A baffle-type directional microphone

Jonathan W. Benson, Yuan-Liang Li, and George W. Swenson, Jr.
University of Illinois at Urbana–Champaign, 1308 W. Main Street, Urbana, Illinois 61801

(Received 21 October 1993; accepted for publication 20 January 1994)

A simple and economical directional microphone has been investigated, consisting of a plane, rectangular baffle with an omnidirectional pressure microphone placed directly on its surface. Outdoor experiments and numerical computations using the method of moments give compatible results and show useful directional properties, comparable with or superior to those of commercially available line (end-fire) or parabolic-reflector microphones of similar dimensions. Variations of beamwidth and beam shape with baffle dimensions and microphone placement are presented.

PACS numbers: 43.38.Kb, 43.58.Vb

INTRODUCTION

Detection and monitoring of low-frequency sounds would in many situations be expedited by the availability of unidirectional microphones of simple design, optimized for long wavelengths. Directional microphones utilizing parabolic reflectors are commonly used at higher frequencies when it is desired to economize on electronic and acoustical complexity; however, at wavelengths of the order of 10 m a parabolic reflector would become expensive and unwieldy. In fact, the dimension of the parabolic reflector commonly used for hand-held or tripod-mounted applications is only of the order of a wavelength in diameter, and in that regime the diffraction pattern of the structure is not strongly dependent on its exact shape. As an analogy, for electromagnetic waves a corner reflector antenna has comparable properties to those of a parabolic antenna of similar (small) dimensions in wavelengths. With these things in mind, a simple shape was sought for a baffle or reflector to produce a well-defined, unidirectional beam pattern of about 90-deg beamwidth in intensity with minimal response in rearward directions.

The simplest shape would appear to be a plane rectangle. The pressure doubling boundary condition at a rigid surface suggests that the position of the microphone for maximum response in the forward direction is on the surface. From Fresnel diffraction theory, the position for minimum response in the rearward direction is on the surface at the center of the baffle. Such a system was modeled, both in physical hardware and in computer simulation. For the computer model the reciprocity relation was invoked and the system modeled as a transmitter, with the microphone replaced by a delta-function source for ease of computation.

I. COMPUTED PERFORMANCE

The layouts for the computation and experiments are shown in Fig. 1. The baffle is normal to the ground plane, the microphone is at the intersection of the two planes, and the azimuth Θ is measured in the ground plane. The baffle and the ground are assumed to be hard, representing pressure-doubling surfaces. From image theory, the solution can thus be assumed to represent either the system as shown or a free-space situation in which the height of the baffle is double and the ground is absent. The microphone is assumed in the calculations to have zero dimension and, in most cases, to be mounted exactly on the surface of the baffle. To avoid a troublesome singularity in the numerical solution a small but finite thickness was assumed for the baffle.

Assume that a point source on a baffle above a ground plane emits a sound wave. The exact solution of this problem can be assumed to represent a free-space situation in which the height of the baffle is double and the ground is absent. Thus the exact solution of the total field $p(\mathbf{r})$ can be written as

$$p(\mathbf{r})=p_i(\mathbf{r})+\int_{s'}\frac{\partial G(\mathbf{r},\mathbf{r}')}{\partial n'}p(\mathbf{r}')ds', \tag{1}$$

where $p_i(\mathbf{r})$ is the incident field from the source and its image. This is the Helmholtz–Kirchhoff integral equation for the problem of acoustic scattering from a hard baffle. In Eq. (1), $G(\mathbf{r},\mathbf{r}')$ is the well-known free-space Green's function and the normal derivatives are evaluated on the surface of the baffle s'.

