A Comparison of Techniques for Evaluation of Loudspeaker Performance at Low Frequencies

STEVE F. TEMME & CHRISTOPHER J. STRUCK

Brüel & Kjær, DK-2850 Nærum, Denmark

ABSTRACT

Evaluation of loudspeaker performance at low frequencies is complicated by long wavelengths, room interaction, and cabinet/baffle diffraction. Since low frequency measurements have traditionally required large, impractical testing environments, different techniques have been developed in an attempt to overcome this requirement. Anechoic chambers, outdoor measurements, half-space measurements, ground plane measurements, cepstral liftering, parametric modelling, and near field techniques are compared with respect to accuracy, speed, bandwidth, and practical implementation.

0 INTRODUCTION

The purpose of this paper is to compare different loudspeaker measurement techniques at low frequencies. Only an overview is presented here. The results shown here will hopefully serve as a guide about the trade-offs and difficulties involved. Detailed explanations of each technique are not given, as these are adequately described in the references. The results are compared only in terms of frequency response magnitude. All measurements and examples in this paper were performed with a Brüel & Kjær Type 2012 Audio Analyzer. All results are dB SPL referred to 1 Watt into 4Ω (2 Volts) at 1m. Unless otherwise stated, the frequency resolution is ISO R80 (1/24 octave).

1 OUTDOOR MEASUREMENTS

The difficulties in performing measurements outdoors are well known. Simply mention the weather to anyone from Canada or Scandinavia and one can quickly exclude measurements during most of the year. In addition, both the test object and the measurement microphone must be suspended high enough above the ground to minimize the effects of reflections. Even during good weather, wind noise can be a factor as well as finding a remote AC power source. Just finding a suitable location for performing the measurements may be a problem. Of course, if these problems can be overcome, the situation is the closest approximation to an ideal free field. The result of an outdoor measurement on a small, 2-way, 4Ω, closed-box loudspeaker is shown in Fig. 1. In this case the height off the ground was 9m.

2 ANECHOIC CHAMBER TESTING

The traditional alternative has been to perform measurements in an anechoic chamber [1]. Because of the cost of such a facility, this can be a luxury. This is especially true if the size of the chamber is large enough to be useful at low frequencies. Anyone familiar with this sort of work knows that setting up a test inside the chamber can be cumbersome and time consuming. More than likely, there will be other persons wanting to use the room. There are advantages in having a good anechoic room. Most importantly, it is very quiet, making it useful for noise and distortion measurements. Also, at higher frequencies, where the absorption is adequate, it offers the possibility of almost infinite resolution, useful for diffraction investigations and directional response measurements.

The lower limiting frequency of a chamber is determined by the amount of free space in the room and the depth of the absorptive material. It is important to note that for large test objects, it may be necessary to move the measurement microphone further away from the test object in order to be in the far field. This in turn, increases the effect of any low frequency reflection from the chamber walls. The result of a measurement on the same loudspeaker in an anechoic chamber is shown in Fig. 2. The size of the chamber is 7.7 x 6.5 x 6.6m [2]. Effects due the size of the chamber and inadequate absorption at low frequencies are clearly evident.

3 HALF-SPACE AND BAFFLE MEASUREMENTS

A variation of the full anechoic chamber is the so-called "half-space" or 2π room [1]. This is sometimes approximated by the use of a standardized baffle [3]. The real baffle is not infinite and therefore introduces diffraction and cancellation effects. If a loudspeaker system, including the enclosure, is encased or buried, naturally occurring diffraction effects due to the cabinet cannot be observed. In addition, this can be problematic for vented systems with a rear-firing port. It can be quickly concluded that this method is really only useful for comparison of driver units. Fig. 2 shows the result of a measurement of the loudspeaker surrounded by a $1.26m^2$ baffle. Note the increase in sensitivity of approximately 6 dB due to 2π loading. The notch at 307 Hz is caused by a cancellation from the nearest edge of the baffle.

