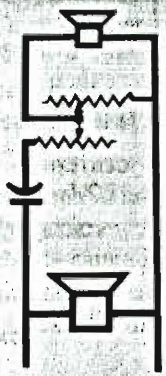
1

How a Speaker Works



The speaker is the part of a sound system that has the fewest specifications, but the greatest effect on quality. Most listeners can't hear the difference with a change of amplifiers, but can immediately sense a switch in speakers. If you want to upgrade your stereo set, the speaker system is a good place to start.

PARTS OF A SPEAKER

The working parts of a dynamic speaker are the cone with its suspension, the voice coil, and the magnet (Fig. 1-1). When an electric current flows through a wire, it sets up a magnetic field around that wire, and for a coiled wire the field is increased. If the coil of wire is located in an external magnetic field, provided by a magnet, the field of the coil interacts with that of the magnet to apply force to the coil. If the current is an alternating current, the field around the coil builds up and collapses in response to the frequencies of the current. In a speaker this changing field interacts with the constant field of the magnet, causing the coil to move in response to the current. As the voice coil moves, it moves the cone, which makes pressure waves in the air near the cone. These pressure waves are heard as sound.

The cone suspension allows the cone to move without shifting sideways far enough for the voice coil to rub the center pole of the magnet. Modern speakers have an outer cone suspension, the *surround,* and a coil centering device called the *spider.*

If you connect the leads of a sensitive AC voltmeter to the terminals of a dynamic speaker and gently push the cone with your

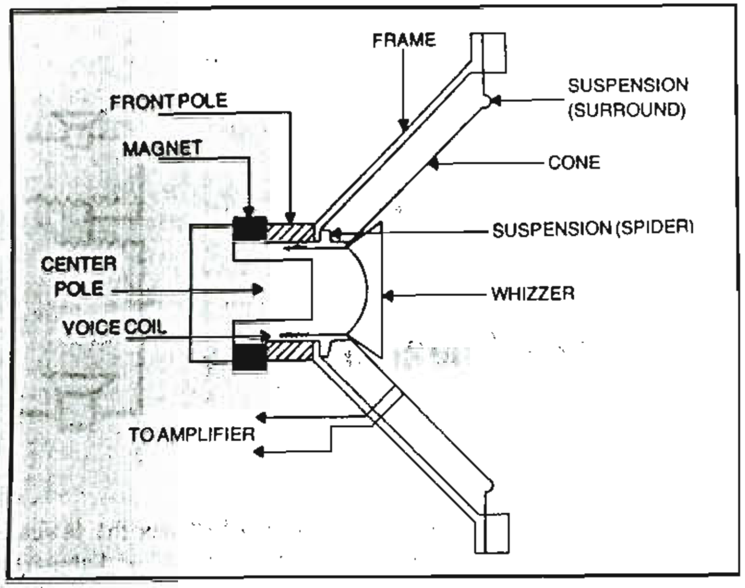


Fig. 1-1. Parts of a loudspeaker.

hand, the meter pointer will move, indicating that you have produced a small voltage across the terminals. When a speaker is connected to the input of a high gain amplifier, it can act as a microphone. Many intercom sets use this principle, with a small speaker in each station that works in a dual role of speaker during the receiving mode and microphone during the sending mode.

When a speaker is in use, each voice coil movement produces a voltage in the same way. The direction of the electromotive force (emf) produced is always that which will oppose the change of current direction in the current that drives the speaker. Because of its direction, this force is called the *back emf.* The stronger the magnetic field, the greater the back emf and the higher the electrical damping on the voice coil and cone movement.

FREQUENCY RESPONSE

In selecting a speaker for music reproduction, smoothness of response is more important than extended range alone. A speaker with a smooth response from 100 to 10,000 Hz can produce music more faithfully than one with a 50 to 15,000 Hz range but with significant peaks within that range.

The requirements for a wide frequency range from a single cone are contradictory. For good performance above 10,000 Hz the cone must be light, with a mass no greater than about 5 grams. But light cones bend at low frequencies, producing distortion. For good bass response the cone should be large to "grab" enough air to have good radiation resistance, but for good dispersion at high frequencies it must be small. A heavy bass cone will have a lower frequency of resonance and a smoother response than a light one, but the heavy cone will have poorer transient response as well as a limited high range.

One way that speaker designers solve these problems in full range speakers is to add a secondary cone, called a *whizzer.* A whizzer cone is less expensive than a separate tweeter because it is driven by the same magnet and voice coil as the main cone. It can improve the radiation pattern of the highs as well as extend the frequency range.

Even those large cones that have no whizzer can produce some high frequency sound. They do this by cone *reduction.* At low frequencies the entire cone vibrates as a single piston, but as the frequency of the signal is increased, the central part of the cone vibrates independently. Having lower mass, a small section of the cone can emit sound at relatively high frequencies.

TRANSIENT RESPONSE

A speaker's ability to handle short pulses without altering their duration is called its *transient response.* For good transient performance a speaker must start to move almost immediately after receiving the amplifier's signal to do so, then stop promptly when the signal ends. The trait of oscillating after the signal has ended is called *hangover.*

The first requirement for good transient response is a smooth frequency response. A peaky response curve indicates multiple cone resonances, and each resonance can be kicked off by any signal which contains the resonance frequency in either the fundamental tones or in its natural overtones. Each resonance adds its share of hangover, and the aural effect of hangover is muddy sound.

