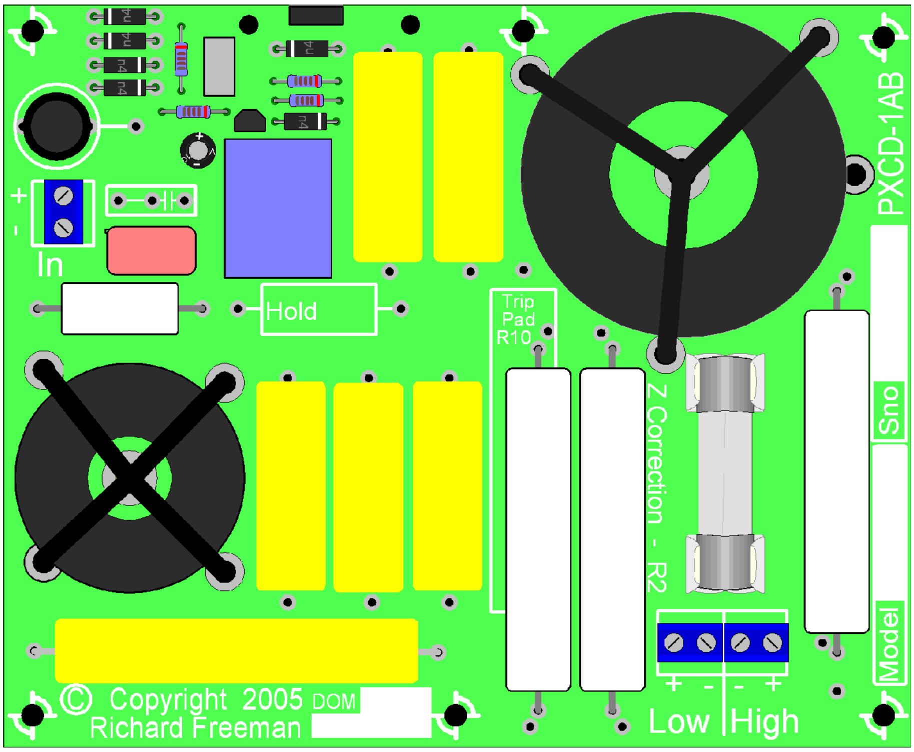
Australian Technical Production Services

2 way Crossover with tweeter protection



Further information may be found at www.atps.net.

Revision history:

6/8/2008	write up of project started
13/05/2013	Tidy up, corrections and completion

Credits

This Article contains contributions by:

Richard Freeman

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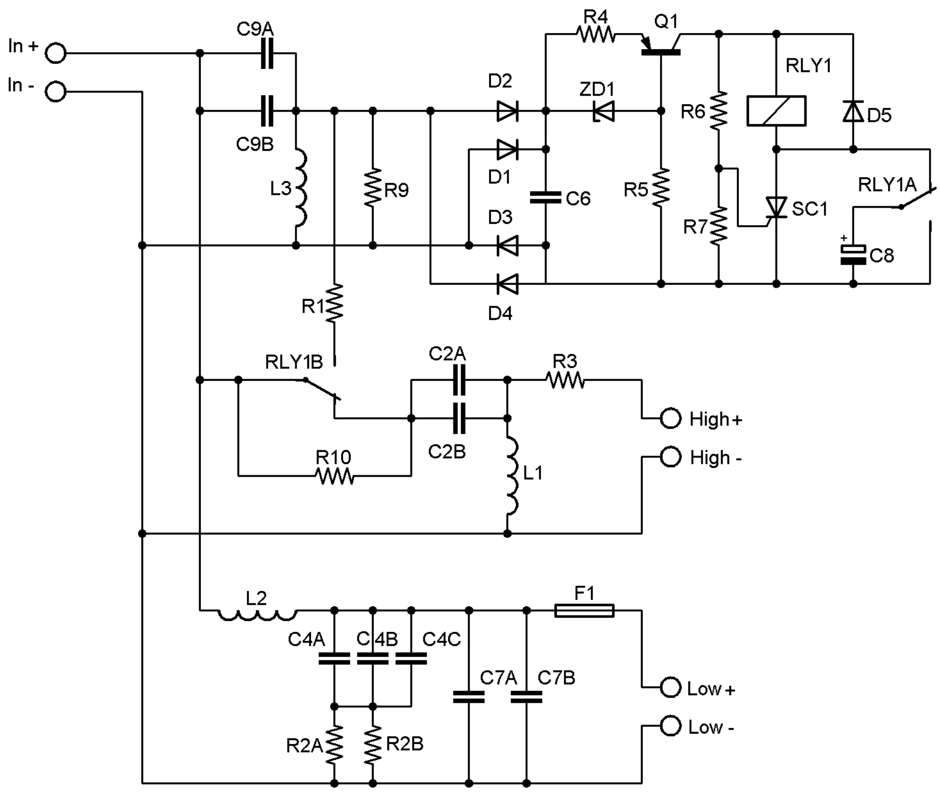
Description



The circuit consists of four sections: the Protection Circuit, the Low pass filter for the woofer, the high pass filter for the tweeter and the protection circuit.

