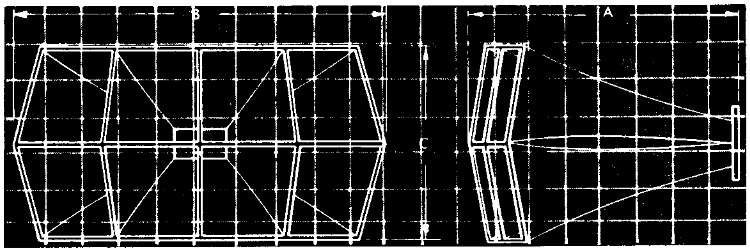

ALTEC LANSING ENGINEERING NOTES

TECHNICAL LETTER NO. 237

DIRECTIVITY RESPONSE OF SINGLE DIRECT-RADIATOR LOUDSPEAKERS IN ENCLOSURES

By
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When designing multi-way loudspeaker systems, you'd like to know the directivity response of each component. Most mid- to high-frequency horns available for commercial applications are supplied with specifications for −6 dB angle and Q or DI vs. frequency. The low-frequency units are, unfortunately, rarely supplied with this information and are generally assumed to have a Q of 5 or a −6 dB angle of 120° or so. To compound the problem, custom boxes and non-standard speaker-box combinations are used, all of which exhibit different directivity responses.

Fortunately, *all single speakers in enclosures*[1] *behave in an identical manner as far as directivity is concerned*. Furthermore, *this behavior is independent of cone geometry* (dome, deep-dish, shallow cone, etc.) as pointed out by Kates[2] and experiments at Altec on various woofers. The following is a description of the mechanisms affecting directivity and how directivity may be predicted using this knowledge.

We learn from articles by Hopkins and Stryker and from Baranek's text, "Acoustics," that the directivity index response of any direct radiator rises at 6 dB/octave once the wave length is several times smaller than the circumference. This is shown in Figure 1.

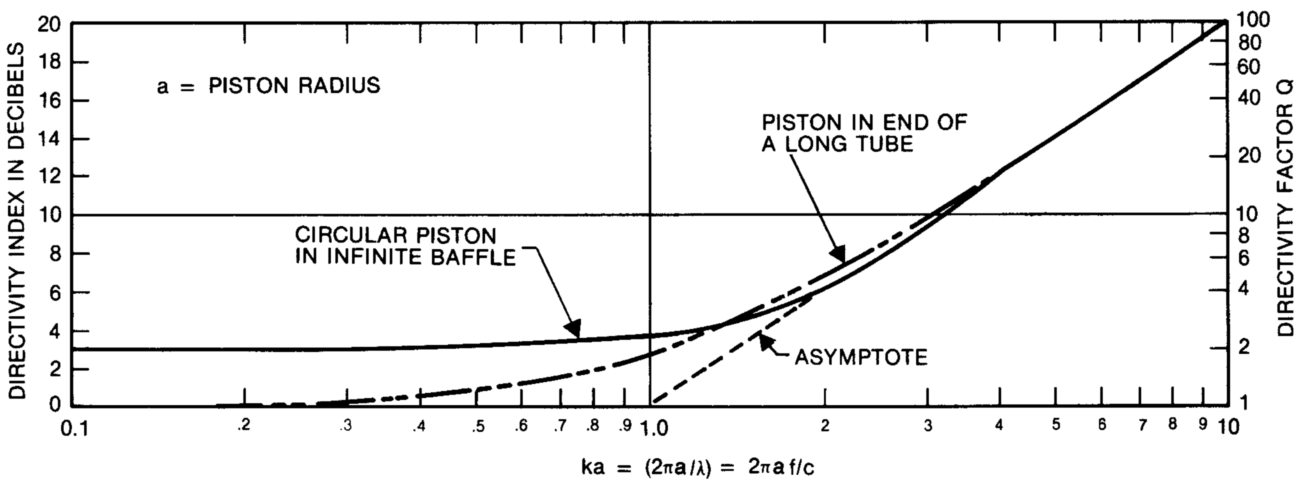

Figure 1. Directivity Index Response of Direct-Radiator Pistons in Various Baffle Configurations