4 GROUND PLANE MEASUREMENTS

Instead of attempting to completely control the test environment, a "stable" environment may be established that allows artifacts such a single reflection to be easily quantified. This, along with the theory of image sources, led to the development of the ground-plane technique [4]. The advantage of this technique is its lost cost and the need for very little post-processing. Here, however, we encounter many of the same difficulties as with outdoor testing. Locating a large, open, flat, surface can be difficult (ask everyone who works at your company to move their cars to clear the parking lot !). It must also be remembered that the measured response includes the image source, effectively doubling the source size. This creates an artificial gain of as much as 3 dB in the midband and can also radically alter the radiation pattern. These effects are clearly visible in Fig. 4. In practice, it is always necessary to tilt or slightly raise the test object, as shown in the graph. The lower limiting frequency in this case is determined by the amount of available surface area and the test object size.

5 CEPSTRAL LIFTERING

The low frequency resolution of a measurement can be extended by the application of post-processing to eliminate the effects of reflections. This can be in the form of simple time domain windowing of by the use of "cepstrum" methods which operate on the logarithm of the response [5]. "Liftering" of the cepstrum yields an apparent improvement in low frequency resolution of one octave compared to time windowing [6]. This is most likely due a "flattening" of the response and a smoothing of the lifter function caused by the logarithm and exponentiation operations used in this process, respectively. In this case, the processing can become quite involved and somewhat difficult to interpret. If it is necessary to preserve the phase response, the complex cepstrum must be used (as opposed to the simpler power cepstrum).

Fig. 5 shows a comparison of the results of cepstral liftering versus time windowing. In this graph, the FFT size is 1600 lines in a 5 kHz bandwidth resulting in a linear frequency resolution of 3.125 Hz before processing. After processing, the resulting frequency resolution is determined by the reciprocal of the width of the time window applied [7] or the length of the short pass lifter. In either case, this is determined by the arrival of the first reflection. In Fig. 5, the resulting frequency resolutions are 67 Hz for the liftered cepstrum and 133 Hz for the time windowed data. The original measurement was taken in a reasonably large room. Note that below these frequencies there is no longer any information and the functions are now oversampled, i.e. even 67 Hz is not enough resolution for proper low frequency investigations. The results from the liftered cepstrum might be slightly improved by the use of a cepstral "edit" instead of the "short-pass" lifter, although this still assumes that the direct sound and reflections are well separated, which is never the case in practice.

6 PARAMETRIC MODELLING

Often, assumptions about the expected low frequency response are made based upon the loudspeaker system's physical configuration, i.e. closed box, ported, etc. At low frequencies, the system is effectively a high pass filter [8], [9]. A simple model of the low frequency response of the loudspeaker measured in the previous examples is shown in Fig. 6. For the closed box system, the parameters Q_T and f_0 determine the complex pole locations [10]. These were extracted from a measurement of the system's electrical impedance. A near field measurement can also be performed for verification or as an initial step in an iterative process (i.e. curve fitting) for improving the model. Unless a more complex model is used taking into account higher frequency effects, this technique is only useful up to resonance. Naturally, a ported system would require a more complex model.

7 NEAR FIELD MEASUREMENTS

The near field technique offers a simple and convenient solution to many of the previously mentioned difficulties. At low frequencies, the response measured in the near field is directly related to the far field response and is independent of the environment into which the system radiates [11]. The increase in measured sensitivity due to the proximity of the measurement microphone can be easily compensated for. Ported systems can be evaluated by performing individual measurements of the active and passive sources, scaling these results, and adding the complex responses to find the overall low frequency response [11]. The result of a near field measurement on the test loudspeaker is shown in Fig. 7. In this case, the upper limiting frequency is determined solely by the size of the test object [7]. At these higher frequencies, the size of the test object is on the order of the wavelength of sound and the radiation begins to gradually change from 4π to

2π as the frequency increases. For this loudspeaker, this occurs above 470 Hz. Often, the near field technique is combined with modelling and/or time selective techniques to extend the useful frequency range even higher [7]. A comparison of the results using all of the different techniques is shown in Fig. 8. Here, it is apparent that the near field technique offers the widest useable bandwidth.

