Australian Technical Production Services

2 Way Second order Passive Crossover with Tweeter protection for AST0801

Assembly Instructions for Revision PXCD-1AB

Document Revision history:
rev 1.2 12/04/2010
rev 1.1 12/09/2009 - Derived from Document PXCD-1AB

Parts list – Note spaces left blank are for values calculated for your specific application – please see notes in the text for calculating these values

Parts List / Bill of Materials – AST0801

Part no	Qty	Description	Part no	Qty	Description
C2A	**1**	1uF 250V	**L3**	**1**	10mH
C2B	**1**	2.2uF 250V	**Q1**	**1**	MJE340 or similar
C4A	**0**	--	**R1**	**0**	--
C4B	**0**	--	**R2**	**0**	--
C4C	**0**	--	**R3A**	**1**	8.2 Ω 5 Watt
C6	**1**	0.82uF 100V polyester	**R3B**	**1**	6.8 Ω 5 Watt
C7A		6.8uF 250V	**R4**	**1**	82 **Ω** ¼ W
C7B	**0**	--	**R5**	**1**	15K Ω ¼ W
C8	**1**	10uF 63V Electrolytic	**R6**	**1**	24K Ω ¼ W
C9A	**1**	0.47uF	**R7**	**1**	560 **Ω** ¼ W
C9B	**0**	--	**R9**	**1**	150 **Ω** 5W
D1-4	**4**	UF4004 high speed diode or equivalent	**R10**	**0**	--
D5	**1**	1N4001	**RLY1**	**1**	**FRS6-S5-DC12V or TR99-12VDC-SB-CD or Ningbo 4099 (JVC-7F) or similar**
F1	**1**	3AG 5 Amp	**SC1**	**1**	BT169
	2	fuse holder - 3AG clip	**ZD1**	**1**	3.3V 1W Zener
L1	**1**	1.5mH		**6**	Cable ties 3mm x 100mm
L2	**1**	0.82mH		**6**	6mm Spacers

Parts List / Bill of Materials – Blank / Generic

Part no	Qty	Description	Part no	Qty	Description
C2A			**L3**		
C2B			**Q1**	**1**	MJE340 or similar
C4A			**R1**		
C4B			**R2**		
C4C			**R3A**		
C6	**1**	0.82uF 100V polyester	**R3B**		
C7A			**R4**	**1**	82 **Ω** 1/4W
C7B			**R5**	**1**	15K **Ω** 1/4W
C8	**1**	10uF 63V Electrolytic	**R6**		
C9A			**R7**	**1**	560 **Ω** 1/4W
C9B			**R9**	**1**	150 **Ω** 5W
D1-4	**4**	UF4004 high speed diode or equivalent	**R10**		
			RLY1	**1**	**FRS6-S5-DC12V or TR99-12VDC-SB-CD or Ningbo 4099 (JVC-7F) or similar**
D5	**1**	1N4001			
F1	**1**	3AG	**SC1**	**1**	BT169
	2	fuse holder - 3AG clip	**ZD1**	**1**	3.3V 1W Zener
L1				**6**	Cable ties 3mm x 100mm
L2				**6**	6mm Spacers