Note the introduction of a new variable, "ka". Ka is *normalized frequency* and is simply the ratio of the circumference of the speaker (or baffle, as we will see later) to a wavelength; high ka numbers indicate high frequency and so on. We see that the DI vs. log of ka line becomes a 1:1 slope at high frequency (6 dB/octave) which asymptotes to a DI of zero (Q = 1) at ka = 1. This observation is

[1]Enclosures with frontal aspect ratios (height:width) 1:1 to 2:1.
[2]"Radiation from a Dome" — AES

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crucial to the construction of our directivity plot for a loudspeaker in a baffle. Note also that for a piston in an infinite baffle, the directivity makes a transition to half-space (DI = 3, Q = 2) at low frequencies.

Since the directivity varies at 6 dB/octave, it seems reasonable to expect the −6 dB angle on a polar response curve for a direct-radiator system to vary similarly.

From data taken on a large variety of speaker-box combinations, we can observe some very encouraging behavior. First of all, *there is a direct relationship between DI (or Q) and −6 dB angle* for all cone speaker-and-box systems. This is shown in Figure 2.

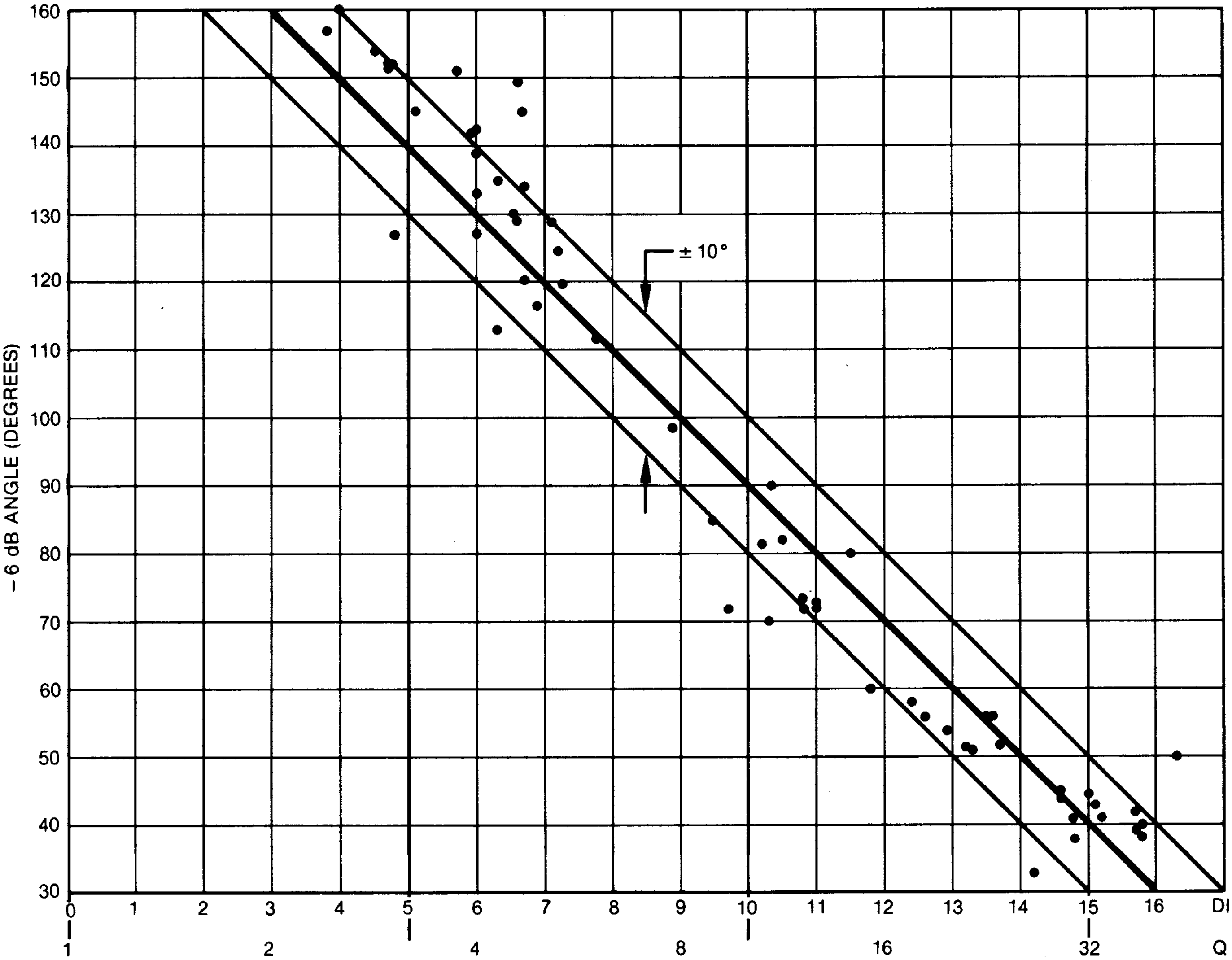

Figure 2. Relationship of Directivity Index to −6 dB Angle for Many Different Cone-Type Loudspeakers and Baffles

