Layman's Guide to LOUDSPEAKER SPECIFICATIONS

Part One

VICTOR BROCINER*

INTERPRETATION OF SPEAKER SPECIFICATIONS probably presents more of a problem to the layman than understanding the specifications of any other component of a sound reproducing system. This is partly because of the complicated nature (despite a speaker's simple appearance) of its functioning. Tuners, amplifiers, and tape units have both inputs and outputs that are electrical. Phonograph pickups convert a mechanical input to an electrical output. But speakers accomplish a double transformation: electrical to mechanical to acoustics. Also, the acoustic output does not appear at a convenient pair of terminals where it can be measured, but is diffused, usually nonuniformly, through space. The sound field produced is markedly altered by the listening room itself, so measurement is not easy. Mainly because of this, no complete, generally accepted standards exist. There is a natural tendency for manufacturers to present data in a manner that is most favorable to their product based on measurements made, at least partly, to their own standards.

Speaker systems present great variety in concept and design. Their description is necessarily made in somewhat technical terms, many of which may be unfamiliar to the layman both as to definition and significance.

The purpose of this article is to define the technical terms used, in an understandable manner; to provide some information about what they mean in terms of speaker performance; and to acquaint the reader with speaker specifications so that he will be able to evaluate them and to ask pertinent questions when more complete information is required.

The terms referred to include not only performance specifications such as frequency response and power-handling capability, but also descriptive terms such as air suspension, loading, flux density, and the like. The definitions do more than explain what the speaker manufacturer is talking about; they include a brief treatment of the effect each item has on speaker performance; in fact, they even help to explain how a speaker works.

Definitions and Explanations

Let's begin with a definition of the subject of our discussion. A *speaker system* is an assembly consisting of one or more speaker units in an appropriate enclosure. The enclosure itself may constitute a horn, loading the woofer. The remaining terms are listed in alphabetical order. This means that a given definition may use words not defined until later.

Acoustic Lens—A device that is used to widen the dispersion of the higher frequencies which otherwise tend to form a narrow beam of sound. Acoustic lenses can take the form of parallel, bent plates, closely-spaced arrays of bars, rods, or other solid objects, or multiple holes or slots in plates.

Acoustic Suspension (also called "air suspension")—The speaker cone has a highly compliant suspension; it moves very freely, so its motion is determined more by the spring-like action of the air in the box behind it than by the mechanical action of the suspension itself. An air spring is much more linear than mechanical deformation of the suspension, reducing distortion in the bass range, where the cone goes through large excursions.

Annulus—See "Surround."

Baffle—In free air, there is cancellation between the sound wave produced by the front of the speaker cone and that produced by the rear. When the cone moves forward, it compresses the air in front of it, which flows around the edge of the speaker and tends to annul the partial vacuum created at the rear of the cone. This effect also occurs, of course, with reverse motion of the cone. It is appreciable only at low frequencies. A flat baffle must be quite large to be effective at low frequencies. At 30 Hz it would have to be about 19 feet in diameter! Since this is not very practical, especially for bookshelf speakers, flat baffles are no longer used. One exception is a speaker mounted in a wall, with its rear radiating into an adjacent room. However, the term is still sometimes applied to any device used to separate the front and back waves, such as a closed box. See "Infinite baffle."

The reader may wonder why cancellation takes place only at low frequencies. A really good explanation is not simple and (like the large baffle) would not fit into this series of definitions. But a rather good analogy is the motion of a paddle in still water. For a slow back-and-forth motion, the water flows around the paddle. A fast motion produces waves that spread out from the center of disturbance.

Basket—See "Frame."

Bass Reflex—When a speaker is mounted in a closed box with an auxiliary opening, or port, whose size is suitably related to the volume of the box, the rear wave emerges *in phase* with the front wave and reinforces it over an appreciable part of the low-frequency range. The mass of the air in and near the port and the stiffness (or compliance, or springiness) of the air in the box form a resonant system which produces a phase reversal. The action can be explained by means of a mechanical analogy. Consider a heavy pendulum, whose weight is the analog

*Vice President Planning, H. H. Scott Inc., Maynard, Mass.

of the mass of air in the port. Attach a rubber band to the pendulum. The rubber band's compliance corresponds to that of the air in the box. Hold the other end of the rubber band in your hand and move it forward and back very slowly. The pendulum will swing in step with the motion of your hand. Now gradually increase the speed of motion. At one critical speed (frequency) the pendulum will swing forward when your hand moves backward, and vice-versa. This means that its phase has been reversed, as is the phase of the back wave in the bass reflex cabinet. For this reason it is also referred to as a "phase inverter" system. Other terms used are "ported cabinet." See "ducted port."

