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LOCATION OF A SOUND SOURCE USING A VERTICAL ARRAY OF 2 OR 3 MICROPHONES NEAR TO POROUS GROUND.

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INTRODUCTION

Alternatives to radar for the ranging and classification of enemy aircraft are becoming of increasing interest, as methods of evading radar screens become more successful. The work reported here applies fundamental knowledge and computing techniques developed in studies of outdoor and underwater sound propagation to the problem of ranging and classifying low flying aircraft and helicopters. Sound propagation outdoors is influenced by many meteorological factors as well as the nature and topography of the ground surface. Ray-tracing techniques that have been successful in the prediction of areas and focusing and shadow zones from intense sources such as blasting operations, break down whenever the dominant portion of the sound path is near grazing incidence on the ground surface. If we consider ranging a helicopter flying at a height of 100 m, then at a horizontal range of 1000 m, the grazing angle is only 5.7 degrees.

The last twenty years have seen a considerable increase in the understanding of the propagation of sound at near-grazing incidence over open, flat, acoustically-soft, continuous terrain [1]. The basis for the techniques developed here was first suggested as a way of locating individual noise sources on road vehicles [2].

BASIS OF TECHNIQUES

Level difference spectrum

The spectrum of the differences in sound levels recorded at two microphones, one of which is on the ground and the other is vertically above the first (Figure 1);

(a) is independent of the source spectrum

(b) exhibits various peaks or troughs depending upon which way round the levels are subtracted.

Above a rigid, or infinite impedance, surface, the direct and reflected sound waves interfere to produce a series of maxima and minima in the sound field measured by each microphone. When the surface has a finite impedance, the field at each microphone exhibits an additional minimum which occurs at a lower frequency than the others. The location and depth of this peak is influenced considerably by the acoustical characteristics of the ground and by the angle of specular reflection (ϕ). If the lower microphone is on the ground surface then the first peak in the level difference spectrum corresponds to the first minimum in the field at the upper microphone, and subsequent peaks are dependent mostly on geometrical interference effects between direct and ground-reflected waves and hence on the path-length difference (δ) between these rays to the upper microphone illustrated in Figure 1.

The level difference-spectrum may be calculated for various geometries and ground surfaces using the basic theory for the propagation of a spherical sound wave over a finite impedance boundary [3] and a suitable model for the acoustical characteristics of the ground [4]. The impedance model used in the studies reported here is that for porosity varying with depth. This introduces two parameters; effective flow resistivity (σ) and effective exponential rate of decrease of porosity with depth (α). A typical fit is shown in Figure 2.

Three microphone algorithm

For a given angle of specular reflection (ϕ) with respect to an upper microphone 1m above the ground, the level difference spectrum is independent of horizontal source-receiver separation. With the range dependence eliminated, theoretical predictions are made for individual pairs of parameters α and σ over the frequency range of interest. This may be 100 to 1000 Hz. The values of α, σ and ϕ may be found that result in the least sum of squared errors between predicted and measured spectra. The effect of varying σ is mainly to alter the location of the first level-difference peak and those of varying α and ϕ are mainly to alter the height of the peak, but in different ways.

Once the angle and ground parameters are deduced from the level difference between microphones at 0 and 1 m height, then range can be determined from measured data of the level difference between microphones at the ground surface and at a height greater than 1 m. For an upper microphone height between 3 and 4 m, the sensitivity to range is significant up to a distance of 1 km. For greater ranges the upper microphone height needs to be raised to produce the required range sensitivity.

Two microphone algorithm

By extending the frequency range over which signal processing takes place up to 5kHz, the need for the highest microphone may be eliminated. This is possible since path length difference provides an alternative parameter to range. The value of δ deduced from the high-frequency interference pattern combined with the angle of specular reflection deduced from the level-difference spectrum measured with a range-insensitive upper-microphone height enable deduction of sourced location.

