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Subwoofer

12-inch (30 cm) subwoofer driver (loudspeaker). A driver is commonly installed in an enclosure (often a wooden cabinet) to prevent the sound waves coming off the back to cancel out the sound waves being generated from the front of the subwoofer.

A **subwoofer** (or **sub**) is a woofer, or a complete loudspeaker, which is dedicated to the reproduction of low-pitched audio frequencies known as bass and sub-bass. The typical frequency range for a subwoofer is about 20–200 Hz for consumer products,[1] below 100 Hz for professional live sound,[2] and below 80 Hz in THX-approved systems.[3] Subwoofers are intended to augment the low frequency range of loudspeakers covering higher frequency bands. While the term "subwoofer" technically only refers to the speaker driver, in common parlance, the term often refers to a subwoofer driver mounted in a speaker enclosure (cabinet).

Subwoofers are made up of one or more woofers mounted in a loudspeaker enclosure—often made of wood—capable of withstanding air pressure while resisting deformation. Subwoofer enclosures come in a variety of designs, including bass reflex (with a port or vent), using a subwoofer and one or more passive radiator speakers in the enclosure, acoustic suspension (sealed enclosure), infinite baffle, horn-loaded, and bandpass designs, representing unique trade-offs with respect to efficiency, low frequency range, cabinet size and cost. Passive subwoofers have a subwoofer driver and enclosure and they are powered by an external amplifier. Active subwoofers include a built-in amplifier.[4]

The first subwoofers were developed in the 1960s to add bass response to home stereo systems. Subwoofers came into greater popular consciousness in the 1970s with the introduction of Sensurround in movies such as *Earthquake*, which produced loud low-frequency sounds through large subwoofers. With the advent of the compact cassette and the compact disc in the 1980s, the easy reproduction of deep *and* loud bass was no longer limited by the ability of a phonograph record stylus to track a groove,[5] and producers could add more low frequency content to recordings. As well, during the 1990s, DVDs were increasingly recorded with "surround sound" processes that included a low-frequency effects (LFE) channel, which could be heard using the subwoofer in home theater systems. During the 1990s, subwoofers also became increasingly popular in home stereo systems, custom car audio installations, and in PA systems. By the 2000s, subwoofers became almost universal in sound reinforcement systems in nightclubs and concert venues.

Contents

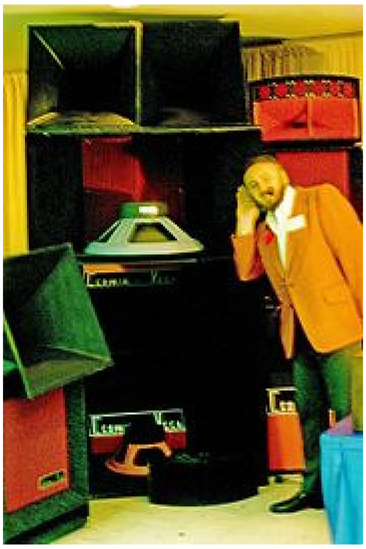
History

In September 1964, Raymon Dones, of El Cerrito, California, received US patent 3150739 which was the first patent for a subwoofer specifically designed to augment omni-directionally the low frequency range of modern stereo systems. Able to reproduce distortion-free low frequencies down to 15 cycles per second (15 Hz), a specific objective of Dones' invention was to provide portable sound enclosures capable of high fidelity reproduction of low frequency sound waves without giving an audible indication of the direction from which they emanate. Dones' loudspeaker was marketed in the US under the trade name "The Octavium"[6] from the early 1960s to the mid-1970s. The Octavium was utilized by several recording artists of that era, most notably the Grateful Dead, bassist Monk Montgomery, bassist Nathan East, and the Pointer Sisters. The Octavium speaker and Dones' subwoofer technology was also utilized, in a few select theaters, to reproduce low pitch frequencies for the 1974 blockbuster movie *Earthquake*. During the late 1960s Dones' Octavium was favorably reviewed by audiophile publications including *Hi-Fi News* and *Audio Magazine*.

Another early subwoofer enclosure made for home and studio use was the separate bass speaker for the Servo

Statik 1 by New Technology Enterprises.[7] Designed as a prototype in 1966 by physicist Arnold Nudell and airline pilot Cary Christie in Nudell's garage, it used a second winding around a custom Cerwin Vega 18-inch (45 cm) driver to provide servo control information to the amplifier, and it was offered for sale at $1795, some 40% more expensive than any other complete loudspeaker listed at *Stereo Review*.[7] In 1968, the two found outside investors and reorganized as Infinity.[7] The subwoofer was reviewed positively in *Stereophile* magazine's winter 1968 issue as the SS-1 by Infinity. The SS-1 received very good reviews in 1970 from *High Fidelity* magazine.[7]

View of the underside of the downward-firing Infinity Servo Statik 1, showing the size of the 18-inch (45 cm) custom-wound Cerwin Vega driver in relation to a can of Diet Coke, to show scale



A display of Cerwin-Vega speaker enclosures at the 1975 Audio Engineering Society meeting

Another of the early subwoofers was developed during the late 1960s by Ken Kreisel, the former president of the Miller & Kreisel Sound Corporation in Los Angeles. When Kreisel's business partner, Jonas Miller, who owned a high-end audio store in Los Angeles, told Kreisel that some purchasers of the store's high-end electrostatic speakers had complained about a lack of bass response in the electrostatics, Kreisel designed a powered woofer that would reproduce only those frequencies that were too low for the electrostatic speakers to convey.[8] Infinity's full range electrostatic speaker system that was developed during the 1960s also used a woofer to cover the lower frequency range that its electrostatic arrays did not handle adequately.

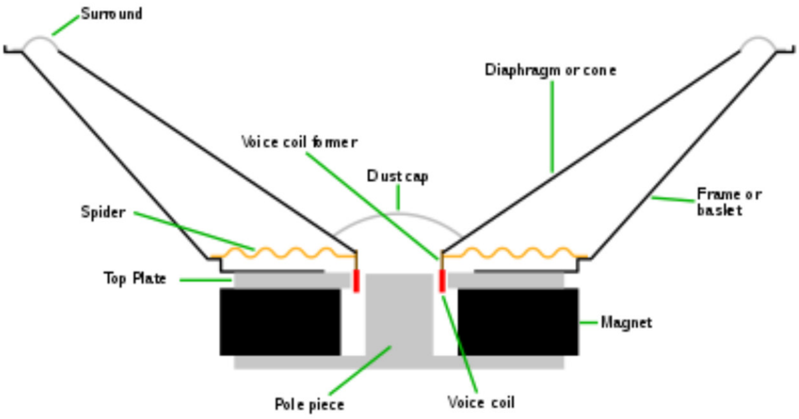
The first use of a subwoofer in a recording session was in 1973 for mixing the Steely Dan album *Pretzel Logic* when recording engineer Roger Nichols arranged for Kreisel to bring a prototype of his subwoofer to Village Recorders.[9] Further design modifications were made by Kreisel over the next ten years, and in the 1970s and 1980s by engineer John P. D'Arcy; record producer Daniel Levitin served as a consultant and "golden ears" for the design of the crossover network (used to partition the frequency spectrum so that the subwoofer would not attempt to reproduce frequencies too high for its effective range, and so that the main speakers would not need to handle frequencies too low for their effective range).