A note before we continue: Since I have no way of knowing what drivers you have, what crossover points you wish to use or what trip point you want on the tweeter protection you will have to work these out for yourself.

In the next section I have broken the equations down – don't let the maths frighten you, just plug the values into the equations and work through them one step at a time.

Low Pass Filter

The Low pass section consists of **L2** and **C7** – these act as a Second order (12dB/Octave) filter for the woofer (leave out **C7** if you merely desire a 6dB per octave crossover) and **C2**,**R4** which provide impedance correction if required.

Low pass Crossover

To Calculate the Value for **L2** you use the formula **L2 =**

$L_2=Z_W/(2\times\pi\times F)$ **L2** is the Inductance of **L2** in Henries,

π is 3.142.

Z_W is the impedance of the woofer

F is the desired crossover Frequency.

To Calculate the value for **C7** use the Formula **C7=**

$C_7=1/(2\times\pi\times F\times Z_W)$ **C7** is the value of capacitor **C7** in Farads,

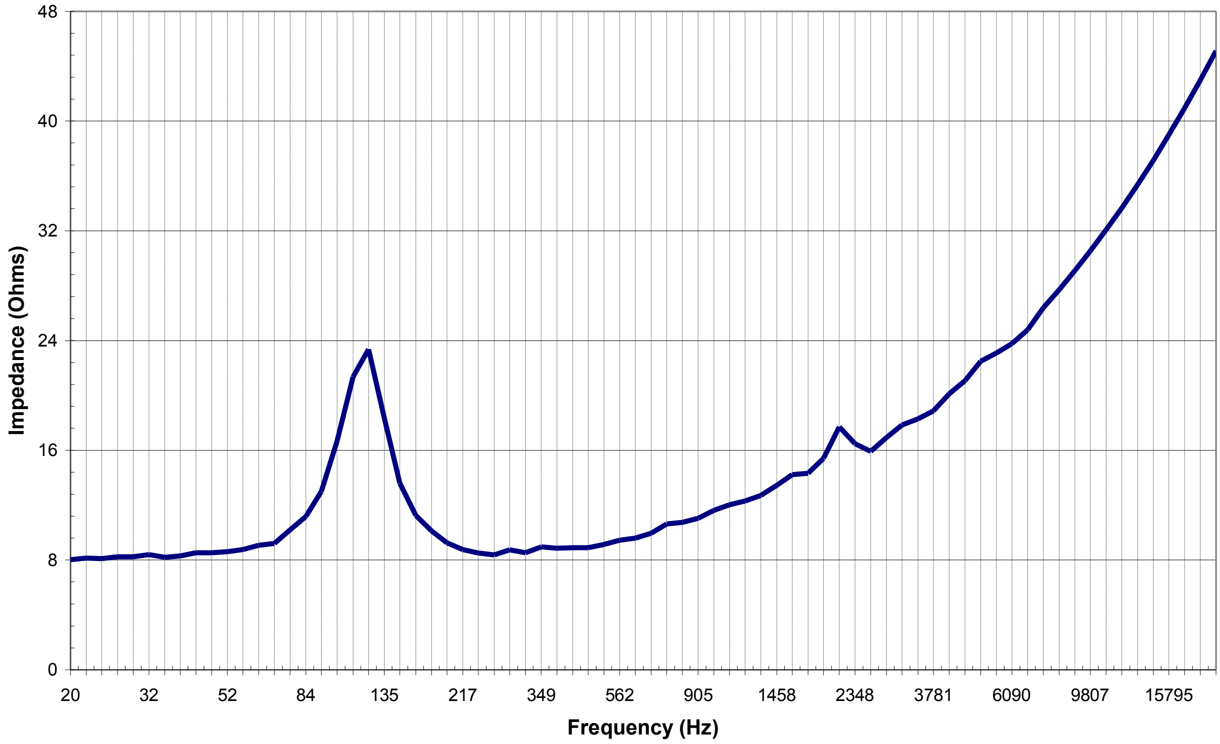
π is 3.142,

Z_W is the impedance of the woofer.

F is the desired crossover Frequency.

Due to the weight of a typical inductor it is strongly recommended that **L1** and **L2** be cable tied down using the holes provided if this crossover is to be used in any portable speakers.