Coaxial Speaker—A speaker with a tweeter mounted on the axis of a woofer and inside its cone. A horn driver unit may be placed within or behind the magnetic structure of the woofer, with the horn throat passing through the center pole of the magnet assembly.

A woofer, mid-range speaker, and tweeter may be mounted coaxially, forming a three-way coaxial speaker. Sometimes the mid-range is covered by an auxiliary cone, attached to the woofer voice coil and having an unsupported or free edge. Opinions differ whether this should be called a three-way speaker. The transition from bass to mid-range is effected mechanicallf and the change to high frequencies electrically, unlike a "pure" three-way system where three distinct electro-mechanical assemblies are used. But it operates in three modes.

Sometimes the units of a coaxial system are not really coaxial but slightly displaced from each other laterally. This can improve the smoothness of the frequency-response curve in the region of the crossover frequency between speakers.

Coaxial speakers are made because they are more convenient to handle by the user who installs them in a cabinet himself; they save space, because the relative positions of the speakers are fixed by the designer to provide smoothest response, and for another reason as well: in a two- or three-way speaker system, the path lengths from the individual speakers to the listener are somewhat different, resulting in different arrival times for the components of a transient. The coaxial construction minimizes the differences in path lengths. Not everybody agrees that this is important, but for those who do there are coaxial speakers.

Compliance—The ease with which a material "gives" when a force is applied. In a speaker, compliance is the distance of cone movement divided by the strength of the applied force. A speaker suspension must have compliance to enable the cone to move, and the compliance must remain as nearly constant as possible over the large excursions that take place in the bass region. Another way to put it is that the motion is linear, that is, proportional to the applied force. This enables the speaker to reproduce low frequencies without distortion. People often say "high-compliance cone" when they are actually referring to the cone *suspension* (the surround and spider).

"High-compliance" speakers are linear over a large excursion range. It is generally thought that this results in a low resonant frequency. This is not necessarily so if the cone and voice coil are very light. In this case efficiency is good in the middle register but bass is not well reproduced. For good bass reproduction the moving system must be heavy and not too strongly damped, either mechanically or electrically.

Cone—The reciprocating diaphragm or sound radiator of a direct-radiator speaker, usually conical in shape. Straight-sided cones are most often used in woofers because they offer maximum rigidity. Curved cones break into concentric modes of vibration at higher frequencies, so that the outer sections become "decoupled" and tend to remain stationary as the frequency is increased. The effective cone size is decreased at high frequencies which reduces the moving mass and holds up the response which would otherwise fall off in the treble range. The smaller effective cone size also produces a wider dispersion and prevents the "beaming" effect of a rigid piston.

Cones are usually made of felted paper, which provides a desirable combination of strength, light weight, and good mechanical damping. The material is "dead"; it does not ring like a bell when struck, and consequently produces far fewer spurious responses than would a "live" material. Cones have also been made of foamed polystyrene and polyurethane because of their high stiffness-to-mass ratio. In general, their internal damping has turned out to be less than anticipated. However, foam cones are being successfully used in some designs, sometimes coated with aluminum foil. Polymerized plastic cloth is also used.

Cone Bead—a thickened section, usually circumferential, used to stiffen a cone.

Cone Break-Up—At low frequencies, a cone moves as a unit, like a piston. As the frequency increases, flexibility and mass of the cone change the nature of its motion. The apex follows the motion of the voice coil, but the remainder of the cone does not. At some frequencies, parts of the cone may actually move backward when the coil moves forward. The irregular manner in which different parts of the cone move is called "break-up."

