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DIFFRACTION STUDIES OF SOME CONVENTIONAL AND NOVEL MICROPHONE BAFFLES

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A directional microphone system for field recording of sounds in the air often involves a parabolic reflector to focus the sound waves on the microphone (transducer) element. Some deficiencies of such a system are noted with respect to reproduction of spectra. The reflector system, involving as it does a structure comparable to a wavelength in linear dimension, is not susceptible to traditional high- or low-frequency approximate methods of computation. Modern numerical techniques now permit precise calculation of the directional responses of small reflectors of various shapes. One result is a proposal for a very economical and effective system involving a plane reflector. Other baffle shapes are also investigated, which may be of interest in special applications.

1. INTRODUCTION

For observing or recording of sound from a discrete direction, particularly in the outdoor environment, it is appropriate to employ a microphone system that receives preferentially from one direction in order to reduce the influence of extraneous noise from other directions and in order to realize a gain in the power received from the desired source. A widely used technique for realizing suitable directional receiving characteristics has been the parabolic reflector, a rigid structure, generally a paraboloid of revolution, that concentrates the incoming sound power at its focal point, where an electroacoustical transducer (microphone element) is located. For portable use in the field, the reflector must be of a convenient size to be carried or deployed, generally not much more than a meter in diameter. At this size, for sounds of frequencies that are efficiently propagated in the terrestrial atmosphere and are discernable to the human ear, the reflector is between, say, 0·5 and 30 wavelengths in diameter. In this range of dimensions the classical high-frequency (geometrical optics) and low-frequency (small-particle scattering) approximate methods of computation of the diffraction characteristics of material objects do not yield precise results. However, with the availability of computers with high speed and extremely large memory capacity, computational methods using discrete-element approximations can be made as precise as desired. Thus, it is now possible to solve the mid-frequency diffraction problem with great accuracy, and to investigate small reflectors in considerable detail.

The approach used here is based on numerical integration of the classical Helmholtz integral equation over the external surface of the diffracting body, with the Green function selected to represent the radiation condition. The "method of moments" [1, 2] formulation of the problem is used for electromagnetic radiation problems and can be applied to acoustical cases, though tests have shown that the "boundary element method" [3] gives equivalent results in the examples presented here. A three-dimensional computation by these methods can be demanding in terms of computing time and memory capacity. Seybert *et al.* [6] have developed an efficient formulation for axisymmetric diffracting bodies which makes use of the symmetry to reduce the computational burden. A line integration is performed along the generator of the body and an integration over the angle is performed partly in terms of elliptic integrals and partly by Gaussian quadrature. A Fortran program has been written [7] to expedite the investigation of microphone baffles; this permits rapid computation of diffraction patterns and allows economical optimization of microphone design.

For this presentation it is assumed that a hand-portable directional microphone system is desired for recording or observing outdoor sounds; for example, a bird song, in the frequency range from, say, 200–5000 Hz. Several baffle or reflector shapes are investigated. Consideration is given to the way in which the performance of each of these systems varies with frequency, size of structure and, in the case of the parabola, with focal length. It is assumed that all surfaces are "hard," that is, that the sound pressure at the surface is twice the incident pressure.

The directional attributes of a microphone system depend on the geometrical shape of its structure, its dimensions measured in wavelengths, and the disposition of its transducer or transducers. The directional characteristics are displayed as diagrams in polar co-ordinates, in which the relative sensitivity of the microphone to the sound amplitude is plotted as the radius, as a function of the angle with respect to the axis of the system. Here, the radius of the plot is linear in amplitude (sound pressure) except as otherwise noted. In the computations it is assumed that the sound emanates from a point source at a great distance from the microphone. Each diagram applies only to a single frequency. Each transducer is assumed to be infinitesimal in dimension.

2. THE PARABOLIC REFLECTOR

Parabolic reflectors are widely used in optical and radio engineering to provide directional characteristics in such diverse applications as automobile headlights, radar antennas, astronomical telescopes, and microwave communications. In most of these cases these reflectors are large in terms of wavelengths in order to provide a high degree of directivity. Under this condition, the directional characteristics of the device can be calculated with reasonable accuracy by the classical methods of physical optics [4], assuming specular reflection at the surface and certain approximations relating to the large size of the reflector.

