BUILDING YOUR OWN AUTOMOTIVE SUBWOOFERS

PRESENTED BY PARTS EXPRESS
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Why Add A Subwoofer?

Sub-bass frequencies can be considered to be the foundation upon which to build an accurate and realistic automobile audio system. Subwoofers reproduce the lower frequencies that other speakers cannot reach, and they can do it with clarity, punch, and depth. As time passes, music styles change and evolve. Today's music playback systems have to deliver a performance that will satisfy the listener's elevated expectations. It is obvious that the quality of the midrange and high frequency components must be optimized because so much critical information is found in those ranges. The use of a subwoofer is of equal importance, however, because a sub will help to fill out the lowest musical octaves of sound and provide a more realistic listening experience. It should be mentioned that bass does not need to be overbearing or exaggerated, but rather, it can be a subtle yet important enhancement to almost any style of music or program. If, on the other hand, your taste for bass runs to the extreme, equipment available today can come close to popping the windshield right out of your vehicle.

Finding a location for all of the speakers large and small can be challenging in an auto environment. Selecting, installing, and integrating the components can be as difficult as any other audio system. Automobiles are an important part of our society, like it or not, and since we spend so much time in them we want to make sure that our audio experience is at least as good as what is achieved with our other systems.

Why Do It Yourself?

There are quite a few really good subwoofer systems on the market today that give excellent performance… for a price. It is not unusual for the actual value of the components and materials to add up to as little as 25% of the total cost in the retail showroom. There is obviously some room for improvement here! When you have control over the components that are used, the enclosure design, and construction materials and methods, the result can be superior sub bass output that requires a lower cash input. With a few common tools, a weekend or two of your time, and some elbow grease, Parts Express can show you how to build a sub that will perform like the commercially available ones and save you money.

Why Parts Express?

Parts Express has specialized in supplying speakers and components to both hobbyist speaker builders and manufacturers for over 16 years. We stock one of the largest selections of loudspeakers in the country from name brands like JBL, Eminence, Vifa, Dayton Loudspeaker, Ultimate, Peerless, Focal, Audax, Pyle, Pioneer, Pyramid, and

more. We are able to offer outstanding values due to our tremendous sales volume, and our technical support before and after the sale is second to none.

Building your own subwoofer

Everybody else is doing it, what's the matter- are you scared?

SET A GOAL

What do you have in mind for your subwoofer, what are your expectations? Acoustical performance is certainly something to consider, but size, shape, and of course cost are also factors that are best established before the project goes very far. Although it can be tempting to select the actual subwoofer driver first because of a super special sale price, or it just looked so shiny and menacing in the picture, resist! The size, shape, and type of enclosure can have a big effect on actual subwoofer performance, and driver selection must be based on matching the speaker to the requirements of the box and it's specific application. We will start by presenting some of the options available at the planning and design stage, followed by an overview of some of the more critical parameters to be aware of when choosing subwoofer components. We will then describe the most popular enclosure designs to help you to determine which will be the best fit for your design goals. The implementation and set-up of your new subwoofer will also be discussed to ensure that you are able to maximize the potential of the new addition to your audio family

DESIGN YOUR OWN

There are many resources available to the people of spirit, vision, wit, intelligence, and courage who choose to design and build their own subwoofer project. Some very popular books would include 500-021 "Designing, Building, and Testing Your Own Speaker Systems" by David Weems, 500-034 "The Loudspeaker Design Cookbook VI" by Vance Dickason, 500-037 "Bullock On Boxes" by Roger Bullock, and 500-040 "Audio Amateur Loudspeaker Projects" from Audio Amateur Magazine. These books present both theoretical and practical information that can be of great assistance to the subwoofer hobbyist.

Users who prefer a computer based design process will want to consider software programs like 500-923 BassBox 6 Pro for Microsoft Windows, or 500-945 Eminence Designer, which is also Windows-based and is produced by the Eminence Loudspeaker Manufacturing Company. Eminence is one of the largest manufacturers of high quality speakers in the world and it would be safe to assume that they know a couple of things about speaker design!