Subwoofers received a great deal of publicity in 1974 with the movie *Earthquake* which was released in Sensurround. Initially installed in 17 U.S. theaters, the Cerwin Vega "Sensurround" system used large subwoofers which were driven by racks of 500 watt amplifiers which were triggered by control tones printed on one of the audio tracks on the film. Four of the subwoofers were positioned in front of the audience under (or behind) the film screen and two more were placed together at the rear of the audience on a platform. Powerful noise energy and loud rumbling in the range of 17 Hz to 120 Hz was generated at the level of 110–120 decibels of sound pressure level, abbreviated dB(SPL). The new low frequency entertainment method helped the film become a box office success. More Sensurround systems were assembled and installed. By 1976 there were almost 300 Sensurround systems leapfrogging through select theaters. Other films to use the effect include the WW II naval battle epic *Midway* in 1976 and *Rollercoaster* in 1977.[10] Deep bass speakers were once an exotic commodity owned by audiophiles. By the mid-1990s, they were much more popular and widely used, with different sizes and capabilities of sound output.[11]

For owners of 33 rpm LPs and 45 singles, loud *and* deep bass was limited by the ability of the phonograph record stylus to track the groove.[5] Some hi-fi aficionados solved the problem by using reel-to-reel tape players which were capable of delivering accurate, naturally deep bass from acoustic sources, or synthetic bass not found in nature. With the popular introduction of the compact cassette and the CD, it became possible to add more low frequency content to recordings, and satisfy a larger number of consumers.[12] Home subwoofers grew in popularity, as they were easy to add to existing multimedia speaker setups and they were easy to position or hide.[13]

Construction and features

Loudspeaker and enclosure design



Cross-section of a subwoofer drive unit

Subwoofers use speaker drivers (woofers) typically between 8-inch (20 cm) and 21-inch (53 cm) in diameter. Some uncommon subwoofers use larger drivers, and single prototype subwoofers as large as 60-inch (152 cm) have been fabricated.[14] On the smaller end of the spectrum, subwoofer drivers as small as 4-inch (10 cm) may be used. Small subwoofer drivers in the 4-inch range are typically used in small computer speaker systems and compact home theatre subwoofer cabinets. The size of the driver and number of drivers in a cabinet depends on the design of the loudspeaker enclosure, the size of the cabinet, the desired sound pressure level, the lowest frequency targeted and the level of permitted distortion. The most common subwoofer driver sizes used for sound reinforcement in nightclubs, raves and pop/rock concerts are 10-, 12-, 15- and 18-inch models (25 cm, 30 cm, 38 cm, and 45 cm respectively). The largest available sound reinforcement subwoofers, 21-inch (53 cm) drivers, are less commonly seen.

The efficiency of a speaker driver is given by:

$$\eta_0 = \left(\frac{4\pi^2 F_s^3 V_{as}}{c^3 Q_{es}}\right) \times 100\%$$

Where the variables are Thiele/Small parameters. Deep low frequency extension is a common goal for a subwoofer and small box volumes are also considered desirable, to save space and reduce the size for ease of transportation (in the case of sound reinforcement and DJ subwoofers). Hofmann's "Iron Law" therefore mandates low efficiency under those constraints, and indeed most subwoofers require considerable power, much more than other individual drivers.

So for the example of a sealed speaker box, the box volume to achieve a given Q_{ts} is proportional to Vas:

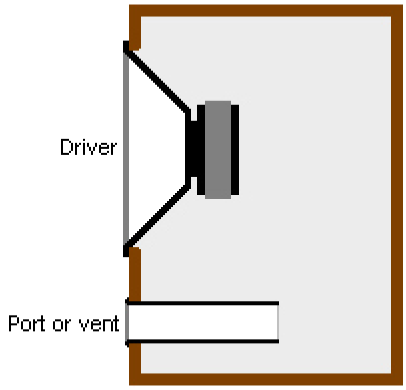
$$V_b = \frac{V_{as}}{\alpha} \text{ Where: } \alpha = \frac{Q_{tc}^2}{Q_{ts}^2} - 1$$

Therefore, a decrease in box volume (i.e. , a smaller speaker cabinet) and the same F_3 will decrease the efficiency of the subwoofer. Similarly the F_3 of a speaker is proportional to Fs:

$$F_c = \frac{(Q_{tc}F_s)}{Q_{ts}}$$

As the efficiency is proportional to Fs^3, small improvements in low frequency extension with the same driver and box volume will result in very significant reductions in efficiency. For these reasons, subwoofers are typically very inefficient at converting electrical energy into sound energy. This combination of factors accounts for the higher amplifier power required to drive subwoofers, and the requirement for greater power handling for subwoofer drivers. Enclosure variations (e.g., bass reflex designs with a port in the cabinet) are often used for subwoofers to increase the efficiency of the driver/enclosure system, helping to reduce the amplifier power requirements.

Subwoofers have been designed using a number of enclosure approaches: bass reflex, acoustic suspension, infinite baffle, horn loaded, tapped horn, transmission line and bandpass. Each enclosure type has advantages and disadvantages in efficiency increase, bass extension, cabinet size, distortion, and cost. Subwoofers are typically constructed by mounting one or more woofers in a cabinet of medium-density fibreboard (MDF), oriented strand board (OSB), plywood, fiberglass, aluminum or other stiff materials. Because of the high air pressure they produce in the cabinet, subwoofer enclosures often require internal bracing to distribute the resulting forces.