In acoustics in the atmosphere, it is unusual to use a parabolic reflector very large in terms of wavelengths, which therefore possesses a narrow reception beam. Winds and spatial variations of temperature produce refraction, making the direction of arrival of the sound waves unpredictable and variable with time. Especially for portable use, it is preferable to use a small reflector with a relatively broad reception beam. A typical reflector sold for field use might be one-half to one meter in diameter. In this size range, and for the frequencies under discussion, the computation methods used extensively in radio and optical technology do not apply. A practical discussion, useful for many purposes, has been given by Wahlström [5]. However, to examine the details of the diffraction pattern of a small reflector it is necessary to use a more precise computational technique.

Boundary element or moment methods can be applied, theoretically with any degree of precision, to diffraction and scattering by arbitrarily shaped structures. For the present study it is economical and convenient to use axial symmetry [6] to reduce the

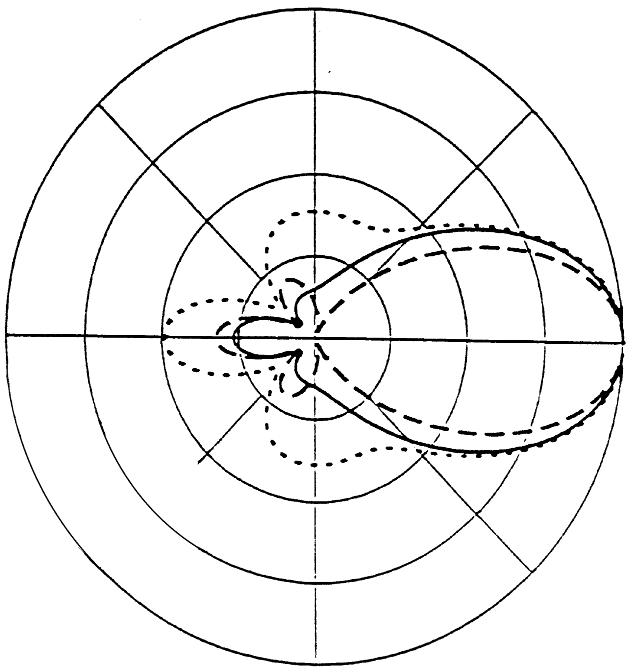

Figure 1. Reception patterns of a paraboloidal microphone, one wavelength in diameter, showing the effect of focal length, a. In each case the transducer is at the focal point. ----, $a = 0{\cdot}15$ wavelength; ——, $a = 0{\cdot}20$ wavelength; ······, $a = 0{\cdot}50$ wavelength.

computational burden, using the program written [7] for this purpose. A curve of the form

$$y + 2a = \sqrt{x^2 + y^2}$$

is assumed, in which the detector (transducer) is at the focal point at the origin, a is the focal length, and the surface is generated by rotation of the curve about the y-axis (see Figure 4(f)). For each case, the source of sound is assumed to be 1000 wavelengths from the origin, and the total sound pressure (incident plus scattered) is computed at the focal point. It is convenient to dimension the problem in terms of wavelength so the results for a given case can then be scaled to any frequency. At a source distance of, say, 1000 wavelengths, the reception pattern is essentially independent of the distance; this is the so-called farfield situation. It should be noted that each of the computed diffraction patterns could be interpreted either as a reception pattern or as a transmission pattern, depending on the locations of source and detector; this is a result of the reciprocity principle [8].

Figure 1 shows reception beams for a parabolic microphone one wavelength in diameter. That would be 50 cm at a frequency of 688 Hz. Results are given for three different focal lengths, showing the critical nature of this parameter. Results are normalized so that the on-axis gain for each case is unity. The paraboloid with focal length 0·2 wavelength clearly has the most desirable pattern, with the smallest rearward lobe. The "front-to-back ratio" for this case is 3·9 or 11·8 dB. For a shallow paraboloid (focal length 0·5 wavelength) the ratio is only 1·6 or 4·1 dB. The deepest paraboloid shown, focal length 0·15 wavelength, shows a distorted pattern with a lobe at about 120°, 8·8 dB lower than the main lobe. The optimum focal length depends on the diameter in wavelengths, so a compromise is necessary for a system that is to accommodate a range of frequencies. For most