At low frequencies, the −6 dB angle is very wide and approaches 360°. At mid-frequencies, there is a transition to half-space radiation, where the −6 dB angle is around 160°. At high frequencies, the half-space region changes to a progressively narrowing or beaming region. The transition rates all appear to be approximately the same (1:1 or 6 dB/octave) and the frequencies at which the transitions occur seem to be related to the size of the loudspeaker and baffle. *This is true for both vented and closed boxes.*

A simple theory to relate all of this is as follows:

1. A loudspeaker will be omnidirectional starting at ka = 1 and the beamwidth will halve for each octave increase in frequency. Therefore, as in Figure 1, the response can be plotted on a log/log graph of −6 dB angle vs. ka or frequency with a 45° triangle.

2. A baffle will act as a half-space baffle until it reaches about ka = 2, where it makes a transition (45° on log/log graph of Step 1) to 360° at ka = 1. Half-space radiation is about 160° (−6 dB) in a real-world situation instead of the 180° predicted theoretically.

3. Any loudspeaker in a large baffle is not affected by that baffle at high frequencies where the "free-air beamwidth" is smaller than 160° or so. This "free-air beamwidth" is found by plotting a 45° line on graph of Step 1 which intersects 360° at ka = 1 for the piston size; e.g., ka = 1 for a 15″ loudspeaker is 317 Hz, since a 15″ speaker is about a 13.5″ piston.

This theory is incorporated into a simple chart, as shown in Figure 3. This chart was used to approximate all the data with straight line curves and it all worked out very nicely. These are shown in Figures 4 through 7.