Bass reflex enclosure schematic (cross-section)

The smallest subwoofers are typically those designed for desktop multimedia systems. The largest common subwoofer enclosures are those used for concert sound reinforcement systems or dance club sound systems. An example of a large concert subwoofer enclosure is the 1980s-era ElectroVoice MT-4 "Bass Cube" system, which used four 18-inch (45 cm) drivers. An example of a subwoofer that uses a bass horn is the Bassmaxx B-Two, which loads an 18-inch (45 cm) driver onto an 11-foot (3.4 m) long folded horn. Folded horn-type subwoofers can typically produce a deeper range with greater efficiency than the same driver in an enclosure that lacks a horn. However, folded horn cabinets are typically larger and heavier than front-firing enclosures, so folded horns are less commonly used. Some experimental fixed-installation subwoofer horns have been constructed using brick and concrete to produce a very long horn that allows a very deep sub-bass extension.[15]


Heavily braced and built subwoofer enclosure

Subwoofer output level can be increased by increasing cone surface area or by increasing cone excursion. Since large drivers require undesirably large cabinets, most subwoofer drivers have large excursions. Unfortunately, high excursion, at high power levels, tends to produce more distortion from inherent mechanical and magnetic effects in electro-dynamic drivers (the most common sort). The conflict between assorted goals can never be fully resolved; subwoofer designs necessarily involve tradeoffs and compromises. Hofmann's Iron Law (the efficiency of a woofer system is directly proportional to its cabinet volume (as in size) and to the cube of its cutoff frequency, that is how low in pitch it will go) applies to subwoofers just as to all loudspeakers.[16] Thus a subwoofer enclosure designer aiming at the deepest-pitched bass will probably have to consider using a large enclosure size; a subwoofer enclosure designer instructed to create the smallest possible cabinet (to make transportation easier) will need to compromise how low in pitch their cabinet will produce.

Frequency range and frequency response

The frequency response specification of a speaker describes the range of frequencies or musical tones a speaker can reproduce, measured in hertz (Hz).[17] The typical frequency range for a subwoofer is between 20–200 Hz.[1] Professional concert sound system subwoofers typically operate below 100 Hz,[2] and THX-approved systems operate below 80 Hz.[3] Subwoofers vary in terms of the range of pitches that they can reproduce, depending on a number of factors such as the size of the cabinet and the construction and design of the enclosure and driver(s). Specifications of frequency response depend wholly for relevance on an accompanying amplitude value—measurements taken with a wider amplitude tolerance will give any loudspeaker a wider frequency response. For example, the JBL 4688 TCB Subwoofer System, a now-discontinued system which was designed for movie theaters, had a frequency response of 23–350 Hz when measured within a 10-decibel boundary (0 dB to -10 dB) and a narrower frequency response of 28–120 Hz when measured within a six-decibel boundary (±3 dB).[18]

A large subwoofer cabinet used in a home hi-fi system

Subwoofers also vary in regard to the sound pressure levels achievable and the distortion levels they can produce over their range. Some subwoofers, such as "The Abyss" by MartinLogan for example can reproduce pitches down to around 18 Hz (which is about the pitch of the lowest rumbling notes on a huge pipe organ with 32-foot (9.8 m)-16 Hz-bass pipes) to 120 Hz (±3 dB). Nevertheless, even though the Abyss subwoofer can go down to 18 Hz, its lowest frequency and maximum SPL with a limit of 10% distortion is 35.5 Hz and 79.8 dB at 2 meters.[19] This means that a person choosing a subwoofer needs to consider more than just the lowest pitch that the sub can reproduce.

Amplification

'Active subwoofers' include their own dedicated amplifiers within the cabinet. Some also include user-adjustable equalization that allows boosted or reduced output at particular frequencies; these vary from a simple "boost" switch, to fully parametric equalizers meant for detailed speaker and room correction. Some such systems are even supplied with a calibrated microphone to measure the subwoofer's in-room response, so the automatic equalizer can correct the combination of subwoofer, subwoofer location, and room response to minimize effects of room modes and improve low frequency performance.

This picture of the internal components of an active (powered) subwoofer shows the circuitry for the power amplifier.

'Passive subwoofers' have a subwoofer driver and enclosure, but they do not include an amplifier. They sometimes incorporate internal passive crossovers, with the filter frequency determined at the factory. These are generally used with third-party power amplifiers, taking their inputs from active crossovers earlier in the signal chain. Inexpensive Home Theatre in a Box packages often come with a passive subwoofer cabinet that is amplified by the multi-channel amplifier. While few high-end home-theater systems use passive subwoofers, this format is still popular in the professional sound industry.[20]

This rear panel of a powered subwoofer shows the heat sinks used to cool the power amplifier.

Equalization

This picture of the rear panel of a Polk subwoofer cabinet shows a low-pass filter adjustment knob.

Equalization can be used to adjust the in-room response of a subwoofer system.[21] Designers of active subwoofers sometimes include a degree of corrective equalization to compensate for known performance issues (e.g., a steeper than desired low end roll-off rate). In addition, many amplifiers include an adjustable low-pass filter, which prevents undesired higher frequencies from reaching the subwoofer driver. For example, if a listener's main speakers are usable down to 80 Hz, then the subwoofer filter can be set so the subwoofer only works below 80.[3] Typical filters involve some overlap in frequency ranges; a steep filter is not generally desired for subwoofers. The crossover section may also include a high-pass "infrasonic" or "subsonic" filter which prevents the subwoofer driver from attempting to reproduce frequencies below its safe capabilities. Setting a subsonic filter is important on bass reflex subwoofer cabinets, as the bass reflex design tends to create the risk of cone overexcursion at pitches below those of the port tuning, which can cause distortion and damage the subwoofer driver. For example, in a ported subwoofer enclosure tuned to 30 Hz, one may wish to filter out pitches below the tuning frequency; that is below 30 Hz.

Some systems use parametric equalization in an attempt to correct for room frequency response irregularities.[22] Equalization is often unable to achieve flat frequency response at all listening locations in part because of the resonance (i.e., standing wave) patterns at low frequencies in nearly all rooms. Careful positioning of the subwoofer within the room can also help flatten the frequency response.[23] Multiple subwoofers can manage a flatter general response since they can often be arranged to excite room modes more evenly than a single subwoofer, allowing equalization to be more effective.[24]

Phase control

The rear panel of a down-firing, active subwoofer cabinet

Changing the relative phase of the subwoofer with respect to the woofers in other speakers may or may not help to minimize unwanted destructive acoustic interference in the frequency region covered by both subwoofer and main speakers. It may not help at all frequencies, and may create further problems with frequency response, but is even so generally provided as an adjustment for subwoofer amplifiers.[25] Phase control circuits may be a simple polarity reversal switch or a more complex continuously variable circuits.

Continuously variable phase control circuits are common in subwoofer amplifiers, and may be found in crossovers and as do-it-yourself electronics projects.[26][27][28][29][30] Phase controls allow the listener to change the arrival time of the subwoofer sound waves relative to the same frequencies from the main speakers (i.e., at and around the crossover point to the subwoofer). A similar effect can be achieved with the delay control on many home theater receivers. The subwoofer phase control found on many subwoofer amplifiers is actually a polarity inversion switch.[31] It allows users to reverse the polarity of the subwoofer relative to the audio signal it is being given. This type of control allows the subwoofer to either be in phase with the source signal, or 180 degrees out of phase.

The subwoofer phase can still be changed by moving the subwoofer closer to or further from the listening position, however this may not be always practical.