Now the problem with the common, simplistic approach to crossover design is that these simple formulae presume that the impedance of a speaker is fixed. Unfortunately Speakers are inductive and this means that the impedance increases as the frequency increases so that an 8 ohm speaker can be 16 ohms or more at the crossover frequency – here's one I measured earlier:



This speaker starts off near 8 ohms but by the time we get to 2.5Khz (a not unusual crossover frequency) the impedance has risen to 16 ohms.

If we based our calculations on the nominal 8 ohm impedance then we get **L2**=0.509mH and **C7**=7.96uF

If we now recalculate crossover frequency using the impedance of the speaker at 2.5Khz L2 suggests a crossover of 5Khz and **C7** 1250Hz.

This means that while the slope of the crossover may not be optimal, the effect of **C7** normally does go some way to compensate for the rising impedance of the driver.

Alternatively if we base our calculation on 16 ohms impedance we get **L2**= 1mH and **C7**=4uF and the crossover starts to cut in somewhere around 1000Hz.

So what do we do? I am afraid that really the best choice for the home constructor at this point is try different values for the crossover and see what results you get – I usually rats nest a basic crossover together and connect it to the speaker using a Speakon connector while testing.

Usually simply basing your calculations on the nominal impedance (in this example 8 ohms) provides more than adequate results. However, if you are having trouble getting good results, the next trick is to try adding impedance correction.

Impedance correction

Impedance correction consists of **R2** and **C4** where **R2** equals the nominal impedance of the speaker.

To calculate the value of **C4** we want the reactance of **C4** to equal **R2** (the nominal speaker impedance) at the frequency where the reactive inductance of the speaker also equals **R2**.

The first step depends on what information you have about the speaker, if you know the speaker inductance you can use the formula:

$F=R_2/(2\times\pi\times Ls)$	**F** is Frequency,
	R_2 = the nominal woofer impedance.
	Ls is the woofer inductance.

Alternatively if you have a graph such as the one above you could simply read the graph to discover at what frequency the impedance is twice the nominal impedance (in this case about 2350Hz).

Next we take the value of **F** that we just calculated (or read) and plug that into the next formula:

$C_4=1/(2\times\pi\times R_2\times F)$ — **F** is the frequency calculated in the previous step; **R_2** = nominal woofer impedance.

Using the driver above as an example:

Ls = 0.54mH

So

F = $8/(2\times\pi\times0.00054)$

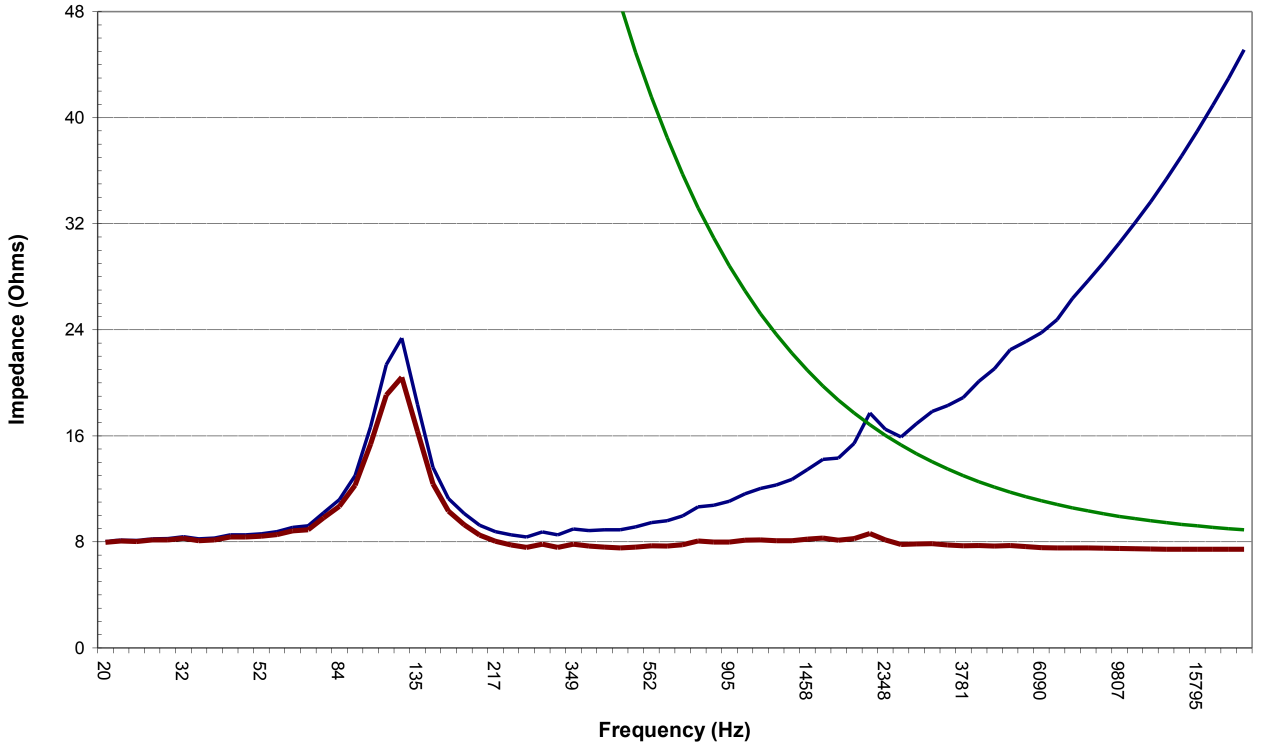
F = 2357Hz

Ok so I didn't read the graph as accurately as I could, but this is still near enough to what the graph says and in reality that would be close enough.

C_4 = $1/(2\times\pi\times8\times2357)$

C_4 = 8.44uF

If we add **C4** and **R2** across the woofer this flattens the impedance significantly:



The Green line shows the impedance of the impedance correction circuit, the blue line is the impedance of the woofer and the red line is the result.

While not dead flat, the resulting impedance above 200 Hz is significantly better than it was making it more than adequate for calculating crossover values.

Note that as the impedance correction circuit doesn't really have a significant affect until around 2Khz or so the components do not usually need to have an exceptionally high power rating and 10 or 20 Watt resistors are usually more than adequate for normal use.

High pass Filter

Fortunately tweeters tend to have a much lower inductance than woofers so we do not need to worry about impedance compensation.

Before we start on the crossover calculations we need to work out the Pad resistor **R3** as this will affect the crossover calculations.

Pad

To calculate the pad resistor we first calculate the difference in sensitivity (in **dB**):

$dB=W_S-T_S$

T_S is the tweeter sensitivity

W_S is the woofer sensitivity

dB is the difference in sensitivity – note that this should give a negative value (i.e. the tweeter is more sensitive than the woofer) if not, then the tweeter may not be a good match with the woofer. If the result is within +/-2dB then you may elect not to bother padding down the tweeter. In this case replace **R3** with a wire link.

We now need to convert **dB** to a voltage ratio (**V**) (as the pad is essentially a voltage divider) this is done using the formula:

$V=\log(dB/20)$ where **dB** is the difference in sensitivity calculated in the previous equation

Now we use the ratio V to calculate the pad resistance:

$R_3=Z_T-(Z_T/V)$

R_3 is the value of **R3** in ohms

Z_T is the nominal impedance of the tweeter

V is the result of the previous equation.

Do to the higher sensitivity of the tweeter, 10 Watts for **R3** is usually more than adequate, however the PCB does have extra pads for mounting an additional 10Watt resistor in parallel if required.

High pass Crossover

To Calculate the Value for **L1** you use the formula

$L_1=(Z_T+R3)/(2\times\pi\times F)$

L1 is the Inductance of **L1** in Henries,

π is 3.142,

Z_T is the impedance of the tweeter,

R_3 is the tweeter pad,

F is the desired crossover frequency.

To Calculate the value for **C2** use the Formula

$C_2=1/(2\times\pi\times F\times(Z_T+R_3))$

C2 is the capacitance in Farads,

π is 3.142,

Z_T is the impedance of the tweeter,

R3 is the tweeter pad

F is the desired crossover Frequency.

Due to the weight of a typical inductor it is strongly recommended that L1 is cable tied down using the holes provided if this crossover is to be used in portable speakers.

Protection circuit

Trigger filter

C9 and **L3** act as a high pass filter while **R9** provides a constant/predictable load for the filter.

To calculate the values of **C9** and **L3** use the formulae

$C_9=1/(2\times\pi\times F\times150)$

F is the crossover frequency

C9 is the value in Farads.

$L_3=150/(2\times\pi\times F)$ where F is still the crossover frequency

L3 is the value in Henries.

L3 does not need to be a high current inductor and **C9** can be a regular 100V Green cap (or caps).

D1 to **D4** are UF4004 high speed diodes which operate as a full wave rectifier and **C6** is a 0.82uF capacitor which acts as the Filter and also provides a slight delay before the circuit triggers – a larger value than 0.82uF will provide a longer delay and the value of C6 may be varied to suit your application.

Trip point

R6 (Set as required) and **R7** (560 Ohm) act as a voltage divider for the trigger for the SCR - **SC1** and set the voltage at which the protector trips.