8 CONCLUSION

Various techniques for evaluating loudspeaker performance at low frequencies have been examined. In order to perform useful low frequency investigations, a minimum of 1/12 octave resolution is typically required. Many of these techniques have inherent logistical difficulties. Measuring outdoors is simply impractical. An extremely large anechoic chamber is required to be useful at low frequencies. This is not typically available to most loudspeaker designers. The standard baffle is really only usable for driver testing and a true half-space, even if it were available, would not include important cabinet diffraction effects. The ground plane technique introduces changes in the midband response, limiting its useful frequency range. Cepstral liftering, while an improvement over simple time windowing, requires extensive post-processing, yet fails to provide adequate resolution. For each of these methods, the result is entirely dependent upon the amount of available space for performing the original measurements, as this determines the arrival of the first reflection. Modelling can be used to estimate the response, but at some point a measurement will be required for verification. Superior results are obtained with the near field technique. It is both simple and convenient, it provides adequate resolution, and it yields useful information in the widest frequency range.

9 REFERENCES

[1] L. L. Beranek, *"Acoustics"*, (McGraw-Hill, New York 1954).

[2] C. Fog, *"Anechoic Chamber at Brüel & Kjær"*, presented at the Nordic Acoustical Meeting, (1986 August 20-22).

[3] IEC Standard 268, *"Sound System Equipment, Part 5: Loudspeakers"*, Second edition (1989 July).

[4] M. Gander, *"Ground-Plane Acoustic Measurement of Loudspeaker Systems"*, J. Audio Eng. Soc., Vol. 30, No. 10 (1982 October).

[5] R. B. Randall, *"Frequency Analysis"*, Brüel & Kjær (1987 September).

[6] G. Niedrist, *"Echo Suppression for Loudspeaker-Microphone System Measurements"*, J. Audio Eng. Soc., Vol. 41, No. 3 (1993 March).

[7] C. J. Struck and S. F. Temme, *"Simulated Free Field Measurements"*, presented at the AES 93rd Convention - San Francisco (1992 October 1-4).

[8] R. Small, *"Closed-Box Loudspeaker Systems, Part 1: Analysis"*, J. Audio Eng. Soc., Vol. 20, No. 10 (1972 December).

[9] R. Small, *"Vented-Box Loudspeaker Systems, Part 1: Small-Signal Analysis"*, J. Audio Eng. Soc., Vol. 21, No. 6 (1973 June).

[10] R. Allison, *"Low-Frequency Response and Efficiency Relationships in Direct Radiator Loudspeaker Systems"*, J. Audio Eng. Soc., Vol. 13, No. 1 (1965 January).

[11] D. B. Keele, *"Low-Frequency Loudspeaker Assessment by Near-Field Sound Pressure Measurement"*, J. Audio Eng. Soc., Vol. 22, No. 4 (1974 April).

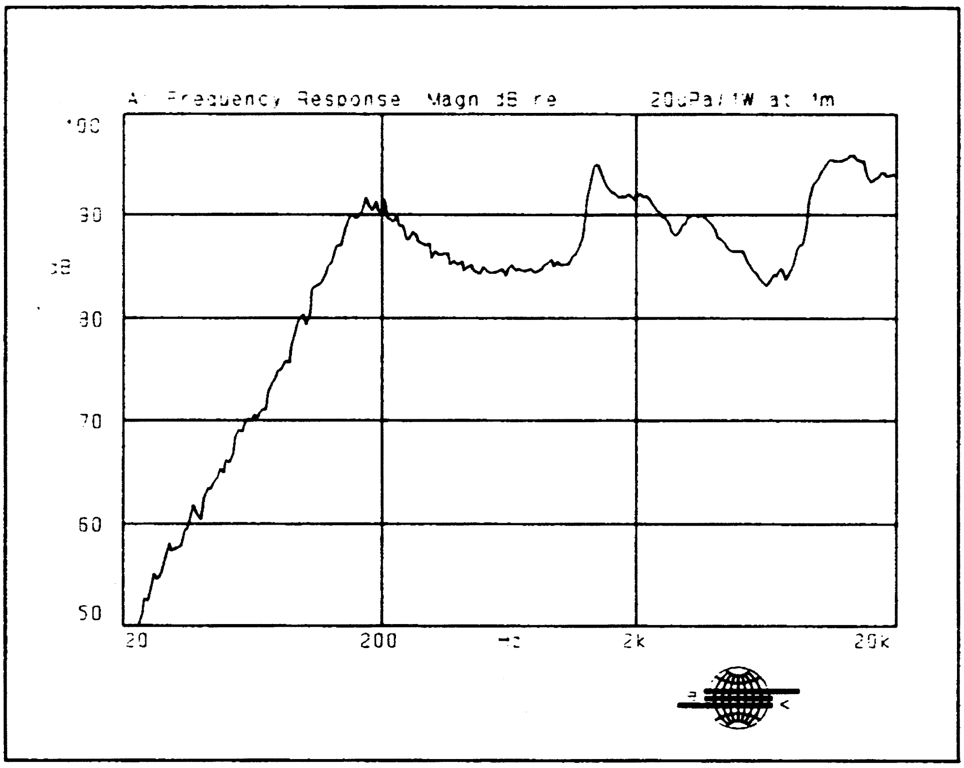


Fig. 1 Measurement of a small loudspeaker performed outdoors.