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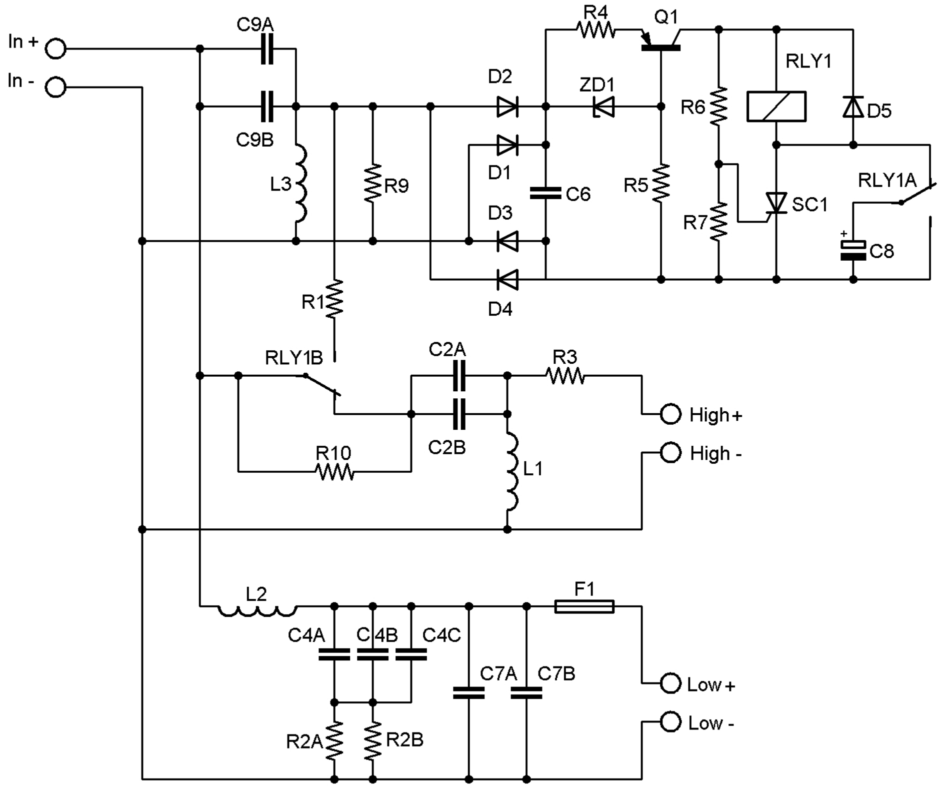
Circuit Description



The circuit consists of three sections the Protection Circuit, the Low pass section for the woofer and the high pass section for the tweeter.

Low Pass Filter

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

Crossover

To Calculate the Value for L2 you use the formula

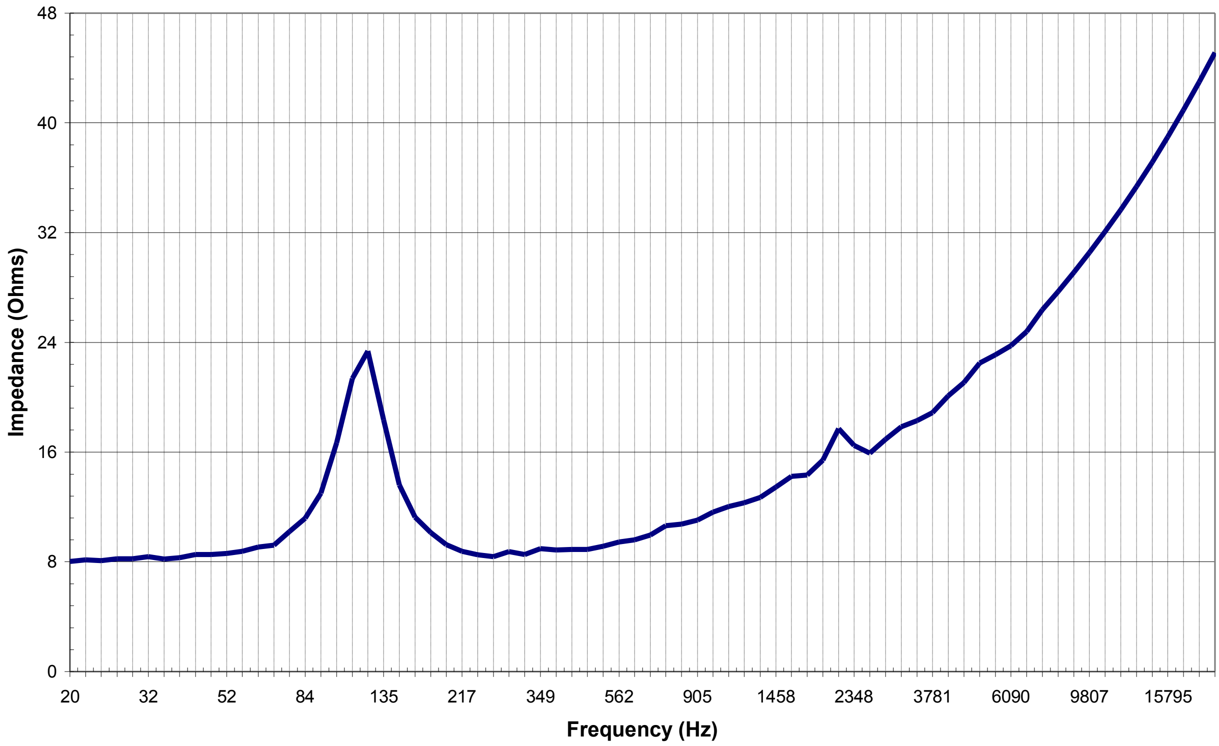
$L_2=Z_W/(2\times\pi\times F)$ where L2 is the Inductance in Henries, π is 3.142, Z_W is the impedance of the woofer and F is the desired crossover Frequency.