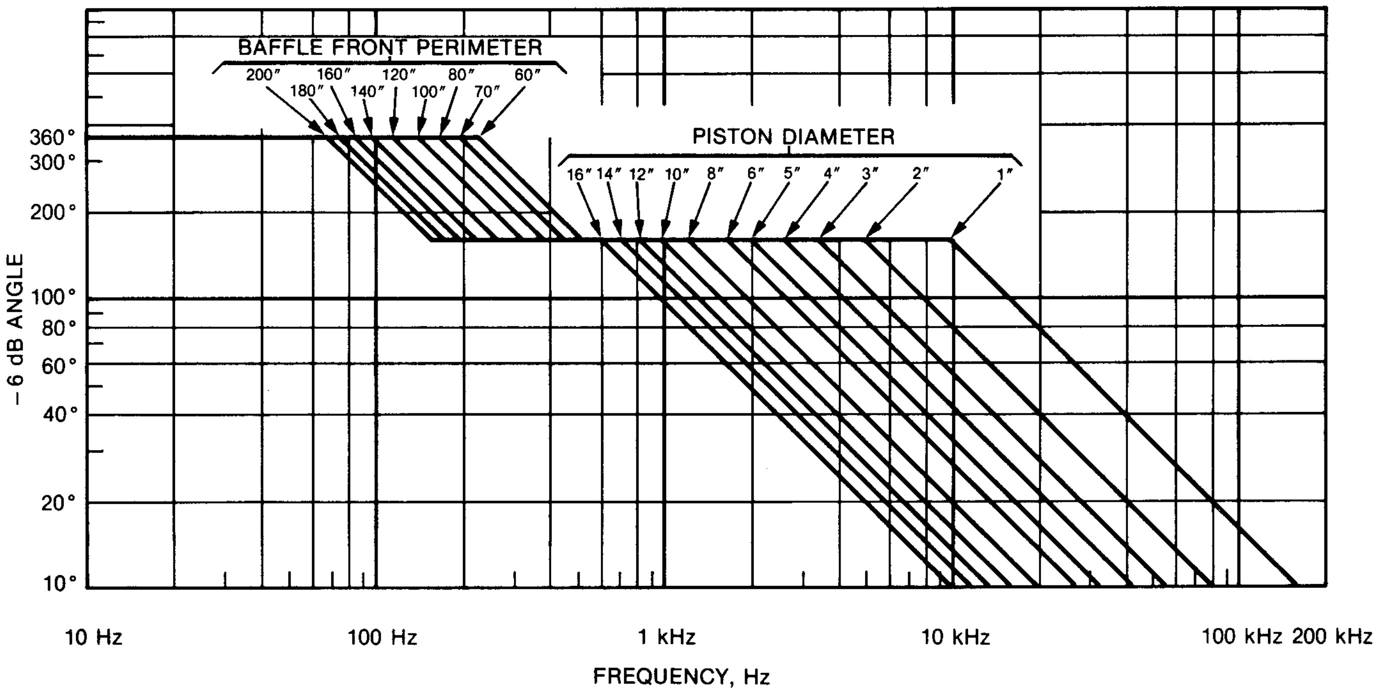

Figure 3. Chart for Predicting −6 dB Angle Response
for Piston-and-Box Systems

Multiple Speaker Systems

When a 2, 3 or 4-way *all-cone* speaker system is used, Figure 3 may be used to predict directivity response. The Altec Model 9 bookshelf system is a good example of a 3-way system. The Model 9 consists of a 12″ woofer (10″ piston size), approximately a 4″ (piston size) midrange and 2″ (piston size) tweeter, crossed over at 800 Hz and 7,000 Hz. Its frontal perimeter measures 80″. The crossover rates are plotted as 45° ascending lines for a 6 dB/octave crossaover, and so on. To obtain a prediction of −6 dB angle, a blank piece of graph paper is layed over Figure 3 and the −6 dB angle plot is laid out per the previous data. Real −6 dB angle points are shown for the Model 9 also and seem to correspond well with the theoretical response as shown in Figure 8.

Conclusion

Using Figures 2 and 3 should give the system designer a reasonable prediction of the directivity behavior of single direct-radiator systems. This is helpful in choosing crossover frequencies by matching "Q" or angular beamwidth of components and can be accomplished very easily once the sizes of the components are known. Prediction of −6 dB angle response is provided, but Q or DI may be obtained also using Figure 2.

