Far-field Criteria for Loudspeaker Balloon Data

by Pat Brown

The most common reference distance for loudspeaker SPL specifications is 1 meter (3.28 feet). The choice is one of convenience - any distance will do. The 1m reference simplifies distance attenuation calculations by eliminating the division required in the first step:

$\Delta dB = 20\log(D_x/1)$ ideal point source

$\Delta dB = 10\log(D_x/1)$ ideal line source

where D_x is the listener position in meters.

Loudspeakers must be measured at a distance beyond which the shape of the radiation balloon remains unchanged. The changes are caused by path length differences to different points on the surface of the device. These differences become increasingly negligible with increasing distance from the source, much in the same way as any object optically "shrinks" as the observer moves to a greater distance. The distance at which the path-length differences become negligible marks the end of the near-field and beginning of the far-field of the device.

An infinitely small source (a point source) can be measured at any distance and the data extrapolated to greater distances using the inverse-square law without error. A very small loudspeaker might possibly be measured at 1 meter, but for larger loudspeakers it's a different story.

For large devices, the beginning of the far-field must be determined, marking the minimum distance at radiation parameters can be measured. The resultant data is then referenced back to the 1 meter reference distance (Figure 1) using the inverse-square law. This calculated

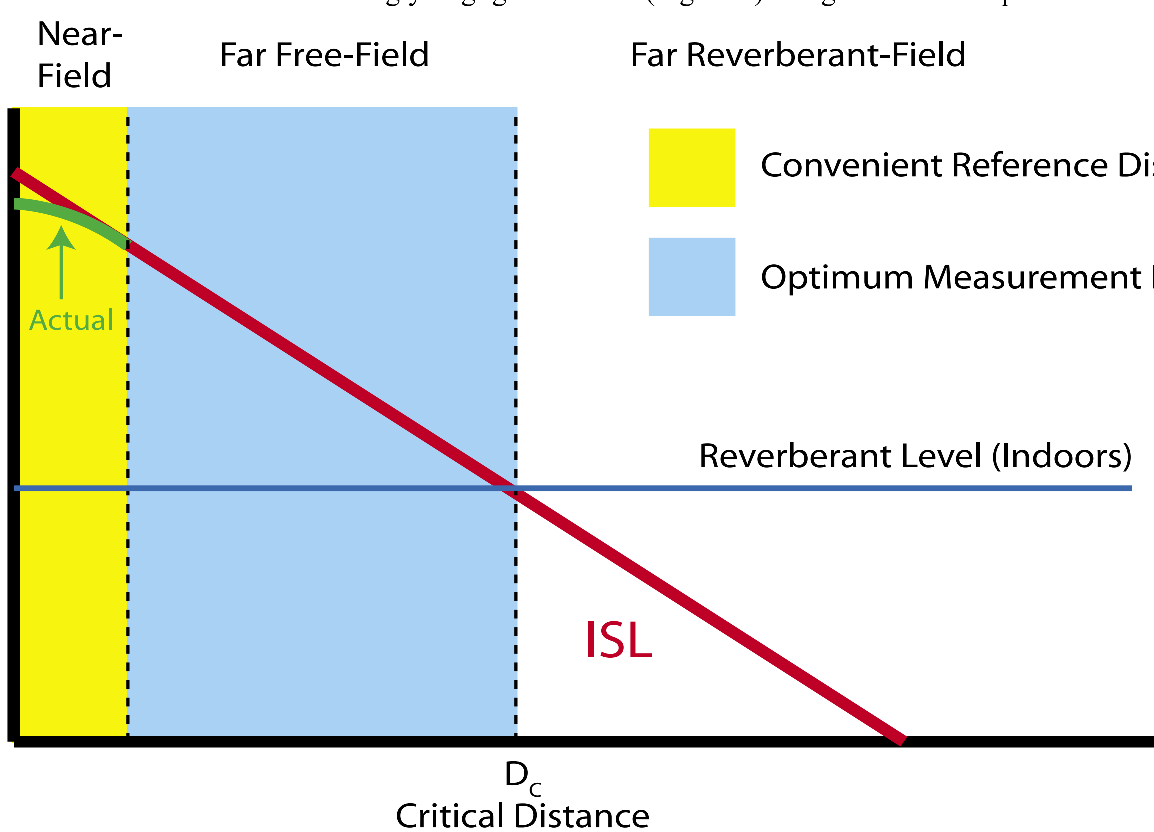
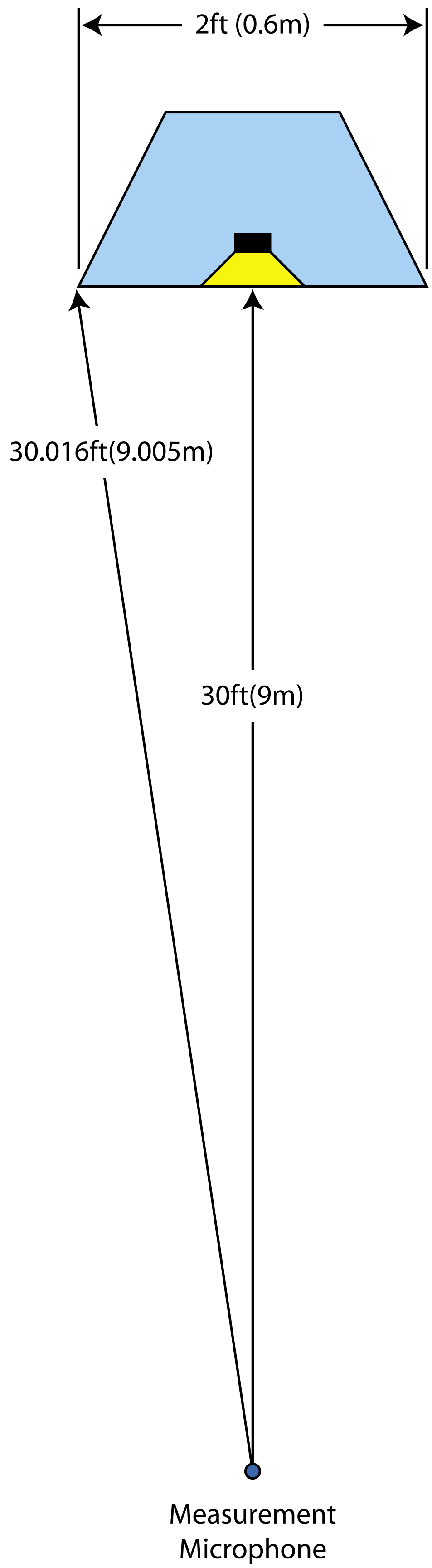