Even if a speaker has a smooth frequency response without higher resonances, it will have at least one resonance, the fundamental cone resonance. The prominence of this resonance varies with system Q; a high Q speaker has low magnetic damping and is prone to peaking at its frequency of resonance.

DISPERSION

All speakers produce sound that is more directional at the upper end of their frequency range. As a rule of thumb a speaker is omnidirectional only up to the frequency where the effective cone diameter is equal to the wavelength of the sound. Following this rule, a 12" speaker is fully omnidirectional to about 1300 Hz, an 8" speaker to 2000, or a 4" speaker to 4000. Speakers can be used to perform at higher frequencies than these because of cone reduction and the use of whizzer cones.

A speaker that has poor dispersion at high frequencies will sound harsh when you are in the beam but dull when you move aside. If such speakers are used in a stereo set, the stereo image may move unnaturally as you turn your head. A speaker that spreads the highs around the room will sound more expansive and the highs will have an airy quality like those of live music.

For the ultimate in good dispersion, small dome tweeters are hard to beat. The dome shape permits the necessary strength for a small vibrating surface, and the small size provides the superior dispersion.

CONE RESONANCE

If you suspend a mass on a spring (Fig. 1-2) and set the mass in motion, it will always vibrate at a certain frequency which is its natural *resonance.* To change the frequency of resonance you can alter the mass or the stiffness of the spring. If you add a blob of modeling clay to the mass, it will vibrate more slowly. Or a more compliant spring will have the same effect. To increase the frequency you would either reduce the mass or get a stiffer spring.

Each speaker has a fundamental frequency of resonance which is determined by the mass of the cone and the compliance of its suspension. Large cones, having greater mass, usually have a lower frequency of resonance than small cones. When the frequency of resonance is measured on a bare speaker, it is called the *free air resonance.*

If you sprinkle some talcum powder on a speaker cone and watch the powder as you vary the frequency of the drive signal from an audio generator, you will see that the cone's vibration increases as you approach the speaker's resonance. At resonance it vibrates wildly. At this frequency the speaker is extremely efficient at converting electrical energy into sound, but, by its greater voice coil movement, the speaker produces more back emf at this frequency than at any other. The stronger the magnet, the higher

the opposition, or *impedance,* to the flow of current through the coil. This is why a strong magnet controls the cone movement at resonance, damping it.

COMPLIANCE

The traditional suspension, which was no more than a single wrinkle around the circumference of the cone, has been largely replaced by a roll edge in high fidelity speakers. High compliance woofers, with roll edge suspensions, can perform well in compact boxes.

Another change in speaker compliance is the way in which the compliance is reported. Instead of the distance the cone moves per unit of applied force, it is reported as that cubic volume of air which has the same compliance for the cone as the speaker's suspension. When reported as a cubic volume, the term is called the V_{AS}. Because any volume of air will offer more resistance to the movement of a large piston than that of a small one, large woofers almost invariably have a high V_{AS}. Before one can say whether a certain box size is large or small for a given speaker, the speaker's V_{AS} must be considered.

DAMPING

The degree of damping for any speaker depends on several factors, the size of the magnet, the suspension, the mass of the moving parts, and the internal resistance of the amplifier. If other factors are equal, an increase in magnet size produces more damping. But the rule "the bigger the better" doesn't go; too much magnet can overdamp a speaker, reducing the level of bass response. Magnet size isn't everything, but you can get an

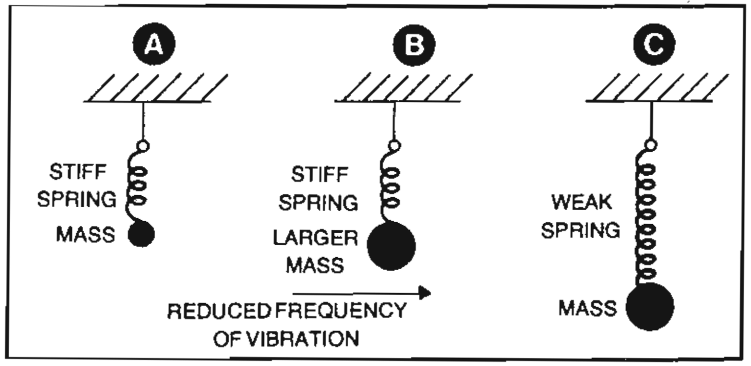


Fig. 1-2. How changing mass or compliance affects resonance.

indication of speaker quality by the size of the magnet simply because the magnet is the most expensive part of a speaker. Manufacturers aren't likely to squander the cost of a big magnet on a poor speaker. For optimum bass performance the magnet must be fitted to the size of speaker and the kind of enclosure to be used.

As a measure of the degree of damping on a speaker a numerical term, called speaker *Q* is used. Q stands for resonance magnification, the tendency of the speaker to peak in response at the frequency of resonance. Values for Q can range from about 0.2 up to 2 or 3 or more. The greater the damping on a speaker, the lower is its output at resonance and the lower is its Q. When a speaker is put into a closed box, its Q, as well as its frequency of resonance, will be raised. It is often accepted that a Q of 1 is a useful design goal for closed box speakers. This is a good compromise between a system that is under-damped and one that is over-damped.

IMPEDANCE

The opposition of the voice coil to current flow at any frequency is called its *impedance.* Most speakers have a nominal impedance rating of 8 ohms, which suggests that a speaker is like a resistor. The units of resistance and impedance (ohms) are the same, but there are important differences between the impedance of a speaker and pure resistance.