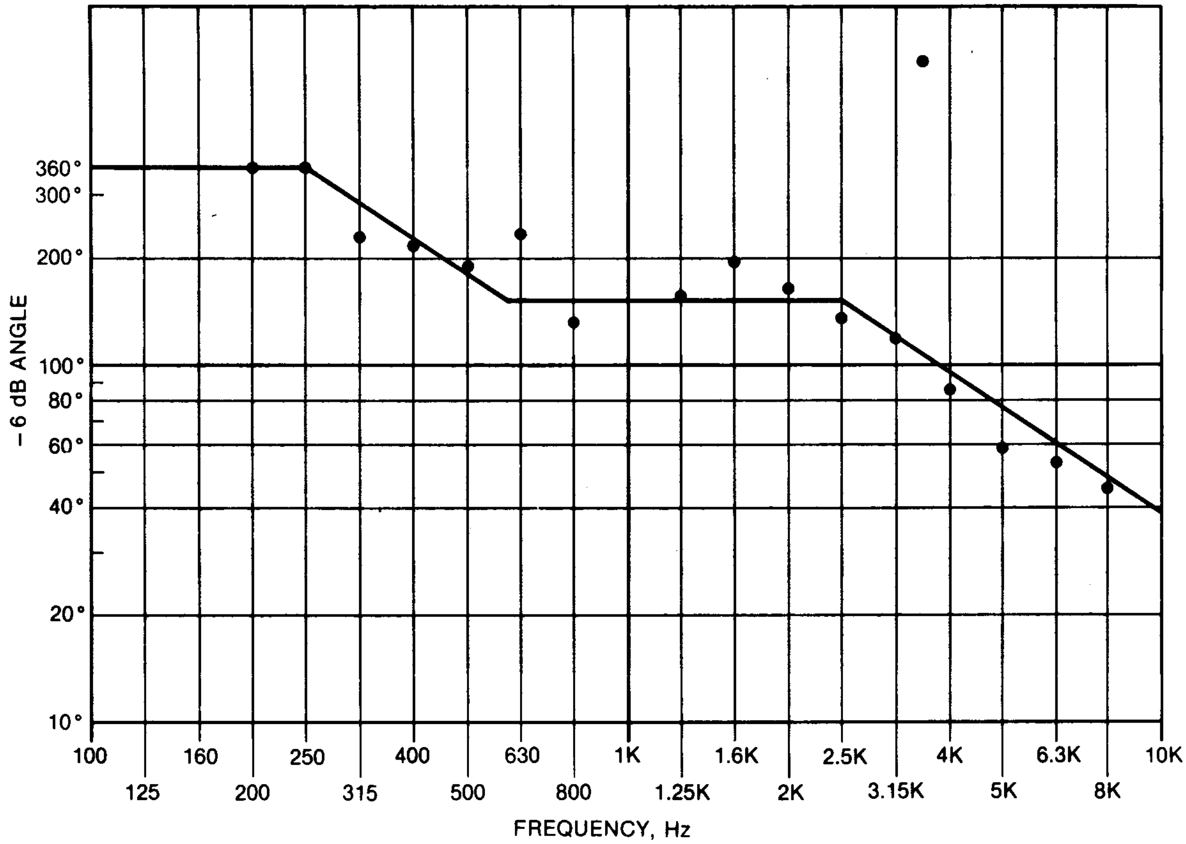

Figure 4. Real vs. Predicted Directivity Response —
Model 405 (4″) in 54″ Perimeter Box