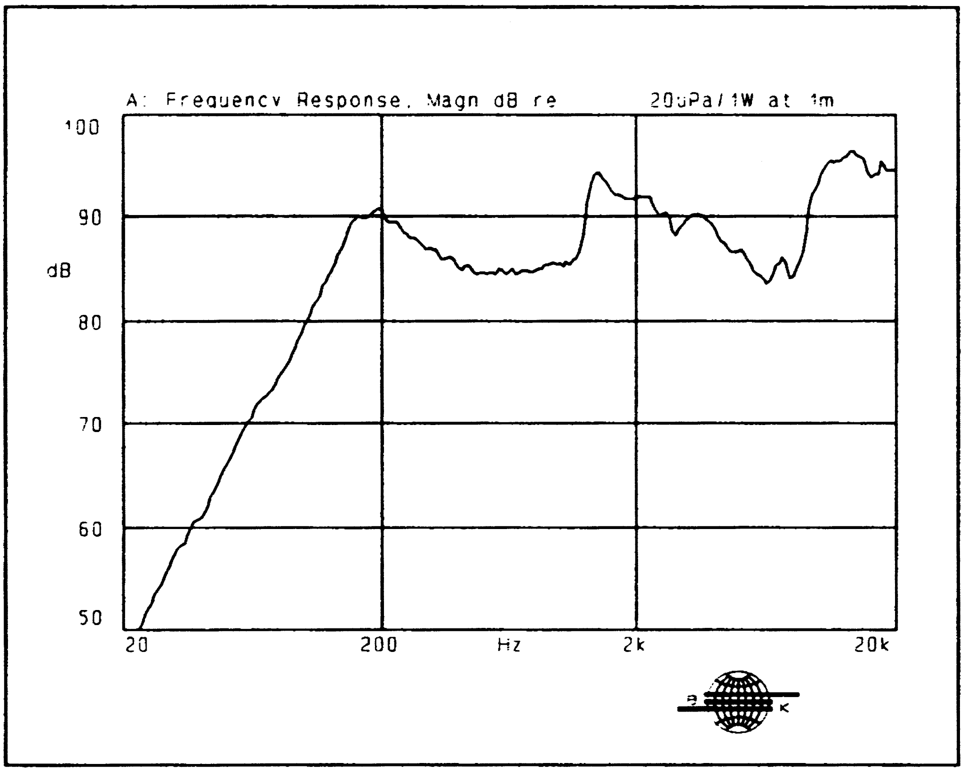


Fig. 2 Measurement of a small loudspeaker performed in an anechoic chamber.