Servo subwoofers

Some active subwoofers use a servo feedback mechanism based on cone movement which modifies the signal sent to the voice coil. The servo feedback signal is derived from a comparison of the input signal to the amplifier versus the actual motion of the cone. The usual source of the feedback signal is a few turns of voice coil attached to the cone or a microchip-based accelerometer placed on the cone itself.[32][33] An advantage of a well-implemented servo subwoofer design is reduced distortion making smaller enclosure sizes possible.[34] The primary disadvantages are cost and complexity.[35]

Servo controlled subwoofers are not the same as Servodrive subwoofers whose primary mechanism of sound reproduction avoids the normal voice coil and magnet combination in favor of a high-speed belt-driven servomotor. The Servodrive design increases output power, reduces harmonic distortion and virtually eliminates the loss of loudspeaker output that results from an increase in voice coil impedance due to overheating of the voice coil (called *power compression*.) This feature allows high power operation for extended periods of time.[36][37][38] Intersonics was nominated for a TEC Award for its Servo Drive Loudspeaker (SDL) design in 1986 and for the Bass Tech 7 model in 1990.[39][40]

Applications

Home audio

The use of a subwoofer augments the bass capability of the main speakers, and allows them to be smaller without sacrificing low frequency capability. A subwoofer does not necessarily provide superior bass performance in comparison to large conventional loudspeakers on ordinary music recordings due to the typical lack of very low frequency content on such sources. However, there are recordings with substantial low frequency content that most conventional loudspeakers are ill-equipped to handle without the help of a subwoofer, especially at high playback levels, such as music for pipe organs with 32' (9.75 meter) bass pipes (16 Hz), very large bass drums on symphony orchestra recordings and electronic music with extremely low synth bass parts, such as bass tests or bass songs.


Basic sealed subwoofer in a residential setting

Frequencies which are sufficiently low are not easily localized by humans, hence many stereo and multichannel audio systems feature only one subwoofer channel and a single subwoofer can be placed off-center without affecting the perceived sound stage, since the sound produced will be difficult to localize. The intention in a system with a subwoofer is often to use small main speakers (of which there are two for stereo and five or more for surround sound or movie tracks) and to hide the subwoofer elsewhere (e.g. behind furniture or under a table), or to augment an existing speaker to save it from having to handle woofer-destroying low frequencies at high levels. This effect is possible only if the subwoofer is restricted to quite low frequencies, usually taken to, say, 100 Hz and below—still less localization is possible if restricted to even lower maximum frequencies. Higher upper limits for the subwoofer (e.g., 125 Hz) are much more easily localized, making a single subwoofer impractical. Home theatre systems typically use one subwoofer cabinet (the "1" in 5.1 surround sound). However, to "improve bass distribution in a room that has multiple seating locations, and prevent "node" or "null points" with weakened bass response, some home cinema enthusiasts use "5.2" or "7.2" surround sound systems with two subwoofer cabinets in the same room. [41]

Some users add a subwoofer because high levels of low bass are desired, even beyond what is in the original recording, as in the case of house music enthusiasts. Thus, subwoofers may be part of a package that includes satellite speakers, may be purchased separately, or may be built into the same cabinet as a conventional speaker system. For instance, some floor standing tower speakers include a subwoofer driver in the lower portion of the same cabinet. Physical separation of subwoofer and "satellite" speakers not only allows placement in an inconspicuous location, but since sub-bass frequencies are particularly sensitive to room location (due to room resonances and reverberation 'modes'), the best position for the subwoofer is not likely to be where the "satellite" speakers are located.

The 1987 Bose Acoustimass 5 stereo bass driver contained one six-inch (152 mm) driver per channel and provided crossover filtering for its two cube speaker arrays[42]

For greatest efficiency and best coupling to the room's air volume, subwoofers can be placed in a corner of the room, far from large room openings, and closer to the listener. This is possible since low bass frequencies have a long wavelength; hence there is little difference between the information reaching a listener's left and right ears, and so they cannot be readily localized. All low frequency information is sent to the subwoofer. However, unless the sound tracks have been carefully mixed for a single subwoofer channel, it is possible to have some cancellation of low frequencies if bass information in one channel's speaker is out of phase with another.

The physically separate subwoofer/satellite arrangement, with small satellite speakers and a large subwoofer cabinet that can be hidden behind furniture has been popularized by multimedia speaker systems such as Bose Acoustimass Home Entertainment Systems, Polk Audio RM2008 Series and Klipsch Audio Technologies ProMedia, among many others.[43][44] Low-cost "home theater in a box" systems advertise their integration and simplicity.

Particularly among lower cost "Home Theater in a Box" systems and with "boom boxes", however, inclusion of a subwoofer may be little more than a marketing device. It is unlikely that a small woofer in an inexpensively-built compact plastic cabinet will have better bass performance than well-designed conventional (and typically larger) speakers in a plywood or MDF cabinet. Mere use of the term "subwoofer" is no guarantee of good or extended bass performance. Many multimedia "subwoofers" might better be termed "mid bass cabinets" (60 Hz to 160 Hz) as they are too small to produce deep bass in the 30 Hz to 59 Hz range. [45]

A small subwoofer cabinet designed for use with a home computer

Further, poorly designed systems often leave everything below about 120 Hz (or even higher) to the subwoofer, meaning that the subwoofer handles frequencies which the ear can use for sound source localization, thus introducing an undesirable subwoofer "localization effect". This is usually due to poor crossover designs or choices (too high crossover point or insufficient crossover slope) used in many computer and home theater systems; localization also comes from port noise and from typically large amounts of harmonic distortion in the subwoofer design. Home subwoofers sold individually usually include crossover circuitry to assist integration into an existing system.

Car audio

Multiple subwoofers in a car hatchback

Automobiles are not well suited for the "hidden" subwoofer approach due to space limitations in the passenger compartments. It is not possible, in most circumstances, to fit such large drivers and enclosures into doors or dashboards, so subwoofers are installed in the trunk or back seat space. Some car audio enthusiasts compete to produce very high sound pressure levels in the confines of their vehicle's cabin; sometimes dangerously high. The "SPL wars" have drawn much attention to subwoofers in general, but subjective competitions in sound quality ("SQ") have not gained equivalent popularity. Top SPL cars are not able to play normal music, or perhaps even to drive normally as they are designed solely for competition. Many non-competition subwoofers are also capable of generating high levels in cars due to the small volume of a typical car interior. High sound levels can cause hearing loss and tinnitus if one is exposed to them for an extended period of time.[46]

A homemade car audio subwoofer speaker box with a 15-inch Boss Audio subwoofer and an empty space for a second driver

In the 2000s, several car audio manufacturers have produced subwoofers using non-circular shapes from manufacturers including Boston Acoustic, Kicker, Sony, Bazooka, and X-Tant. These shapes typically carry some sort of distortion penalties.[47][48][49] In situations of limited mounting space they provide a greater cone area and assuming all other variables are constant, greater maximum output. An important factor in the "square sub vs round sub" argument is the effects of the enclosure used. In a sealed enclosure, the maximum displacement is determined by

$$V_\mathrm{d} = x_\mathrm{max} \times S_\mathrm{d}$$

where

- V_d stands for volume of displacement (in m^3)
- x_{max} to the amount of linear excursion the speaker is mechanically capable of (in m)
- S_d to the cone area of the sub woofer (in m^2).