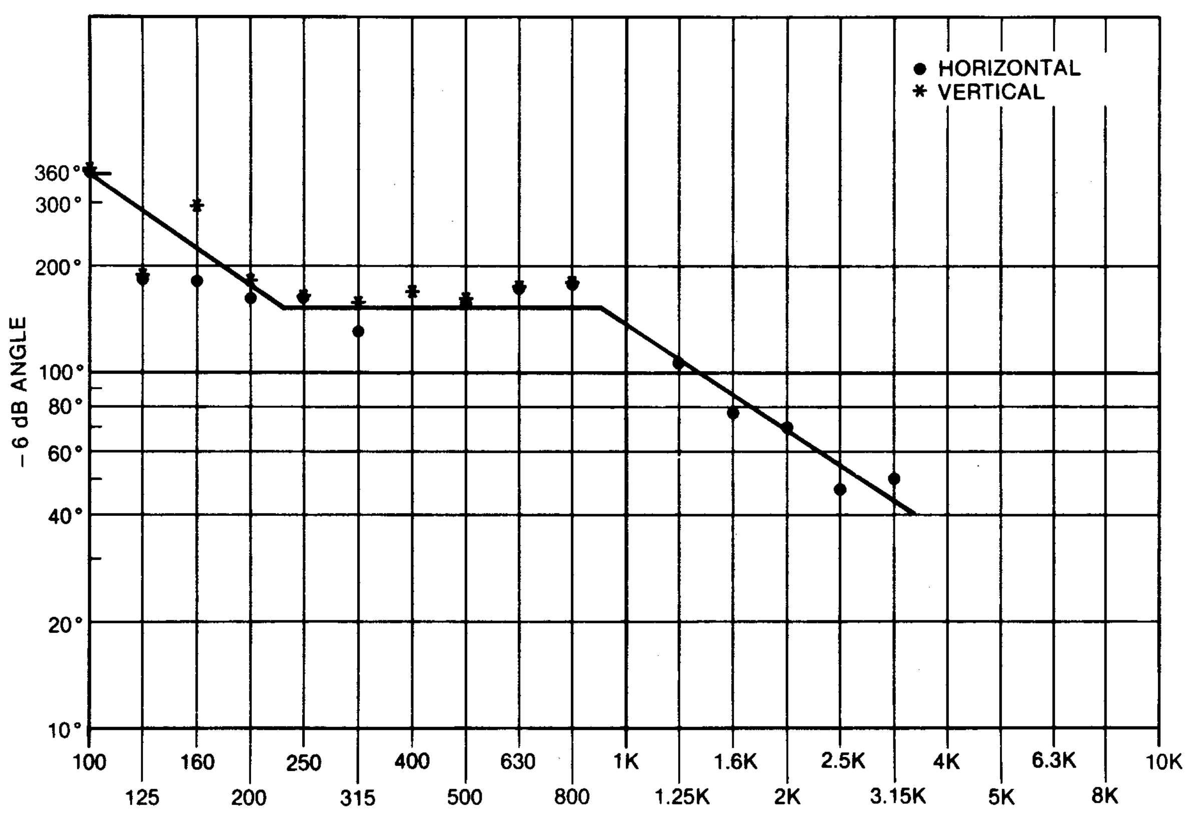

Figure 5. Real vs. Predicted Directivity Response —
12″ Speaker (10″ Piston) in 120″ Perimeter Box