Most tweeters I tested, were lucky to survive even their 'rated' power for any significant period of time, so you may need to be conservative setting the trip point. Also most compression drivers are distorting badly by the time they hit 20 Watts or so, so a trip level of around 20 Watts is a fairly safe bet.

If you have the money, can get replacement diaphragms cheaply enough, or are making more than a couple of speakers then it may very well be worth testing a few tweeters to destruction in order to discover what their real long term power ratings are.

Before we can calculate **R6** we need to know what the required trip voltage is this can be calculated using:

$T_V = \sqrt{((P/Z_T)\times(R_3+Z_T))}$ T_V is the Trip voltage,

P is the maximum power the tweeter can safely handle (in watts),

Z_T is the tweeter impedance

R3 is the pad resistor.

R6 may now be calculated by:

$R6 = (T_V - 0.56)\times 1000$ T_V is the trip Voltage.

R1 allows the Input filter to be bypassed If / when the protection is triggered. This will keep protection active until it is reset by a complete absence of signal.

I have not used this option yet but I would suggest an **R1** of around 39 Ohms to keep the protection active until the signal drops below 10 Watts or so (for an 8 ohm speaker).

C8 (10uF) resets the SCR when the Relay drops out - resetting the protection circuit and stopping any potential false triggering.

Q1(MJE340), **R4** (91 Ohm), ZD1 (3V3) and **R5** act as a current limit to stop the Relay burning out due to excess voltage from the power amplifier.

RLY1 is a Relay with a 400 Ohm coil and **R9** is set at 150 Ohms, This sort of extra load any half decent power amplifier should be able to drive without even noticing and this does make the Circuit self powered.

* I designed the PCB using what was (for me) a readily available relay, with the logic that anything I could get would be widely available overseas also. For Australian buyers this Relay is available from Jaycar

Songle SRE_12VDC_SL_2C is readily available on Ebay which has a 320Ω coil. This Relay (or other Relays with a 320Ω coil) may be used however **R4** will need to be changed to 75Ω.

Component notes

First thing to mention is that Filter components need to be handle adequate current.

Unfortunately capacitors usually have voltage ratings and capacitance but I have yet to see a manufacturer mention current carrying capacity.

As a general rule higher voltage capacitors especially if they have higher voltage ratings will handle more power than smaller lower voltage ones.

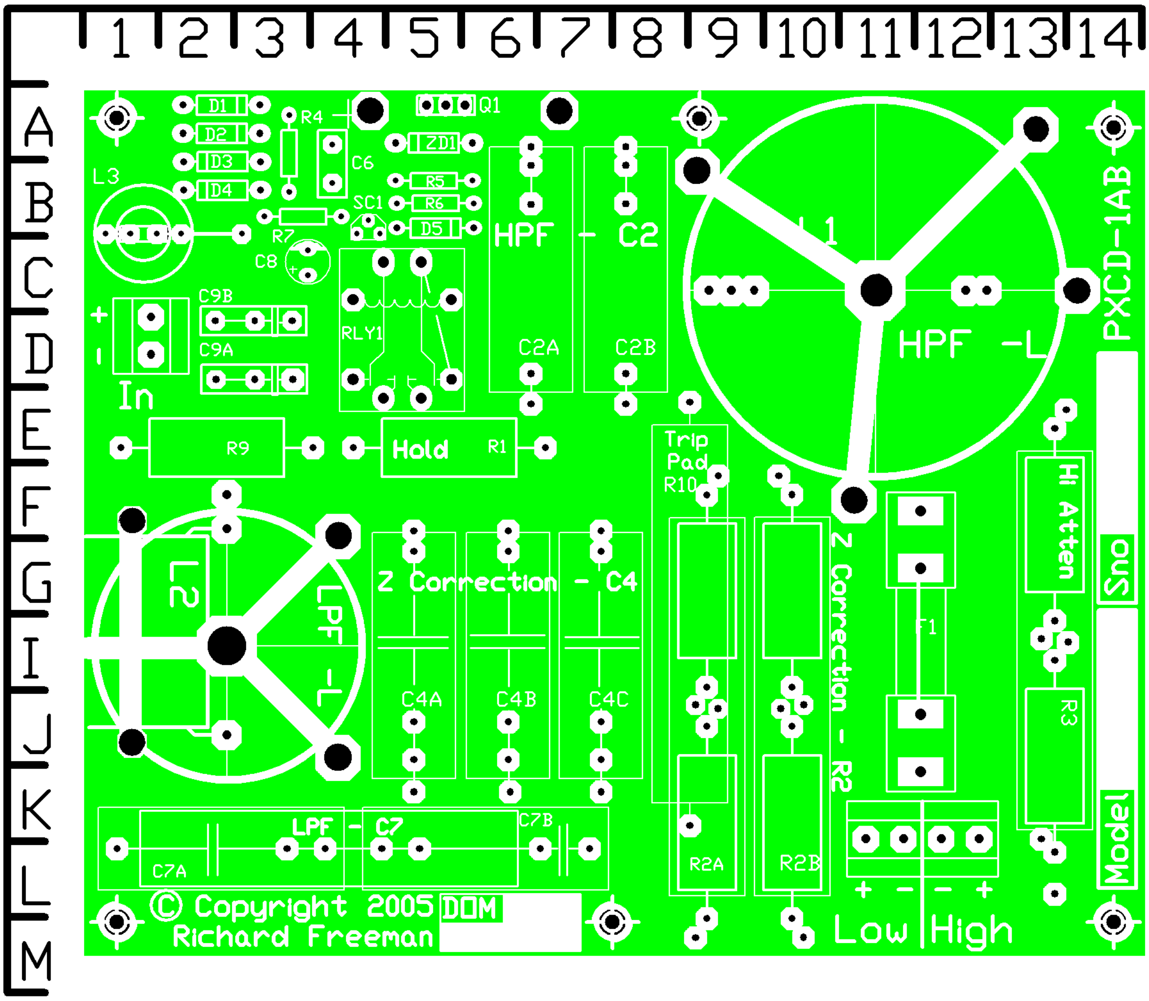
The Patterns for **R2** and **R3** allow for either single 10Watt resistors or two 5Watt resistors in series – this is because for some strange reason it is actually cheaper to purchase 2× 5 Watt resistors than a single 10 Watt resistor.

