Adding this subwoofer to your car audio system will dramatically improve its bass response and lower its distortion.

BUILD THIS SUBWOOFER FOR YOUR CAR

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WHAT'S THE BEST WAY TO UPGRADE your car stereo? For many systems, replacing poor quality speakers with better ones is the best way to upgrade the sound without spending a lot of money. After that, adding a subwoofer tops the list. A high-quality automotive subwoofer system can be assembled for less than $150. This article explains how to assemble it.

A subwoofer provides two main advantages: First, it provides a dramatic improvement in bass, and second, it improves the higher frequencies by letting you turn down the bass frequencies that are fed to the other speakers. That lowers distortion and lets you play the other frequencies louder.

After a subwoofer is added, many people are astounded by the clarity of the resulting sound. This occurs because amplifier clipping and speaker excursion "bottoming" during loud passages are eliminated, and no longer distort the upper bass, midrange, and treble. The main amplifier no longer need supply high-power bass to the main speakers.

Subwoofer strategy

The subwoofer system is composed of three basic components: a subwoofer crossover, a power amplifier, and a subwoofer speaker and enclosure. Many subwoofer installations are based on quality subwoofers and power amplifiers, but include poorly designed (cheap) crossovers. The results are boomy bass, poor imaging, high distortion, and noise. The three most important things to look for in a subwoofer crossover are a steep cutoff slope (at least 18 dB per octave), a selectable cutoff frequency, and a subsonic filter.

A steep cutoff slope is important to prevent midrange and upper bass frequencies from reaching the subwoofer. Midrange and upper bass frequencies are *directional* for the human ear, which means that you can detect the direction where the sounds are coming from. Deep bass is *nondirectional*, which means that you can't determine the direction from which the sounds are coming. Keeping directional frequencies out of the subwoofer is necessary if you want to install the speaker anywhere in the vehicle without degrading the stereo image. It also lets you use a single mono subwoofer rather than separate left and right subwoofers.

Another reason to keep midrange and upper bass out of the subwoofer is to prevent boomy-sounding bass. Only a filter with a steep cutoff slope can effectively eliminate the boomy-sounding upper bass without reducing the desired deep bass frequencies.

Selectable cutoff frequency lets you match the subwoofer to the rest of the system. This prevents a "peak" or "hole" in the combined frequency response. The best way to obtain selectable cutoff frequency is to use a

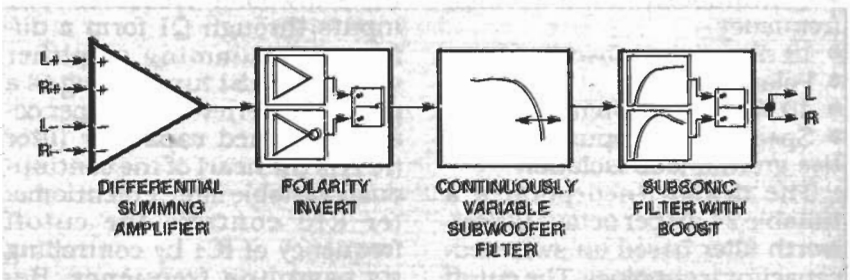

FIG. 1—BLOCK DIAGRAM of the subwoofer crossover. The crossover has a 24 dB per octave cutoff slope and a continuously variable cutoff frequency.