Figure 1 - Loudspeaker radiation characteristics must be measured in the far-free field. They can then be extrapolated back to a reference distance that lies in the near-field (i.e. 1 meter).



1 meter response can then be extrapolated to further distances with acceptable error.

A Rule-of-Thumb

A working "rule-of-thumb" for determining the boundary between near-field and far-field is to make the minimum measurement distance the longest dimension of the loudspeaker multiplied by 3. While this estimate is generally acceptable for field work, it ignores the frequency-dependency of the transition between the near and far fields.

More accurate estimates of the far field are found to be:

1. The point of observation where the path length differences to all points on the surface of the loudspeaker perpendicular to the point of observation are the same. Unfortunately this is at an infinite distance and the pressure is zero.

2. The distance at which the loudspeaker's three-dimensional radiation balloon no longer changes with increasing distance from the source with regard to frequency.

3. The distance from the source where the radiated level begins to follow the inverse-square law for all radiated frequencies.

And, a practical definition useful for determining the required measurement distance:

4. The distance from the source where the path length difference for wave arrivals from points on the device on the surface plane perpendicular to the point of observation are within one-quarter wavelength at the highest frequency of interest (Figure 2).

Consideration of any of these definitions reveals that the far-field is wavelength (frequency)-dependent.

As previously stated, the need to measure loud-

Figure 2 - The figure at left shows the path length difference to the microphone position for a loudspeaker whose largest dimension is 2 feet. Note that even though the transducer is smaller than the cabinet face, the entire front baffle of the enclosure can radiate energy. Attenuation balloons for this loudspeaker can be measured up to 17kHz at 9 meters. The upper practical limit for loudspeaker modeling is 10kHz.

speakers in their far-field arises when it is necessary to project the data to greater distances using the inverse-square law, which is exactly what acoustic modeling programs do. If this is not the purpose of the data, then measurements can be carried out in the near-field. The resultant data will be accurate for the position at which it was gathered, but will be inappropriate for extrapolation to greater distances using the ISL.

It is often thought that a remote measurement position is necessary for low frequencies since their wavelengths are long. Actually the opposite is true. It is more difficult to get into the far-field of a device at high frequencies, since the shorter wavelengths make the criteria in Item 4 more difficult to satisfy.

The most challenging loudspeakers to measure are large devices that are radiating high frequencies from a large area. The near-field can extend to hundreds of feet for such devices, making it impractical or even impossible to get accurate balloon data with conventional measurement techniques. Alternatives for obtaining radiation data for such devices include acoustic modeling and Acoustic Holography - a technique pioneered by Duran Audio. David Gunness of EAW has authored several important papers on how such devices can be handled.