If you measure the resistance of your speaker's voice coil with an ohmmeter, you will find that it is about 75% of the rated impedance. An 8-ohm speaker, for example, will usually have a resistance of about 6 ohms. This tells you that impedance is something more than simple resistance. The ohmmeter measures resistance by putting a *direct* current through the voice coil, but the speaker must operate on *alternating* current. When an alternating current passes through the coil, the constantly swinging flow sets up its own magnetic field which grows and collapses with the frequency of the current. This moves lines of force through the coil, causing a reactance to the alternating current. The more rapidly the current reverses itself, the greater the reactance. This tendency of a coil to resist the flow of high frequency current is called *inductive reactance.* The more turns of wire in the coil, the greater its inductance.

A coil can also have *capacitive reactance,* which produces the opposite effect of inductive reactance. At frequencies where the capacitive reactance is equal to the inductive reactance, the two

reactances cancel, and the speaker's impedance is equal to the DC resistance of the voice coil. At all other frequencies the total reactance to current flow will be greater.

Impedance varies with frequency (Fig. 1-3). Note the hump at the frequency of resonance where the voice coil's back emf is greatest. The rise at high frequencies is caused by voice coil inductance. While the uneven impedance curve may look bad, remember that this is not a response curve. The high peak at resonance is a sign of a strong magnetic field.

When connecting speakers in your stereo system, the important thing to remember about impedance is to avoid a connection that puts a low impedance load on your receiver or amplifier. For many components the danger line is approached if the impedance drops below 4 ohms. Just make sure you don't wire more than two 8-ohm speakers in parallel. And never wire 4-ohm speakers in parallel with any other speakers. Many receivers and amplifiers have speaker switches that put the main speaker system and a secondary set of speakers in parallel when both sets are on, so you should be careful about using 4-ohm speakers in such combinations.

EFFICIENCY

The measure of any speaker's ability to convert electrical energy into sound energy is its *efficiency.* Mathematically, efficiency is sound power output (in acoustical watts) divided by electrical power input (in electrical watts). There are two ways to

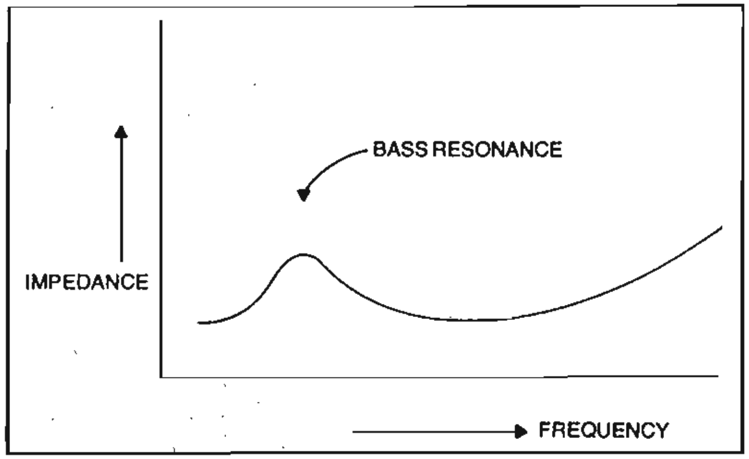


Fig. 1-3. How a speaker's impedance varies with frequency.

increase efficiency: reduce the cone's resistance to motion, or increase the force of the voice coil for a given flow of current.

The easiest way to reduce the cone's resistance to motion is to make it lighter. If the cone mass is halved, the speaker will be 4 times more efficient in the mid-frequency band. But reducing cone mass increases the frequency of resonance and often produces a rougher response curve. Another way to reduce motion resistance is to increase the compliance of the suspension.

To increase the force on the voice coil, the manufacturer can use a stronger magnet or put more turns of wire in the coil. Careful design must be used with these methods to prevent overkill. Too much magnet will over-damp the cone, and if too much wire is added to the coil, the increase in mass will begin to cut efficiency more than the field of the added turns can increase it.

Efficiency is one speaker characteristic that is rarely quoted. For many purposes it is not especially important because of the available power from modern receivers and amplifiers. It may be of importance to listeners who like extremely high sound levels.

Compact, closed box speakers are the most inefficient kind, with efficiency ratings of from 0.25 to 0.5%. Large floor models often have much higher efficiency, sometimes as high as 20 times those of the most compact speakers.

Another way of rating efficiency is to show the sound pressure level (SPL) in decibels (dB) when the speaker is fed 1 watt of electrical energy. This measurement is made with the microphone at 1 meter from the speaker. If you check such ratings, you will see that small speakers and tweeters almost invariably show higher dB ratings than large woofers. This is why tweeters and mid-range speakers often need either specially designed crossover networks or variable controls for proper balance. Such dB ratings should be used as a rough guide and have almost no value in rating speaker quality. A heavy cone woofer, suitable for use in a compact enclosure, will usually seem inefficient when compared to full-range speakers of the same size.

POWER RATING

The power rating that most manufacturers assign to a speaker is the amount of power the speaker can absorb without damage. Some of the electrical energy that goes into a speaker's voice coil is converted to heat by the coil's resistance. The larger the coil, the better it can dissipate heat, so you can estimate the power handling ability of a speaker by checking the diameter of its voice coil.

