Coaxial Loudspeakers: Separating Facts from Hype

A Frazier White Paper

Overview

While the concept of coaxial multiway loudspeakers is not new – the first examples show up in the patent literature as early as the 1930s – there has recently been a major surge of interest in these devices. As the unquestioned industry leader in the development of coincident loudspeakers – we introduced our CAT 40 in 1986, and our entire current line of sound reinforcement loudspeakers is based on coincident designs - we have acquired some unique insights into the behavior of coaxial loudspeakers. In this paper, we will explain, as simply as possible, some of the principles we use in our work. Our goal is to convey a clear distinction between marketing claims and real-world performance.

The term "coaxial" means, "sharing a common axis." In loudspeaker terminology, the "axis" of a cone transducer is defined by the centerline of the pole piece, and the "axis" of a typical horn can be defined as a line connecting the center of its throat to the center of its mouth. In horns with intentionally asymmetric coverage patterns, this definition works somewhat less well, but we can live with it for the purposes of this discussion.

The Attractiveness of the Coaxial Configuration

Symmetry

A coaxial loudspeaker will have the attribute of response behavior that is symmetric about its axis. The meaning of "symmetry" is this: whatever response is observed at a given angle with respect to the axis, the same response will be observed at that angle in the opposite direction. In other words, the loudspeaker's behavior is "mirrored" about its axis. By itself, this symmetry is interesting, but not necessarily useful or even desirable. Other attributes in addition to the coaxial configuration must be present for the symmetric behavior to be desirable.

Non-coaxial loudspeakers cannot exhibit the symmetry behavior described above. Consider a simple two-way system with the HF element directly above the LF unit. On axis, one characteristic response behavior will be observed. Above axis, the arrival time of the LF signal will be delayed relative to the HF arrival, while below axis the reverse is true. This asymmetry cannot be corrected with any electronic signal processing, and such a loudspeaker cannot possibly have an optimal impulse response over a wide area.

Seamless Crossover

The strongest performance-related motivation for using a coaxial design is to make the crossover transition undetectable (inaudible and unmeasurable), not just "on axis," but also at all angles. Whereas only a coaxial design makes this result possible, it is not true that every coaxial loudspeaker will live up to this theoretical potential. Other design elements must be effectively addressed in order for the response of the loudspeaker to be consistent over the design coverage angles. This is one of the areas in which Frazier designs are unquestionably superior to those of our competitors.

Types of Coaxial Loudspeakers

There are several approaches to designing coaxial loudspeakers. Of the approaches that have been tried over the years, only a few offer real advantages over more conventional designs. Here is a brief overview.

1. HF driver mounted on woofer backplate and coupled to a small horn nested in the woofer cone. This is one of the earliest layouts, and many popular loudspeakers have employed it. It has three distinct drawbacks: electronic delay must be applied to the woofer in order to achieve signal alignment, the directivities of LF (direct radiator) and HF (horn) sections are not well-matched, and the close proximity of the woofer cone behind the HF horn creates early HF reflections that usually result in very ragged HF response.

2. LF and HF drivers coupled to a common horn. This configuration has no possibility of achieving good performance due to the very poor coupling of at least one, and usually both, of the drivers to the horn. The LF signal usually enters through slots in the sides of the horn throat, and there are then two paths the sound can take: further into the throat, and outwards towards the mouth. The sound that goes into the throat is reflected forward, reaches the mouth later, and causes major response problems in the LF horn's band. This is inevitable and insoluble. Additionally, the part of the horn that constitutes the HF horn does not extend to the mouth. The portion of the horn that precedes the slots for the LF drivers instead forms it. Beyond these slots, the horn surface creates problems for the HF signal in the same way that nearby wall surfaces can cause problems: the HF energy reflects in various directions off the horn walls and interferes with earlier energy that took a more direct path. Devices using this configuration will have ragged on-axis response and irregular directivity, neither of which can be remedied by external signal processing.

3. HF driver in front of woofer cone, with HF horn centered in LF horn. This configuration can achieve signal alignment with no electronic delay applied to either element, and the problems associated with this layout are minor and soluble, given sufficient insight into acoustics. This is the configuration we have chosen for our CAT 40 CAT 50 product families.

4. Multiple LF drivers coupled to a single horn, with the HF driver situated between the LF units and inside the manifold deflectors. To our knowledge, Frazier is the only manufacturer to have employed this design. As with 3. above, it is possible to achieve signal alignment with this layout with no external processing. Also like 3., the acoustic problems associated with this type of design are very minor and readily soluble. Our CAT60 and CAT 70 product families are of this configuration.

Signal Alignment

Reproduction of transient signals

This is a poorly understood concept in loudspeaker design, particularly as it relates to the attributes of a coaxial device. A multiway loudspeaker with optimized signal alignment will produce impulsive (transient) signals with the least possible change in the shape of the waveform. The sounds we wish to reinforce in a sound system are dominated by transient information. Consonant sounds in speech, percussive sounds, and the attack and decay portions of all musical instrument sounds are transients. They consist of complex combinations of many frequencies. The phase relationships of these individual harmonics are a critical part of the characteristic "sound" of an instrument or voice, and only an optimally aligned loudspeaker can reproduce them accurately. This is a significant element in sonic transparency, definition, and intelligibility, yet it is very seldom even discussed, let alone adequately addressed, in professional audio.

Achieving signal alignment

The term "signal alignment" implies synchronous arrival times of low and high frequency signal components, particularly in the crossover frequency range. A very common mistake is to use impulse-type measurements (e.g., ETCs) to determine signal arrival times for setting delays in a crossover. This is never successful: it cannot result in low and high frequency signals being in alignment at the crossover frequency. The detailed reasons for this are beyond the scope of this paper, but it is due to the fact that both low and high frequency elements are bandpass devices, and neither one behaves like a perfect point source. See the Frazier paper on crossover topologies for more information on this subject.

Essential to the achievement of alignment between LF and HF signals is the choice of crossover filter topologies. None of the currently popular alignments will yield an optimal impulse response. The use of any higher-order (12 dB/octave or more) symmetric (lowpass and highpass both have the same slopes) crossover will audibly degrade the ability of a loudspeaker to reproduce transient signals. Once again, Frazier, alone in our industry, acknowledges this fact and effectively addresses the issue. Frazier loudspeakers are all configured so as to produce the best possible replication of transient sounds. When a biamplified configuration is chosen, the DSP crossover parameters supplied by the factory are also optimal. For this reason, it is essential to use the factory-supplied settings in order to preserve the unique ability of Frazier loudspeakers to produce an optimized impulse response.

Theoretical Advantages vs. Practical Performance

The final determinant of the success of a loudspeaker design is how well actual examples of the design perform in the real world. This is where Frazier products stand out relative to all the competition. Very often, a loudspeaker designer will "discover" one or two principles and base all of his or her design thinking on these ideas. Designs based on such a limited set of concepts usually do not have even the potential of working well. The designer, in focusing narrowly on one or two concepts, ignores other, equally important, ones. Designs resulting from this type of narrowly focused thinking will always be seriously flawed.