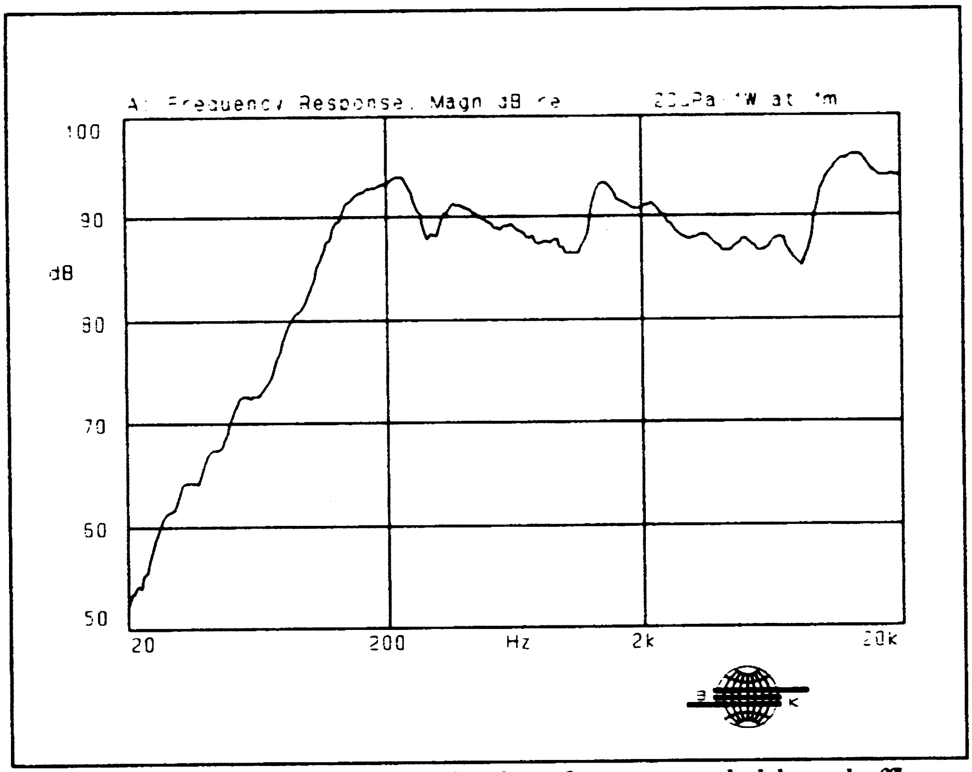


Fig. 3 Measurement of a small loudspeaker surrounded by a baffle.

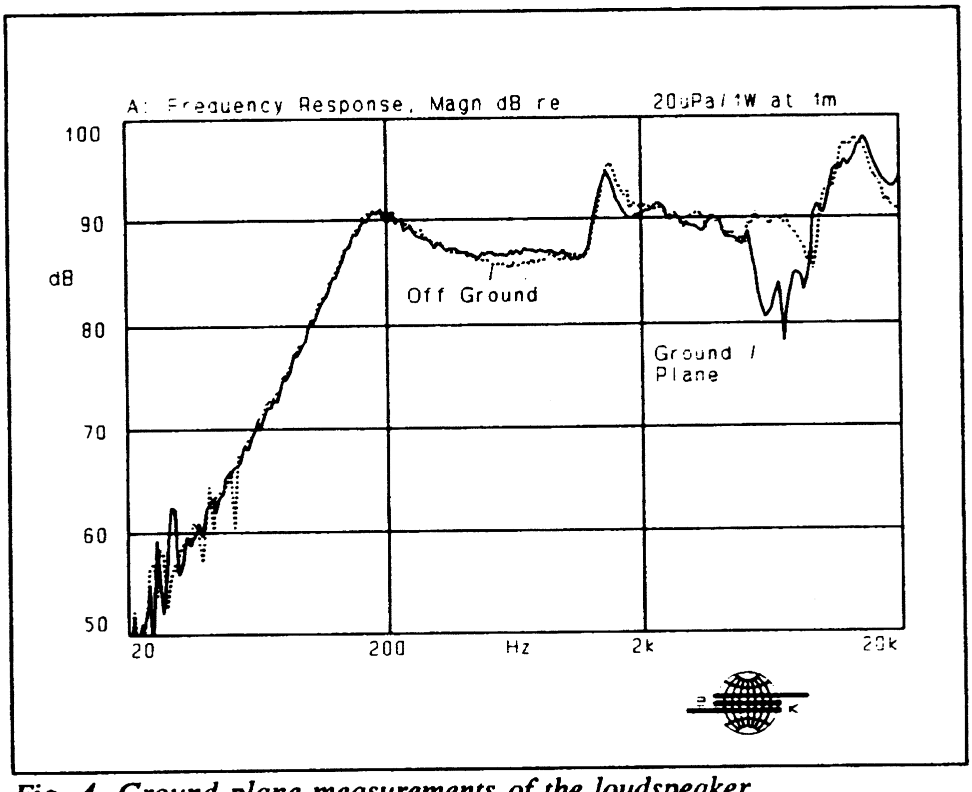


Fig. 4 Ground plane measurements of the loudspeaker.