By letting $\mathbf{r}$ approach the surface, therefore, the integral equation (1) can be reduced to[1]

$$p_i(\mathbf{r})=\frac{1}{2}p(\mathbf{r})-⨍\frac{\partial G(\mathbf{r},\mathbf{r}')}{\partial n'}p(\mathbf{r})ds', \tag{2}$$

where $⨍$ is the principal value of the integral. Now, the integral equation (2) can be solved numerically by the method of moments (also called the boundary element method).[1,2] This method is commonly used in the study of acoustic scattering from an object[3] or a rough surface.[4] Using the moment method, the surface of the reflector is divided into N subareas $\Delta s'$. Then satisfying the resultant equation at the midpoint of each $\Delta s'$, we obtain a matrix equation of the form[1,2,4]

$$a_m=\sum_{n=1}^{N}A_{mn}b_n,\quad m=1,\ldots,N, \tag{3}$$

with

 0001-4966/94/95(5)/2536/3/$6.00

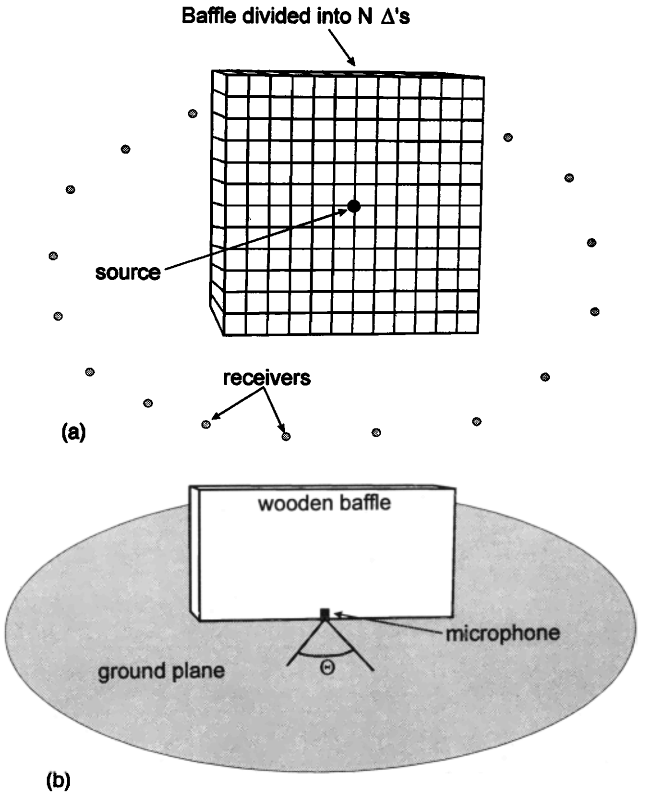

FIG. 1. (a) The configuration assumed for the computations, showing the grid for the method of moments. The receivers are assumed to be in the far field. (b) The configuration used in the physical experiments.

$$a_m = p_i(\mathbf{r}_m), \tag{4}$$

$$A_{mn} = \begin{cases} -\int_{\Delta s'} \frac{\partial G(\mathbf{r}_m, \mathbf{r}_n)}{\partial n'} ds', & m \neq n, \quad (5a) \\ \frac{1}{2}, & m = n, \quad (5b) \end{cases}$$

$$b_n = p(\mathbf{r}_n). \tag{6}$$

The unknown functions b_n can be solved by the matrix operation and then substituted into Eq. (1). The field $p(\mathbf{r})$ can be expressed by

$$p(\mathbf{r}) = p_i(\mathbf{r}) + \sum_{n=1}^{N} b_n \left(\int_{\Delta s'} \frac{\partial G(\mathbf{r}, \mathbf{r}_n)}{\partial n'} ds' \right), \tag{7}$$

where $p(\mathbf{r})$ is the total pressure field, $p_i(\mathbf{r})$ is the field that would exist in the absence of the baffle and ground plane, and the summation term is the field scattered by the baffle. The integral in (7) can be easily calculated by standard integration routines.

Examples of the computed beam patterns are shown in Figs. 2–4, in which the relative response (in amplitude) as a function of azimuth is presented for three representative cases. In Fig. 5 the beamwidth between half-power (0.707 amplitude) points is plotted as a function of the baffle width in wavelengths.

II. PHYSICAL EXPERIMENTS

The physical measurements were performed outdoors on flat areas, surfaced either with asphalt concrete or gravel. The results do not depend on the ground surface, apparently. The baffle was of 1.9-cm-thick particle board and was mounted on a turntable with the microphone 7.6 cm above the ground. The microphone was an electret in a 1.0-cm-diam housing whose center was 2.5 cm from the surface of the baffle. The sound source was a loudspeaker on a fixed mount 46 m from the microphone, producing single-frequency signals of at least 90 dB (referenced to 20 μPa) at the microphone to ensure adequate signal-to-noise ratios. Care was taken that the receiving system never saturated. Frequencies in the range 200–600 Hz were used. Windy periods were avoided.

