Passive Crossovers MADE EASY

PAC

MOBILE AUDIO INTERFACING EQUIPMENT

A publication of
Pacific Accessory Corporation

Pacific Accessory Corporation - 1502 S. Santa Fe Street, Santa Ana, CA 92705
www.go2pac.com Voice: 714-835-3133 Fax: 714- 835-3233 techsupport@go2pac.com

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ON ALL CHARTS THE L (COIL) VALUES ARE IN mHy AND THE C (CAPACITOR) VALUES ARE IN MFD.

note: these pages are unavailable at this time

All correspondence and inquiries should be directed to the President of Pacific Accessory Corporation at 1502 S. Santa Fe Street, Santa Ana, CA 92705.

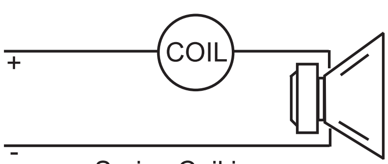
WHAT IS A LOW PASS FILTER?

In it's simplest form, it is a coil in series with a speaker. As diagrammed below, amplifier output passes through the coil. The coil allows only low frequencies to pass through it to the speaker. The speaker could receive 5,000 Hz and lower or it could receive 100 Hz and lower depending on the size or value of the coil on its speaker lead.

These frequencies (5,000 Hz and 100 Hz) are referred to as the crossover frequency of the particular coil/low pass filter. The larger a coil is, the lower the crossover frequency is. Coil size is determined by its measurement in millihenries (mHy).

This is a measurement of Inductance, not necessarily of physical size. A coil is manufactured by winding wire around either a non-metallic or a metallic core or bobbin. In either case, the more winding on the bobbin the greater the mHy.

As an example, a 6.4 mHy coil is required to allow 100 Hz and down to pass through it to a 4ohm woofer. A .13 mHy coil allows 5,000 Hz and down to pass to a 4 ohm speaker.



Series Coil is a lowpass filter

fig 1

If both coils use the same bobbin types (metallic or non-metallic), the 6.4 would physically be 4 or 5 times larger. The physical size difference would be the many more turns of wire required to produce 6.4 mHy versus the .13 mHy.

To summarize, a coil in series as pictured in fig 1 Is a low pass filter. Low pass means lows are allowed to pass through the filter and the highs (above the coil's crossover frequency) are not allowed to pass.

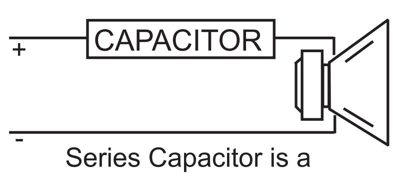
WHAT IS A HIGH PASS FILTER?

It is a capacitor in series with a speaker, usually a midrange speaker or tweeter. As diagrammed below, the amplifier output passes through the capacitor. The capacitor allows only high frequencies to pass through it to its speaker. A midrange could receive 100 Hz and higher and a tweeter 5,000 Hz and higher.

These frequencies (100 Hz and 5,000 Hz) are referred to as the crossover frequency of the particular capacitor used. Capacitors are measured in microfarads (mfd). The greater the mfd of a capacitor the lower the frequency at which it allows the higher frequencies to begin to pass through it.

More microfarads generally mean greater physical size as well. As with coils, the size can vary with capacitor type. For instance, a 398 mfd capacitor gives a high pass crossover frequency of 100 Hz when attached to a 4 ohm midrange. A capacitor of 8 mfd produces a high pass crossover frequency of 5,000 Hz when in series with a 4 ohm tweeter.

To summarize, a capacitor in series as pictured in fig 2 Is a high pass filter. High pass means highs are allowed to pass through the filter and the lows (below the capacitor's crossover frequency) are not allowed to pass.



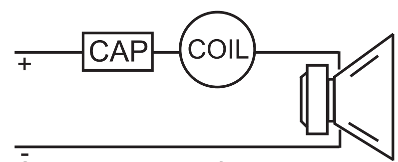
Series Capacitor is a highpass filter

fig 2

WHAT IS A BAND PASS FILTER?

It is both a capacitor and coil in series with a speaker. Amplifier output passes through both the capacitor and the coil. The series capacitor allows a certain frequency (100 Hz as an example) and higher to pass through it. The coil does not allow frequencies higher than its crossover point to pass through it (5,000 Hz, .13 mHy coil as an example).

In essence, the combination of the capacitor and coil allow a limitation of both the low and high frequencies. Therefore, a midrange speaker would receive only the mid frequencies. A band pass filter is pictured in fig 3. Either the coil or capacitor could be first in line.



Series capacitor followed by a series coil is a bandpass filter

fig 3

In summary there are three types of passive crossover filters:

LOW PASS: which allows low frequencies only to pass through it or it blocks out high frequencies. COILS in series are low pass filters.

HIGH PASS: which allows high frequencies only to pass through it or it blocks out low frequencies. CAPACITORS In series are high pass filters.

BAND PASS: is a combination of a high pass capacitor and low pass coil that creates a mid band with both the lows and highs blocked out.

Each filter (coil and/or capacitor) has a crossover frequency. The crossover frequency is determined by the value of the coil (In mHy) or capacitor (in mfd) and the impedance of the speaker or speakers connected to the coil or capacitor.

WHAT IS A THREE WAY PASSIVE NETWORK?

It is a combination low-pass, band pass, and high pass filters needed to limit the frequencies to all the speakers in a system, which consists of a woofer, midrange and tweeter for both left and right channels. Fig 4 shows the coils and capacitors necessary for the very popular frequency divisions (crossover frequencies) of 100 Hz and 5,000 Hz. All speakers in the system are 4 ohm.

The system depicted in fig 4 is very typical and is successfully Installed In many cars. The coils and capacitors used for the left channel would be the same for the right channel. Therefore, only one channel is identified.

HOW DO COILS AND CAPACITORS WORK?

Coils and capacitors (both are non polar) are like frequency sensitive variable resistors. Let's take a 6.4 mHy coil on a 4 ohm speaker lead. We know it gives us a crossover frequency of 100 Hz.

At about 75 to 80 Hz the coil begins to add resistance to the speaker circuit. At each higher frequency, more resistance is added. When 100 Hz has been reached, enough resistance has been added to reduce the power reaching the speaker by 50 % or 3 db. The resistance continues to increase as frequencies passing through the coil become higher.

At one octave up (75 or 80 Hz times 2 which is 150 to 160Hz), the reduction would equal 6 db.

Each additional octave up would gradually reduce another 6 db. The "Power Reduction Chart' gives you an Idea of power vs. db reduction.

POWER REDUCTION CHART

Power Reduction	Reduction in dB
NONE	0
50%	3
75%	6
87.5%	9
93.75%	12
96.75%	15
98.75%	18

As we can see from the chart, it doesn't take much of a frequency change to substantially reduce power allowed to pass to a speaker.