Cone break-up causes irregularities in the frequency-response distribution pattern of a speaker. Break-up can be designed into a speaker to provide extended high-frequency response and improved dispersion. A rigid piston becomes more and more directional as the frequency increases, and its response drop off as well. If the outer zones of a cone can be made to move less than the inner ones at high frequencies, the cone acts like a smaller, lighter cone with more high-frequency response and wider distribution. Cone design and fabrication are the most critical of any of the aspects of speaker design and manufacturing, and more of an art than a science. The term "cone break-up" is generally used to refer to the *undersirable* modes of operation.

Cone Corrugation—A circumferential U-shaped bend in a cone that acts against unsymmetrical deformation of the cone. Since it is compliant in a radial direction it is used to divide the cone's motion into circular zones at the higher frequencies. A number of corrugations can be designed progressively to decouple the outer sections of a cone as the frequency increases, producing better treble response and improved angular distribution. Multiple corrugations at the outer edge of a cone are often used as a compliant edge suspension that supports the cone while permitting axial movement. See "Surround."

Cone Stiffness—Stiffness is the opposite of compliance. Cones made of stiff materials are strong but tend to break up into undesirable modes of vibration. Often incorrectly used to refer to the stiffness of the *suspension*. (The surround and spider.) Stiff cones deform only slightly when pressure is applied.

Crossover Network—(Dividing Network)—In multi-speaker systems the incoming signal to each speaker must be restricted to the frequency range for which that speaker is used. This is done by means of an electric filter. In inexpensive systems this may be a single element—a capacitor—in series with the tweeter. More elaborate systems use both inductors and capacitors. These are called LC filters. In these, the signal fed to the woofer is cut off *above* a certain frequency in addition to cutting off the signal to the tweeter *below* its working range.

The *Crossover Frequency* is the transition point from one speaker to the other. Two-way systems have one crossover frequency, three-way systems have two, and so on. Dividing networks do not cut off abruptly but have slopes to their frequency characteristics. Accordingly, they may have 6 dB-per-octave, 12 dB-per-octave or even higher slopes. The sharper slopes require more L and C elements. For the reasons for choosing particular frequencies and slopes, see the discussion under 2-way and 3-way systems.

Damping—The cone/voice-coil assembly has inertia, and is held in place by a springy suspension. Because of inertia a cone tends to keep moving after the applied force has been removed. The springy mounting results in a tendency to oscillate. At the (so-called) resonant frequency of a cone, at the lower end of the reproduced frequency range, the effect is quite large. See "Hangover." The duration of the oscillation is determined by the "Q" of the speaker, as in an electrical tuned circuit.

Appreciably above the resonant frequency, the inertia determines the behavior of the speaker: the velocity of the cone decreases as the frequency increases. But the ability of the cone to transform the energy of its motion into sound increases with frequency, making up for the reduced velocity, so that the frequency response is uniform.

At resonance, there is likely to be a peak in response. The height of the peak is greater the higher the Q, which can be controlled by adding a resistive element to the motion. This reduces the peak; its effect is called damping.

If the amount of damping is too much, the motion at resonance is restricted too greatly. With too little, it would still be excessive. *Critical damping* results in a condition for which the moving element does not overshoot its rest position after being deflected. Response is down 6 dB at resonance. Less-than-critical damping results in increased response at resonance; a slight amount (one-half of critical, to be exact) produces flat response. Increased damping beyond critical produces a fall-off in bass response. So, while damping is desirable and in fact necessary, there can be too much of a good thing.

Damping can be mechanical, acoustical, or electrical. An example of mechanical damping is friction. Acoustical damping utilizes resistance to air flow, as by covering the back of the speaker by a perforated material. Electrical damping is caused by the "back e.m.f." (a voltage opposing the signal voltage when the voice coil moves through the magnetic field in the gap). This reduces the flow of current and the resulting motion. Electrical damping is improved by using high flux density in the gap. It is operative only when the speaker is connected to an operating amplifier. Amplifier damping factors greater than 5 to 10 have no significant effect.

Diameter—The specified diameter of a speaker is the outside diameter of the speaker frame; the *cone* diameter is less—considerably so if a wide surround is used to provide high compliance. We will not discuss the rare cases where frames are made oversize to increase the nominal diameter.

Diaphragm—The moving, sound-radiating element of a loudspeaker. See "Cone." This terms also applies to elements such as the dome-shaped radiators of some tweeters and mid-range units, the variously-shaped moving elements of horn-loaded speakers, and the driven elements of electrostatic speakers.