Some speaker enthusiasts catch the bug and build speaker after speaker, trying different variations and refinements. Doctors are working around the clock, trying to find a cure for this disease. There are other audio do-it-yourselfers who take a more casual approach,

completing a single project or occasional upgrade. These infrequent builders may not want to invest in a book library or software system, and we at Parts Express invite them to use our free design services. Our Technical Support staff can help with the selection of speaker components, amplifiers, and cabinet accessories; more importantly we can provide customers with tuning and design information using the popular BassBox 6 Pro design software. There is a lot of information that is just a phone call or email away, don't be afraid to ask!

BUILD A KIT

Were you scared by math as a small child? Does your job as a lighthouse keeper prevent you from having the spare time to spend designing speakers? Did the apartment manager make you take your table saw out of the laundry room? You are looking for a high performance subwoofer, the store-bought ones seem puny and overpriced, and you still want to smell that crisp, fresh subwoofer when it comes out of the cardboard box for the first time. What to do?

Parts Express offers pre-cut MDF enclosures like the 300-729 that are shipped knocked down and require assembly and finishing. The knock-down boxes can be completed with basic power hand tools like a router (if you have one handy), a drill, and a jig saw. All of these enclosure options give you the opportunity to experience as much of the subwoofer design and construction process as your skills, workspace, and time permit.

FOLLOW A PLAN

If you would like to embark on a subwoofer project, but would prefer to follow a proven path rather than blaze a new trail, you might want to consider following one of the many available speaker plans. Some of the excellent books previously mentioned include well thought out and easy to build plans that can speed your progress and help you to predict the outcome. The Parts Express Project Showcase is also a great resource for speaker concepts and plans.

Many plans can be considered a place to start, and you can certainly make alterations or substitutions that suit your needs or your budget. If you do make changes, make sure that it is clear what effect your changes will have on the rest of the design.

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Component selection

ACTIVE OR PASSIVE CROSSOVER

A crossover network for a subwoofer has the primary job of filtering out high frequency program that is above the intended operating range of the sub. This application is known as a low pass filter, also sometimes referred to as a high cut filter. As a matter of either convenience or system integration the low pass filter is sometimes combined with a second filter that removes low frequencies from the high range speakers. The name for that filter is a high pass filter (or low cut). Whatever bandpass we are shaping, there are two approaches to the application of these concepts. The most common approach is the passive network, which in various configurations is by far the most common for loudspeaker systems in general. A passive network refers to the use of high power handling capacity components AFTER the amplifier and before the speaker load itself. While there are some advantages as far as flexibility and cost, there are some significant downsides as well. The insertion loss that results from the inductive components lowers system efficiency, and passive filter circuits can also affect phase response and damping.

An active network derives its name from the placement of the filter BEFORE the amplifier; the network is designed to operate at line level. The formulas that are used to calculate the crossover are similar in theory to the passive designs, but the voltage and current involved are obviously much lower. There is consequently much less of the associated distortion and loss that we have described for the passive network, plus a few other significant advantages. Active crossovers send the filtered output to the amplifier responsible for each particular frequency range. Although there are cost, space, and complexity issues with using multiple amps, the advantages are improved headroom, lower distortion, and much greater control.

SUBWOOFER DRIVER SELECTION

The selection of the actual subwoofer driver must by necessity be considered throughout the process of choosing the actual type of enclosure. Each enclosure type can demand that a driver of a particular specification is used in order to provide the performance that is expected. In general, sealed box designs tend to expect a driver to have a relatively high Qts, low Fs, very good xmax, and relatively soft suspension. Vented boxes will usually expect the driver to have a somewhat lower Qts, and remember that Fs will need to also be fairly low since you cannot usually tune the box below that frequency. Horn loaded designs do not need a driver to have a low resonance because the length of the path of expansion, and the mouth area of the horn, determine low frequency cutoff.

A useful formula to determine the suitability of a particular driver for a particular box is the Equivalent Bandwidth Product (EBP), also known as the Equivalent Bandwidth Ratio (EBR). It is determined by taking the driver free air resonance (Fs) and dividing it by the

electrical Q (Qes). If the resulting number is around 50 or less, you are looking at a driver that is best suited to a sealed type box. If the EBP is between 50 and around 100 or more, the speaker will work best in a vented enclosure. Horn loaded designs will perform best with an EBP of 150 or even higher.