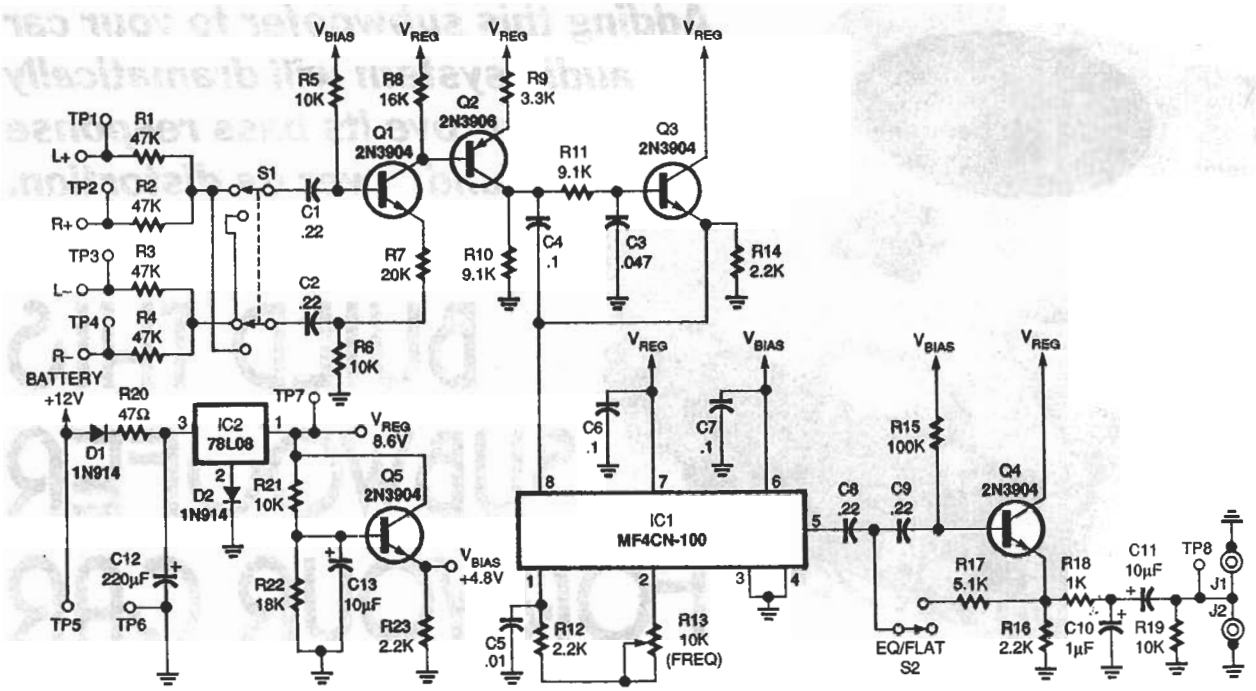

FIG. 2—SCHEMATIC OF THE SUBWOOFER CROSSOVER. Potentiometer R13 controls the cutoff frequency of IC1 by controlling its sampling frequency.

continuously variable filter that lets you fine tune the subwoofer response for the best sound. Then you can tailor it for the vehicle's interior acoustics and mask the low-frequency effects of road noise.

A subsonic filter prevents subaudible energy from reducing dynamic headroom and distorting the bass. It also eliminates annoying turn-on thumps. To be effective without sacrificing the deep-bass response, the subsonic filter should have a slope of at least 12 dB per octave.

Subwoofer crossover

Figure 1 is the block diagram of the subwoofer crossover. The crossover has the following features:

- 24 dB/octave cutoff slope
- Continuously variable cutoff frequency
- 18 dB/octave subsonic filter
- Polarity switch
- 40 Hz boost switch
- Speaker level inputs with active ground-loop isolation

The design incorporates a tunable 24 dB per octave Butterworth filter based on switched-capacitor technology. The cutoff frequency is continuously variable from 50 to 150 Hz. The subsonic filter is 18 dB per octave, and has a cutoff frequency of 20 Hz. In addition, the frequency response of the subsonic filter is switchable between a "flat" characteristic and a "boost" characteristic (which provides a 5 dB peak at 40 Hz). This boost can extend low-end response and provide deep bass punch without damaging the woofer.

The subwoofer crossover is engineered to prevent system noise problems. It has a differential amplifier at the front end to provide ground-loop isolation and a precision linear regulator to provide clean power for clean sound. This combination eliminates such problems as alternator whine, blower motor pickup, and ignition noise.

Figure 2 is the schematic for the subwoofer crossover. The inputs through Q1 form a differential summing amplifier with switch S1 functioning as a polarity inverter. A 24 dB per octave switched capacitor filter (IC1) is the heart of the continuously variable filter. Potentiometer R13 controls the cutoff frequency of IC1 by controlling its sampling frequency. Because of the inherent sampling action of switched capacitor filters, an anti-aliasing filter is required at the input of IC1. Transistors Q2 and Q3, along with the surrounding components, form this second-order, low-pass, anti-aliasing filter.