Diffraction Horn—See "Horn."

Direct Radiator—A speaker whose cone or diaphragm radiates sound directly into the air. The word "directly" includes cases where the air in front of the speaker may be partially confined by a partition with openings, forming a front air chamber, or by obstacles such as an acoustic lens. A direct-radiator speaker facing into an expanding passage coupling it to the air becomes a *horn speaker* (see definition). A direct-radiator speaker *system* is simply one or more speakers mounted in an enclosure. The speaker itself is called a direct radiator if it is designed for use in a direct-radiator system.

Direct-radiator speaker systems are relatively simple, can be made quite compact and have low efficiency. The latter is not necessarily bad.

Distributed Port—In a bass-reflex cabinet, a port consisting of a series of small holes. The air friction in the holes increases the acoustic resistance of the port which may be desirable in some cases.

Dividing Network—See "Crossover Network."

Doublet (Dipole)—A speaker without a baffle radiates sound into the air from both sides of its diaphragm. This is called an acoustic doublet. Its frequency response and power capability fall off rapidly as the frequency decreases. It can provide reasonable bass response if made large enough, as in some electrostatic speakers. At low frequencies, its distribution pattern concentrates sound along the speaker's axis, with a minimum in the plane of the cone edge. The distribution is made more uniform by reflections from the room walls.

Doubling—The creation of large amounts of second-harmonic distortion by non-linearity; an effect that occurs in the bass range. This component, of double the fundamental frequency, can actually be much greater than the fundamental itself, producing a false illusion of bass response. Driving a speaker hard at low frequencies causes mostly third-harmonic distortion, or *tripling*. Its effect is similar to doubling. These types of distortion can be avoided by designing a speaker for *linearity*. See reference.

(continued on page 89)

LAYMAN'S GUIDE TO SPEAKER SYSTEMS

(Continued from page 24)

Driver Unit—Speakers with relatively small, light diaphragms designed for use in horn speakers (see definition). Also used on occasion to refer to a direct-radiator speaker itself to distinguish it from the assembly of a speaker or speakers in an enclosure, or speaker system.

Dynamic Speaker (Moving-Coil Speaker)—A speaker in which the varying magnetic field produced by the varying signal current in a coil of wire interacts with a surrounding fixed magnetic field produced by a permanent (or electro-) magnet, to produce motion of the diaphragm. The *voice coil* is generally composed of a number of turns of wire forming a cylinder. Some unusual designs use a zig-zag metal ribbon as a voice coil; "printed-circuit" construction has also been used.

Ducted Port—A tube or duct joining the air outside the cabinet to that inside. In small bass-reflex cabinets designed to produce extended bass response, the required size of a simple port is so small that there are excessive energy losses due to friction as the air oscillates back and forth in the port. A duct permits the opening to be made larger and the losses reduced.

Edge Damping—A viscous compound applied to the surround of a cone speaker. When a signal current starts in a speaker, the motive force generated by the voice coil is applied to the apex of the cone. Because of the mass and flexibility of the cone, a wave is set up that travels radially outward along the cone to its edge, at the surround. Here it is reflected and travels back toward the voice coil and is reflected outward again. The resulting wave-like motion of the cone surface gives rise to irregularities in the frequency response. A viscous material on the surround absorbs the outward travelling wave and smooths the response because of its internal energy loss.

Electrostatic Speaker—A force is exerted between electrically charged particles: similar charges repel; unlike charges attract. The force is proportional to the intensity of the charge.

This effect is utilized in electrostatic speakers. In the simplest type, the diaphragm is a thin, conductive membrane, spaced a short distance away from a perforated metal plate. The signal voltage is applied between the two conducting surfaces, together with a fixed d. c. bias voltage. The push-pull type of electrostatic speaker uses a diaphragm suspended between *two* conducting surfaces or a series of closely spaced wires. It operates much like a push-pull amplifier; distortion is greatly reduced. Electrostatic speakers require a connection to the power line for the high-voltage bias supply but consume very little current and can be left plugged in all the time. The diaphragms are very light. Since they are driven virtually uniformly over their entire surfaces, response can be made very smooth. They are used mostly for the higher frequencies.

(To be continued)