Representative measured beam patterns are plotted with the calculated patterns in Figs. 2–4.

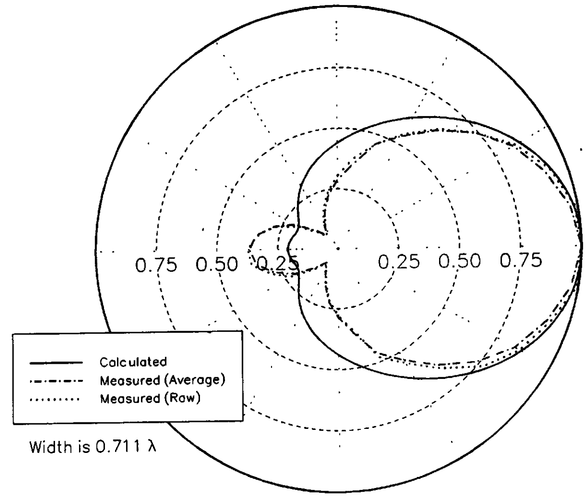

FIG. 2. Polar diagram of the amplitude response in the azimuthal plane. Baffle dimensions: 61 cm wide × 30.5 cm high. Frequency: 400 Hz. Radial scale is linear in amplitude.

III. DISCUSSION

It will be noted that the measured beamwidths are somewhat narrower than are those of the calculations and

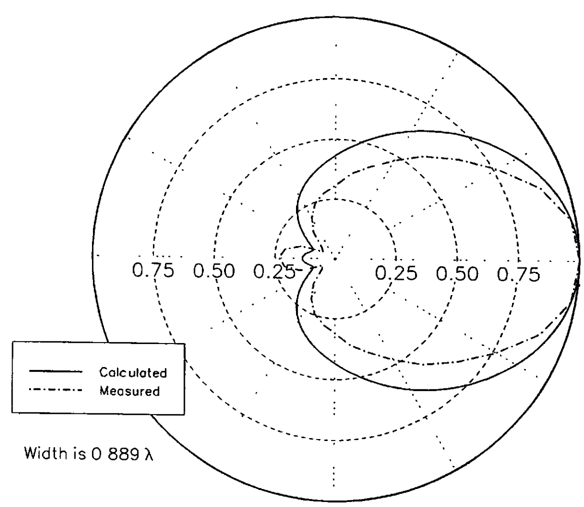

FIG. 3. As in Fig. 2. Frequency: 500 Hz.

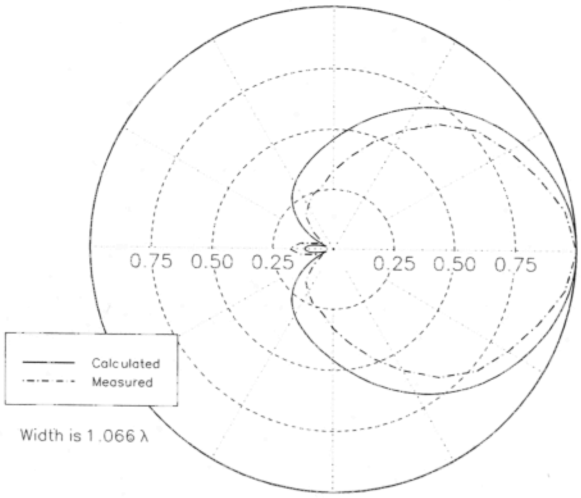

FIG. 4. As in Fig. 2. Frequency 600 Hz.