Look closely at xmax values and any indicators of excursion limits for the driver that you are evaluating. The lowest musical octave that the subwoofer has to reproduce will cause far more stress than any higher frequencies. Linear long excursion capabilities combined with good cone control will provide high output low distortion sub bass. Most modern subwoofers will run out of mechanical power handling before they exceed their thermal power handling capacity.

Some users prefer to mount their subwoofer in a "down-firing" orientation, although this particular configuration is not that common for automobile applications. The cone mass of the driver must be taken into consideration, as the tendency for the cone to settle downward can move the voice coil out of the gap and affect xmax and excursion capabilities. As long as the amount of "sag" does not exceed 5% of xmax, the driver will work just fine in a horizontal configuration.

SINGLE OR DUAL VOICE COILS

A conventional woofer has a single voice coil that moves in the magnetic field and provides the motive force for the cone. A dual voice coil has a second coil wound concentrically with the first coil, and has its own separate terminations. The primary advantage of this arrangement is the ability of the dual voice coil subwoofer to accept both left and right amplifier outputs in a single driver. This can be of obvious benefit in compact, low cost applications since bass is non-directional anyway. An alternative feature of the dual coil speaker is that choices can now be made to most effectively connect the subwoofer to the amplifier. If for example the dual coils are rated at 4 ohms each, you can decide whether to connect them in series (8 ohms) or parallel (2 ohms). This leads to even greater flexibility because the connected voice coil pairs can be connected to additional voice coil pairs to achieve a specific target impedance. For more on this subject, please go to our FAQ, or our driver wiring diagram page.

What do all these numbers mean?

Understanding the specs that matter…

When you begin to choose a loudspeaker component, you will soon begin to feel a little overwhelmed by the confusing and somewhat contradictory numbers and words thrown at you. For a quick overview of the specifications that matter the most for subwoofer selection, we will begin with the ones that are the most broadly applicable. When we get a little further along with discussing particular subwoofer box configurations, we will

more thoroughly examine the parameters that affect those individual designs. Please feel free to jump over to our very comprehensive Technical Resources Page, and especially our Speaker FAQ Page, for more detailed explanations of some of these terms.

POWER HANDLING

The industry seems to have almost convinced us that power handling capacity is the most important number to consider when choosing speakers. High power handling is certainly a factor to consider, depending on your application, but be sure that you are looking at the right numbers. The RMS rating is based on a mathematical formula (RMS= .707 X peak measured power) for determining average power that the speaker is subjected to, and it is usually a fairly conservative number compared to the continuous program power or peak power ratings that we will discuss in a moment. RMS ratings are only as good as the "qualifiers" that accompany them, for example, rating a hypothetical subwoofer at 600 watts/RMS doesn't mean much if the frequency chosen for measurement (1000 Hz) is outside the range that you intend for the subwoofer to be used (25 to 125 Hz). In the case of this example, the power handling number would give us some idea of what the subwoofer could withstand in terms of thermal power handling capacity, but it would not reveal much about the mechanical limits at the lower frequencies where the subwoofer will be used. Lower frequencies require greater cone travel, and we will be expecting that subwoofer cone to be moving quite a bit! For the purpose of selecting a speaker it is useful to know the range of frequencies tested, or the single frequency if that is what was used. Since these qualifiers are sometimes a little hard to nail down, your best bet is to stick with manufacturers that demonstrate the greatest credibility, and suppliers that take performance specifications seriously.

Continuous program power is generally understood to be double a given RMS rating, and tends to represent the kind of stress that a speaker is subjected to when that amount of music program is played through it. Although music can place dynamic stresses on a speaker, it also gives the components a chance to "rest" at intervals, even if those intervals are only a few milliseconds in duration. If you use a subwoofer rated at 200 watts RMS or 400 watts continuous program power, with an amp rated at 250 watts RMS, you are actually getting a pretty good match as long as the amp is not driven so hard that it exceeds it's "clean" power rating of 250 watts RMS. When overdriven, the amp can exceed it's RMS power rating and produce even more power, and that extra power will be loaded with a lot of harmful distortion.