To Calculate the value for C7 use the Formula

$C_7=1/(2\times\pi\times F\times Z_W)$ where C7 is the capacitance in Farads, π is 3.142, Z_W is the impedance of the speaker and F is the desired crossover Frequency.

Due to the weight of a typical inductor it is strongly recommended that 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, while 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.
Simply basing your calculations on the nominal impedance (in this example 8 ohms) usually 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:

$\mathbf{F=R_2/(2\times\pi\times L)}$ where F is Frequency, $R_2 =$ the nominal woofer impedance and L is the driver inductance.

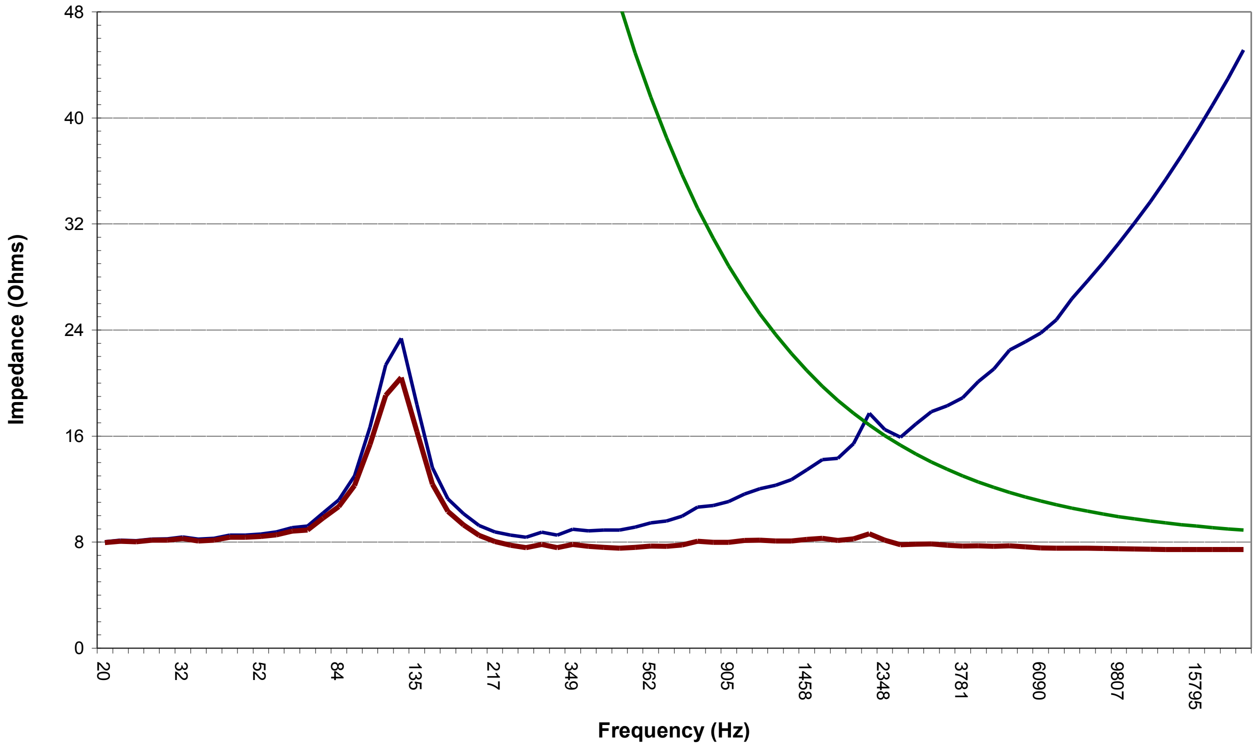
Alternatively if you have a graph such as the one above you could simply read the graph to discover at what frequency the impedance is twice the nominal impedance (in this case about 2350Hz)

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

C_4=1(/2×π×R_2×F) where F is the frequency calculated in the previous step and R2 is the nominal woofer impedance.