The subsonic filter with a boost stage follows the output of IC1 at pin 5. When switch S2 is closed, the boost is added. Additional subsonic filtering action is provided by C1 and C2 at the inputs of the crossover circuit. A "reconstruction filter" that eliminates sampling artifacts is formed by R18 and C10 at the output of IC1.

The power-supply circuit, based on the 78L08 voltage regulator IC2, provides both an 8.6-volt main supply and a 4.8-volt bias supply. Diode D1 protects against negative voltage spikes and incorrect hookup. Diode D2 biases the 78L08 regulator reference pin at 0.6 volt to provide an output of 8.6 volts rather than 8 volts.

Crossover construction

Figure 3 is the parts-placement diagram for the crossover PC board. You can make your own board from the foil pattern provided here, or you can purchase one from the source men-

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tioned in the Parts List. The board is designed to accommodate two different crossover circuits. This article is written about only one of them. That is why many of the pads on the board are unpopulated. Mount Potentiometer R13 in a socket so that its height from the board equals those of the bodies of the switches. That way it can project through an opening in the cover of the case and be adjusted with the case cover in place.

Be sure that all electrolytic capacitors, especially C10 and C11, are rated for operation at 105°C. Electrolytic capacitors rated at 85°C will deteriorate to a lower capacitance value after a few years of operating in high-temperature automotive environments.

The prototype crossover board provides two RCA output jacks (J1 and J2) for connecting the mono subwoofer signal to both inputs of a stereo amplifier. The jacks included with the kit mount on the underside of the board in holes drilled especially for them. The electrical connections to the jacks are made on the top of the board by soldering the jack leads to the two wire jumpers that span the board. This can be seen in the photo of the board shown in Fig. 4.

Make the input and power connections to the crossover board by soldering 10-inch wire leads to the pads on the underside of the board as shown in Fig. 3. Solder the leads to the board after the board is fully populated. The PC board is designed to fit perfectly in the case available from the source given in the Parts List. The case is supplied predrilled for the RCA

PARTS LIST

All resistors are ⅛-watt, 5%, unless noted.
R1–R4—47,000 ohms
R5, R6, R19, R21—10,000 ohms
R7—20,000 ohms
R8—16,000 ohms
R9—3300 ohms
R10, R11—9100 ohms
R12, R14, R16, R23—2200 ohms
R13—10,000 ohms, linear taper potentiometer
R15—100,000 ohms
R17—5100 ohms
R18—1000 ohms
R20—47 ohms
R22—18,000 ohms
Capacitors
C1, C2—0.22 µF, Mylar
C3—0.047 µF, Mylar
C4, C6, C7—0.1 µF, Mylar
C5—0.01 µF, Mylar
C8, C9—0.22 µF, Mylar
C10—1 µF, 25 volts, radial electrolytic, 105 degrees C
C11, C13—10 µF, 25 volts, radial electrolytic, 105 degrees C
C12—220 µF, 25 volts, axial electrolytic
Semiconductors
Q1, Q3–Q5—2N3904 NPN transistor
Q2—2N3906 PNP transistor
D1, D2—1N914 diode
IC1—MF4CN-100 switched capacitor filter
IC2—78L08 voltage regulator
Other Components
S1—DPDT switch
S2—SPST switch
J1, J2—RCA jack, PC mount
Miscellaneous: PC board, project case, hardware, 18 AWG stranded wire
Note: The following items are available from MFR Engineering, 10308 Indian Lake Blvd S., Indianapolis IN 46236:
- **Crossover PC board (drilled and plated)—$10**
- **PC board and IC1 and IC2—$14**
- **PC board and all electrical components including switches and jacks—$29**
- **Complete kit of all parts (includes PC board, all parts, and project case—$39**
- **Assembled and tested crossover unit—$59**

Shipping and handling is included in all prices (Continental U.S.). Certified or cashiers checks, money orders, and personal checks accepted. (Shipping will be delayed until personal checks clear.)