Peak power is probably the least helpful rating for speakers. Any speaker can handle extremely high peaks of undistorted signal for milliseconds or microseconds, but these impressive numbers are rarely qualified by the disclosure of the test conditions that were used to determine them. In effect, peak power ratings are an example of a "numbers game" that marketing pressures have forced the manufacturers to compete in because higher numbers impress some buyers. The key to power handling ratings is reviewing and understanding the specifications that actually apply to the job at hand.

IMPEDANCE

Speaker impedance can be defined as the combined total of all resistance, inductance, and capacitance that the speaker presents to an amplifier. It is also referred to as "nominal impedance" because the actual number measured in ohms can vary quite a lot over the frequency range of the speaker. The actual nominal impedance value of 2, 4, 6, 8, or 16 ohms has no connection whatsoever with subwoofer performance or quality, but it is important for the proper match of an amplifier to the intended load. The lower the impedance value, the more power will flow through the speaker. If a 4 ohm and an 8 ohm speaker are connected to the same amplifier, the 4 ohm speaker will receive twice the power of the 8 ohm speaker, so matching values within the same frequency range can be pretty important. Multiple driver designs will require an awareness of the impedance of the intended drivers as various wiring configurations can increase or decrease the total value that the amp will see. It is also important to correctly identify subwoofer impedance as it is also a factor in establishing the values used to determine passive crossover components.

XMAX, EFFICIENCY, AND SENSITIVITY

Xmax is the term used to describe the linear excursion capability of a loudspeaker. It is basically determined by the length of the voice coil relative to the height of the magnetic gap of the speaker "motor". The subwoofer can only provide clear, undistorted output if the magnet is able to maintain control of the voice coil, and lower frequencies demand greater travel or excursion. The voice coil tends to have greater mass due to the increased amount of wire required for the longer surface area covered; this usually results in a reduction in higher frequency response, and lower overall driver efficiency.

Efficiency and sensitivity are very closely related. Efficiency is usually shown as a percentage that describes the ability of the speaker to convert an electrical input into an acoustical output. You will hear a lot of advertisements for speakers that declare the product to be "high efficiency", but in fact that is a relative term.

Sensitivity ratings for loudspeaker products are representations of relative loudness, using a scale of decibels (dB), and with an input power of 1 watt (w). The resulting Sound Pressure Level (SPL) generated is typically measured at a distance of 1 meter (m) from the loudspeaker, so it would appear that we have everything we need to compare one speaker to another, right? Actually, it is just a start…

It is a surprising fact that loudspeakers in general and subwoofers in particular are very inefficient devices, electrically speaking. An "efficient" pro sound 12" midrange speaker with a sensitivity rating of 103 dB at one watt/one meter might have a reference efficiency of around 5 or 6%. This means that for all of the amplifier power going into the speaker, as much as 94% is wasted as heat and mechanical losses. Wait, it gets worse! Your state-of-the-art subwoofer loudspeaker has a sensitivity of only 87 dB 1w/1m, or a

reference efficiency of only 0.27%, so what good is that? Before you get mad at your speakers for being very expensive round heating elements, just relax and enjoy the benefits of modern technology! High performance amplifier power has gotten relatively cheap and reliable, and improvements with adhesives and high tech design have pushed speaker power handling to limits that could only have been dreamed of a generation ago. It was not that long ago that you were the king of the hill if your (probably tube) amp was cranking out a blazing 25 watts per channel, and your woofers (probably not subwoofers) were rated at 50 watts each. The high efficiency designs of that era were actually able to provide a very dynamic hi fi experience, but there are some alternatives for the contemporary user.

The most popular current thinking regarding efficiency relative to subwoofer output is to select a driver with a fairly high mass stiff cone, good linear excursion capability, and power handling that is high enough to withstand the power required to move that massive cone and long voice coil. This driver will have a fairly low sensitivity rating because of these design characteristics. In a properly designed enclosure, and driven by the appropriate amplifier, our example subwoofer will be able to deliver deep, clean, high impact bass.