METEOROLOGICAL INFLUENCES

The basis for the technique explained above assumes the absence of meteorological effects. These contribute (i) wind noise which restricts the lower frequency limit of the fitting process (ii) a constant shifting in the level difference spectrum due to wind shear and (iii) the elimination of high frequency interference peaks by time-averaging of received signals as a consequence of turbulence. At long ranges the effect of temperature stratification will also be observed. Under turbulent conditions the high-frequency peaks are extracted by means of 'snap-shot' measurements of 200 ms duration. The frequency locations of the peaks obtained from each snap shot are averaged rather than the signal itself.

Analysis of the variation of the level-difference spectrum with time for a known geometry over a ground, whose surface has been characterized by repeated measurements under calm conditions, has shown the possibility of deducing a meteorological spectrum filter (Figure 3). This offers a purely empirical method for correcting for meteorological influences. A more fundamental basis for these corrections will require study of theories for propagation through turbulent and stratified atmosphere near to the ground.

RESULTS AND CONCLUSIONS

Tables I and III show the results of applying the algorithms previously described over various ground surfaces and with a range of source-receives geometries. The method is shown to work well at relatively short ranges (<50m). As the horizontal range increases the meteorological influences increase. The results show that some compensation is possible by taking "snap-shot" spectra and by allowing the second ground parameter (α) to take negative values (which are physically meaningless). Even at the longest range for which we have data (450 m) it has been found possible to predict source elevation to within 2°.

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TABLE I

ARRAY SPECIFICATION	MEASURED GEOMETRY		PREDICTED GEOMETRY		BANDWIDTH IN Hz
RECEIVER HEIGHTS IN m	SOURCE HEIGHT IN m	HORIZONTAL RANGE IN m	SOURCE HEIGHT IN m	HORIZONTAL RANGE IN m	
0, 2.6	3.0	75	3.4	78	3500
For the remainder of these data the same basic geometry was retained but the array was shifted along a small arc around source between each measurement.			3.6 3.86 3.11 3.11	78 84 71 68	
0, 2.4	7.0	50	7.21	54	1200

TABLE II

GROUND TYPE	ARRAY SPECIFICATION	MEASURED GEOMETRY		PREDICTED GEOMETRY	
	RECEIVER HEIGHTS IN m	SOURCE HEIGHT In m	RANGE IN m	SOURCE HEIGHT IN m	RANGE IN m
FOREST	0, 1.2, 2.5	1.3	24	1.21	26
	0, 1.2, 2.5	1.3	48	1.16	50
SPORTS FIELD	0, 1, 2.4	7	50	6.13	45
	0, 1, 2	2.1	56	2.62	56
	0, 1, 2	2.1	65	2.09	71
	0, 0.93, 2.6	3.0	75	3.9	66

Table III

Geometry	$\alpha(m^{-1})$	σ(mksrayls)	φ(deg)
450/9/1	-30.0	2350000	2.5(1.28)
"	90.0	2150000	0.5 "
"	-350.0	3300000	4.5 "
"	-40.0	1900000	3.6 "
270/8/1	-150.0	1500000	3.0(1.93)
"	-270.0	3900000	3.0 "
"	-10.0	2700000	2.5 "
"	-260.0	3300000	2.2 "
"	-75.0	5200000	4.0 "

Geometry=range/source ht./upper microphone ht.(m)
the angle in brackets is the actual known angle.

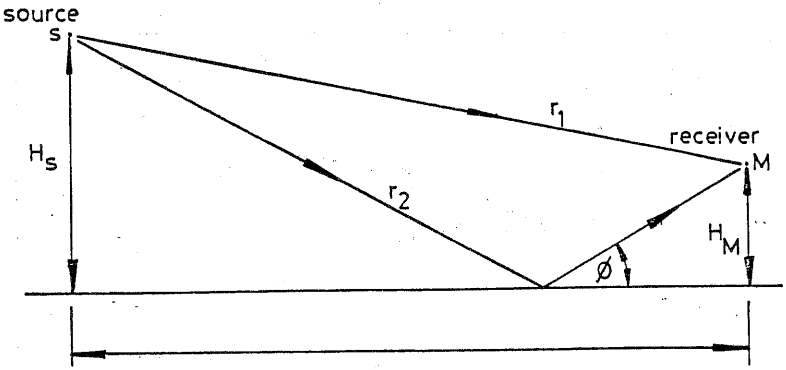

Figure 1. Target and remote sensor geometry.