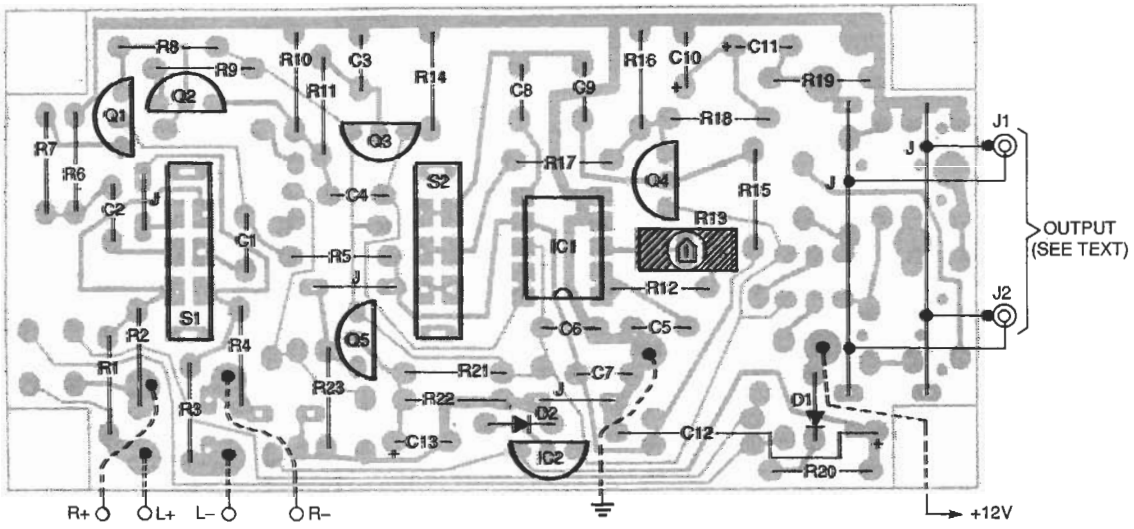


FIG. 3—PARTS-PLACEMENT DIAGRAM for the crossover PC board. The board is designed to accommodate two different crossover circuits; That's why many parts appear to be left out.

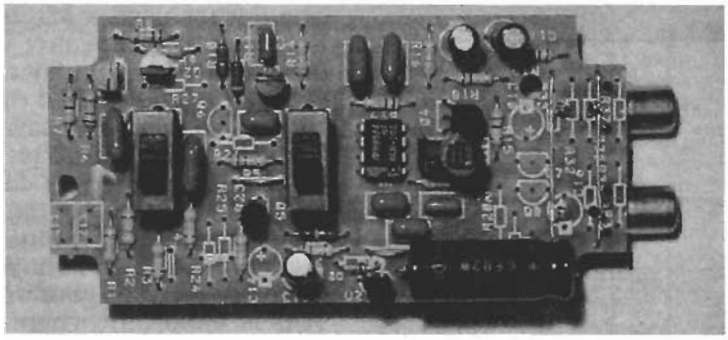


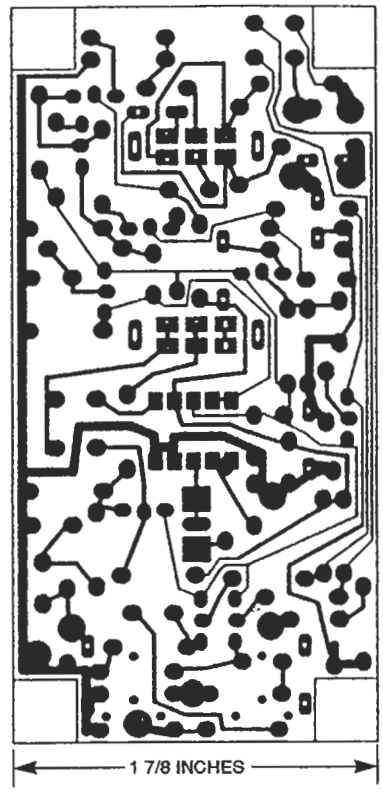
FIG. 4—PROTOTYPE CROSSOVER BOARD. The two RCA output jacks are mounted on the underside of the board, and the electrical connections are made by soldering the jack leads to the two wire jumpers that span the board.