We have established that power handling ratings are only relevant within a driver's actual operating range; sensitivity ratings for a subwoofer only count in the sub-bass region below approximately 125 Hz. A subwoofer could actually have a response that is rising at frequencies that are outside the range that you intend for the sub to be used. The sound pressure of these higher frequencies will affect a sensitivity rating if the manufacturer has averaged the boosted response of the higher frequencies with the reduced output that we would expect at lower frequencies.

FREQUENCY RESPONSE

The frequency response of a subwoofer is important but becomes far more meaningful when we are able to determine the actual response in the enclosure of our choice. As we have seen with other key specifications, frequency response numbers mean little without some kind of qualification. To simply state that a driver has a response "from 19 Hz to 1000 Hz" is leaving out critical information. If the relative output (remember SPL?) versus frequency is not disclosed, we could be looking at a response at 19 Hz that is 3, 6, or even 16 dB below the average response for the speaker. Similarly, there could be a 10 dB peak at 90 Hz. Frequency response graphs can be far more helpful, because the associated graph will display the variations in sound pressure level at any given frequency. Be sure to try to determine if the woofer shown on the graph was tested in an enclosure or free air, because free air plots will make the bass response look very puny indeed. Computer modeling programs like BassBox Pro can fill in a lot of information as far as what to expect for bass response from a given enclosure design. Keep in mind that since we are discussing subwoofers, the response of the driver above 125 or 150 Hz is not a matter of great importance to us.

Choosing a type of subwoofer, and adding it to your system
So many boxes, so little time…

A NOTE ABOUT CABIN GAIN

Before we begin to consider all of the different box and woofer configurations that are available for your auto sub project, it would be helpful to briefly describe an acoustical property of small enclosed spaces that can have a significant impact on your choices. Cabin gain is the bass boost effect that is caused by the concentration of space and reflections in an automotive interior, although home environments of average size will provide a moderate increase in bass response due to the same effect. The boost in deep bass response in autos can be around 6 dB or more at 50 Hz, and as much as 20 dB at 20 Hz. Keep this in mind when you choose a box style, and your drivers, because you are getting "free bass" that will either offset or exaggerate the system's own conventionally measured response.

SEALED BOX

Sealed box subwoofer enclosures have advantages that appeal to beginners because of the simplicity of box design and construction, and to experts because of the compact enclosure dimensions, very good power handling, and outstanding transient response. They are noted for their tight "non-boomy" sound, and relatively small size compared to other designs. The driver will tend to have a fairly low free air resonance (Fs), long excursion capability (xmax), and loose suspension (the air loading of the small box provides restoring force). A bigger version of the contemporary compact sealed box is the classic "infinite baffle" which, because of the increased compliance of the air in the larger enclosure, requires a stiffer mechanical suspension to provide loading for the woofer cone. The larger cabinet volumes for infinite baffles are not always practical for all applications. All sealed box designs, large or small, tend to have lower sensitivity and higher bass roll off characteristics than other designs. Cabin gain will actually compensate for this falling bass curve and will bring the response closer to flat, which helps to explain why small sealed boxes are by far the most popular configuration for automotive installations.

VENTED BOX

Vented, ported, ducted, bass reflex; these terms all describe the same type of enclosure. Vented designs have been around for quite a while, but really came on with a bang after acoustic researchers devised a way to effectively identify speaker parameters (the mechanical and acoustical characteristics of the driver in question) and use those parameters as elements in mathematical formulas that consistently model or predict the response of a given driver in a given enclosure. Simply put, the driver is matched to what is essentially a tuned resonant air chamber. As the driver goes lower in frequency, the driver excursion is reduced and the air in the vent proportionately increases its pressure