These are some of the Thiele/Small parameters which can either be measured or found with the driver specifications.

Cinema sound

After the introduction of Sensurround, movie theater owners began installing permanent subwoofer systems. Dolby Stereo 70 mm Six Track was a six channel film sound format introduced in 1976 that used two subwoofer channels for stereo reproduction of low frequencies. In 1981, Altec introduced a dedicated cinema subwoofer model tuned to around 20 Hz: the 8182. Starting in 1983, THX certification of the cinema sound experience quantified the parameters of good audio for watching films, including requirements for subwoofer performance levels and enough isolation from outside sounds so that noise did not interfere with the listening experience.[50]

This helped provide guidelines for multiplex cinema owners who wanted to isolate each individual cinema from its neighbors, even as louder subwoofers were making isolation more difficult. Specific cinema subwoofer models appeared from JBL, Electro-Voice, Eastern Acoustic Works, Kintek, Meyer Sound Laboratories and BGW Systems in the early 1990s. In 1992, Dolby Digital's six-channel film sound format incorporated a single LFE channel, the "point one" in 5.1 surround sound.

Tom Horral, a Boston-based acoustician, blames complaints about modern movies being too loud on subwoofers. He says that before subwoofers made it possible to have loud, relatively undistorted bass, movie sound levels were limited by the distortion in less capable systems at low frequency and high levels.[51]

Sound reinforcement

Professional audio subwoofers used in rock concerts in stadiums, DJ performances at dance music venues (e.g., Electronic dance music) and similar events must be capable of very high bass output levels, at very low frequencies, with low distortion. This is reflected in the design attention given in the 2010s to the subwoofer applications for sound reinforcement, public address systems, dance club systems and concert systems. Cerwin Vega states that when a subwoofer cabinet is added to an existing full-range speaker system, this is advantageous, as it moves the "...lowest frequencies from your main [full-range] PA speakers" thus "...eliminat[ing] a large amount of the excess work that your main top [full-range] box was trying to reproduce. As a result, your main [full-range] cabinets will run more efficiently and at higher volumes."[52] A different argument for adding subwoofer cabinets is that they may increase the "level of clarity" and "perceived loudness" of an overall PA system, even if the SPL is not actually increased.[53] *Sound on Sound* states that adding a subwoofer enclosure to a full-range system will reduce "cone excursion", thus lowering distortion, leading to an overall cleaner sound.[54]

Each stack of speakers in this sound reinforcement setup consists of two EAW SB1000 slanted baffle subwoofers (each contains two 18-inch drivers) and two EAW KF850 full range cabinets for the mid and high frequencies.

Consumer applications (as in home use) are considerably less demanding due to much smaller listening space and lower playback levels. Subwoofers are now almost universal in professional sound applications such as live concert sound, churches, nightclubs, and theme parks. Movie theatres certified to the THX standard for playback always include high capability subwoofers. Some professional applications require subwoofers designed for very high sound levels, using multiple 12-, 15-, 18- or 21-inch drivers (30 cm, 40 cm, 45 cm, 53 cm respectively). Drivers as small as 10-inch (25 cm) are occasionally used, generally in horn-loaded enclosures.

The number of subwoofer enclosures used in a concert depends on a number of factors, including the size of the venue, whether it is indoors or outdoors, the amount of low-frequency content in the band's sound, the desired volume of the concert, and the design and construction of the enclosures (e.g., direct-radiating versus horn-loaded. A tiny coffeehouse may only need a single 10-inch subwoofer cabinet to augment the bass provided by the full-range speakers. A small bar may use one or two direct-radiating 15-inch (40 cm) sub cabinets. A large dance club may have a row of four or five twin 18-inch (45 cm) subwoofer cabinets, or more). In the largest stadium venues, there may be a very large number of subwoofer enclosures. For example, the 2009–2010 U2 360° Tour uses 24 Clair Brothers BT-218 subwoofers (a double 18-inch (45 cm) box) around the perimeter of the central circular stage, and 72 proprietary Clair Brothers cardioid S4 subwoofers placed underneath the ring-shaped "B" stage which encircles the central main stage.[55][56]


A row of subwoofer cabinets in front of the stage of a rock concert. One enclosure out of every stack of three is turned backward to make a cardioid output pattern.

The main speakers may be 'flown' from the ceiling of a venue on chain hoists, and 'flying points' (i.e., attachment points) are built into many professional loudspeaker enclosures. Subwoofers can be flown or stacked on the ground near the stage. One of the reasons subwoofers may be installed on the ground is that on the ground installation can increase the bass performance, particularly if the sub is placed in the corner of a room (conversely, if a sub cabinet is perceived as too loud, alternatives to on the ground or in-corner installation may be considered. There can be more than 50 double-18-inch (45 cm) cabinets in a typical rock concert system. Just as consumer subwoofer enclosures can be made of Medium-density fibreboard (MDF), Oriented strand board (OSB), plywood, plastic or other dense material, professional subwoofer enclosures can be built from the same materials.[57][58] MDF is commonly used to construct subwoofers for permanent installations as its density is relatively high and weatherproofing is not a concern. Other permanent installation subwoofers have used very thick plywood: the Altec 8182 (1981) used 7-ply 28 mm birch-faced oak plywood.[59] Touring subwoofers are typically built from 18–20 mm thick void-free Baltic birch (Betula pendula or Betula pubescens) plywood from Finland, Estonia or Russia; such plywood affords greater strength for frequently transported enclosures.[60] Not naturally weatherproof, Baltic birch is coated with carpet, thick paint or spray-on truck bedliner to give the subwoofer enclosures greater durability.[61][62]


Large subwoofer enclosures

Touring subwoofer cabinets are typically designed with features that facilitate moving the enclosure (e.g., wheels, a "towel bar" handle and recessed handles), a protective grill for the speaker (in direct radiating-style cabinets), metal or plastic protection for the cabinets to protect the finish as the cabinets are being slid one on top of another, and hardware to facilitate stacking the cabinets (e.g., interlocking corners) and for "flying" the cabinets from stage rigging. In the 2000s, many small-to mid-size subwoofers designed for bands' live sound use and DJ applications are "powered subs"; that is, they have an integrated power amplifier. These models typically have a built-in crossover. Some models have a metal-reinforced hole in which a speaker pole can be mounted for elevating full-frequency range cabinets.