FIG. 5—THE BOARD IS HELD IN PLACE by the RCA jacks on one end. The other end of the board rests on the grommet. The case cover holds the board down by pressing on the switch bodies.

jacks and includes a rubber grommet for the input and power leads.

The board is held in place in the case by the RCA jacks on one end. The other end of the board rests on the grommet. The case cover holds the board down by pressing on the bodies of the switches.

After checking your soldering, pass the input and power leads through the single opening in one end of the case, fit the RCA jacks through the openings on the other side of the case, and push the board down into place. Pull any excess wire out of the case before installing the grommet. Figure 5 shows what the assembled case looks like.



SUBWOOFER CROSSOVER foil pattern shown full size.

TABLE 1

	Lower Limit	Upper Limit	Units
Test 1: Supply Current			
• Measure power supply current	7	12	mA
Test 2: Output Level			
• Verify that output is sinusoidal			
• Measure output level	.80	.90	VRMS
Test 3: Polarity Switch			
• Change polarity switch to up position			
• Measure output level change	–.05	+.05	VRMS
Test 4: Frequency Response			
• Change signal frequency to find lower –3 dB frequency	19	23	Hz
Test 5: Equalization Frequency			
• Set Eq. switch to boost position			
• Change signal frequency to find peak frequency	37	44	Hz
Test 6: Equalization Boost			
• Set Eq. switch to flat position			
• Measure output level decrease	4	6	dB
Test 7: Filter Range			
• Set signal frequency to 50 Hz			
• Rotate pot fully CCW			
• Measure output level change	–7	–3	dB
Test 8: Regulator Dropout			
• Monitor DC at 8.6V regulator output, TP7			
• Reduce power supply until DC decreases .1V			
• Measure power supply voltage	10.5	11.7	VDC

Crossover test

The following test procedure will thoroughly check the operation of the subwoofer crossover before installation. Test points are shown in the schematic in Fig. 2.

As an initial setup, apply 15 volts DC to TP5 and ground TP6. Apply a 3-volt RMS, 130-Hz signal the left and right inputs (TP1–TP4). Ground the low side of the signal source. The output impedance should be about 600 ohms. Set potentiometer R13 fully clockwise and open switch S2. The polarity switch (S1) should be in the "down" position. Monitor the output signal at TP8 with an oscilloscope, and follow the instructions given in Table 1.

Amplifier

A 2×18-watt automotive stereo amplifier will provide a good match for original equipment factory or aftermarket stereos and provide the best price/