Speakers with the smallest voice coils, from ½" to 9/16", are usually rated at no more than 5 watts. The power ratings rise with increased coil diameter, so that a speaker with a 1" voice coil can handle from 15 to 30 watts. Speakers with coils larger than 1" can usually handle much more power. A 2" voice coil speaker, for example, can be rated at 100 watts or higher.

These ratings are rms values, which means that you can use an amplifier with a much higher power rating than the speaker. Music is full of transient sounds rather than sustained tones. When music power ratings are quoted, the figure is always considerably higher than the rms figure.

In some cases an amplifier or receiver with a high power rating is safer for your speakers. Low powered amplifiers can produce distortion that adds upper harmonics, placing an undue load on small tweeters. Ordinary music contains little power in the high frequency range, but a poor 10-watt amplifier can blow a tweeter which would normally be perfectly safe in a 20-watt or even more powerful system. By going into harmonic distortion at transient peaks, the low powered amplifier tremendously increases the power to the tweeter from the normal milliwatt range into several watts.

SPEAKER POLARITY

If you hook up a single speaker to a mono amplifier or receiver, it makes no difference which speaker lead goes to each terminal. But when two or more speakers cover the same frequency range in the same room, they must push and pull together or the sound from one will cancel that of the other (Fig. 1-4).

Stereo speakers have coded speaker terminals. The positive terminal is usually marked with a red dot, sometimes with a plus mark. Make sure that the lead from the positive terminal of each stereo speaker goes to the receiver terminal of the same polarity in each channel.

If you think your speakers may be out of phase, try reversing the leads to one speaker. Note that you must reverse the wires to just one speaker; if you reverse the wires to both stereo speakers, their polarity with relation to each other will be the same as in the first wiring. The easiest way to note proper polarity is to place the two speakers face to face and feed a mono signal with prominent bass tones to them. Switch the connections on one speaker only. Choose the connection that gives the greatest bass response.

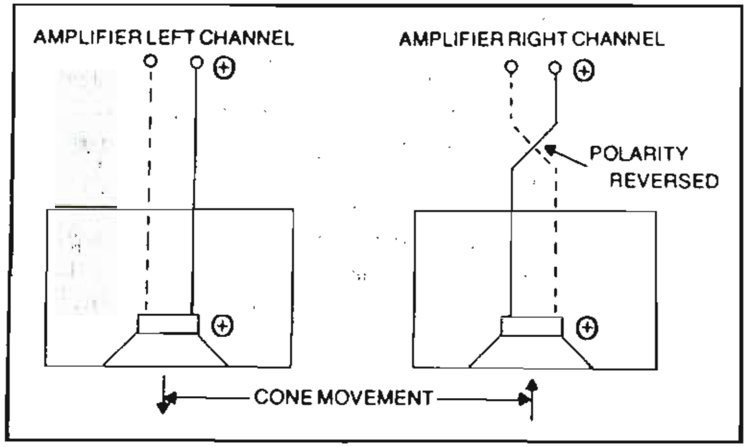


Fig. 1-4. Why stereo speakers must be in phase.

It is also important to observe polarity in wiring together woofers and tweeters in 2-way systems or the three drivers in 3-way systems. Failure to do this can produce holes in the response curve. Unless you are instructed to do otherwise, the various drivers should be wired in phase. Some crossover networks, such as second-order 12 dB per octave networks, produce a phase difference in adjacent drivers of 180° and require reversed phase wiring to prevent a hole in the response curve. If reversed polarity is necessary, it will be indicated in either the instructions or the schematic diagram.

KINDS OF DRIVERS

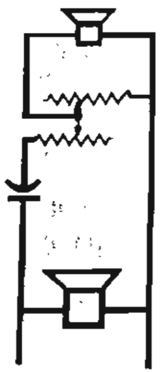
Any direct radiator speaker is called a *driver*. Because of the conflicting demands placed on a single cone driver for full-range duty, nearly all systems with a driver larger than 8" in diameter are multiple speaker systems. These systems have a large driver for the low frequencies, often called a *woofer*, and at least one other driver for the highs, a *tweeter*. A 2-way system consists of a woofer and tweeter; a 3-way system of a woofer, mid-range driver, and tweeter.

Most woofers have an advertised diameter of at least 8 inches. If a driver is designed to be a woofer, it will have limited high frequency response. This limitation is desirable because it makes the crossover network's job easier. A woofer will also have a low frequency of resonance, low enough that its bass range will be adequate when the speaker is put into a suitable box.

Mid-range drivers are often considered unimportant on the theory that any speaker can reproduce mid-range. This attitude is a mistake because the ear is most sensitive to response variations in the mid-range. For best mid-range performance, choose a driver that is designed for the purpose. And if your woofer is larger than 8" or 10" in diameter, you will probably need a mid-range driver for good mid-range performance.

The best tweeters are usually small in diameter, giving better dispersion than large tweeters. This is no problem in 3-way systems; the tweeter can be a 1" dome. But small tweeters must be used with adequate crossover networks. If the crossover frequency is placed too low, or if the tweeter is incorrectly wired, it won't last long. Remember that the power ratings assigned to tweeters are based on the assumption that an adequate crossover network will be used.