A capacitor does exactly the same thing as a coil only in reverse. A398 mfd capacitor gives a 100 Hz crossover frequency Into a 4 ohm driver. It starts reducing power around 150 Hz and as lower frequencies pass through the capacitor they are gradually reduced. At 100 Hz the reduction equals 3 db and around 75 Hz (one octave down) the reduction has reached 6 db.

The reduction continues as the frequencies passing through the capacitor become lower. Fig 5 depicts the power reduction of a 100 Hz coil and a 100 Hz capacitor.

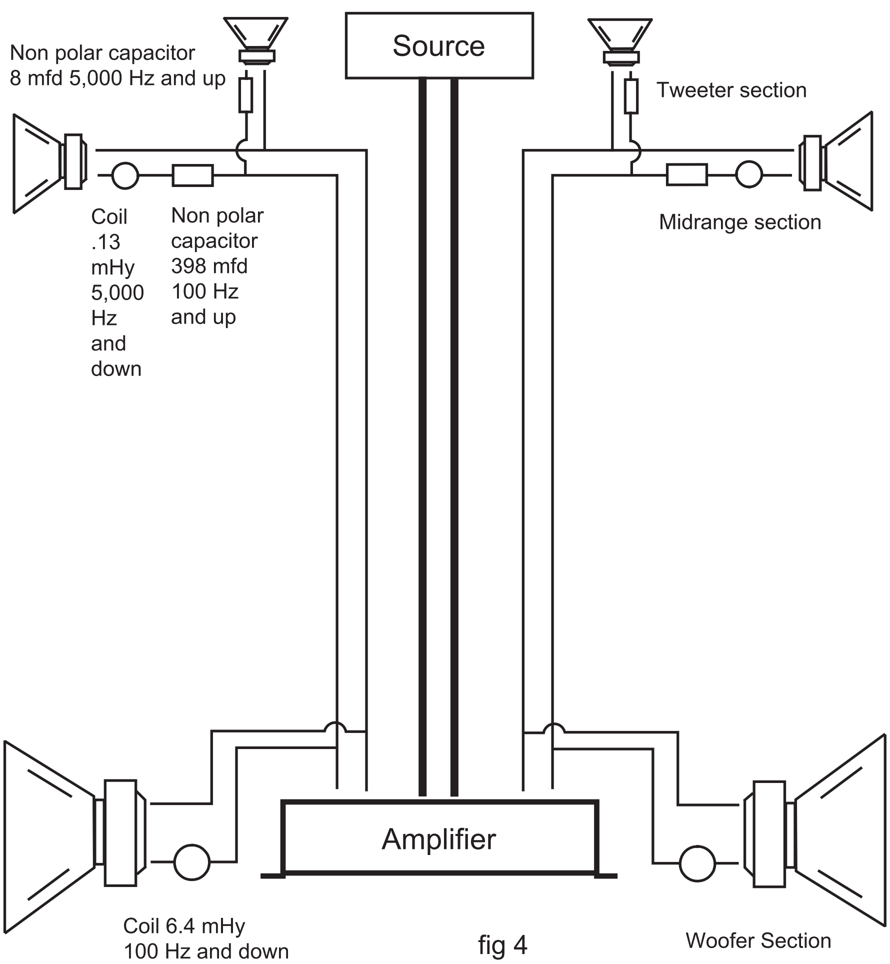


fig 4

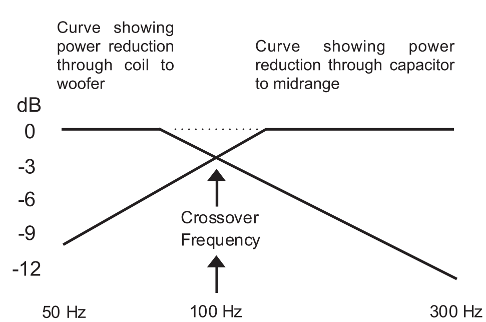


fig 5

There are some important things to note about all crossover filters (coils and capacitors or combinations of coils and capacitors):

1. If the adjoining low pass and high pass filters have the same crossover frequency, the speaker to which each one is connected will reach -3 db at that frequency. If the filters' crossover frequencies are spread (the low pass lower than the high pass, Ie: 100 Hz low pass; 200 Hz high pass), the db reduction at the crossover frequency will be at greater than -3db. A dip in the output will occur and the crossover frequency will change to somewhere between 100 and 200 Hz. If the filters are overlapped, low pass at 200 Hz and high pass at 100 Hz, the crossover frequency will beat less than -3 db and a peak will be present at the crossover frequency.

2. Two speakers in the same car, which are playing the same information, will increase the combined acoustical output by up to 3 db depending on relative location and signal phase. In a crossover situation, even though the low pass filter's speaker is down 3 db and the high pass filter's speaker is down 3 db, their combined output is up to 3 db higher. The dashes in fig 5 represent the combined acoustical output of the woofer and midrange in the crossover area when there is a 3db increase.

3. The effect of crossovers is to separate the frequency ranges for the various speakers in a system. It also separates these ranges for the amplifier as well. If three 4 ohm speakers are connected to an amplifier without coils and capacitors, the amplifier would see a load of 1.33 ohms. When each section is divided or separated by coils and capacitors, the amplifier sees a load of 4 ohms. The increased resistance In and around the crossover frequency, which is created by the coils and capacitors, separates the frequency sections for the amplifier. Overlapping the crossover frequency of adjoining low pass and high pass filters may partially negate the impedance separation for the amplifier.

Refer to fig 4. If the coil, which stops the midrange from receiving higher frequencies, were removed, the midrange and tweeter would both be working in the 5,000 Hz and higher range. In that case, the amplifier would see two 4 ohm speakers in parallel or a 2 ohm load from 5,000 Hz and up.

Thus far we have discussed 1st Order or 6 db per octave passive crossover filters. As mentioned previously, 1st Order filters are used very successfully.

WHAT ARE THE THREE COMMONLY USED FILTER ORDERS?

The three filter orders are 1st Order, 2nd Order (12 db per octave) and 3rd Order (18 db per octave). 6 db per octave or 1st Order filters are a series coil (low pass filter), a series capacitor (high pass filter) or a series capacitor followed by a series coil (band pass filter) - fig 1, fig 2 and fig 3.

A 2nd Order filter reduces power at a much faster rate than a 1st Order filter. The first octave of reduction is 12 db and by the end of the second octave reduction reaches 24 db. A 3rd Order filter reduces power at an even faster rate; 18 db in the first octave and by the end of the second octave reduction reaches 36 db.

A 2nd Order low pass filter has a coil in series, which is followed by a capacitor, which shunts, to ground (one lead attaches to speaker plus and the other to speaker ground). A 2nd Order high pass filter is a capacitor in series, which is followed by a coil shunting to ground. The values of the coils and capacitors used for 2nd Order filters for the same frequency are different from 1st Order filters:

1st Order Low Pass at 100 Hz: 6.4 mHy coil.