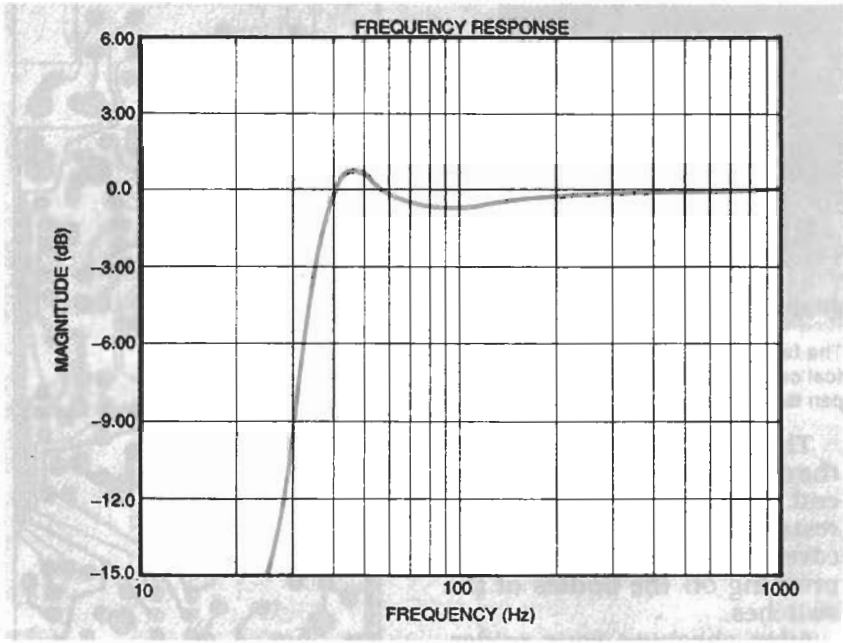
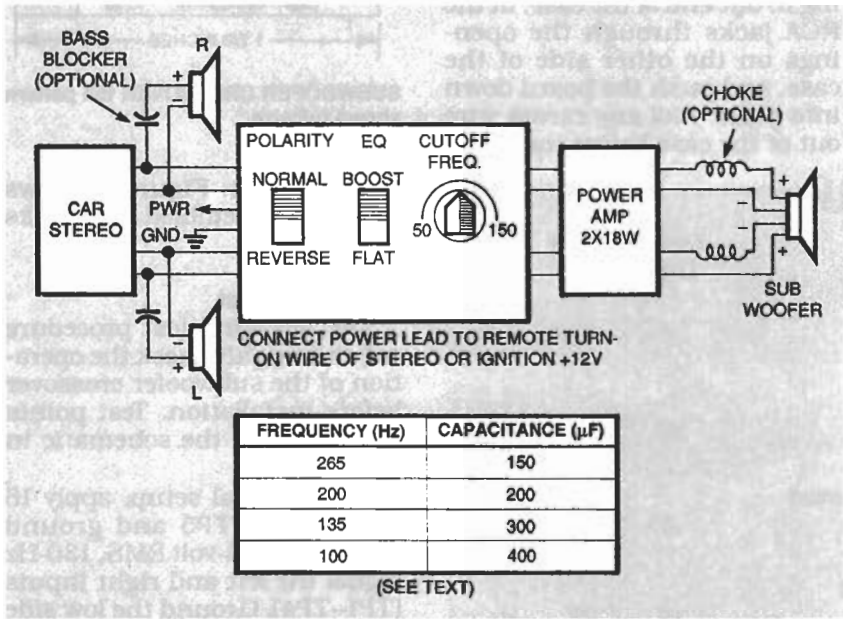


FIG. 6—COMPUTER-GENERATED FREQUENCY RESPONSE CURVE of the Madisound 81524DVC speaker in a 1.25 cubic foot enclosure.



FREQUENCY (Hz)	CAPACITANCE (μF)
265	150
200	200
135	300
100	400

(SEE TEXT)

FIG. 7—CONNECTION DIAGRAM. Bass-blocking capacitors will reduce the burden of producing deep bass on the main speakers. The capacitor values for popular bass-blocking frequencies are listed below. The choke coils will prevent power amplifier oscillation problems.

power ratio. For systems with higher power separate components, a larger power amplifier and subwoofer should be considered to equal out the system.

Speaker and enclosure

To get the best value here, build your own enclosure and use a dual-voice coil speaker. A dual-voice coil speaker can be connected directly to both outputs of a 2×18 amplifier, eliminating the need for two speakers. This essentially cuts the cost in half. A single 8- to 12-inch dual-voice-coil woofer is adequate for systems that will not have to entertain the whole neighborhood.

Choosing the right speaker is important. Polypropylene cone speakers are preferred because they are resistant to moisture. The author used a Madisound No. 81524DVC speaker which has an 8-inch diameter polypropylene woofer and dual 4-ohm voice coils. It is available from Madisound for $34.

Building your own cabinet not only saves a lot of money, it also lets you build cabinet with exactly the size and shape cabinet you want for your vehicle. This is important where space is tight or where an unusual interior would let you take advantage of some obscure location. Avoid installing the crossover and power amplifier where they are subject to excessive temperature (such as in direct sunlight) or where they are exposed to moisture or dirt. For a professional touch, speaker box carpet is available in colors to match almost any vehicle's interior, and it can be applied to the outside of the enclosure. If you prefer to use a premade speaker box, it can be purchased from Crutchfield, Parts Express, MCM Electronics, and other audio-supply distributors.

The prototype subwoofer is housed in a 1.25 cubic foot enclosure, which is the best trade-off between size and bass response. This box volume provides a cutoff frequency of 37 Hz.