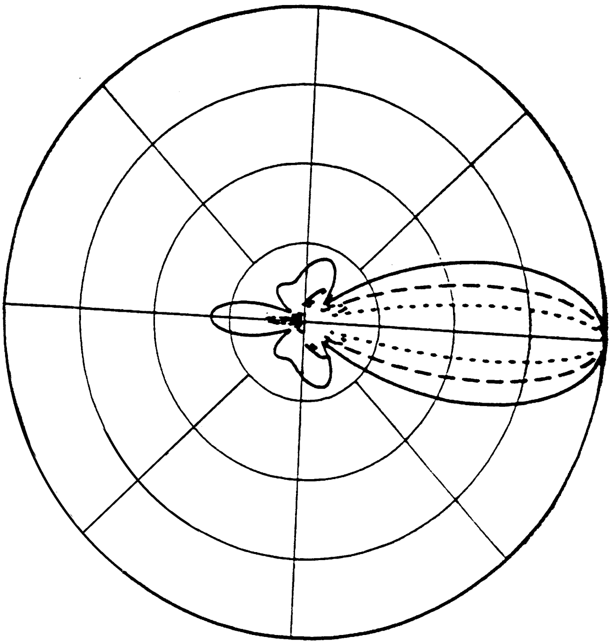

Figure 2. Reception patterns of a paraboloidal microphone, 47·6 cm in diameter, showing the effect of frequency on the pattern. Focal length is 30·3 cm; transducer at focal point. Frequency: ——, 1 kHz; – – – –, 2 kHz; ······, 3 kHz.

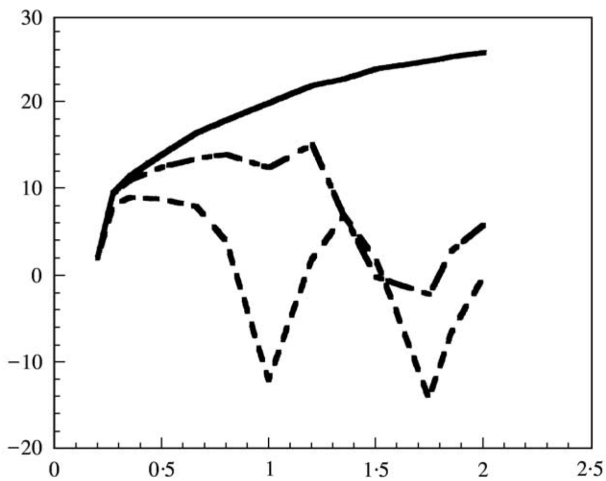

Figure 3. Variation of gain with frequency for a paraboloidal reflector 1·0 m in diameter, focal length 40 cm, at various directions within the main beam: ——, on the principal axis; – – – –, 15° off axis; – – –, 30° off axis; Abscissa is frequency in kHz; ordinate is gain in dB.

applications, the highest front-to-back is preferable to discriminate against sounds from unwanted directions. It is to be noted that all the patterns have minor lobes in addition to the main lobe, indicating some sensitivity to directions other than the desired one.

Figure 2 illustrates the performance of a paraboloid 47·6 cm in diameter with a focal length 30·3 cm, for frequencies of 1, 2, and 3 kHz. Higher frequencies produce narrower beams. A rough rule of thumb applying to reflectors two or more wavelengths in diameter is that the amplitude beamwidth is approximately 60° divided by the diameter in wavelengths. Here, "beamwidth" is defined as the angle between the directions at which the amplitude gain is 0·707 times that on axis. The minor lobe structure is highly frequency dependent.