The PCB allows for two or more capacitors in parallel for **C2**,**C4** and **C7,** this is because you would be very unlikely to be able to get Capacitors with the exact required value and you will need to make up the required value using two capacitors in parallel.

You would be lucky to get inductors the exact value you need and what I do is buy the next value up and unwind the inductor (measuring as I go) until I get the value I am after.

Construction

Parts locator



Part	Location	Description	Part	Location	Description
C2A	C6		L1	C11	
C2B	C7		L3	B1	
C4A	I5		Q1	A5	MJE340 or similar
C4B	I6		R1	E5	
C4C	I7		R2	J9 - 10	
C6	B4	0.82uF 100V polyester	R3	K13	
C7A	L3		R4	A3	91Ω or 75Ω 1/4W *
C7B	L5		R5	B5	15K 1/4W
C8	C3	10uF 63V Electrolytic	R6	B5	
C9A	E2		R7	B3	560 Ω 1/4W
C9B	D2		R9	E2	150 Ω 5W
D1-2	A2	UF4004 high speed diode	R10	G8	
D3-4	B2	UF4004 high speed diode	RLY1	D5	320 or 400 Ω DPDT 5A Relay *
D5	B5	1N4001			
F1	I11	3AG	SC1	B4	BT169
	F11, J11	fuse holder - 3AG clip	ZD1	A5	3.3V 1W Zener
L2	I2				

Calculation Summary and scratch pad:

The blank area to the right of these equations is to give you room to rewrite these equations using the correct Values.

Low pass filter

Impedance correction (R2 and C4)

Where **R2** = the nominal impedance of the woofer in ohms, **C4** is in Farads, **F** is the frequency at which woofer impedance is twice its nominal impedance and **Ls** is the woofer inductance

R2= **C4=**

$F=R_2/(2\times\pi\times Ls)$

$C_4=Ls/(2\times\pi\times R_2\times F)$

Low pass crossover (L2 and C7)

C7 is in Farads, **L2** is Inductance in Henries, π is 3.142, Z_W is the impedance of the woofer and **F** is the desired crossover Frequency.

L2= **C7=**

$L_2= Z_W /(2\times\pi\times F)$

$C_7=1/(2\times\pi\times F\times Z_W)$

High pass filter

Tweeter pad (R3)

W_S is woofer sensitivity (in dB*), T_S is tweeter sensitivity (in dB*), **V** is the ratio of sensitivity expressed as a voltage and Z_T is the tweeter impedance

R3=

$dB=W_S-T_S$

$V=\log (dB/20)$

$R_3=Z_T-(Z_T/V)$

High pass crossover (C2 and L1)

F is the crossover frequency, Z_T is the tweeter impedance and R_3 is the tweeter pad

C2= **L1=**

$L_1= (Z_T+R_3) /(2\times\pi\times F)$

$C_2=1/(2\times\pi\times F\times(Z_T+R_3))$

Protection

Trip level (R6)

P is the maximum power rating for the tweeter, **T_V** is the trip voltage, **Z_T** is the tweeter impedance and **R_3** is the tweeter pad