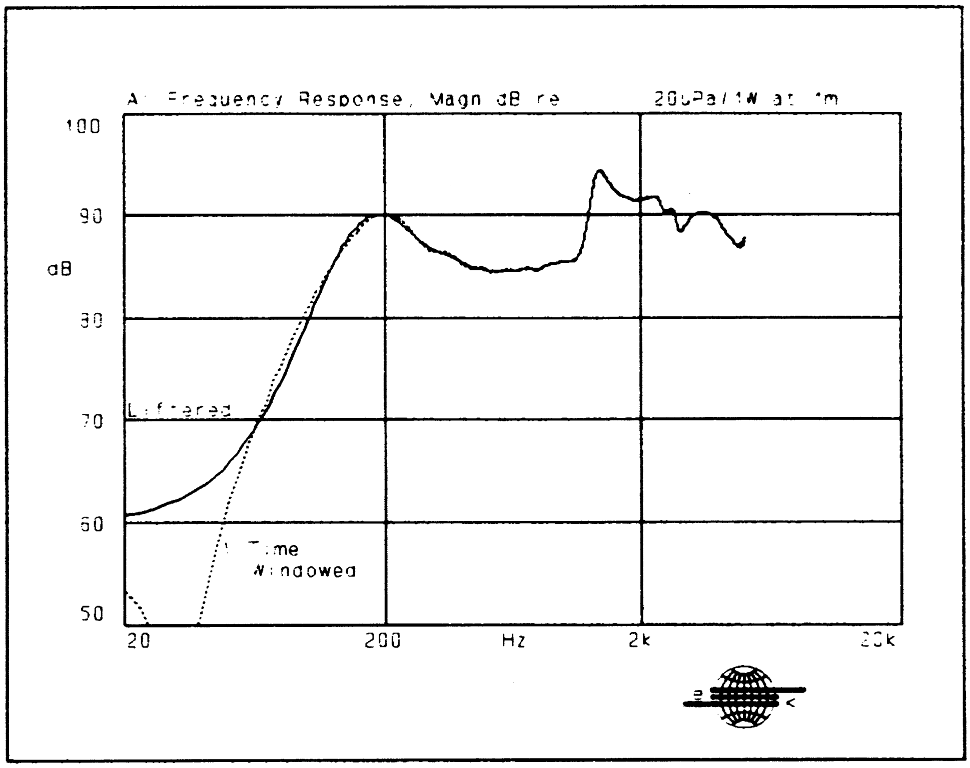


Fig. 5 Loudspeaker response resulting from cepstral liftering and time windowing.

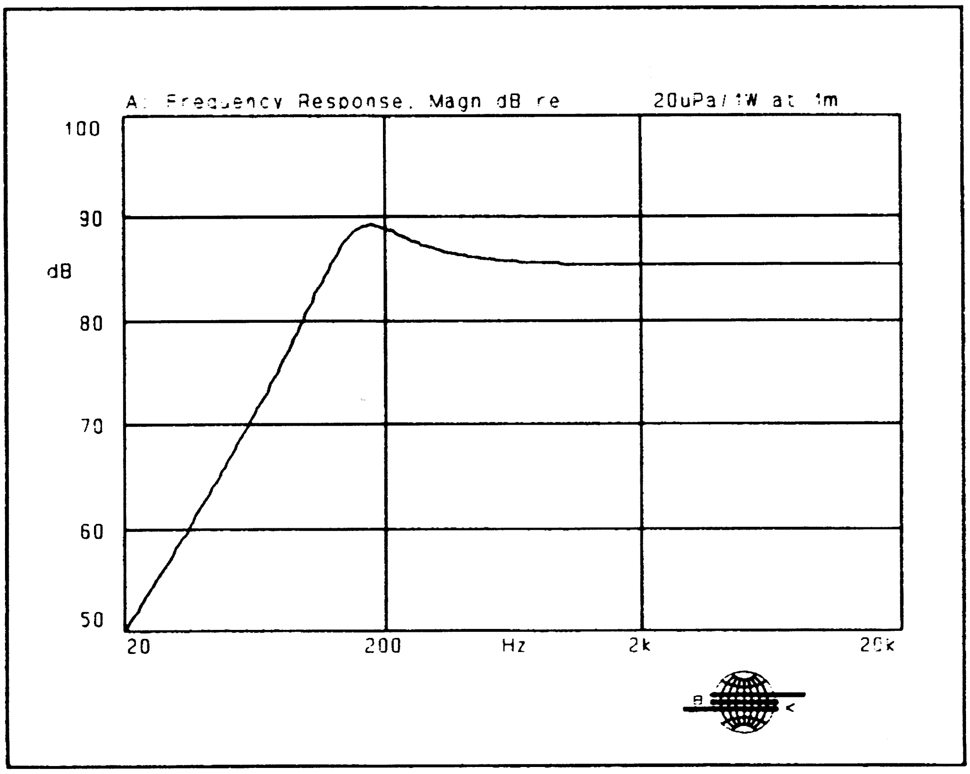


Fig. 6 Loudspeaker response obtained by a simple pole - zero model.