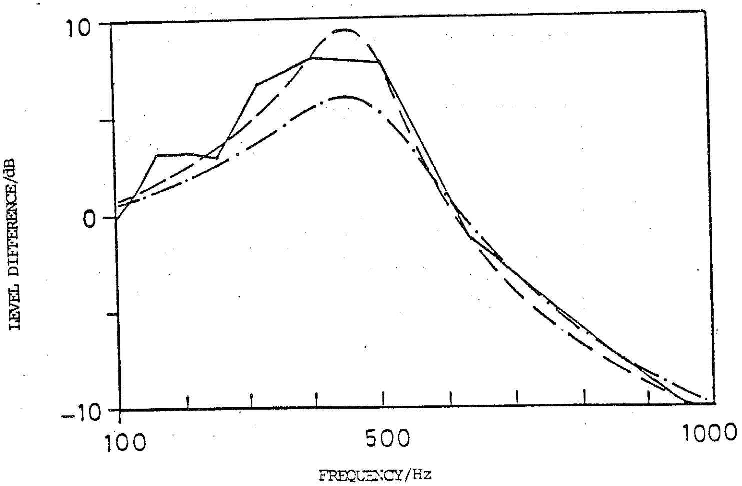

Figure 2. Measured and best-fit predicted level-difference spectrum at a horizontal range of 65m with source and upper microphone 2m above open flat grassland.

——— Measured

- - - - - Uses 2 parameters for ground properties

_._._._ Uses 1 parameter for ground properties

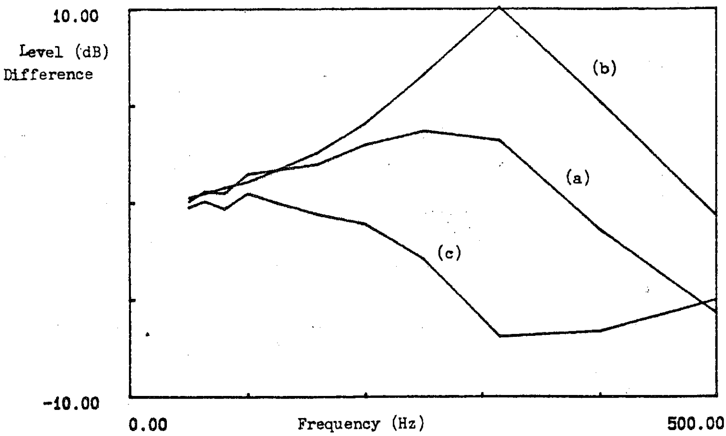

Figure 3a. Construction of mean meteorological filter from a series of measurements. Curve (a) is the mean data (b) is the isothermal prediction and (c) is the resulting filter.

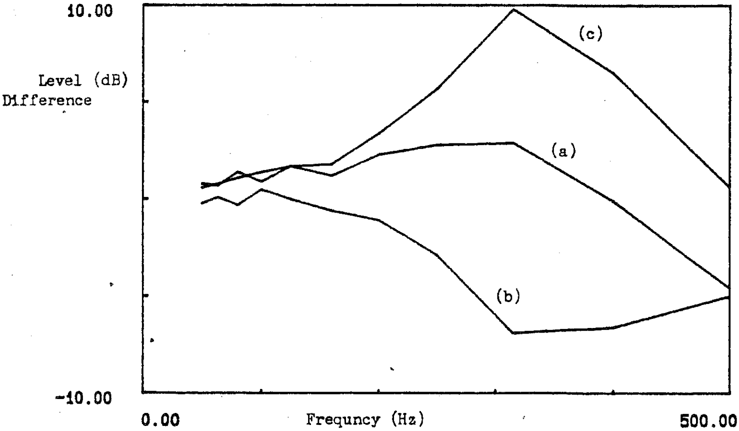

Figure 3b. Correction of individual measurements using the filter of figure 3a. Curve (a) is the measurement, curve (b) is the filter and (c) is the corrected data for analysis.