Using the driver above as an example:
L=0.54mH
So
F=8/(2×π×0.00054)
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 would be close enough)

C_4= 1/(2×π×8×2357)
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 and W_S is the woofer sensitivity and 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 use the ratio V to calculate the pad resistance:

$R_3=Z_T-(Z_T/V)$ — where Z_T is the nominal impedance of the tweeter and 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 a second 10Watt resistor in parallel if required.

Crossover

To Calculate the Value for L1 you use the formula

$L_1=Z_W/(2\times\pi\times F)$ — where L1 is the Inductance in Henries, π is 3.142, Z_T is the impedance of the tweeter, R3 is the tweeter pad and F is the desired crossover frequency.

To Calculate the value for C2 use the Formula

$C_2=1/(2\times\pi\times F\times(Z_T+R_3))$ — where C2 is the capacitance in Farads, π is 3.142, Z_T is the impedance of the tweeter, R3 is the tweeter pad and F is the desired crossover Frequency.

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

$C_9=1/(2\times\pi\times F\times 150)$ — where F is the crossover frequency and C9 is the value in Farads.

$L_3=150/(2\times\pi\times F)$ — where F is still the crossover frequency and L3 is the value in Henries.

L3 does not need to be a particularly high current inductor and C9 can be made up using regular 100V Green caps.

D1 to D4 are UF4004 high speed diodes which operate as a full wave rectifier and C6 is a 0.82uF (May be varied to suit application) capacitor which acts as the Filter and also provides a slight delay before the circuit triggers.

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 their ‘rated’ power for any significant period of time so you will need to be conservative with the trip point, also most compression drivers are distorting badly by the time they hit 20Watts or so, making a trip level of 20 Watts a fairly safe bet in most cases.
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:

$T_V = \sqrt{((P/Z_T)\times(R_3+Z_T))}$ where TV is the Trip voltage, P is the maximum power the tweeter can safely handle (in watts), ZT is the tweeter impedance and R3 is the pad resistance.

R6 may be calculated by

$R6 = (T_V - 0.56)\times 1000$ where 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 suggest R1 of around 39 Ohms will 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 (85 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.

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 will be lucky to get inductors the exact value you need – what I do is buy the next value up and unwind the inductor until I get the value I am after.

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

Crossover (L2 and C7)

L2= **C7=**

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

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

Impedance correction (R2 and C4)

R2= **C4=**

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

$C_4 = 1(/2 \times \pi \times R_2 \times F)$

High pass filter

Tweeter pad (R3)

R3=

$dB = W_S - T_S$

$V = \log(dB/20)$

$R_3 = Z_T - (Z_T/V)$

Crossover (C2 and L1)

C2= **L1=**

$L_2 = (Z_T + R_3)/(2 \times \pi \times F)$

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

Protection

Trip level (R6)

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)

C9= **L3=**

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

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

Circuit Board Layout

Part no		Location		Part no		Location
C2 A,B	**1uF and 2.2uF 250V**	**B 5**		**R1**	**--**	**D4**
C4 A,B,C	**--**	**G 4**		**R2**	**--**	**G6**
C6	**0.82uF 100V**	**A 2**		**R3A**	**8.2 Ω 5W**	**E10**
C7	**6.8uF 250V**	**I 2**		**R3B**	**6.8 Ω 5W**	**H10**
C8	**10uF 63V Electrolytic**	**B 2**		**R4**	**82 Ω 1/4W**	**A2**
C9 A,B	**0.47uF**	**C 1**		**R5**	**15K Ω 1/4W**	**B3**
D1,D2,D3	**UF4004 or equivalent**	**A 1**		**R6**	**24K Ω 1/4W**	**B3**
D4	**UF4004 or equivalent**	**B 1**		**R7**	**560 Ω 1/4W**	**B2**
D5	**1N4001 or equivalent**	**B 3**		**R9**	**150 Ω 5W**	**D1**
F1	**5A 3AG**	**G9**		**R10**	**--**	**F6**
L1	**1.5mH**	**B9**		**RLY1**	**FRS6-S5-DC12V**	**C3**
L2	**0.82mH**	**G1**		**SC1**	**BT169**	**B3**
L3	**10mH**	**B0**		**ZD1**	**3.3V 1W Zener**	**A3**
Q1	**MJE340 or equivalent**	**A3**