R6=

$$T_V = \sqrt{(P/Z_T)\times(R_3+Z_T)}$$

$$R6 = (T_V - 0.56)\times 1000$$

High pass filter (C9 and L3)

F is the crossover frequency

C9= **L3=**

$$C_9 = 1/(2\times\pi\times F\times 150)$$

$$L_3 = 150/(2\times\pi\times F)$$

Parts list

Part no	Qty	Description	Part no	Qty	Description
C2A			L3		
C2B			Q1	1	MJE340 or similar
C4A			R1		
C4B			R2		
C4C			R3		
C6	1	0.82uF 100V polyester	R4	1	85Ω or 75Ω 1/4W *
C7A			R5	1	15K 1/4W
C7B			R6		
C8	1	10uF 63V Electrolytic	R7	1	560 Ω 1/4W
C9A			R9	1	150 Ω 5W
C9B			R10		
D1-4	4	UF4004 high speed diode or equivalent	RLY1	1	400 Ω DPDT 5A Relay *
D5	1	1N4001	SC1	1	BT169
F1	1	3AG	ZD1	1	3.3V 1W Zener
	2	fuse holder - 3AG clip		6	Cable ties 3mm x 100mm
L1				6	6mm Spacers
L2			CN1-3	3	Dual 5mm PCB screw terminals

* Relay notes

I designed the PCB using what was (for me) a readily available relay, with the thought that anything I could get would be widely available overseas also. For Australian buyers this Relay is available from Jaycar

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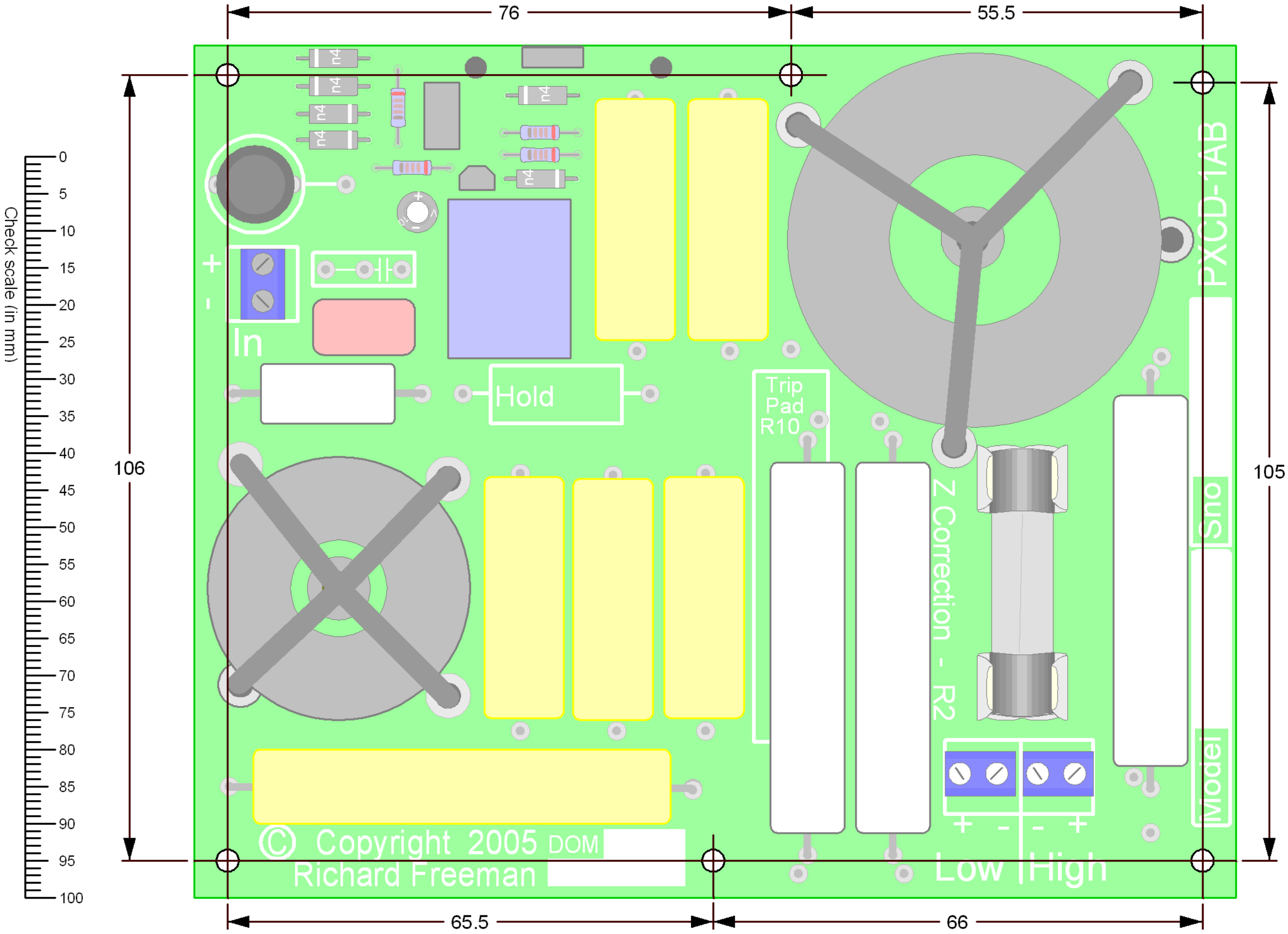
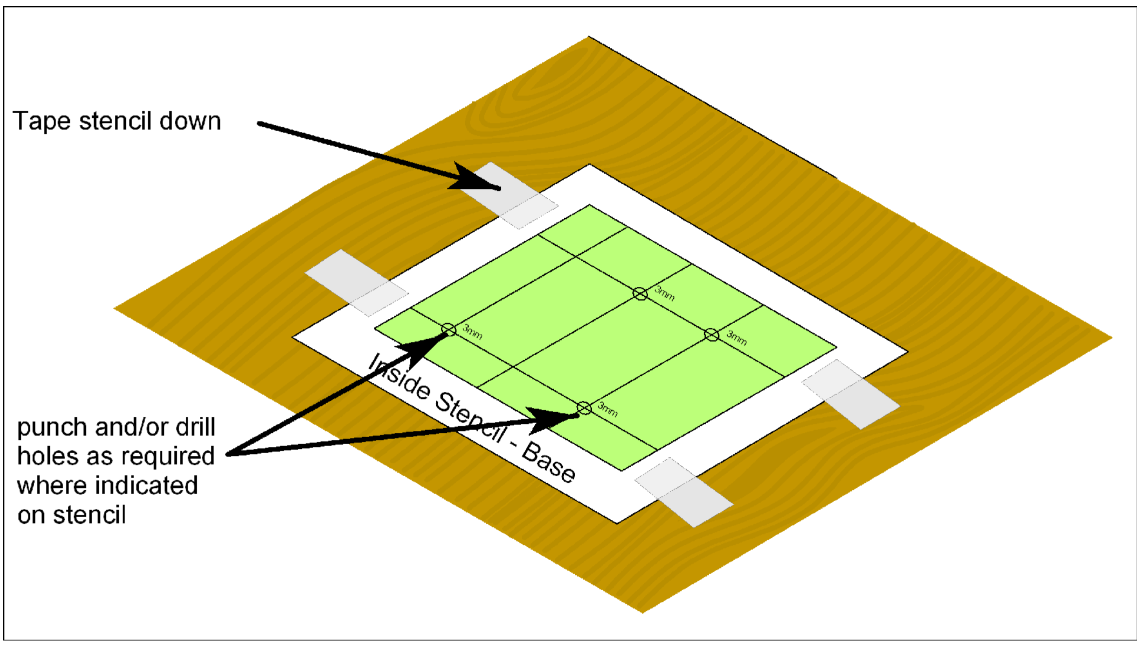
Template