Piezoelectric tweeters can solve many problems of high frequency reproduction. These tweeters have such a high impedance at low frequencies that they are effectively out of the circuit there. This means that they can be used without a crossover network, wired directly to the amplifier output line. Such tweeters are unusually rugged, able to take driving voltages of up to 35 volts rms without failing. For continuous high power level operation a current-limiting resistor is suggested because these tweeters have low impedance at frequencies above 50,000 Hz.



2

Kinds of Speaker Enclosures

A speaker in free air is like a fish out of water. Tests on unbaffled speakers vs. properly enclosed speakers show that after installation in a suitable box a speaker can deliver up to 100 times greater sound intensity at low frequencies than it can in free air. The unbaffled speaker's lack of ability in bass performance explains why its sound is so thin and unbalanced.

FUNCTIONS OF ENCLOSURES

To see why a bare speaker sounds bad, consider Fig. 2-1. The plus signs represent an increase in pressure as the cone moves against the air; the minus signs, a decrease. When air from the high pressure side of the cone mixes with air from the low pressure side, sound cancellation occurs. At high frequencies the sound is directional, so little mixing occurs, but at frequencies where the wavelength is long compared to the diameter of the speaker, the waves can curve back around the cone so that the out-of-phase waves mix. One of the basic requirements of a speaker enclosure is that it block this unwanted mixing of out-of-phase waves.

A baffle or enclosure does more for a speaker than merely prevent cancellation. When an unbaffled speaker tries to pump air, it meets little air resistance, so, like a piston out of a car engine, it can do little work. Any speaker, large or small, can work better if it is installed in a baffle or box so that the air cannot get away so easily when the cone moves against it.

Another function that various kinds of enclosures serve, in different degrees, is to damp the speaker. Hangover kills definition, the speaker's ability to define individual tones and instruments. A mismatched enclosure can aggravate hangover, but a properly designed box will reduce it to a minimum. When a speaker is installed in a box, the air pressure against the cone adds an acoustical resistive load to it. Like the damping pads on a piano, this box air pressure damps excessive cone movement. An unbaffled speaker has electrical damping but little mechanical damping.

TYPES OF ENCLOSURES

There are four kinds of speaker enclosures in general use: closed boxes, ported boxes, labyrinths and their variations, and horns. A fifth type, the flat baffle, is found occasionally. The first two types, closed boxes and ported boxes, are used for the great majority of stereo speaker systems.

Closed Box Enclosures

When a speaker is installed in a closed box, the air in the box acts as a spring against the cone, particularly if the box is small. The smaller the box, the stiffer the air spring. For high compliance speakers, labeled as "air suspension" or "acoustic suspension" types, the box air usually provides more restoring force to the moving cone than the suspension. One of the arguments for such speakers, when they first appeared, was that the air behind the cone provided a more linear restoring force than the stiff suspensions used in earlier speakers.

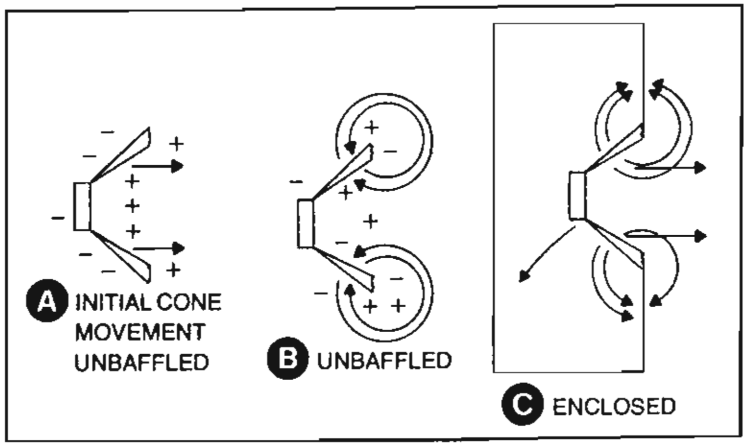


Fig. 2-1. Why an unbaffled cone is inefficient at low frequencies.

To take full advantage of the compact closed box principle, air suspension speakers must be specially designed. They need longer voice coils so the cone can move farther without carrying the coil too far from the magnet. The cones are also made heavier, which reduces the frequency of resonance and makes for a smoother frequency response curve.

After analyzing earlier large closed box speakers, the engineers who developed the compact acoustic suspension speakers made a clever trade-off. They swapped a large high compliance box for a small box with low air compliance, then to maintain low frequency bass range they replaced the low compliance stiff cone with a loose cone suspension (Fig. 2-2). Note the combinations: loose (large) box, stiff speaker; stiff (small) box, loose speaker. Almost everyone likes to save space, so the popularity of the compact closed box came as no surprise.

Like all other kinds of speakers, small closed box systems have their disadvantages. The most frequently mentioned one is lack of efficiency. Another weakness, the longer voice coils and greater cone mass in high compliance woofers put a strict upper limit on the woofer's frequency response. This means that with these woofers you must either use a tweeter that will extend well down into the mid-range or go to a 3-way system.

Ported Box Enclosures

Like the closed box, the ported box, or *bass reflex*, is easy to build; unlike the closed box, its action is complex. If you cut a small hole in a closed speaker box, the air in the box retains its ability to act like a spring, while the air in the hole acts like another piston. This air piston vibrates in phase with the cone at some frequencies, out of phase at others (Fig. 2-3).