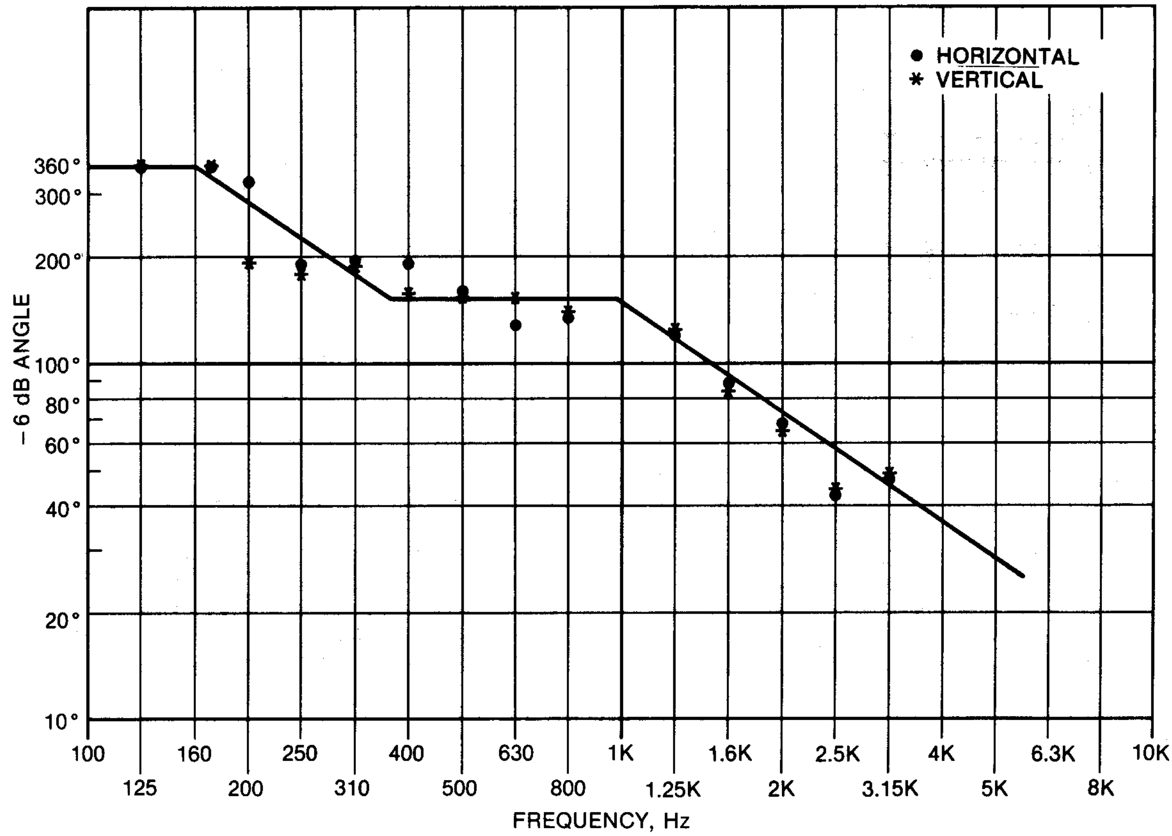

Figure 6. Real vs. Predicted Directivity Response — 12″ Speaker (10″ Piston) in 80″ Perimeter Box

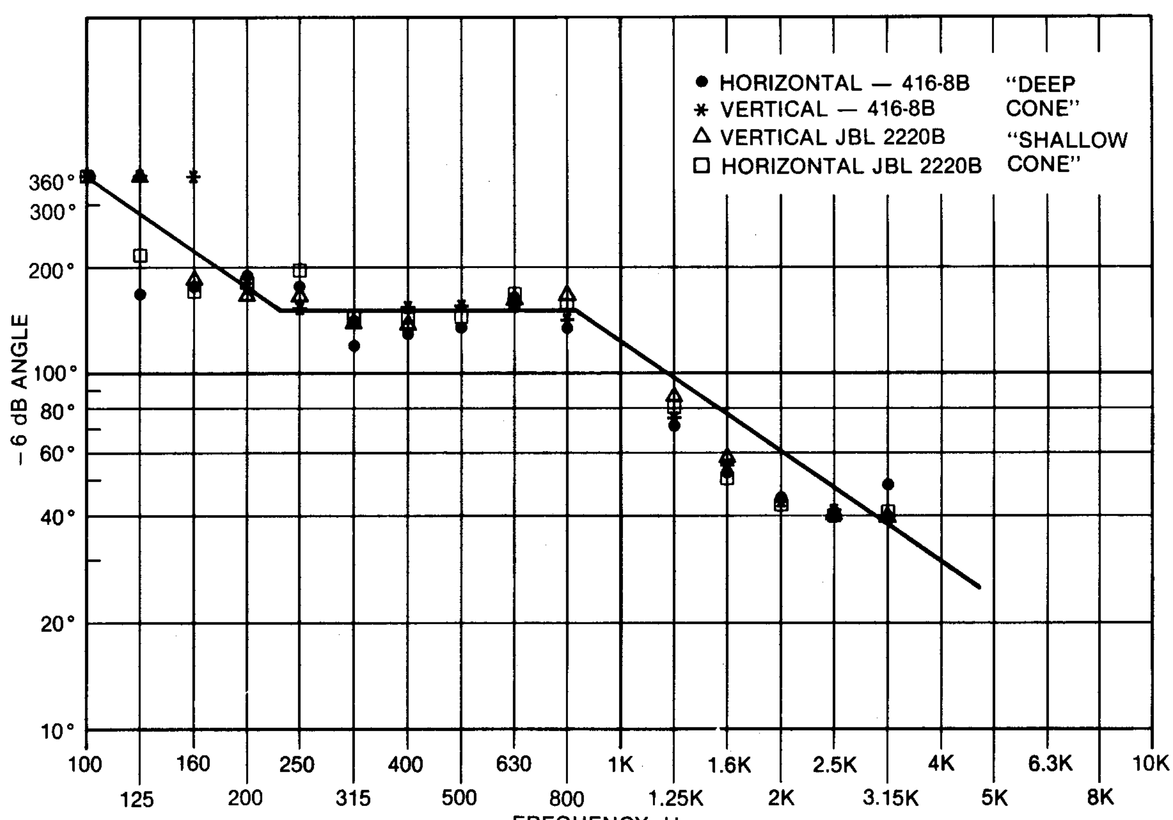

Figure 7. Real vs. Predicted Directivity Response — Various 15″ Speakers (13½″ Piston) in 140″ Perimeter Box