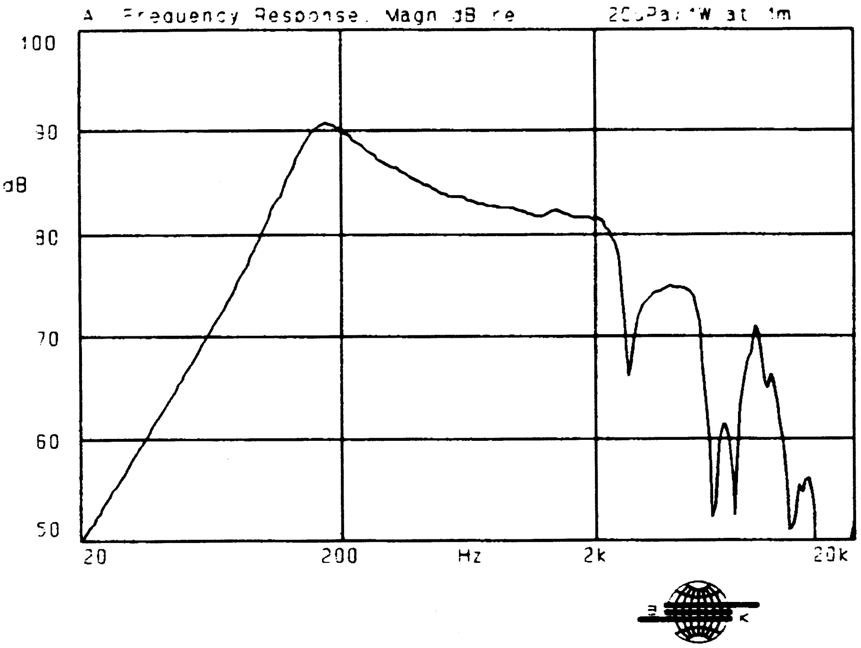
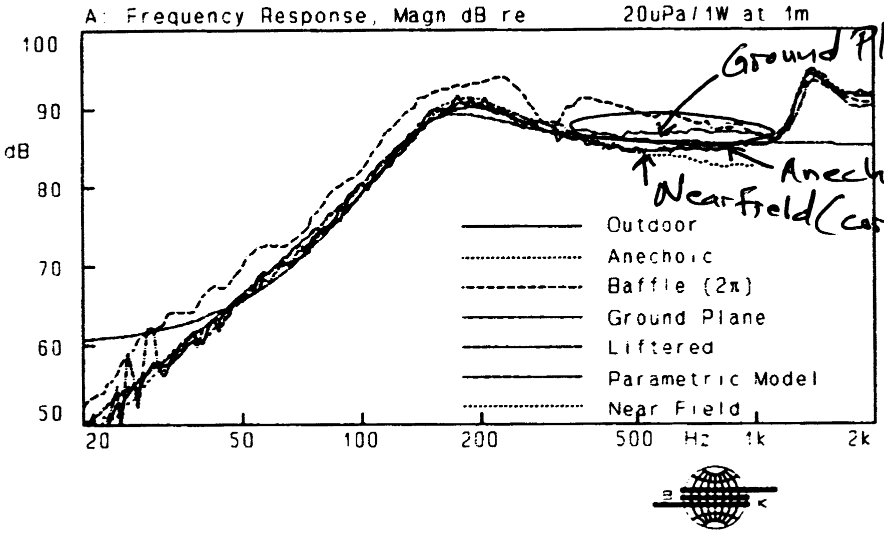


Fig. 7 Near field measurement of loudspeaker response.



Ground Plane (incorrect)

Anechoic & Outdoor (corr

Nearfield (correct up to this freq.

Fig. 8 Comparison of responses obtained using different techniques.