Use in a full-range system

In professional concert sound system design, subwoofers can be incorporated seamlessly with the main speakers into a stereo or mono full-range system by using an active crossover. The audio engineer typically adjusts the frequency point at which lower frequency sounds are routed o the subwoofer speaker(s), and mid- and higher frequency sounds are sent tio the full-range speakers. Such a system receives its signal from the main mono or stereo mixing console mix bus and amplifies all frequencies together in the desired balance. If the main sound system is stereo, the subwoofers can also be in stereo. Otherwise, a mono subwoofer channel can be derived within the crossover from a stereo mix, depending on the crossover make and model. While 2010-era subwoofer cabinet manufacturers suggest placing subwoofers on either side of a stage (as implied by the inclusion of pole cups for the full-range PA cabinets, Dave Purton argues that for club gigs, having two subwoofer cabinets on either side of a stage will lead to gaps in bass coverage in the venue; he states that putting the two subwoofer cabinets together will create a more even, omnidirectional sub-bass tone.[63]

PA systems by size and subwoofer approach

PA system set-up	Venue size
Small system: 2 pole-mounted mid/high frequency PA speaker cabinets and 2 small subwoofer cabinets with 15” or 18” subwoofers (Note: this would be used in club where jazz, acoustic music, country music or soft rock is played)	Small club with capacity for up to 300 people
Small high amplifier power system: 2 high amplifier power-rated mid/high frequency PA speakers with 15” woofers and a large horn-loaded tweeter; two high amplifier power-rated subwoofer cabinets with one or two 18” subwoofer cabs (front-firing, also known as "front loaded", or manifold-loaded subwoofer cabinets)	Small club with capacity for up to 500 people
Mid-size PA system: 4 larger multiwoofer mid/high frequency PA speaker cabs (e.g., each with two 15” woofers) and four subwoofer cabinets, either front-firing, manifold loaded or a folded horn	Large clubs with capacity for 500+ people, small music festivals, fairs
Large-size PA system: Multiple mid/high frequency PA speakers, possibly “flown” up high in rigging, and a number of subwoofer cabinets (either front firing, manifold loaded or folded horn)	Large venues with capacity for 1000+ people, larger music festivals

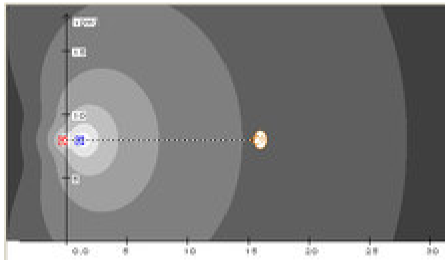
[64]

Aux-fed subwoofers

Instead of being incorporated into a full-range system, concert subwoofers can be supplied with their own signal from a separate mix bus on the mixing console; often one of the auxiliary sends ("aux" or "auxes") is used. This configuration is called "aux-fed subwoofers", and has been observed to significantly reduce low frequency "muddiness" that can build up in a concert sound system which has on stage a number of microphones each picking up low frequencies and each having different phase relationships of those low frequencies.[2] The aux-fed subs method greatly reduces the number of sources feeding the subwoofers to include only those instruments that have desired low frequency information; sources such as kick drum, bass guitar, samplers and keyboard instruments. This simplifies the signal sent to the subwoofers and makes for greater clarity and low punch.[65] Aux-fed subs can even be stereo, if desired, using two auxiliary mix buses.

Directional bass

To keep low frequency sound focused on the audience area and not on the stage, and to keep low frequencies from bothering people outside of the event space, a variety of techniques have been developed in concert sound to turn the naturally omnidirectional radiation of subwoofers into a more directional pattern. Several examples of sound reinforcement system applications where sound engineers seek to provide more directional bass sound are music festivals, which often have several bands performing at the same time on different stages; large raves or EDM events, where there are multiple DJs performing at the same time in different rooms or stages; and multiplex movie theatres, in which there are many films being shown simultaneously in auditoriums that share common walls. These techniques include setting up subwoofers in a vertical array; using combinations of delay and polarity inversion; and setting up a delay-shaded system. With a cardioid dispersion pattern, two end-fire subwoofers can be placed one in front of the other. The enclosure nearest the listener is delayed by a few milliseconds The second subwoofer is delayed a precise amount corresponding to the time it takes sound to traverse the distance between speaker grilles.

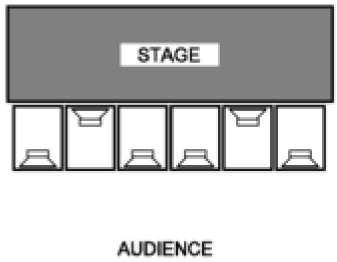


Cardioid dispersion pattern of two end-fire subwoofers placed one in front of the other. The signal feeding the enclosure nearest the listener is delayed by a few milliseconds.[66]

Vertical array

Stacking or rigging the subwoofers in a vertical array focuses the low frequencies forward to a greater or lesser extent depending on the physical length of the array. Longer arrays have a more directional effect at lower frequencies. The directionality is more pronounced in the vertical dimension, yielding a radiation pattern that is wide but not tall. This helps reduce the amount of low frequency sound bouncing off the ceiling indoors and assists in mitigating external noise complaints outdoors.

Rear delay array



CSA: Six subwoofers arranged for less bass energy on stage. Signal going to the reversed enclosures is delayed a few milliseconds.

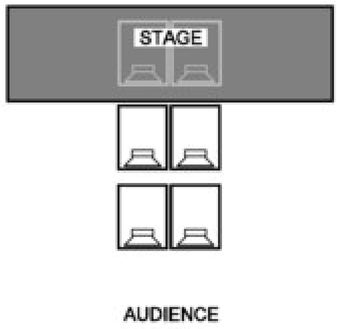
Another cardioid subwoofer array pattern can be used horizontally, one which takes few channels of processing and no change in required physical space. This method is often called "cardioid subwoofer array" or "CSA"[67] even though the pattern of *all* directional subwoofer methods is cardioid. The CSA method reverses the enclosure orientation and inverts the polarity of one out of every three subwoofers across the front of the stage, and delays those enclosures for maximum cancellation of the target frequency on stage. Polarity inversion can be implemented electronically, by reversing the wiring polarity, or by physically positioning the enclosure to face rearward. This method reduces forward output relative to a tight-packed, flat-fronted array of subwoofers, but can solve problems of unwanted low frequency energy coming into microphones on stage. Compared to the end-fire array, this method has less on-axis energy but more even pattern control throughout the audience, and more predictable cancellation rearward. The effect spans a range of slightly more than one octave.[67]

A second method of rear delay array combines end-fire topology with polarity reversal, using two subwoofers positioned front to back, the drivers spaced one-quarter wavelength apart, the rear enclosure inverted in polarity and delayed by a few milliseconds for maximum cancellation on stage of the target frequency.[68] This method has the least output power directed toward the audience, compared to other directional methods.