Figure 3 shows how the gain of a parabolic microphone depends on the frequency for three different directions within the main beam. It should be noted that a sound containing several different frequency components is not faithfully represented in the output of the microphone, even if the reflector is accurately aimed at the source. For the mis-aimed situation, the lack of fidelity is more pronounced. As the frequency increases, the beam narrowing accentuates the loss of gain, and the increasingly complex minor lobe structure

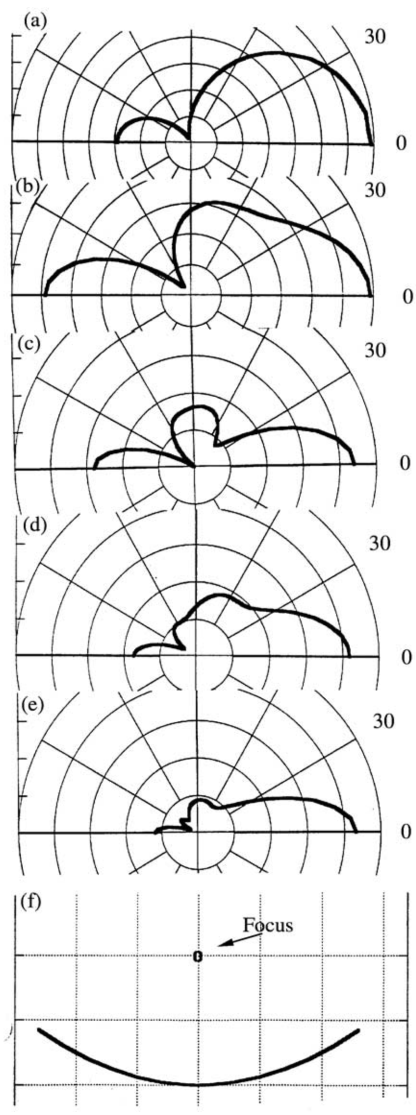

Figure 4. Reception patterns of a paraboloidal microphone, 2·6 m in diameter, showing how the pattern varies when the frequency is in the vicinity of that for which the reflector is one wavelegth in diameter. Frequency = (a) 50 Hz, (b) 100 Hz, (c) 140 Hz, (d) 175 Hz, (e) 250 Hz, (f) configuration of the reflector. Diagrams are not all to the same scale in amplitude.

causes strong fluctuations in gain. Although Figure 3 is specific to its particular reflector parameters, such considerations apply in general to all reflector microphones. Clearly, directional microphones cannot be relied upon to yield accurate spectra of sound sources except possibly under rigidly controlled laboratory conditions; see also reference [9]. Figure 4 shows how the pattern varies in the vicinity of the frequency, in this case 132 Hz, for which the reflector diameter is one wavelength.

3. THE FLAT REFLECTOR MICROPHONE

Structures that are small in terms of wavelength do not scatter waves in narrow beams. By the reciprocity principle, it follows that a small microphone structure cannot have a highly directional reception pattern. From this it can be argued that, for a sufficiently small reflector, the specific shape of the reflector has only a small influence on the reception pattern. Thus, a small parabolic reflector may not be the most economical or convenient choice for field use, depending on the circumstances. Use of a flat reflector has been investigated [10] as an easily constructed means of achieving moderate directivity. The logical location for the transducer in such an arrangement is directly on the reflector surface, as the sound pressure at that point is double the pressure in the incident wave. Figure 5 shows the computed sound pressure reception pattern of a flat circular disk 0·889 wavelength in diameter with a transducer on the surface at the center. Also shown is the measured pattern of a square, flat panel of the same dimension. This measured pattern is almost identical with the pattern computed [10] by the method of moments, confirming the accuracy of the computational method. If the square and circular reflectors of Figure 5 are assumed to be 16 cm in dimension, their patterns are those for a frequency of 1911 Hz.