on the air outside of the enclosure. This "high pressure air" in the port is just as effective a diaphragm at those frequencies as an actual hard diaphragm made of solid material. Talk about getting something for nothing! The vented box has a lot to offer, with advantages like flatter response down to the cutoff frequency or lower limit (although this is generally higher in frequency than a sealed box), reduced cone excursion near the box resonance frequency, and overall higher efficiency than most sealed box designs. There are also some significant limitations to this type of design. The transient response of the subwoofer is generally not as good as a sealed box design, but this can be minimized by careful driver selection and critical box tuning. Another problem is that there is no acoustic loading on the driver below the specific tuning frequency of the enclosure, meaning there is no control over cone motion beyond the subwoofer's own mechanical suspension at those frequencies below the box resonance. This results in "bottoming out" and the ultimate destruction of the driver. A simple solution is to use a low cut or rumble filter before the amplifier to prevent the subsonic frequencies from affecting the speaker below cutoff. The overall design of a vented box can be a bit trickier for the casual speaker builder, but modern software programs like BassBox Pro or the technical support staff at Parts Express can help you to develop a high performance project. The flatter frequency response of vented designs can be problematic in automotive applications, because the rising cabin gain effect on top of this flat output will result in an overall boost. This boosted response might appeal to the sub bass fan that is looking for a more exaggerated or boomy sound quality.

PASSIVE RADIATORS

Passive radiators are an alternative to vented designs and are in fact part of the same family of enclosure design. It is the simple substitution of an actual diaphragm (usually similar to a speaker without a magnet and voice coil) for the virtual diaphragm of air in the vent that we just described in the last section. Advantages would include the absence of wind noises from a vent, and the ability to block higher frequency sound reflected from the back of the driver and out through the vent. They are also useful when a particular tuning requires a vent length longer than what the enclosure can accommodate. Some disadvantages are inferior transient response due to the actual mass of the passive radiator diaphragm, and greater difficulties in tuning compared to vented designs.

BANDPASS BOXES

Bandpass boxes are designs that use multiple chambers to create an acoustical filter that will focus and increase sound output within a specific frequency range. The most common of the many variations is the 4^{th} order bandpass, which consists of a woofer loaded in a conventional sealed box enclosure, but the output of the woofer is directed through a second vented chamber in front of the driver. The port increases gain in a fairly narrow range, but also acts as a low pass filter to help reduce high frequency output above the bass frequencies. The actual vent diameter should be as large as possible or practical, as these designs are particularly susceptible to vent noise- the whole output of the woofer is passing through that opening! Bandpass designs offer transient response

approaching that of a conventional sealed box, combined with output that can actually be greater than a vented box. The downside of this family of boxes is a tendency toward an unnatural or "one note" sound, due to the peaky nature of their operating range. Once again, the cabin gain effect helps to broaden the narrow frequency response of the design. Bandpass boxes have proven to be popular in automotive applications, primarily due to their efficiency.

TRANSMISSION LINES AND HORN LOADED DESIGNS

Transmission lines and horn loaded subwoofers are difficult to implement in automotive applications, mainly because of their sheer size and complexity. If you are interested in these designs, check out our Home Stereo/Home Theatre or Pro Sound sections on subwoofers.

BASS ACTUATORS

The small but mighty bass actuator does not require an enclosure of any kind, but still has a place in our general discussion concerning sub bass performance. A bass actuator is a small servo device or motor that converts an audio input signal into a mechanical force that is placed in direct contact with a solid surface. Conventional subwoofers transmit information through air, while a bass actuator delivers low frequency program directly through solids. The sensation is very much the same as it would be if the sub bass had come from a speaker first and then vibrated the solid surface, so actuators can be useful in situations where space is too limited for large speaker enclosures. The actuators connect to an amp just like a speaker, but you should be prepared to use them in multiples because the coverage of the effect is limited by the nature of the solid object to which the bass actuator is attached.

Putting it all together

CABINET SHAPES

Modern analysis seems to suggest that special cabinet dimension ratios do not have as much of an effect on performance as what was once assumed. Standing waves are caused by the reflection of frequency wavelengths that happen to be the same size as the distance between parallel surfaces, or surfaces that are at right angles to the first surface and of the same size. This effect can be minimized by using enclosure designs with non-parallel panels, or using proportions that can reduce the opportunities for the offending frequencies to reinforce themselves. The generally accepted "golden ratio" for these proportions is said to be 2.6/1.6/1, but the use of this ratio is not critically important when designing and building subwoofers. An airtight box, well braced, and adequately stuffed with damping material, will be as important as the shape of the enclosure. A free standing subwoofer enclosure must by necessity complement the environment in which it is used,

and some custom boxes can follow the contours of the specific vehicle into which they are placed. Even built in subs face constraints imposed on them by the structure into which they are built.