End-fire array

The end-fire subwoofer method, also called "forward steered arrays",[69] places subwoofer drivers co-axially in one or more rows, using destructive interference to reduce emissions to the sides and rear. This can be done with separate subwoofer enclosures positioned front to back with a spacing between them of one-quarter wavelength of the target frequency, the frequency that is least wanted on stage or most desired in the audience. Each row is delayed beyond the first row by an amount related to the speed of sound in air; typically a few milliseconds. The arrival time of sound energy from all the subwoofers is near-simultaneous from the audience's perspective, but is canceled out to a large degree behind the subwoofers because of offset sound wave arrival times. Directionality of the target frequency can achieve as much as 25 dB rear attenuation, and the forward sound is coherently summed in line with the subwoofers.[70] The positional technique of end-fire subwoofers came into widespread use in European live concert sound in 2006.[71]

The end-fire array trades a few decibels of output power for directionality, so it requires more enclosures for the same output power as a tight-packed, flat-fronted array of enclosures. Sixteen enclosures in four rows were used in 2007 at one of the stages of the Ultra Music Festival, to reduce low frequency interference to neighboring stages.[72] Because of the physical size of the end-fire array, few concert venues are able to implement it. The output pattern suffers from comb-filtering off-axis, but can be further shaped by adjusting the frequency response of each row of subwoofers.[69]



End-fire array using three rows of subwoofers. Each row is delayed a few milliseconds more than the previous row.

Delay-shaded array

A long line of subwoofers placed horizontally along the front edge of the stage can be delayed such that the center subs fire several milliseconds prior to the ones flanking them, which fire several milliseconds prior to *their* neighbors, continuing in this fashion until the last subwoofers are reached at the outside ends of the subwoofer row (beamforming). This method helps to counteract the extreme narrowing of horizontal dispersion pattern seen with a horizontal subwoofer array. Such delay shading can be used to virtually reshape a loudspeaker array.[73]

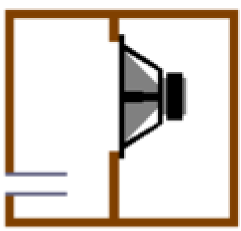
Directional enclosure

Some subwoofer enclosure designs rely on drivers facing to the sides or to the rear in order to achieve a degree of directionality.[74][75] End-fire drivers can be positioned within a single enclosure that houses more than one driver.[76]

Variants

Some less commonly-used bass enclosures are variants of the subwoofer enclosure's normal range, such as the mid-bass cabinet (60-160 Hz) and the infrasonic (extra low) subwoofer (below 30 Hz).

Enclosure designs


Compound or 4th order band-pass enclosure

Front loaded subwoofers have one or more subwoofer speakers in a cabinet, typically with a grille to protect the speakers. In practice, many front-loaded subwoofer cabinets have a vent or port in the speaker cabinet, thus creating a bass reflex enclosure. Even though a bass reflex port or vent creates phase delay, it adds SPL, which is often a key factor in PA and sound reinforcement system applications. As such, non-vented front-firing subwoofer cabinets are rare in pro audio applications.

Horn-loaded subwoofers have a subwoofer speaker that has a pathway following the loudspeaker. To save space, the pathway is often folded, so that the folded pathway will fit into a box-style cabinet.Cerwin-Vega states that its folded horn subwoofer cabinets, "...on average, produce 6 dB more output at 1 watt than a dual 18" vented box" giving "four times the output with half the number of drivers." [77]The Cerwin Vega JE-36C has a five feet long folded horn chamber length in the wooden cabinet.[78]

Manifold subwoofers have two or more subwoofer speakers that feed the throat of a single horn. This increases SPL for the subwoofer, at the cost of increased distortion. EV has a manifold speaker cabinet in which four drivers are mounted as close together as practical. This is a different design than the "multiple drivers in one throat" approach. An unusual example of manifold subwoofer design is the Thomas Mundorf (TM) approach of having four subwoofers facing each other and sitting close together, which is used for theatre in the round shows, where the audience surrounds the performers in a big circle (e.g., Metallica has used this in some concerts). The TM approach produces an omnidirectional bass sound.[79] Cerwin Vega defines a manifold enclosure as one in which "..the driver faces into a tuned ported cavity. You hear sound directly from the back of the driver in addition to the sound that emanates out of the port. This type of enclosure design extends the frequency capability of the driver lower than it would reproduce by itself.[80]

Bandpass subwoofers have a sealed cabinet within another cabinet, with the "outer" cabinet typically having a vent or port.

Bass instrument amplification

In rare cases, sound reinforcement subwoofer enclosures are also used for bass instrument amplification by electric bass players and synth bass players. For most bands and most small- to mid-size venues (e.g., nightclubs and bars), standard bass guitar speaker enclosures or keyboard amplifiers will provide sufficient sound pressure levels for onstage monitoring. Since a regular electric bass has a low "E" (41 Hz) as its lowest note, most standard bass guitar cabinets are only designed with a range that goes down to about 40 Hz. However, in some cases, performers wish to have extended sub-bass response that is not available from standard instrument speaker enclosures, so they use subwoofer cabinets. Just as some electric guitarists add huge stacks of guitar cabinets mainly for show, some bassists will add immense subwoofer cabinets with 18-inch woofers mainly for show, and the extension sub cabinets will be operated at a lower volume than the main bass cabinets.

Bass guitar players who may use subwoofer cabinets include performers who play with extended range basses that include a low "B" string (about 31 Hz); bassists who play in styles where a very powerful sub-bass response is an important part of the sound (e.g., funk, Latin, gospel, R & B, etc.); and/or bass players who perform in stadium-size venues or large outdoor venues. Keyboard players who use subwoofers for on-stage monitoring include electric organ players who use bass pedal keyboards (which go down to a low "C" which is about 33 Hz) and synth bass players who play rumbling sub-bass parts that go as low as 18 Hz. Of all of the keyboard instruments that are amplified onstage, synthesizers can produce some of the lowest pitches, because unlike a traditional electric piano or electric organ, which have as their lowest notes a low "A" and a low "C", respectively, a synth does not have a fixed lowest octave. A synth player can add lower octaves to a patch by pressing an "octave down" button, which can produce pitches that are at the limits of human hearing.

Several concert sound subwoofer manufacturers suggest that their subs can be used for bass instrument amplification. Meyer Sound suggests that its 650-R2 Concert Series Subwoofer, a 14-square-foot (1.3 m^2) enclosure with two 18-inch drivers (45 cm), can be used for bass instrument amplification.[81] While performers who use concert sound subwoofers for onstage monitoring may like the powerful sub-bass sound that they get onstage, sound engineers may find the use of large subwoofers (e.g., two 18" drivers (45 cm)) for onstage instrument monitoring to be problematic, because it may interfere with the "Front of House" sub-bass sound.