2nd Order Low Pass at 100 Hz: 9 mHy coil and 281 mfd capacitor.

1st Order High Pass at 100 Hz: 398 mfd capacitor.

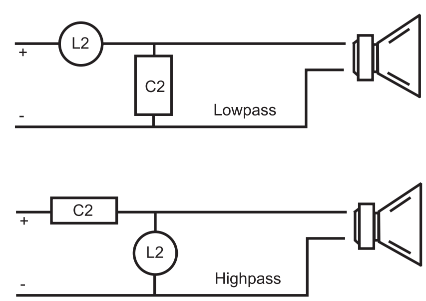
2nd Order High Pass at 100 Hz: 281 mfd capacitor and 9 mHy coil.

Note that with 2nd Order fitters for the same frequency, the low pass and high pass use exactly the same value coils and capacitors. With a low pass filter, the coil Is in series and the capacitor shunts.

With a high pass filter, the capacitor is in series and the coil shunts. In all other filters, the values are different for low pass and high pass at the same crossover frequency.

3rd Order filters use a whole new set of values. Low pass filters have a series coil followed by a capacitor in shunt and then another series coil (different value than first coil). A high pass filter has a series capacitor followed by a coil in shunt and then another series capacitor (it is also different from the first capacitor). Fig 6 diagrams these filters.

2nd Order Filters



3rd Order Filters

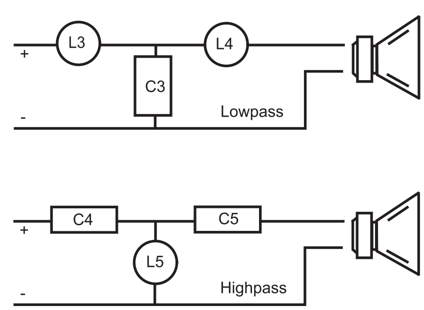


fig 6

Although band pass filters are a combination of high pass and low pass filters (in series with each other), the two filters need not be of the same order. None of the adjoining filters need to be of the same order.

As an example, the low pass for a woofer could be 1st Order; the high pass, which starts the band pass, could be 2nd Order; the low pass, which ends the band pass, could be 1st order; and, the high pass for the tweeter could be 3rd Order. All crossover filters are rated at their crossover frequency, therefore, different orders can be mixed successfully.

WHY DO WE HAVE DIFFERENT SLOPES?

Although 1st Order networks are successful in cars, there are reasons to use the steeper slopes. Tweeter crossover filters are the best example.

Low frequencies can damage a tweeter. Consequently, it may be beneficial to quickly reduce the frequencies below the crossover frequency.

A 1st Order capacitor, which begins at 3,000 Hz, would allow 25 % of the power to pass -at 1.500 Hz. A 2nd Order filter would allow only 6.23 % of power to pass and a 3rd Order only 1.54% of power to pass at 1,500 Hz.

If a small midrange speaker is being used and you wish to take it to the lower edge of its efficiency, a steeper slope may be necessary. There are other instances, which make it necessary to use a steeper slope. The need is usually detected when real time equipment shows there are acoustical peaks caused by the vehicle interior, speaker placement or the speaker it-self needs a sharper cutoff.

Traditionally, with home sound, crossovers are 12 db per octave (2nd Order). The acoustical environment of a vehicle is completely different than a room or auditorium. The many reflections in a vehicle make speaker placement much more Important than the slope of the crossover filters, except as already noted.

ARE COILS AND CAPACITORS OF DIFFERENT VALUES NEEDED WHEN THE SPEAKER IMPEDANCE IS DIFFERENT?

Yes, very definitely. Coils and capacitors interrelate not only to frequency, but also to the impedance of the speaker. Each component itself adds impedance.

For explanation, let's look at Impedance. If speaker load impedance is doubled, amplifier output is cut in half. If Impedance is cut in half, amplifier output is doubled.

if we change the speakers driven by an amplifier from 4 ohms to 8 ohms the amplifier output will be cut in half. If we change the 4 ohm speakers to 2 ohms, the output of the amplifier is doubled (if the amplifier Is capable of full output at 2 ohms).

If the speaker load were reduced to 1 ohm, the amplifier output would double again (if the amplifier is capable of full output at 1 ohm). A 6.4 mHy coil will develop the same Impedance as a 4 ohm speaker at 100 Hz. This doubling of impedance cuts the power by half (50%) or 3 db. The same coil connected to an 8 ohm speaker begins reducing power at a higher frequency and does not develop 8 ohms of impedance until 200 Hz (its crossover frequency).

The important idea to keep in mind is that different values of coils and/or capacitors are required for different speaker impedance connected to them. Not only Is there interaction between coils/capacitors and speakers, there is also a detrimental Interaction between series coils and capacitors if their frequency values are fairly close together as discussed below.

SPECIAL NARROW BANDWIDTH BAND PASS FILTERS

A band pass filter contains a series capacitor followed by a series coil. This is true whether it is a 1st, 2nd or 3rd Order filter. If the crossover frequencies of a band pass are at or less than a decade*, there are noticeable changes in the actual crossover frequencies and there is distortion within the band. To correct this interaction of the series coil and capacitor, special formulas are used to compensate for their interaction.

If you review the formulas and charts in the back of this booklet, the interaction and interrelationship we have been discussing become academic. We only need to know that when a band pass bandwidth is close together, we use a different chart or different formulas.

The impedance of a frequency section speaker(s) (i.e. woofer section, midbass section, midrange section or tweeter section) will determine which coil or capacitor to use and which chart or formula to use. It should be noted that when an amplifier is used in the mono bridged mode, the amplifier sees a load which is 1/2 the speaker load. The crossover filter always uses the speaker load, not the amplifiers.

*A decade bandwidth is 10 times the lower frequency. A bandwidth of 100 to 1,000 Hz (10 time. 100 = 1,000) is a decade.

A bandwidth of 100 to 500 is less than a decade and one of 100 to 2,500 is greater than a decade bandwidth.

HOW DO WE CHOOSE CROSSOVER FREQUENCIES?

There are three considerations necessary to choose a crossover frequency. They are:

- ·The efficient range of each speaker
- ·The imaging desired in the vehicle
- ·The most commonly used frequencies

We want to keep the range, which is allowed to proceed to a speaker well within its efficient and effective range. Most manufacturers of separate speakers publish the desired range for each of their speakers.

Your own experience with a particular speaker or speakers also should be kept in file to give you a complete reference. As an example, let's say you use brand X 4" speaker.

Your experience in systems utilizing 100 watts per channel has been that this speaker operates fine from 500 Hz and up. The manufacturers specs may indicate it can be used as low as 400 Hz, which may be the case with less power.