The box with the hole in it acts as a resonator, properly called a *Helmholtz resonator*, after the nineteenth-century German physicist who first described the behavior of tuned acoustical resonators. An empty pop bottle acts as a Helmholtz resonator when you blow across the open end of the bottle. The frequency of resonance for any Helmholtz resonator is determined by the compliance of the air in the container and the mass of the air in the port. Like the speaker itself, a ported box is a tuned circuit in which a mass resonates against a compliance. At the Helmholtz frequency of resonance, the air in the port vibrates easily, compressing and decompressing the air in the box.

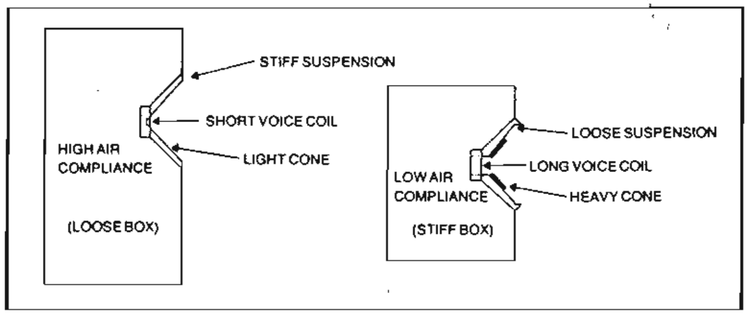


Fig. 2-2. How speaker type affects closed box size.

When a speaker is installed in a ported box, and is closely coupled to the tuned circuit of the box, the original speaker resonance is replaced by two new resonances, one at a higher frequency than the original, the other at a lower frequency (Fig. 2-4). At the upper resonance the air in the port moves in phase with the cone, but, because this frequency is well above that of the box resonance, the damping action is reduced. This is the frequency at which some reflex systems produce too much output, particularly small enclosures whose upper resonance peaks occur within the frequency range of the male voice.

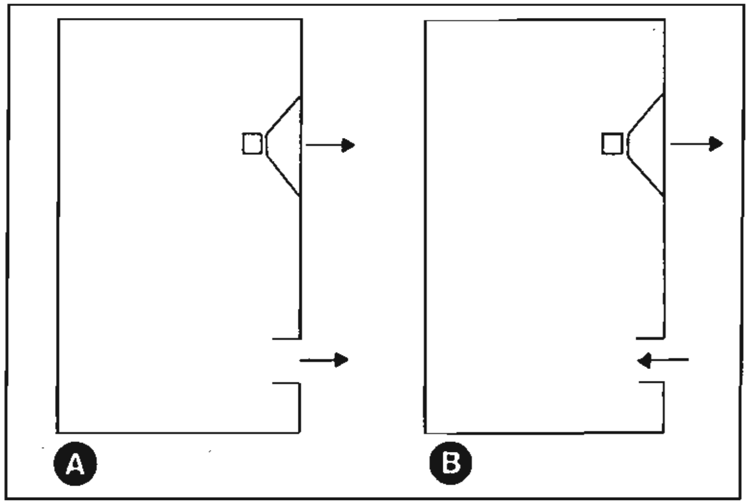


Fig. 2-3. At the frequency to which the box is tuned the port air moves in phase with the speaker cone, damping it (A). At ultra low frequencies the port air no longer moves with the cone and the speaker may be unloaded. This disadvantage of ported speakers can be relieved by use of the infrasonic filter on the receiver or amplifier.

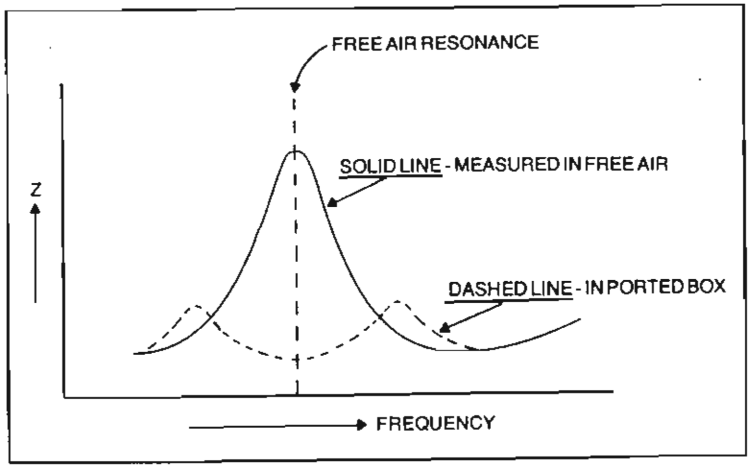


Fig. 2-4. How the impedance curve of a speaker changes when it is placed in a classic bass reflex enclosure.

If the box is properly tuned, the vibrating air piston works in phase with the cone over a selected band of frequencies to reinforce bass output. This action is most effective at the Helmholtz frequency. Here the port air acts to damp the cone so that it hardly moves, although the port air is moving at maximum velocity. In the "classic" bass reflex system illustrated by Fig. 2-4 the box is tuned to the speaker's free air resonance. Note the dip in the impedance curve at that frequency, indicating restricted cone movement. This shows the damping action of the port. Because distortion varies directly with cone movement, this cone damping action reduces distortion.

Below the box resonance frequency, there is a rapid phase shift in the output of the port so that at the lower resonance the port radiation is 180 degrees out of phase with that of the cone (Fig. 2-3). The out-of-phase radiation, plus the normal roll-off in speaker response at ultra low frequencies, produces a low bass cut-off rate much sharper than that of closed box speakers.