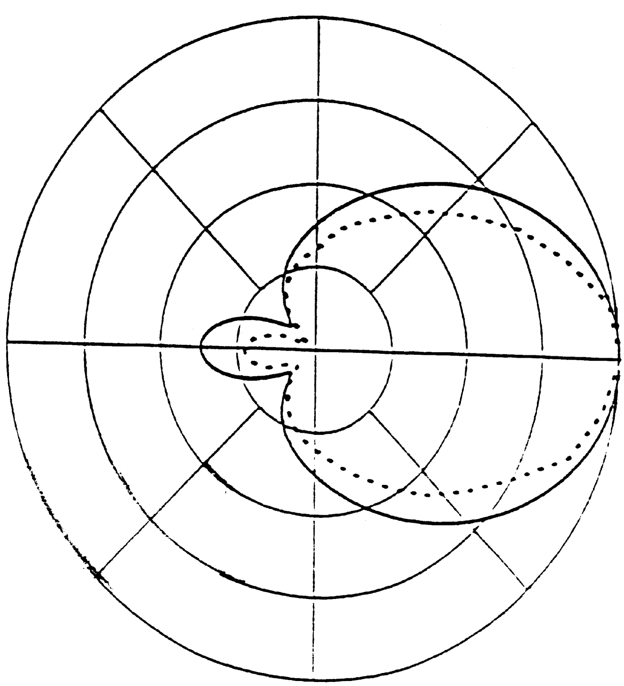

Figure 5. Reception patterns of flat reflector microphones, square and circular in shape and 0·89 wavelength in dimension. ——, "Circular" pattern was computed; – – – –, "square" pattern was measured, (after reference [10]).

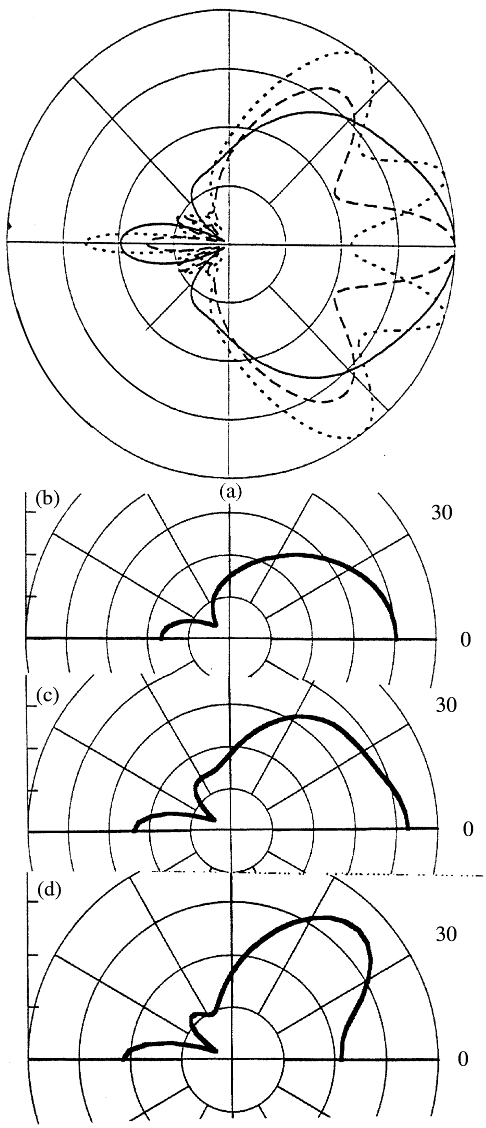

Figure 6. Reception patterns of a flat disk microphone, 16 cm in diameter, showing effect of frequency. Transducer is on the surface at the center of the disk. (a) ——, 1572 Hz; - - - -, 786 Hz; ······, 525 Hz, (b) 2 kHz, (c) 3 kHz, (d) 3·5 kHz.

Figure 6 shows the effect of frequency on the reception pattern of the circular disk, here assumed to be 16 cm in diameter. This simple device gives useful directivity and reasonable pattern shapes, though at the lowest frequency the scalloping of the principal lobe amounts to 7·0 dB. For the experimental measurements, the reflectors were sawed from 1·3-cm thick particleboard, and the transducers were very inexpensive electret microphone elements fastened directly to the surface.

A photograph of a flat-reflector microphone designed for the frequency band 10–40 Hz is shown in Figure 7 [11]. Such low frequencies are characteristic of the sounds produced by explosions, and the device illustrated was constructed to monitor the environmental noise