With this information, I would make sure its high pass filter was 500 Hz or above. If the 4 inch was to be your midrange, then either the woofer would have to have a low pass of 500 Hz or a mid bass speaker needs to be added to handle the frequencies from a lower woofer low pass (such as 100 Hz) and the 4 inch speakers 500 Hz high pass.

The basic Imaging desired for a car audio system is front staging. To accomplish front staging, the rear speakers, except rear fill speakers, should be reproducing no higher than 200 Hz. if you are using a 4 inch as we discussed above, it would be necessary to use a mid bass speaker which would be mounted in the door or in the front of the vehicle.

Woofer

80 or 85 Hz
100 Hz
125 Hz
150 Hz

Mid Bass

85 or 100 to 300, 400 or 500 Hz

Midrange

85, 100, 125, 150, 300, 400
or 500 Hz
to
4,000, 5,000, 6,000, 8,000 or 10,000 Hz

Tweeter

4,000, 5,000, 6,000, 8,000 or 10,000 Hz

HOW DO WE BUILD PASSIVE CROSSOVER FILTERS?

First, please review figs 1, 2 and 3. These drawings show how the various crossover filters are arranged. Each frequency section must be kept separate from the others. One crossover filter must not be connected to the other filters or their speakers.

This is accomplished by wiring each frequency section (woofer section, midrange section, etc.) in parallel with the other sections.

Within a frequency section, there may be more than one speaker. They may be wired in parallel, in series or a combination of both.

Each crossover filter will use the values of coils/capacitors indicated by the net impedance in its section only. Two 4 ohm woofers in parallel in a woofer section are a 2 ohm load for its filter. The same woofers in series would be an 8 ohm net impedance.

There are 3 ways to wire a system to keep each frequency section in parallel. One way is what is referred to as rail wiring. Rail wiring uses one set of plus and minus wires run from the amplifier to the speaker which is the farthest away from the amplifier. This is usually the tweeter well forward in the car. Its crossover filter is mounted fairly close to the speaker.

The woofer and midrange tap off of the single long run (rail) of wire, which end at the tweeter. All filters are inserted close to the speakers and are kept separate (in parallel) from the others.

A second method of wiring would be to mount all of the filters on a board near the amplifier. This board may be a circuit board, but in most cases it is just a piece of wood or masonite. In show or competition cars, many installers make a see through plastic box for all the filters.

The leads to each frequency section start at the board or box and are only for that section. This type of wiring usually provides easy access to the crossover filters, but does require more speaker wire.

The third method of wiring is to run the wires for each frequency section directly from the amplifier, through its filter, to the section's speaker or speakers. The filter may be mounted anywhere between the amplifier and its speaker(s). Figs 7,8 and 9 on page 6 show these three methods of wiring.

HOW DO WE COMPUTE NET IMPEDANCE?

Before one can compute a crossover filter, the net impedance of the speaker or speakers it filters must be determined. The net impedance, which an amplifier sees, is important to know to make sure the speakers it is driving will not activate its protection circuitry.

As previously discussed, frequency sections using crossover filters separate impedance relative to the amplifier. As an example, if each channel of a system has two parallel 4 ohm woofers, one 4 ohm mid bass, one 4 ohm midrange and one 8 ohm tweeter, per channel, and an amplifier which is 2 ohm stable, It will not shut down if each section has appropriate crossover filters.

Pictures not available

fig 7

fig 8

fig 9

The amplifier will see 2 ohms in the woofer section (i.e. 100 Hz and down). It will see 4 ohms in the mid bass section (I.e. 100 to 300 Hz). It will see 4 ohms In the midrange section (i.e.
300 to 5,000 Hz) and 8 ohms in the tweeter section (i.e. 5,000 Hz and up).

If a band pass filter was not used In the midrange system and only a high pass filter at 300 Hz, then there would be an overlap in the tweeter section between it and the portion of the midrange section above 5,000 Hz. The result would be net impedance for the amplifier above 5,000 Hz of 2.67
ohms.

Using the chart below, fig 10, let's compute the Impedance In the tweeter section lust discussed. The 4 ohm midrange has a decimal equivalent of .25. The 8 ohm tweeter has a decimal equivalent of .125.

Adding the two together equals .375. 1 divided by .375 equals 2.66666 or 2.67. If all the speakers of the above example were attached to each channel of an amplifier without crossover filters, the net impedance to each channel of the amplifier would be:

0.25 + 0.25 for each woofer; plus 0.25 for mid bass driver; plus 0.25 for midrange; and plus 0.125 for tweeter; a total decimal equivalent of 1.125. 1 divided by 1.125 equals a net impedance of 0.8888 or 0.89.

Impedance chart
Parallel Speakers

Speakers in ohms	Net Ohms
4+4	2
4+4+4	1.33
4+4+4+4	1
4+8	1.67
4+4+8	1.6
4+8+8	2
4+4+8+8	1.33

Where crossover filters are used, the amplifier will have the same net Impedance as the frequency section. The exception to this is a section which Is mono bridged. Usually an amplifier In the mono bridged mode will see one half of the net Impedance of the mono bridged frequency section. In the above woofer section example, two 4 ohm woofers in parallel equal a 2 ohm load for the crossover filter. If this section were mono bridged, the amplifier would see 1 ohm In the woofer section (Note: the crossover filter for this section would still see 2 ohms).

Computing Load Impedance

$$\text{Ohms} = \frac{1}{1/SI + 1/SI + 1/SI + 1/SI\ (ETC)}$$

SI represents the nominal impedance of parallel speakers. ETC could be as many additional parallel speakers as desired. If there are three 4 ohm speakers in parallel, the bottom line would add up to 3/4 or 0.75 (1/4 +1/4 +1/4). 1 divided by 0.75 = 1.33 ohms. Two 4 ohm speakers plus one 8 ohm speaker would equal 1.6 ohms.

Let's summarize the diagrams of all the standard passive crossover filters we have previously discussed. In addition, below are the formulas used to obtain the coil and capacitor values needed to build each of these filters at your desired crossover frequency.

When you are building a passive crossover, you may not find the exact coil or capacitor values as called out by the formulas (or charts which list values for particular crossover frequencies). When using formulas, round off the answer.

For instance, the coil required to do a low pass filter into 4 ohms at 200 Hz is 3.18 mHy. This rounds off to 3.2 mHy. If the value actually used Is within ± 5 percent of the rounded and computed value or of a charted value, the crossover you are building will operate successfully.

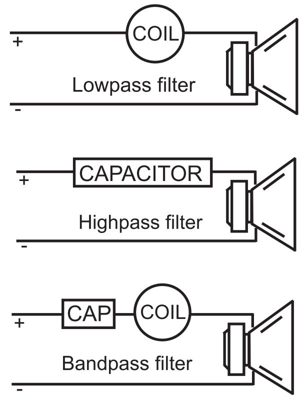
The same type of approach is used with capacitors. In many cases, the microfarad value of the capacitor will be a much higher number than with coils; as an example, a 398 mfd capacitor. This isa round off of a computed 4 ohm, 100 Hz high pass of 397.899.