To tune a ported box you can change the area or the length of the port. Compact ported boxes are usually tuned by a ducted port because the use of a duct increases the mass of the vibrating air, tuning the box to a lower frequency. If the box has a simple port with no duct behind it, you can increase the mass of the vibrating air by making the port smaller. While this may seem surprising, a smaller port increases the air velocity and permits the port air to carry more air with it.

When the audio world first became aware that a tube behind the port made it possible to tune small boxes to lower frequencies, this discovery was greeted with enthusiasm in the belief that it permitted small enclosures to give a bass range and level equal to that of large ones. This idea confused tuning with total performance. It neglected the important relationship of speaker compliance to box air volume compliance. The only small reflex enclosures that can outperform larger ones are those with a compliance and tuning that is optimum for a specific driver.

One of the peculiarities of a reflex system is that port radiation does not vary with the size of the port. A small port will radiate just as much sound as a large port, but at higher velocity. If the port is too small, it can produce unmusical noises by its high air velocity. This weakness of small reflex enclosures can be solved by substituting an extra diaphragm, usually called a *passive radiator*, for the air in the port. A passive radiator is made like a woofer but has no magnet or voice coil. It can be tuned by changing the mass of the vibrating diaphragm.

The most important advantage of the ported box is its damping control on the speaker. It also offers more efficiency by permitting a more efficient woofer. A woofer designed for a ported box does not have to have as heavy a cone or as long a voice coil as a sealed box woofer, so it can have more extended mid-range response. This makes a 2-way woofer-tweeter system a practical possibility.

The biggest disadvantage of the reflex is the complexity of speaker to box relationships, requiring careful design for good performance. A less obvious disadvantage is its tendency to unload the speaker below resonance. Here, turntable rumble or other subsonic pulses can overload the speaker, causing distortion or even damage. The cure is to make sure that any receiver or amplifier to be used with a ported system has a low-cut filter to remove low frequency garbage from the signal. Such filters don't remove useful bass; instead they make the bass more solid by removing unheard pulses that can stress the amplifier as well as the speaker.

Labyrinths and Transmission Lines

A labyrinth is a tuned pipe with the driver at one end and a port at the other end (Fig. 2-5). When the wave from the driver reaches the end of the pipe, it expands into the room, causing a sudden pressure drop. This drop in pressure is reflected back through the pipe to the speaker. At the frequency where the length of the pipe is equal to a quarter wavelength ($\lambda/4$) of the sound, the air at the

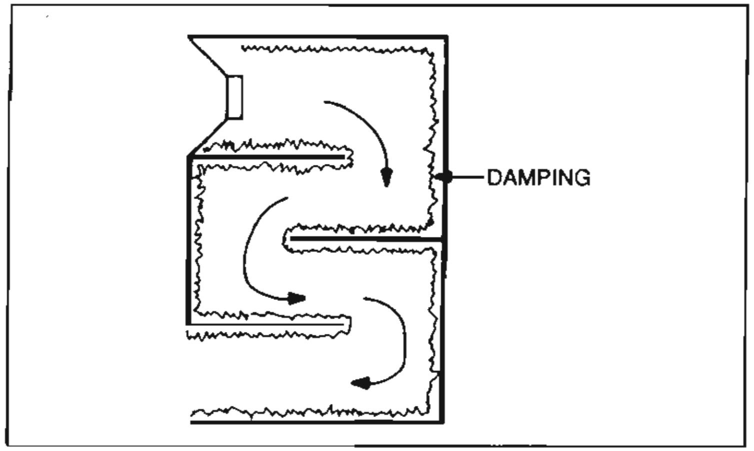


Fig. 2-5. Labyrinth.

mouth of the pipe is at minimum velocity, but maximum pressure. At that frequency, the change of pressure is also at a maximum, and the reflection to the speaker of the rarefaction produces maximum damping. A labyrinth that has a length equal to one quarter wavelength at the speaker's resonance frequency will damp the speaker at resonance, an action similar to the bass reflex. Labyrinths usually have a series of resonant peaks, occurring at harmonics of the fundamental pipe resonance, but these can be subdued by lining the walls with damping material.

A transmission line is a stuffed labyrinth (Fig. 2-6). The theory behind the transmission line was developed by A.R. Bailey, a professor in England. Bailey suggested that reflex enclosures, by their sharp cut-off rates, were likely to produce ringing. He reasoned that an acoustic line behind the speaker that was infinitely long would absorb the backwave without causing troublesome reflections, but to keep the line within practical limits, he substituted stuffing for length. Extremely low frequency waves are not absorbed by the stuffing but emerge from the mouth of the line to augment the speaker's low bass response. While labyrinths usually have a cross-sectional area that is equal to the speaker cone area, transmission lines are often tapered to spread the resonances. The large end is usually greater in area than the cone, the port end smaller.

Transmission lines have obvious disadvantages. They are large, require a complicated structure, and can be unpredictable. Fine tuning a transmission line is largely a matter of trial and error.