Inside Stencil - Base

Note: print PDF as "Actual size" DO NOT "Fit" " Shrink oversized pages" or "Custom scale". Cut around the template, tape where you wish to mount the crossover and using a punch. Mark where the screws to mount the PCB are to go, as shown below.



Bill of Materials

Part no	Qty	Description	Notes
C2A		Calculate	
C2B		Calculate	
C4A		Calculate	
C4B		Calculate	
C4C		Calculate	
C6	1	0.82uF 100V polyester	
C7A		Calculate	
C7B		Calculate	
C8	1	10uF 63V Electrolytic	
C9A		Calculate	
C9B		Calculate	
D1-4	4	UF4004 high speed diode or equivalent	
D5	1	1N4001	
F1	1	3AG	
	2	fuse holder - 3AG clip	
L1		Calculate	
L2		Calculate	
L3		Calculate	
Q1	1	MJE340 or similar	
R1			
R2		Calculate	
R3		Calculate	
R4	1	91 or 75 Ω 1/4W	
R5	1	15K 1/4W	
R6			
R7	1	560 Ω 1/4W	
R9	1	150 Ω 5W	
R10		Calculate	
RLY1	1	FRS6-S5-DC12V 400 Ω DPDT 5A Relay	
SC1	1	BT169	
ZD1	1	3.3V 1W Zener diode	
	7	Cable ties 3mm x 100mm	
	6	6mm Spacers	
	3	2 way 5mm PCB Screw terminal	