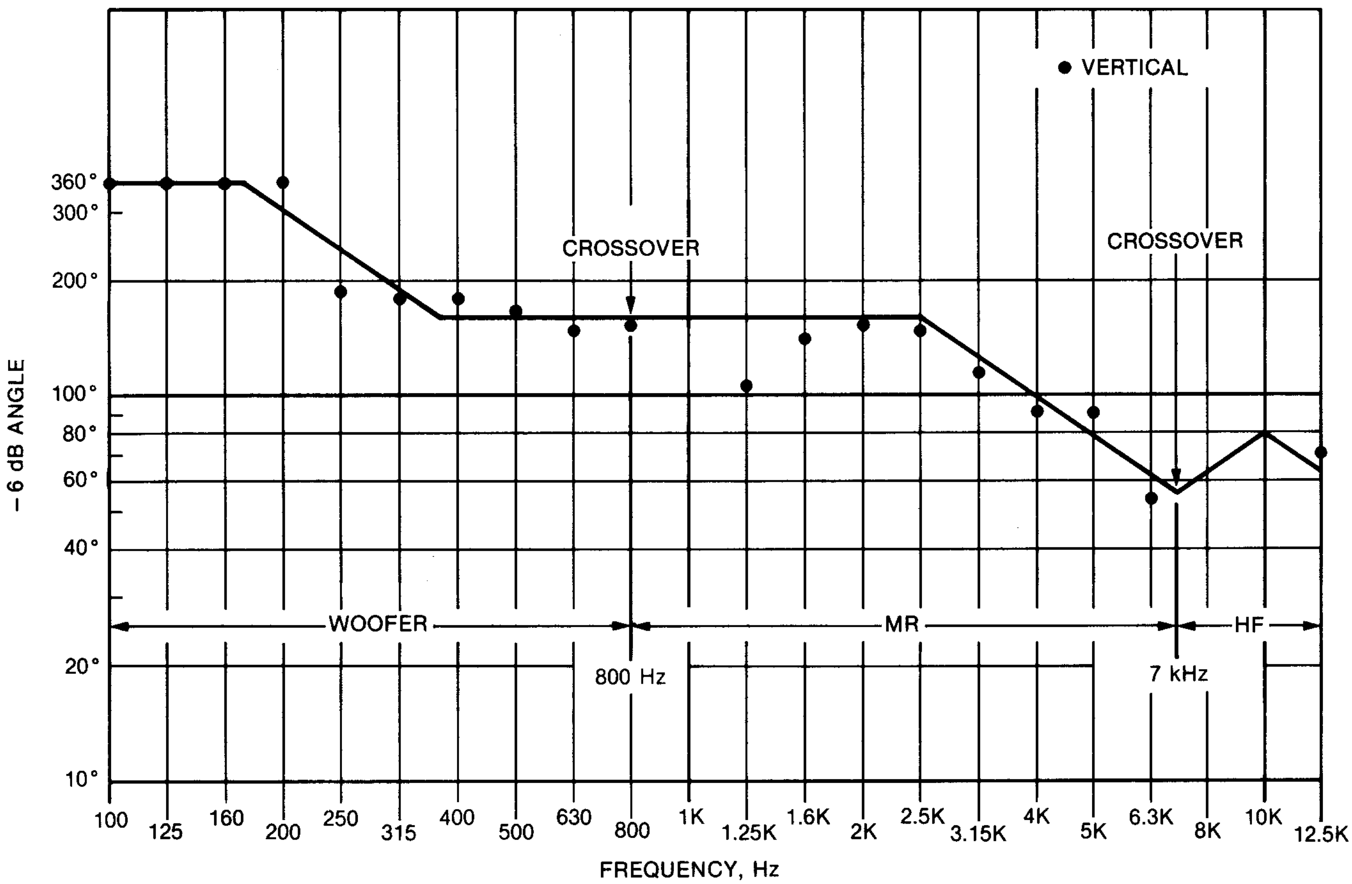

Figure 8. Real vs. Predicted Directivity Response of Model 9 3-Way Bookshelf System