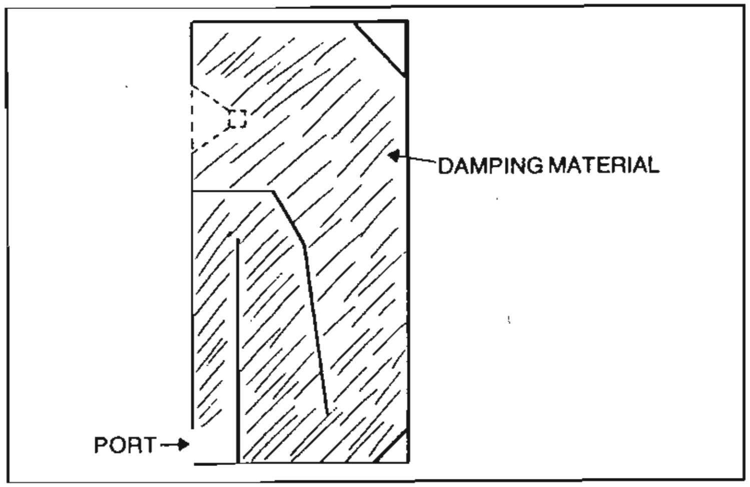


Fig. 2-6. A transmission line enclosure. It differs from the labyrinth by its taper and stuffing.

Horns

A horn acts as an acoustical transformer. It matches the high acoustical impedance at the driver to the low impedance of the room air by its smooth rate of increased cross-sectional area from the driver cone to the horn mouth (Fig. 2-7). An acoustical megaphone, the kind used by cheerleaders, has some of the virtues of the horn. However, being straight sided, it does not permit the sound waves to expand at a constant rate. As the area of a megaphone increases, the distance between the points where the area doubles also increases. A true horn has a flare which forces the sound waves to expand at a constant rate. Because of its impedance-matching characteristics, a horn offers much higher efficiency than other types of speaker enclosures. The horn permits a lower distortion at high output than any other enclosure because of its high damping on the driver.

The disadvantages are obvious. The size required for a bass horn is tremendous; some are 30 feet long. Folded horns are

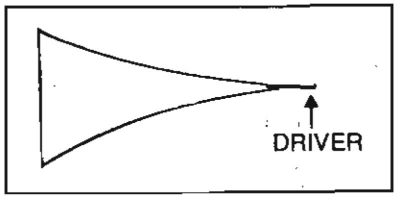


Fig. 2-7. Straight exponential horn.

Table 2-1. Summary: Closed Box vs. Reflex.

ADVANTAGES OF CLOSED BOX	ADVANTAGES OF REFLEX
1. SIMPLE TO DESIGN AND BUILD	1. HIGHER OUTPUT AND LOWER DISTORTION IN OCTAVE ABOVE f_b
2. MORE GRADUAL CUT-OFF RATE OF 12 dB/OCTAVE	2. GREATER BASS RANGE OR HIGHER EFFICIENCY FROM EQUAL BOX VOLUME
3. GOOD FOR SUB-MINIATURE ENCLOSURES	3. CAN USE SINGLE CONE SPEAKER WITH REDUCED PHASE PROBLEMS
4. CAN USE WITH HIGHER POWERED AMPLIFIERS BECAUSE IT DOESN'T UNLOAD SPEAKER AT LOWEST FREQUENCIES*	4. LOWER COST BECAUSE OF #3
5. SPEAKER VARIABILITY HAS LESS EFFECT ON PERFORMANCE	5. GREATER CHALLENGE—GREATER REWARD IF DONE RIGHT

*THIS ADVANTAGE FOR THE CLOSED BOX CAN BE NEUTRALIZED IF AN EQUALIZER OR INFRASONIC FILTER IS USED WITH REFLEX SYSTEMS.

sometimes used in home stereo systems, but because of their size and complexity, horns are found chiefly in theater sound systems or other high level applications.

WHICH ENCLOSURE IS BEST?

Even if one of the enclosure types described here could be proven to give the best performance in every system, it would not automatically become the universal choice. The bass horn is a good example of a high performance enclosure that is made rare by its cost and complexity. Table 2-1 summarizes the chief advantages of the two most commonly used types of enclosures.

Table 2-2. Parts List for Project 1.

¾" Plywood or Particle Board:	
2 8" × 17¼"	Sides
2 8" × 11¼"	Top & bottom
2 9¾" × 15¾"	Speaker board & back
¾" Pine:	
4 ¾" × ¾" × 15¾"	Side cleats
4 ¾" × ¾" × approx. 8¼"	Top & bottom cleats
⅝" Plywood:	
1 9⅝" × 15⅝"	Grille board
¼" Hardboard:	
1 7" × 8"	Crossover board
Speakers and Components:	
1 6½" woofer	Radio Shack Cat. No. 40-1009
1 Cone tweeter	Radio Shack Cat. No. 40-1270
1 8-ohm L-pad	Radio Shack Cat. No. 40-980
1 4 μF capacitor	(supplied with tweeter)
Miscellaneous:	
Fiberglass insulation	Radio Shack Cat. No. 42-1082
Grille cloth	

PROJECT 1: A C

This proje
tweeter (Table
capacitor, supp
bass response
this book, it is s
This speal
get left over sc
do the job (Fig
beveled cuts a
joints. Just mal
the same as tho

Construction

Cut out th
together to tes
hold the speake
especially in a
side cleats, at l
strap the parts
cleats needed.
further assemb
about ⅛", can

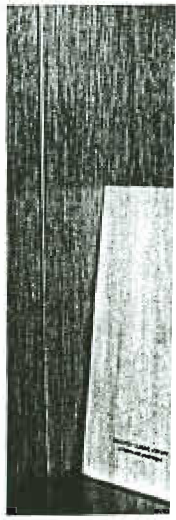


Fig. 2-8. Finished