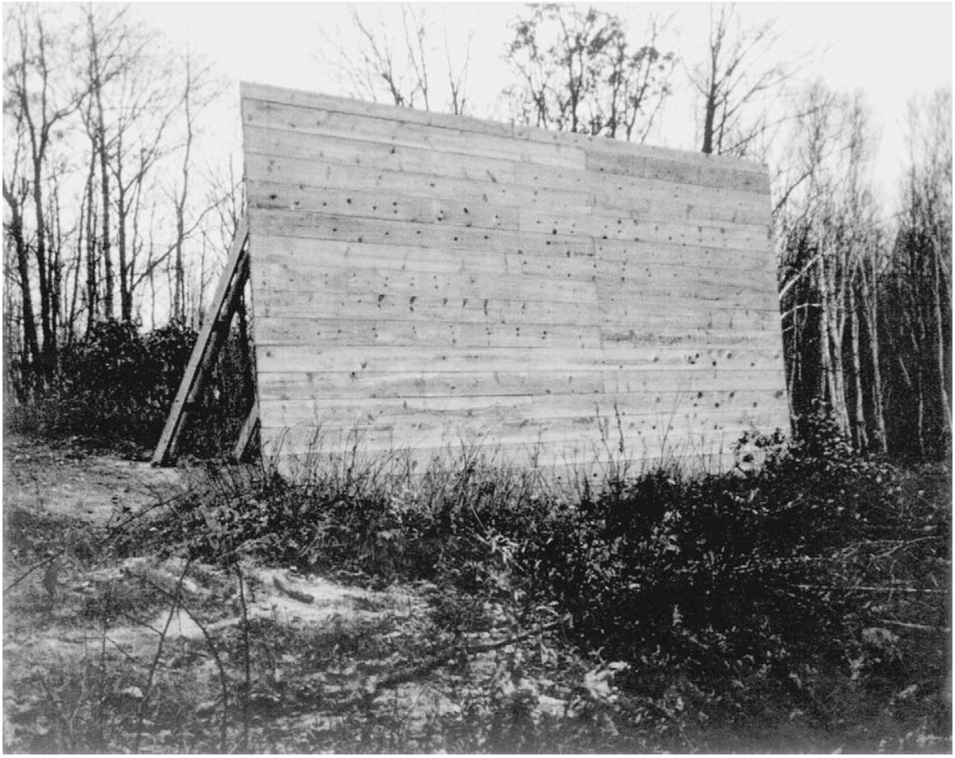

Figure 7. A flat reflector microphone baffle for low frequencies (10–40 Hz). Dimensions are $4{\cdot}5 \times 9{\cdot}0$ m. Transducer is at ground level, center.

of a military artillery training facility. The dimensions of the reflector are $4{\cdot}5 \times 9{\cdot}0$ m, and the microphone is mounted at ground level immediately in front of the surface. The system, including the ground surface which is assumed impermeable at these frequencies, is equivalent (with respect to its reception pattern) to a 9·0-m square reflector in unbounded air.

4. THE DEEP PAN BAFFLE

Figure 8 shows directional patterns of a microphone baffle in the form of a cylindrical "pan" or container with a transducer centered 10 cm from the bottom. This system is notable in that it has the highest front-to-back ratio (21·8 dB), at its optimum frequency, of any configuration examined in this study.

5. SPHERES

Figure 9 shows the reception patterns for several diameters of spherical baffle microphone with a transducer on the surface at zero degrees. These diagrams are quite similar to one another except for those of spheres in the immediate neighborhood of one wavelength diameter. This broadband behavior appears to be the best of any system studied.