The prototype's enclosure was constructed of ¾-inch particle board, and a port was made from a 7½-inch length of 3-inch diameter PVC pipe. The computer-generated frequency response curve of the Madisound 81524DVC speaker in this enclosure is shown in Fig. 6.

Installation

The subwoofer can be mounted inside the vehicle or in a trunk. If you install it in a trunk, use quick-connects for the wiring and adjustable straps or Velcro to keep the subwoofer from sliding around. This will also allow you to take the subwoofer out easily when you need the extra trunk room.

Connect the crossover inputs to the left and right speaker outputs of the car stereo, as shown in Fig. 7. If the stereo has front and rear outputs, use the out-

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SUBWOOFER

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puts that will be turned up for the loudest sound. Because the subwoofer crossover has a high input impedance, it does not load the receiver, and full power is still provided to the main speakers. The subwoofer crossover sums the signals from the left and right channels, so the left and right inputs are interchangeable.

Since the inputs of the subwoofer crossover are isolated from ground, the positive and negative inputs are also interchangeable. Be sure to observe the same polarity for both the left and right channels. This interchangeability feature is particularly useful when speaker polarity is unclear. The crossover's phase switch can reverse the input polarity to provide the correct phase.

Use a short cable to connect the subwoofer crossover to the power amplifier to prevent ignition noise pickup.

Adding bass-blocking capacitors in line with each of the main speakers is recommended, as shown in Fig. 7. This reduces the burden of reproducing deep bass on the main speakers, allowing higher volume with less distortion.

The capacitor values to use with 4-ohm speakers for popular bass-blocking frequencies are listed in Fig. 7. Bass-blocking capacitors should be nonpolarized (bipolar). Use 135-Hz bass-blockers for most applications. Choose a higher frequency when the main speakers are weak in bass response.

Adding a choke coil in series with each side of the dual-voice-coil subwoofer (see Fig. 7) will prevent power amplifier oscillation problems. The inter-winding capacitance or mutual inductance of dual-voice-coil subwoofers can cause some power amplifiers to oscillate. You can purchase choke coils inexpensively, or wind your own. Twenty turns of No. 22 wire wrapped around a ¼-inch diameter steel bolt will provide an approximate value of inductance of about 20 microhenries.

Power for the subwoofer crossover and power amplifier can be supplied from the automobile's +12-volt ignition lead or from the remote turn on/power antenna lead.

First power up

Before turning the system on for the first time, set the volume controls of the subwoofer amplifier and the receiver to minimum. Set the crossover cutoff frequency control to maximum (fully clockwise).

After turn on, increase the receiver volume slightly to verify that sound is coming from each of the main speakers. If it does not, check for short circuits or open connections.

If sound comes from each of the main speakers, increase the subwoofer power amplifier level. Listen for bass from the subwoofer. If little or no sound is heard, try setting the receiver's balance control all the way to one limit. If this produces bass, one of the crossover inputs is connected backwards.

The most important step in adjusting a subwoofer system is to set (and keep) the stereo's bass control at or below the flat (middle) position. Vehicle interior acoustics are notorious for overemphasizing upper bass

SOURCES

Crutchfield
1 Crutchfield Park
Charlottsville, VA 22906
(800) 955-3000
(car stereo components)

Madisound Speaker Components
8608 University Green
P.O. Box 44283
Madison, WI 53744-4283
(608) 831-3433
(speaker building supplies)

MCM Electronics
650 Congress Park Drive
Dayton, OH 45459-9955
(800) 543-4330
(speakers, boxes, car stereo, electronic components)

Parts Express
340 East First Street
Dayton, OH 45402-1257
(800) 338-0531
(speakers, boxes, car stereo, electronic components)

frequencies. By turning the bass control down, boomy-sounding upper bass is reduced. By adjusting the subwoofer crossover cutoff frequency for optimum sound, the subwoofer will fill in a deep, solid sounding bottom end.

Set the crossover polarity switch (S1) to position which gives the most bass. Set the crossover Eq. switch (S2) in the "boost" position to increase deep bass frequencies and to help extend the subwoofer's response. Use the "flat" position if you hear distortion from the subwoofer. Adjust the crossover cutoff frequency and the level control of the amplifier to provide the best sounding bass. Ω