There will be situations where the available value of coils and capacitors will not be within 5 % of the required value.

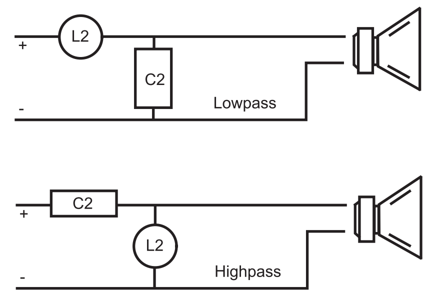
In those instances, capacitors may be placed in parallel which adds their values. A 99 mfd capacitor in parallel with a 9.9 mfd capacitor equals the same as a single capacitor of 108.9.

On the other hand, to obtain more millihenries, coils are placed in series. A 10.6 mHy coil in series with a 5.1 mHy equals the same as one 15.7 mHy coil.

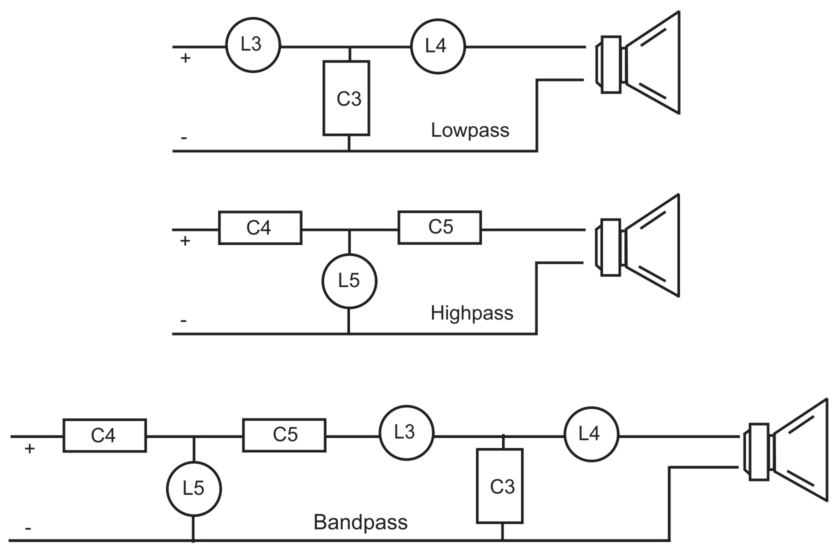
1st Order Filters
6 dB per octave



2nd Order Filters
12 dB per octave



3rd Order Filters
18 dB per octave



Formulas to compute coil values

$$\text{L1 (in mHy)} = \frac{1{,}000 \times \text{speaker impedance}}{6.283 \times \text{desired crossover frequency}}$$

L2 (in mHy)= L1 x 1.414
L3 (in mHy)= L1 x 1.5
L4 (in mHy)= L1 x 0.5
L5 (in mHy)= L1 x 0.75

Formulas to compute capacitor values

$$\text{C1 (in mfd)} = \frac{1{,}000{,}000}{6.283 \times \text{speaker impedance} \times \text{desired crossover frequency}}$$

C2 (in mfd)= C1 x 0.707
C3 (in mfd)= C1 x 1.33
C4 (in mfd)= C1 x 0.667
C5 (in mfd)= C1 x 2

1 OHM LOAD

CROSSOVER FREQUENCY CHART

1ST ORDER		2ND ORDER		**CROSSOVER**	3RD ORDER			3RD ORDER		
L1	C1	L2	C2	**FREQUENCY**	L3	C3	L4	C4	L5	C5
mHy	mfd	mHy	mfd		mHy	mfd	mHy	mfd	mHy	mfd
2.65	2653	3.74	1876	60	3.98	3528	1.33	1769	1.99	5305
2.25	2274	3.2	1608	70	3.41	3024	1.13	1517	1.71	4547
2.1	2122	3	1501	75	3.20	2822	1.06	1416	1.59	4244
1.99	1990	2.8	1407	80	3.00	2646	0.99	1327	1.5	3979
1.87	1873	2.65	1324	85	2.80	2490	0.94	1249	1.4	3745
1.59	1592	2.25	1125	100	2.39	2117	0.8	1062	1.19	3183
1.33	1326	1.88	938	120	1.99	1764	0.66	885	0.99	2653
1.27	1273	1.8	900	125	1.91	1694	0.64	849	0.95	2547
1.06	1061	1.5	750	150	1.59	1411	0.53	708	0.8	2122
0.8	796	1.13	563	200	1.19	1058	0.4	531	0.6	1592
0.64	637	0.9	450	250	0.95	847	0.32	425	0.48	1273
0.58	579	0.8	409	275	0.90	770	0.29	386	0.43	1158
0.53	531	0.75	375	300	0.80	706	0.27	354	0.4	1061
0.4	398	0.56	281	400	0.60	529	0.2	265	0.3	796
0.32	318	0.45	225	500	0.48	423	0.16	212	0.24	637
0.27	265	0.38	188	600	0.40	353	0.13	177	0.2	531
0.2	199	0.28	141	800	0.30	265	0.1	133	0.15	398
0.16	159	0.23	113	1000	0.24	212	0.08	106	0.12	318
0.08	80	0.11	56	2000	0.12	106	0.04	53	0.06	159
0.06	64	0.09	45	2500	0.10	85	0.03	43	0.05	127
0.05	53	0.08	38	3000	0.08	70	0.03	35	0.04	106
0.05	46	0.06	32	3500	0.07	60	0.02	30	0.03	91
0.04	40	0.06	28	4000	0.06	53	0.02	27	0.03	80
0.03	32	0.05	23	5000	0.05	42	0.02	21	0.02	64
0.02	27	0.04	19	6000	0.04	35	0.01	18	0.02	53
0.02	23	0.03	16	7000	0.03	0.3	0.01	15	0.02	46
0.02	20	0.03	14	8000	0.03	27	0.01	13	0.01	40
0.02	18	0.03	13	9000	0.03	23.5	0.01	12	0.01	35
0.02	16	0.02	11	10000	0.02	21	0.01	11	0.01	32