So, some factors tend to increase the required measurement distance, and, as with all engineering endeavors, there are also some factors that tend to reduce the required distance. They include:

1. Large loudspeakers with extended HF response do not typically radiate significant HF energy from the entire face of the device. HF by nature is quite directional, making it more likely that the radiated energy is localized to the HF component. As such, only the dimension of the HF device itself may need to be considered in determining the far-field.

2. Beam-steered line arrays (i.e. Duran Intellivox™ or EAW DSA™) do not radiate HF energy from their entire length. The array length is made frequency-dependent by band pass filters on each device. This may allow a closer measurement distance than may be apparent at first glance.

Passive line arrays (i.e. Bose MA12™) are among the most difficult devices to measure, especially when used in multiples. Each device is full-range, so the path length difference between the middle and end devices can be quite large. A compromise is to measure the radiation balloon of a single unit and predict the response of multiples using array modeling software. Equally difficult are large ribbon lines and planar loudspeakers, again due to the large area from which high frequency energy radiates.

It would appear that all that is necessary is to pick a very large measurement distance. While this solves the far-field problem, it creates a few also. They include:

1. Air absorption losses increase with distance. While these can be corrected with equalization, the HF boost puts a greater strain on the DUT.

2. It becomes increasingly difficult to maintain control over climate with increasing distance (drafts, temperature gradients, etc.). These effects produce variations in the measured data, making the collection of phase data difficult or impossible.

3. Indoors, the anechoic time span becomes shorter with increasing distance, since the path length difference to the ceiling, floor, or side walls is reduced as the microphone is moved farther from the source. The effect is an increase in the lowest frequency that can be measured anechoicly (a reduction in frequency resolution).

4. Direct field attenuation will be 10dB greater at 30m (100ft) than at 9m (30ft). This reduces the signal-to-noise ratio of the measured data by 10dB, or requires that ten times the power be delivered to the DUT to maintain the same S/N ratio that exists at 30 feet.

5. Outdoor measurements are difficult

Lgst HF Dim.	HF Limit@30’(9m)	HF Limit at 100’(30m)
0.5 ft	271kHz	904kHz
1.0 ft	68kHz	226kHz
1.5 ft	30kHz	100kHz
2.0 ft	17kHz	56kHz
2.5 ft	11kHz	36kHz
3.0 ft	7.5kHz	25kHz
4ft	4.2kHz	14kHz
5ft	2.7kHz	9kHz
6ft	1.9kHz	6.3kHz
7ft	1.4kHz	4.6kHz
8ft	1.0kHz	3.5kHz
9ft	840Hz	2.8kHz
10ft	680Hz	2.2kHz

Fig. 3 - The upper frequency limit for two measurement distances based on the size of the HF radiator.

due to unstable noise and climate conditions over the time span of the measurement (up to 8 hours).

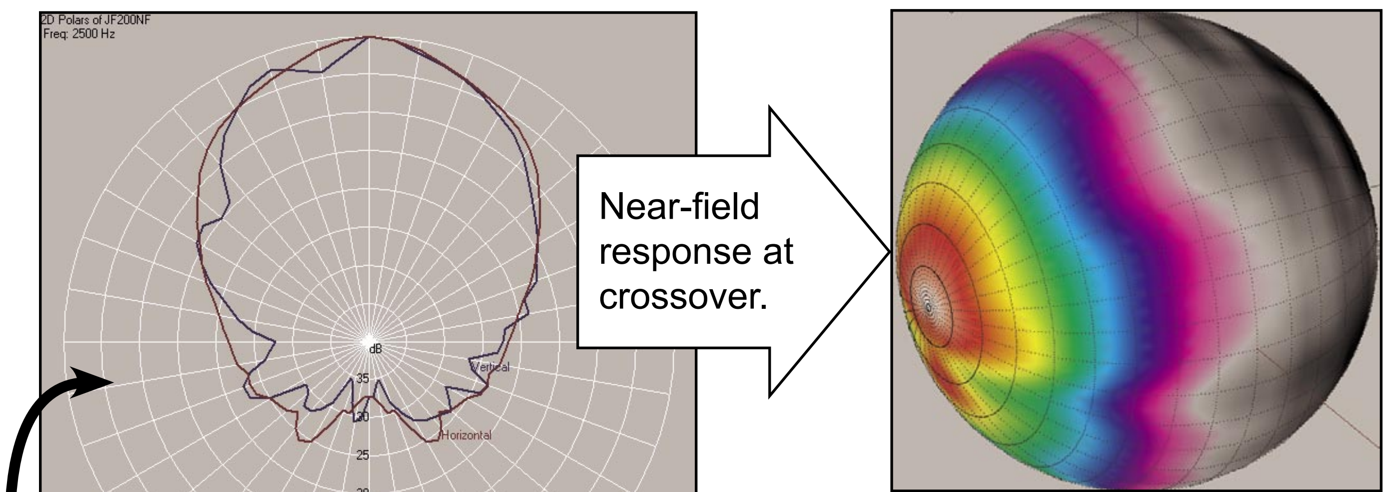
Large measurement distances are possible if the above problems are solved. A large aircraft hanger with a time windowed impulse response represents a good way to collect balloon data at remote distances.