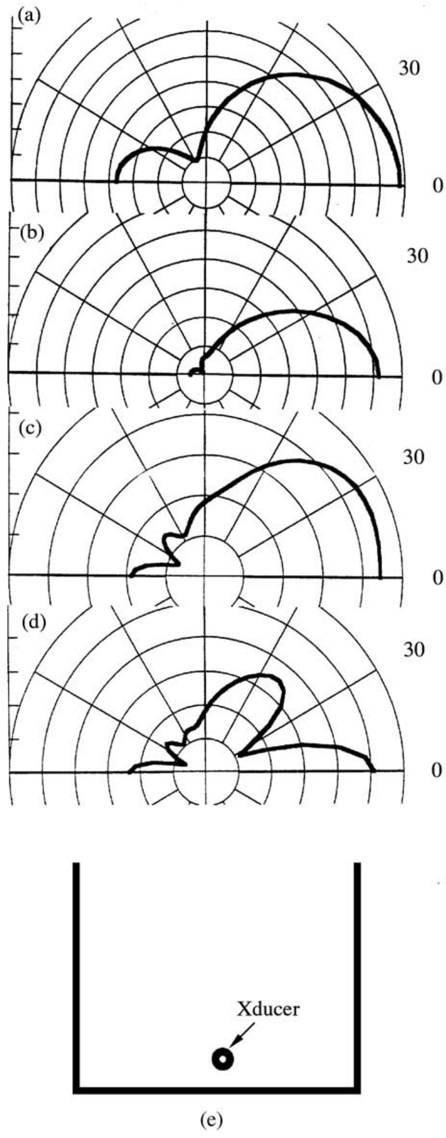

Figure 8. Reception patterns of the "deep pan" baffle. Configuration is shown in the bottom diagram (e). Proportions are 1·0 unit wide × 0·7 unit deep. Transducer is centered 10·0 cm from the bottom. Diameter of pan in wavelength (λ): (a) 0·35, (b) 1·12, (c) 1·22, (d) 1·53.

The sphere is one of the configurations that is compatible with the classical "separation of variables" method. Many solutions exist in the literature (e.g., reference [12]). A stable numerical solution of any one of the examples of Figure 9 can require summation of as many as 150 spherical harmonics [13]. The present solutions conform to these and are obtained with less effort.

6. DISCUSSION

Reflector microphones are inexpensive and effective for field use; however, it should be appreciated that all directional microphones have definite limitations with respect to

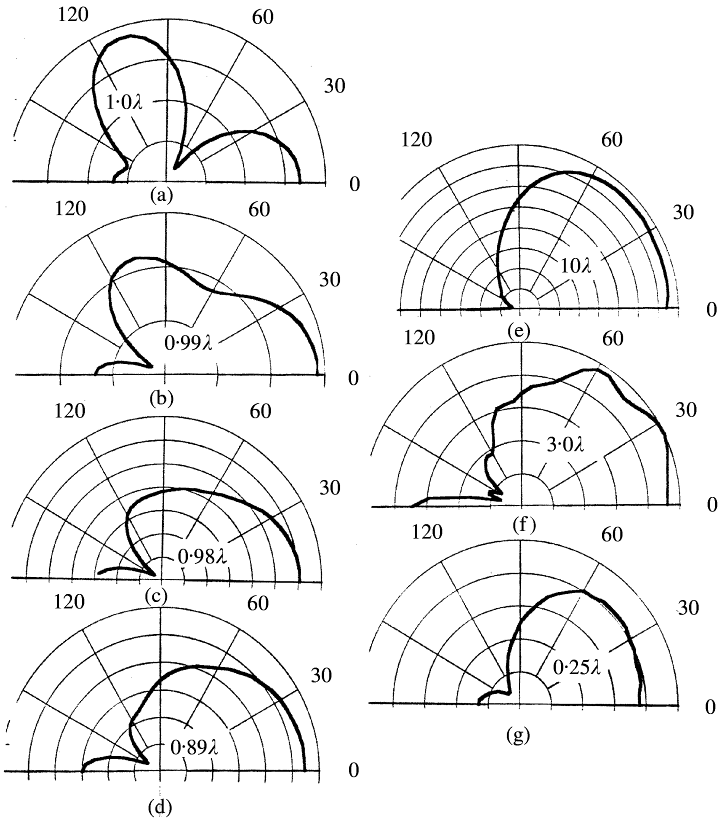

Figure 9. Reception patterns of a sphere with the transducer on the surface at 0°. Diameter of sphere in wavelengths (λ): (a) 1·0, (b) 0·99, (c) 0·98, (d) 0·89, (e) 10·0, (f) 3·0, (g) 0·25. Graphs (a)–(d) show the behavior in the vicinity of one wavelength diameter, while graphs (e)–(g) illustrate the broadband character of the spherical baffle. All patterns have rotational symmetry about the horizontal axes.

fidelity of sound reproduction. Wind noise is troublesome. It can be mitigated somewhat by use of windscreens; this topic, however, is outside the scope of this discussion. The presence of nearby obstacles such as the ground, buildings, persons, etc., especially in *ad hoc* situations, produces essentially unpredictable variations in gain and pattern. The conclusion must be that it is not productive to seek the ultimate in performance from a microphone system for use in the field, and that these limitations must be considered in interpreting field data.

For a given application, it is possible to select from a variety of small (in wavelengths) baffle configurations, some of which appear to have significant advantages over the traditional paraboloid.

ACKNOWLEDGMENTS

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