YOU MAY SUCCESSFULLY USE COIL AND CAPACITOR VALUES WHICH ARE WITHIN +/- 5% OF THOSE LISTED ABOVE

1.33 OHM LOAD

CROSSOVER FREQUENCY CHART

1ST ORDER		2ND ORDER		**CROSSOVER**	3RD ORDER			3RD ORDER		
L1	C1	L2	C2	**FREQUENCY**	L3	C3	L4	C4	L5	C5
mHy	mfd	mHy	mfd		mHy	mfd	mHy	mfd	mHy	mfd
3.5	1995	5	1410	60	5.30	2653	1.8	1330	2.65	3989
3	1710	4.2	1209	70	4.50	2274	1.5	1140	2.27	3419
2.8	1596	4	1128	75	4.20	2122	1.41	1064	2.1	3191
2.65	1496	3.74	1058	80	3.97	1990	1.32	998	1.98	2992
2.5	1408	3.52	996	85	3.74	1873	1.27	939	1.87	2816
2.1	1197	3	846	100	3.20	1592	1.06	798	1.59	2393
1.76	997	2.5	705	120	2.65	1326	0.9	665	1.32	1995
1.69	957	2.39	677	458	2.50	1273	0.85	639	1.27	1915
1.41	798	2	564	150	2.10	1061	0.71	532	1.06	1596
1.06	598	1.5	423	200	1.59	796	0.53	398	0.8	1197
0.85	479	1.2	339	250	1.27	637	0.42	318	0.64	957
0.77	435	1.06	308	275	1.13	579	0.38	290	0.6	870
0.71	398	1	281	300	1.06	531	0.35	265	0.53	798
0.53	299	0.75	212	400	0.80	398	0.26	199	0.4	598
0.42	239	0.6	169	500	0.64	318	0.21	159	0.32	479
0.35	199	0.5	141	600	0.53	265	0.18	133	0.26	398
0.26	150	0.37	106	800	0.40	199	0.13	99	0.2	299
0.21	120	0.3	85	1000	0.32	159	0.11	80	0.16	239
0.11	60	0.15	42	2000	0.16	80	0.05	40	0.08	120
0.08	47	0.12	34	2500	0.13	64	0.04	32	0.06	96
0.07	40	0.1	28	3000	0.11	53	0.04	27	0.05	80
0.06	34	0.09	24	3500	0.09	46	0.03	23	0.05	68
0.05	30	0.07	21	4000	0.08	40	0.03	20	0.04	60
0.04	24	0.06	17	5000	0.06	32	0.02	16	0.03	47
0.04	20	0.05	14	6000	0.05	27	0.02	13	0.03	40
0.03	17	0.04	12	7000	0.05	23	0.02	11	0.02	34
0.03	15	0.04	11	8000	0.04	20	0.01	9.9	0.02	30
0.02	13	0.03	9.4	9000	0.04	18	0.01	8.8	0.02	27
0.02	12	0.03	8.5	10000	0.03	16	0.01	8	0.02	24

YOU MAY SUCCESSFULLY USE COIL AND CAPACITOR VALUES WHICH ARE WITHIN +/- 5% OF THOSE LISTED ABOVE

2 OHM LOAD

CROSSOVER FREQUENCY CHART

1ST ORDER		2ND ORDER		**CROSSOVER**	3RD ORDER			3RD ORDER		
L1	C1	L2	C2	**FREQUENCY**	L3	C3	L4	C4	L5	C5
mHy	mfd	mHy	mfd		mHy	mfd	mHy	mfd	mHy	mfd
5.3	1326	7.5	938	60	8.00	1764	2.65	885	4	2653
4.5	1137	6.4	804	70	6.80	1512	2.27	758	3.4	2274
4.2	1061	6	750	75	6.40	1411	2.1	708	3.2	2122
4	995	5.6	703	80	6.00	1323	2	664	3	1990
3.74	936	5.3	662	85	5.60	1245	1.8	625	2.8	1873
3.2	796	4.5	563	100	4.80	1058	1.59	531	2.4	1592
2.65	663	3.74	468	120	4.00	882	1.33	442	2	1326
2.5	637	3.6	450	125	3.74	847	1.27	425	1.9	1273
2.1	531	3	375	150	3.20	706	1.06	354	1.59	1061
1.59	398	2.25	281	200	2.40	529	0.8	265	1.2	796
1.27	318	1.8	225	250	1.90	423	0.64	212	0.95	637
1.16	289	1.64	205	275	1.80	385	0.58	193	0.9	579
1.06	265	1.5	188	300	1.59	353	0.53	177	0.8	531
0.8	199	1.13	141	400	1.19	265	0.4	133	0.6	398
0.64	159	0.9	113	500	0.95	212	0.32	106	0.48	318
0.53	133	0.8	94	600	0.80	176	0.27	89	0.4	265
0.4	99	0.56	70	800	0.60	133	0.2	66	0.3	199
0.32	80	0.45	56	1000	0.48	106	0.16	53	0.24	159
0.16	40	0.23	28	2000	0.24	53	0.08	27	0.12	80
0.13	32	0.18	23	2500	0.19	42	0.06	21	0.1	64
0.11	27	0.15	19	3000	0.16	35	0.05	18	0.08	53
0.09	23	0.13	16	3500	0.14	30	0.05	15	0.07	46
0.08	20	0.11	14	4000	0.12	27	0.04	13	0.06	40
0.06	16	0.09	11	5000	0.10	21	0.03	11	0.05	32
0.05	13	0.08	9.4	6000	0.08	18	0.03	8.8	0.04	27
0.05	11	0.06	8	7000	0.07	15	0.02	7.6	0.03	23
0.04	9.9	0.06	7	8000	0.06	13	0.02	6.6	0.03	20
0.04	8.8	0.05	6.3	9000	0.05	12	0.02	5.9	0.03	18
0.03	8	0.05	5.6	10000	0.05	11	0.02	5.3	0.02	16