Our chamber at ETC, Inc. allows measurement out to 9 meters (30 feet). This is an adequate distance for the majority of commercial sound reinforcement loudspeakers, but not all of them. The loudspeaker rotator is portable, so devices that cannot be measured at 9 meters are measured in a very large space at a distance out to 30 meters (100 feet). A time window provides the required reflected-field rejection. Determination of the required measurement distance is made on a case-by-case basis after considering the device-to-be-tested.

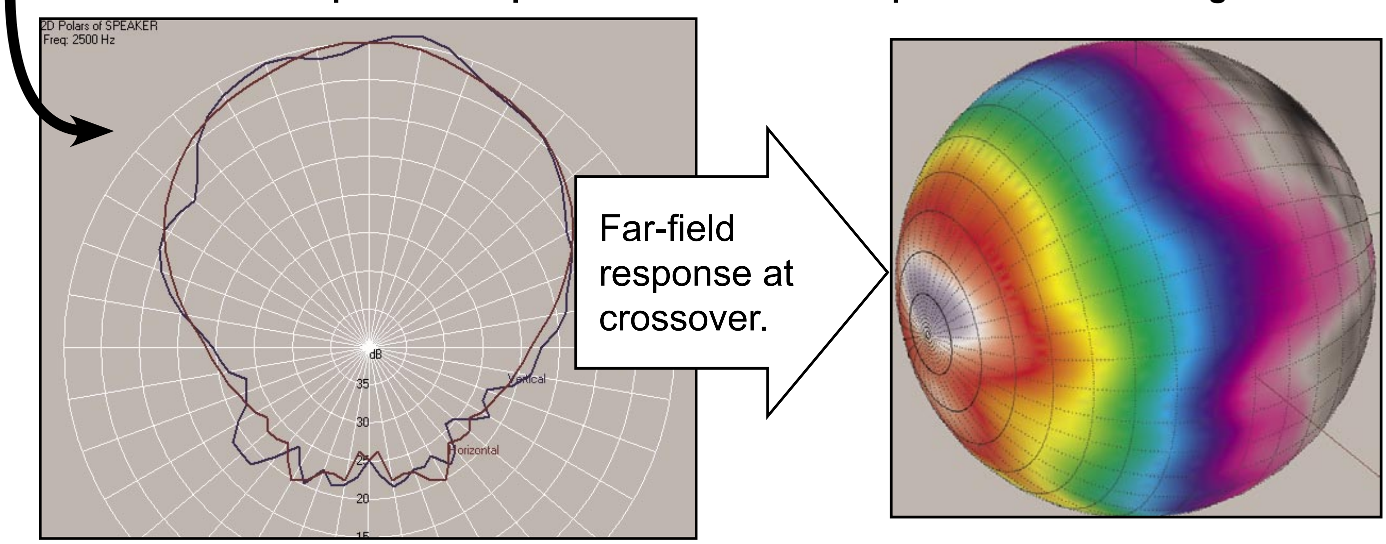
Using the above criteria for the far-field, and fixing a measurement distance of 30 feet (9m), the highest frequency balloon possible for different size devices can be determined (Figure 3).

Note that this is the largest dimension of the HF device. If the far-field condition is met for it, it will typically be met for all lower frequencies.

The far-field prerequisite for loudspeaker attenuation balloons must be met to allow the data to be projected from one meter to listener seats with acceptable error. The condition is easily satisfied for physically small devices, i.e. bookshelf loudspeakers. Since sound reinforcement loudspeakers are often physically large, there exists a highest frequency limitation in what can be measured at a fixed measurement distance. Ideally, data for which the far-field criteria is not met should be excluded or marked as suspect on specification sheets or within design programs. Usually it is not, so the user must use some intuition in HF modeling of sound coverage in auditoriums. *pb*



The near-field response "morphs" into the far-field response with increasing distance.



Edge-diffraction and reduced path-length differences smooth the balloon in the far-field.