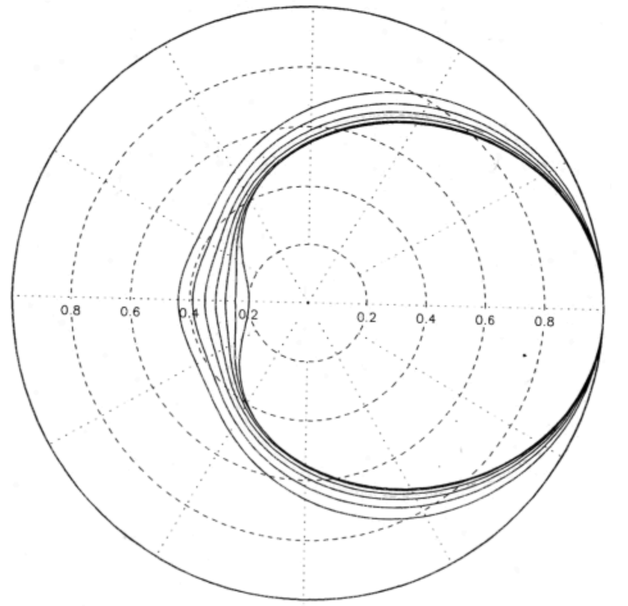

FIG. 6. Effect on amplitude beam pattern of microphone distance from the baffle. Inner curve: zero spacing. Outer curve: 15.2 cm. Interval: 2.5 cm.

that the rearward responses of the measured patterns are higher. These effects might be explained by one or more of the following considerations. The actual baffle may have had some flexural resonances, while the theory assumed zero thickness and perfect rigidity. The actual microphone was not exactly in the corner between ground plane and baffle, which is what the theory assumes. There may have been some reflections from structures and personnel in the vicinity, though the excellent azimuthal symmetry observed in the data appears to argue against that effect. Very slight asymmetries were observed, in fact, but so small as to be insignificant. In Fig. 2 the actual and averaged data are plotted separately. The other plots presented here represent the averages of both halves of the measured patterns, and thus are perfectly symmetrical.

To investigate the effect of microphone placement, numerical calculations were performed for a baffle 0.7 wavelengths wide with the microphone at various positions from zero to 15.2 cm from the baffle surface. The results are given in Fig. 6, and show that the microphone position has a significant effect on the beamwidth and the ratio of forward to rearward response (front-to-back ratio). For the best front-to-back ratio the microphone should be placed directly on the surface of the baffle.

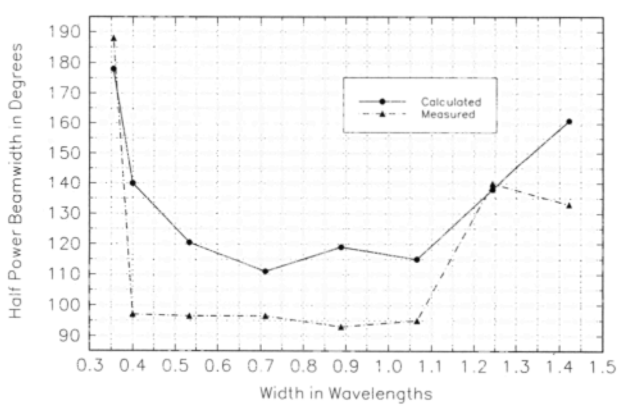

FIG. 5. Azimuthal beamwidth versus baffle width in wavelengths.

IV. CONCLUSIONS

The plane baffle with surface-mounted transducer represents an inexpensive, simple, and effective solution to the need for a unidirectional microphone. It could be used as a portable unit, or, for longer wavelengths, as a fixed installation for environmental noise monitoring.

The method of moments is a reliable way to predict the performance of a system such as this. In this case, it was able to achieve solutions for a diffraction problem that does not yield to traditional Fresnel or Fraunhofer formulations.

ACKNOWLEDGMENT

This work was performed in the facilities of and with the support of the U. S. Army Construction Engineering Research Laboratories, Champaign, Illinois 61826-9005.

[1] N. Morita, N. Kumagai, and J. R. Mautz, *Integral Equation Methods for Electromagnetics* (Artech House, Boston, 1990).
[2] R. F. Harrington, *Field Computation by Method of Moments* (Macmillan, New York, 1968).
[3] A. F. Seybert, T. W. Wu, and X. F. Wu, "Radiation and scattering of acoustic waves from elastic solids and shells using the boundary element," J. Acoust. Soc. Am. **84**, 1906–1912 (1988).
[4] Y. L. Li, S. J. Franke, and C. H. Liu, "Wave scattering from a ground with a Gaussian bump or trough in an inhomogeneous medium," J. Acoust. Soc. Am. **94**, 1067–1075 (1993).