YOU MAY SUCCESSFULLY USE COIL AND CAPACITOR VALUES WHICH ARE WITHIN +/- 5% OF THOSE LISTED ABOVE

2.67 OHM LOAD

CROSSOVER FREQUENCY CHART

1ST ORDER		2ND ORDER		**CROSSOVER**	3RD ORDER			3RD ORDER		
L1	C1	L2	C2	**FREQUENCY**	L3	C3	L4	C4	L5	C5
mHy	mfd	mHy	mfd		mHy	mfd	mHy	mfd	mHy	mfd
7	994	10	703	60	10.60	1321	3.5	663	5.3	1987
6	852	8.58	602	70	9.00	1133	3	568	4.5	1703
5.6	795	8	562	75	8.40	1057	2.8	531	4.2	1590
5.3	745	7.5	527	80	8.00	991	2.66	497	4	1490
5	701	7	496	85	7.50	933	2.5	468	3.74	1403
4.2	596	6	422	100	6.40	793	2.1	398	3.2	1192
3.54	497	5	351	120	5.30	661	1.08	331	2.66	994
3.4	477	4.8	334	125	5.10	634	1.7	318	2.5	954
2.8	398	4	281	150	4.20	529	1.42	265	2.1	795
2.1	298	3	211	200	3.20	398	1.06	199	1.59	596
1.7	234	2.4	165	250	2.50	318	0.85	159	1.27	477
1.5	217	2.1	153	2.75	2.30	288	0.08	145	1.16	434
1.4	199	2	141	300	2.10	265	0.71	133	1.06	398
1.06	149	1.5	105	400	1.59	199	0.53	99	0.8	298
0.85	117	1.2	83	500	1.27	159	0.42	80	0.64	234
0.71	99	1	70	600	1.06	132	0.35	66	0.53	199
0.53	75	0.75	53	800	0.80	99	0.27	50	0.4	149
0.42	60	0.6	42	1000	0.64	79	0.21	40	0.32	117
0.21	30	0.3	21	2000	0.32	40	0.11	20	0.16	60
0.17	24	0.24	17	2500	0.25	32	0.08	16	0.13	47
0.14	20	0.2	14	3000	0.21	26	0.07	12	0.11	40
0.12	17	0.17	12	3500	0.18	23	0.06	11	0.09	34
0.11	15	0.15	11	4000	0.16	20	0.05	9.9	0.08	30
0.08	12	0.12	8.4	5000	0.13	16	0.04	8	0.06	24
0.07	9.9	0.1	7	6000	0.11	13	0.04	6.6	0.05	20
0.06	8.5	0.09	6	7000	0.09	11	0.03	5.6	0.05	17
0.05	7.5	0.08	5.3	8000	0.08	9.9	0.03	5	0.04	15
0.05	6.6	0.07	4.7	9000	0.07	8.8	0.02	4.4	0.04	13
0.04	6	0.06	4.2	10000	0.06	8	0.02	4	0.03	12

YOU MAY SUCCESSFULLY USE COIL AND CAPACITOR VALUES WHICH ARE WITHIN +/- 5% OF THOSE LISTED ABOVE

3 OHM LOAD

CROSSOVER FREQUENCY CHART

1ST ORDER		2ND ORDER		**CROSSOVER**	3RD ORDER			3RD ORDER		
L1	C1	L2	C2	**FREQUENCY**	L3	C3	L4	C4	L5	C5
mHy	mfd	mHy	mfd		mHy	mfd	mHy	mfd	mHy	mfd
8	884	11.3	625	60	11.90	1176	4	590	6	1768
6.8	758	9.7	536	70	10.20	1008	3.4	506	5.1	1516
6.4	707	9	500	75	9.60	941	3.2	472	4.8	1415
6	663	8.4	468	80	9.00	882	3	442	4.5	1326
5.6	624	8	441	85	8.40	830	2.8	416	4.2	1245
4.77	531	6.8	375	100	7.20	706	2.4	354	3.6	1061
4	442	5.6	313	120	6.00	588	2	295	3	884
3.8	424	5.4	300	125	5.70	565	1.9	281	3	849
3.2	354	4.5	250	150	4.80	470	1.59	234	2.4	707
2.39	265	3.3	188	200	3.60	353	1.2	177	1.8	531
1.9	212	2.7	150	250	3.00	281	0.95	141	1.4	424
1.74	193	2.4	133	275	2.60	257	0.9	129	1.3	386
1.59	177	2.25	125	300	2.40	234	0.8	117	1.2	354
1.2	133	1.7	94	400	1.80	176	0.6	89	0.9	265
0.95	106	1.4	75	500	1.40	141	0.48	70	0.72	212
0.8	88	1.13	63	600	1.20	117	0.4	59	0.6	177
0.6	66	0.84	47	800	0.90	88	0.3	44	0.45	133
0.48	53	0.68	38	1000	0.72	70	0.24	35	0.36	106
0.24	27	0.34	19	2000	0.36	35	0.12	18	0.18	53
0.19	21	0.27	15	2500	0.30	28	0.1	14	0.14	42
0.16	18	0.23	13	3000	0.24	24	0.08	12	0.12	35
0.14	15	0.19	11	3500	0.20	20	0.07	9.9	0.1	30
0.12	13	0.17	9.4	4000	0.18	18	0.06	8.8	0.09	27
0.1	11	0.14	7.5	5000	0.14	14	0.05	7	0.07	21
0.08	8.8	0.11	6.3	6000	0.12	12	0.04	5.9	0.06	18
0.07	7.6	0.1	5.3	7000	0.10	9.9	0.03	5	0.05	15
0.06	6.6	0.08	4.7	8000	0.09	8.8	0.03	4.4	0.04	13
0.05	5.9	0.08	4.2	9000	0.08	8	0.03	3.8	0.04	12
0.05	5.3	0.07	3.8	10000	0.07	7	0.02	3.5	0.04	11

YOU MAY SUCCESSFULLY USE COIL AND CAPACITOR VALUES WHICH ARE WITHIN +/- 5% OF THOSE LISTED ABOVE

4 OHM LOAD

CROSSOVER FREQUENCY CHART

1ST ORDER		2ND ORDER		**CROSSOVER**	3RD ORDER			3RD ORDER		
L1	C1	L2	C2	**FREQUENCY**	L3	C3	L4	C4	L5	C5
mHy	mfd	mHy	mfd		mHy	mfd	mHy	mfd	mHy	mfd
10.6	663	15	468	60	15.90	882	5.3	442	8	1326
9	568	12.8	398	70	13.60	756	4.5	379	6.8	1137
8.4	531	12	375	75	12.80	706	4.2	354	6.4	1061
8	467	11.3	352	80	12.00	662	4	331	6	995
7.5	468	10.6	331	85	11.00	623	3.74	312	5.6	936
6.4	398	9	281	100	9.60	529	3.2	265	4.8	796
5.3	331	7.5	234	120	8.00	441	2.7	225	4	663
5.1	318	7.2	225	125	7.60	423	2.5	212	3.8	637
4.2	265	6	188	150	6.40	353	2.1	177	3.2	531
3.2	199	4.5	141	200	4.80	265	1.59	133	2.4	398
2.5	159	3.6	113	250	3.80	212	1.27	106	1.9	318
2.3	145	3.2	102	275	3.50	192	1.2	97	1.7	289
2.1	133	3	94	300	3.20	176	1.06	89	1.59	265
1.59	99	2.25	70	400	2.40	133	0.8	66	1.2	199
1.27	80	1.8	56	500	1.90	106	0.64	53	0.95	159
1.06	66	1.5	47	600	1.59	88	0.53	44	0.8	133
0.8	50	1.13	35	800	1.20	66	0.4	33	0.6	99
0.64	40	0.9	28	1000	0.95	53	0.32	27	0.48	80
0.32	20	0.45	14	2000	0.48	27	0.16	13	0.24	40
0.25	16	0.36	11	2500	0.38	21	0.13	11	0.19	32
0.21	13	0.3	9.4	3000	0.32	18	0.11	8.8	0.16	27
0.18	11	0.26	8	3500	0.27	15	0.09	7.6	0.14	23
0.16	9.9	0.23	7	4000	0.24	13	0.09	6.6	0.12	20
0.13	8	0.18	5.6	5000	0.19	11	0.06	5.3	0.1	16
0.11	6.6	0.15	4.7	6000	0.16	8.8	0.05	4.4	0.08	13
0.09	5.6	0.13	4	7000	0.14	7.6	0.05	3.8	0.07	11
0.08	5	0.11	3.5	8000	0.12	6.6	0.04	3.3	0.06	9.9
0.07	4.4	0.1	3.1	9000	0.11	5.9	0.04	2.9	0.05	8.8
0.06	4	0.09	2.8	10000	0.10	5.3	0.03	2.7	0.05	8