CABINET MATERIALS AND CONSTRUCTION TECHNIQUES

The material of choice for subwoofer enclosures is MDF or medium density fiberboard. It has greater mass and density than particle board, which comes in second due to the use of larger particles or flakes of wood in its composition and lower glue content. Void free birch plywood is more appropriate for portable speakers because it is stronger and lighter than composition products, but unfortunately is not as dense. An airtight enclosure with well braced and damped panels will ensure that more sound energy reaches the listener instead of simply vibrating the cabinet walls or pushing the air out of small gaps. The use of a silicone or latex caulk should be used for all cabinet joints and even input terminals, no matter how solid things seem to be. Speaker sealing caulk or foam tape are convenient products that can ensure that the driver's mounting will not contribute to leaks. Special care should also be given to the grill cloth or screen that many users install to prevent the exposure of the driver to dust or foreign objects (golf clubs or the probing fingers of inquisitive small children). The excursion limits of the subwoofer can be quite considerable and could exceed the clearances provided by some methods of protection, resulting in buzzes, rattles, or even damage to the driver.

Automotive subwoofer boxes seem to have their exteriors covered in carpet more often than not. Other finishes could be used, including paint, wood veneer, laminate, or spray on/roll on truck bed liner. Each has its own advantages and disadvantages, but it is probably one of the most subjective decisions that will be made during the whole subwoofer project. The one that you like the most or feel most comfortable applying is the best one for your project, as exterior finish will have little noticeable effect on subwoofer system performance.

What will have a serious effect on performance is stuffing. Stuffing, or filling, is used primarily to absorb or minimize standing wave reflections within the box. The proper use of stuffing can also affect the virtual box size that the subwoofer "sees" and can provide an increase in effective volume of 25% or more. This can be useful for applications where the enclosure size is marginally smaller than optimum, or to make up for internal volume losses from driver or brace displacements. Fiberglass, Dacron, Acousta-Stuf, acoustic foam, and long fiber wool are all popular and readily available acoustic damping materials. Be sure to identify the basic stuffing requirements or recommendations for your chosen project, but consider those to be a suggested starting point. Experimentation can lead to an amount of filling somewhat greater or smaller than originally specified, but can result in performance that satisfies the user's personal requirements.

Placement, set-up, integration, tweaking

I can't fit the groceries in the trunk because my subwoofer is, like, big.

The sawdust has settled, there are still a few splinters under your fingernails, and you can always put the tools away later, really. It's time to see if you can pop your trunk lid open from sheer SPL. The non-directional nature of bass has already been discussed, and you will recall that specific placement of the subwoofer is not as critical as other speakers in your system. Many vehicles will permit the bass to pass through the actual back seat and into the listening area without cutting holes. We also touched on the subject of standing waves inside the speaker enclosure; it shouldn't surprise us that we will need to address standing waves in the listening space as well. Bass energy is easily reinforced by reflection, and as those reflections recombine, the resulting buildup can cause very irregular response in the vehicle interior in the form of peaks. Similarly, phase cancellations can occur when the sound waves at a specific frequency cause destructive interference and cancel each other out, and create holes or nulls in the response. In general, we will be able to enjoy the benefits of cabin gain that have already been mentioned, but be aware that there will probably be a few dead spots as well. When properly integrated, the actual location of the subwoofer will disappear and the bass will seem to be coming from the little bitty speakers on either side or even in front. Test tones and measurement equipment can help you with your system setup, but good results can also be achieved by spending time with a couple of well recorded CDs with which you are especially familiar. After satisfying yourself that your driver's seat position is sounding good, try the passenger and back seats to get a sense of what other occupants will be experiencing. You probably won't be able to hear them yelling at you later.