Bass shakers

Since infrasonic bass is felt, sub-bass can be augmented using tactile transducers. Unlike a typical subwoofer driver, which produces audible vibrations, tactile transducers produce low-frequency vibrations that are designed to be felt by individuals who are touching the transducer or indirectly through a piece of furniture or a wooden floor. Tactile transducers have recently emerged as a device class, called variously "bass shakers", "butt shakers" and "throne shakers". They are attached to a seat, for instance a drummer's stool ("throne") or gamer's chair, car seat or home theater seating, and the vibrations of the driver are transmitted to the body then to the ear in a manner similar to bone conduction.[82][83] They connect to an amplifier like a normal subwoofer. They can be attached to a large flat surface (for instance a floor or platform) to create a large low frequency conduction area, although the transmission of low frequencies through the feet is not as efficient as through the seat.[84]

The advantage of tactile transducers used for low frequencies is that they allow a listening environment that is not filled with loud low frequency waves. This helps the drummer in a rock music band to monitor his or her kick drum performance without filling the stage with powerful, loud low frequency sound from a 15" (40 cm) subwoofer monitor and an amplifier, which can "leak" into other drum mics and lower the quality of the sound mix. By not having a large, powerful subwoofer monitor, a bass shaker also enables a drummer to lower the sound pressure levels that they are exposed to during a performance, reducing the risk of hearing damage. For home cinema or video game use, bass shakers help the user avoid disturbing others in nearby apartments or rooms, because even powerful sound effects such as explosion sounds in a war video game or the simulated rumbling of an earthquake in an adventure film will not be heard by others. However, some critics argue that the felt vibrations are disconnected from the auditory experience, and they claim that that music is less satisfying with the "butt shaker" than sound effects. As well, critics have claimed that the bass shaker itself can rattle during loud sound effects, which can distract the listener.[85]

World record claims

With varying measures upon which to base claims, several subwoofers have been said to be the world's largest, loudest or lowest.

Matterhorn

The Matterhorn is a subwoofer model completed in March 2007 by Danley Sound Labs in Gainesville, Georgia after a U.S. military request for a loudspeaker that could project infrasonic waves over a distance. The Matterhorn was designed to reproduce a continuous sine wave from 15 to 20 Hz, and generate 94 dB at a distance of 250 meters (820 ft), and more than 140 dB for music playback measured at the horn mouth.[86] It can generate a constant 15 Hz sine wave tone at 140 dB for 24 hours a day, seven days a week with extremely low harmonic distortion. The subwoofer has a flat frequency response from 15 to 80 Hz, and is down 3 dB at 12 Hz.[87] It was built within an intermodal container 20 feet (6.1 m) long and 8 by 8 feet (2.4 m × 2.4 m) square.[88] The container doors swing open to reveal a tapped horn driven by 40 long-throw 15-inch (40 cm) MTX speaker drivers each powered by its own 1000-watt amplifier.[89][90] The manufacturer claims that 53 13-ply 18 mm 4-by-8-foot (1.2 m × 2.4 m) sheets of plywood were used in its construction,[89] though one of the fabricators wrote that double-thickness 26-ply sheets were used for convenience.[91]

A diesel generator is housed within the enclosure to supply electricity when external power is unavailable.[88] Of the constant tone output capability, designer Tom Danley wrote that the "target 94 dB at 250 meters is not the essentially fictional 'burst' or 'peak SPL' nonsense in pro sound, or like the 'death burp' signal used in car sound contests."[92] At the annual National Systems Contractors Association (NSCA) convention in March 2007, the Matterhorn was barred from making any loud demonstrations of its power because of concerns about damaging the building of the Orange County Convention Center.[86] Instead, using only a single 20 amp electrical circuit for safety, visitors were allowed to step inside the horn of the subwoofer for an "acoustic massage" as the fractionally powered Matterhorn reproduced low level 10–15 Hz waves.

Royal Device custom installation

Another subwoofer claimed to be the world's biggest is a custom installation in Italy made by Royal Device primarily of bricks, concrete and sound-deadening material[15] consisting of two subwoofers embedded in the foundation of a listening room.[93] The horn-loaded subwoofers each have a floor mouth that is 2.2 square meters (24 sq ft), and a horn length that is 9.5 meters (31 ft), in a cavity 1 meter (3 ft 3 in) under the floor of the listening room. Each subwoofer is driven by eight 18-inch subwoofer drivers with 100 millimeters (3.9 in) voice coils. The designers assert that the floor mouths of the horns are additionally loaded acoustically by a vertical wooden horn expansion and the room's ceiling to create a 10 Hz "full power" wave at the listening position.

Concept Design 60-inch

A single 60-inch (1,500 mm) diameter subwoofer driver was designed by Richard Clark and David Navone with the help of Dr. Eugene Patronis of the Georgia Institute of Technology. The driver was intended to break sound pressure level records when mounted in a road vehicle, calculated to be able to achieve more than 180 dBSPL. It was built in 1997, driven by DC motors connected to a rotary crankshaft somewhat like in a piston engine. The cone diameter was 54 inches (1,400 mm) and was held in place with a 3-inch (76 mm) surround. With a 6-inch (150 mm) peak-to-peak stroke, it created a one-way air displacement of 6,871 cubic inches (112,600 cm^3).[94] It was capable of generating 5–20 Hz sine waves at various DC motor speeds—not as a response to audio signal—it could not play music. The driver was mounted in a stepvan owned by Tim Maynor but was too powerful for the amount of applied reinforcement and damaged the vehicle.[94] MTX's Loyd Ivey helped underwrite the project and the driver was then called the MTX "Thunder 1000000" (one million).[95]

Still unfinished, the vehicle was entered in an SPL competition in 1997 at which a complaint was lodged against the computer control of the DC motor. Instead of using the controller, two leads were touched together in the hope that the motor speed was set correctly. The drive shaft broke after one positive stroke which created an interior pressure wave of 162 dB. The Concept Design 60-inch was not shown in public after 1998.[96]

MTX Jackhammer

The heaviest production subwoofer intended for use in automobiles is the MTX Jackhammer by MTX Audio, which features a 22-inch (560 mm) diameter cone. The Jackhammer has been known to take upwards of 6000 watts sent to a dual voice coil moving within a 900-ounce (26 kg) strontium ferrite magnet. The Jackhammer weighs in at 369 pounds (167 kg) and has an aluminum heat sink.[97] The Jackhammer has been featured on the reality TV show *Pimp My Ride*.[98]

See also

- Bass management
- Bass test
- Bass song
- Mid-range speaker
- Power Alley
- Super tweeter
- Rotary woofer
- Thiele/Small
- Tweeter

- Woofer

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