YOU MAY SUCCESSFULLY USE COIL AND CAPACITOR VALUES WHICH ARE WITHIN +/- 5% OF THOSE LISTED ABOVE

6 OHM LOAD

CROSSOVER FREQUENCY CHART

1ST ORDER		2ND ORDER		**CROSSOVER**	3RD ORDER			3RD ORDER		
L1	C1	L2	C2	**FREQUENCY**	L3	C3	L4	C4	L5	C5
mHy	mfd	mHy	mfd		mHy	mfd	mHy	mfd	mHy	mfd
15.9	442	22.5	313	60	23.90	588	8	295	11.9	884
13.6	379	19.3	265	70	20.50	504	6.8	253	10.6	758
12.8	354	18	250	75	19.10	470	6.4	234	9.6	707
12	331	16.9	234	80	17.90	441	6	225	9	663
11.2	312	15.9	225	85	16.90	415	5.6	208	8.4	624
9.6	265	13.5	188	100	14.40	353	4.8	177	7.2	531
8	225	11.3	159	120	12.00	294	4	147	6	442
7.6	212	10.6	150	125	11.50	281	3.8	141	5.7	424
6.4	177	9	125	150	9.60	234	3.2	117	4.8	354
4.8	133	6.8	94	200	7.20	176	2.4	89	3.6	265
3.8	106	5.4	75	250	5.70	141	1.9	70	2.9	212
3.5	99	4.9	68	275	5.20	128	1.7	64	2.6	193
3.2	88	4.5	63	300	4.80	117	1.59	59	2.4	177
2.4	66	3.4	47	400	3.60	88	1.2	44	1.8	133
1.9	53	2.7	38	500	2.90	70	0.95	35	1.4	106
1.59	44	2.25	31	600	2.40	59	0.08	30	1.2	88
1.2	33	1.7	23	800	1.80	44	0.6	22	0.9	66
0.95	27	1.4	19	1000	1.40	35	0.48	18	0.72	53
0.48	13	0.68	9.4	2000	0.72	18	0.24	8.8	0.36	27
0.38	11	0.54	7.5	2500	0.57	14	0.19	7	0.29	21
0.32	8.8	0.45	6.3	3000	0.48	12	0.16	5.9	0.24	18
0.27	7.6	0.39	5.4	3500	0.41	9.9	0.14	5.1	0.2	15
0.24	6.6	0.34	4.7	4000	0.36	8.8	0.12	4.4	0.18	13
0.19	5.3	0.27	3.8	5000	0.29	7	0.1	3.5	0.14	11
0.16	4.4	0.23	3.1	6000	0.24	5.9	0.08	2.9	0.12	8.8
0.14	3.8	0.19	2.7	7000	0.20	5	0.07	2.5	0.1	7.6
0.12	3.3	0.17	2.3	8000	0.18	4.4	0.06	2.2	0.09	6.6
0.11	2.9	0.15	2.1	9000	0.16	3.9	0.05	2	0.08	5.9
0.1	2.7	0.14	1.9	10000	0.14	3.5	0.05	1.8	0.07	5.3

YOU MAY SUCCESSFULLY USE COIL AND CAPACITOR VALUES WHICH ARE WITHIN +/- 5% OF THOSE LISTED ABOVE

8 OHM LOAD

CROSSOVER FREQUENCY CHART

1ST ORDER		2ND ORDER		**CROSSOVER**	3RD ORDER			3RD ORDER		
L1	C1	L2	C2	**FREQUENCY**	L3	C3	L4	C4	L5	C5
mHy	mfd	mHy	mfd		mHy	mfd	mHy	mfd	mHy	mfd
21	331	30	234	60	31.30	441	10.6	225	15.9	663
18	281	25.7	199	70	27.30	378	9	188	13.6	568
17	265	24	188	75	25.50	353	8.4	177	12.8	530
16	249	22.5	176	80	23.90	331	8	165	12	497
15	234	21.2	165	85	22.50	311	7.5	159	11.2	468
12.8	199	18	141	100	19.00	235	6.4	133	9.6	398
10.6	165	15	117	120	15.90	225	5.3	113	8	331
10	159	14.4	113	125	15.00	212	5.1	106	7.6	318
8.4	133	12	94	150	12.80	176	4.2	89	6.4	265
6.4	99	9	70	200	9.60	133	3.32	66	4.8	199
5.1	80	7.2	56	250	7.60	106	2.6	53	3.8	159
4.6	72	6.4	50	275	7.00	96	2.3	48	3.5	145
4.2	66	6	47	300	6.40	88	2.1	44	3.2	133
3.2	50	4.5	35	400	4.80	66	1.59	33	2.4	99
2.5	40	3.6	28	500	3.80	53	1.27	27	1.9	80
2.1	33	3	23	600	3.20	44	1.06	22	1.59	66
1.59	25	2.25	18	800	2.40	33	0.8	17	1.2	50
1.27	20	1.8	14	1000	1.90	27	0.64	13	0.95	40
0.64	9.9	0.9	7	2000	0.95	13	0.32	6.6	0.48	20
0.51	8	0.72	5.6	2500	0.76	11	0.25	5.3	0.38	16
0.42	6.6	0.6	4.7	3000	0.64	8.8	0.21	4.4	0.32	13
0.36	5.7	0.51	4	3500	0.55	7.6	0.18	3.8	0.27	11
0.32	5	0.45	3.5	4000	0.48	6.6	0.16	3.3	0.24	9.9
0.25	4	0.36	2.8	5000	0.38	5.3	0.13	2.7	0.19	8
0.21	3.3	0.3	2.3	6000	0.32	4.4	0.11	2.2	0.16	6.6
0.18	2.8	0.26	2	7000	0.27	3.8	0.09	1.9	0.14	5.7
0.16	2.5	0.23	1.8	8000	0.24	3.3	0.08	1.7	0.12	5
0.14	2.2	0.2	1.6	9000	0.21	2.9	0.07	1.5	0.11	4.4
0.13	2	0.18	1.4	10000	0.19	2.6	0.06	1.3	0.1	4

YOU MAY SUCCESSFULLY USE COIL AND CAPACITOR VALUES WHICH ARE WITHIN +/- 5% OF THOSE LISTED ABOVE