AN AIR ACOUSTIC SONAR SYSTEM

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1. INTRODUCTION

This paper describes the design and testing of an air sonar system using a 15 element array. The aim of this work was mainly to investigate the possibility of using such a system for the guidance of robotic vehicles and to see if some of the modern high resolution algorithms could be applied to such a system. The system comprises two main parts, the array itself and the digital receiving system used to collect and process the data.

2. AIR ARRAY DESIGN

The array comprised 15 elements arranged in echelon with 8 elements in the upper row and 7 elements in the lower row as can be seen in Fig.1. The elements of the array are about 5 wavelengths diameter at the centre frequency of 50 kHz and if a simple line array had been used the resulting diffraction secondaries would have been unacceptable. By using this echelon formation the spacing of the elements is effectively halved although care has to be taken if the objects in the far field are off the horizontal plane containing the normal to the centre of the array. The operating frequency used in the experiments was 40 kHz which helped to reduce the spacing in terms of wavelength.

2.1 Transducers

The transducers used in the array were made by the Polaroid Company as part of an automatic focussing system for use in cameras. They have very good acoustic characteristics. The relative sensitivities of the elements used in the array have been measured and the standard deviation was only about 10% of the mean.

2.2 Measurement circuit

The measurement system is shown in Fig.2. The output of each transducer is amplified by a 40 dB pre-amplifier, and sent either to the beam plotter or to the digital receiver. Details of the beam plotter and the digital receiver are given in [3,4,5] respectively.

3. BEAM PATTERN CALCULATION

3.1 Beam pattern of one transducer

The elements of the array are circular plane transducers and the beam pattern of such a transducer can be shown to be

$$S(\phi) = \frac{J_1(\phi)}{\phi} \tag{1}$$

where $[J_1(\phi)]$ is the first-order Bessel function of $[\ \phi\ ]$, $[\phi = 2\pi r \sin(\theta)/\lambda]$ and r is the radius of the circular plane [1].

3.2 Beam pattern of the 15 element array

The air array is a two line echelon structure but in the far-field, if the sources are in the horizontal containing the normal to the centre of the array, then it can be assumed to be a linear array with an inter-element spacing of 23 mm. The wave length at the transmitting frequency of 40 kHz is 8.5 mm and so $d/\lambda = 2.7$.

The beam pattern of a linear array using nondirectional elements can be shown to be

$$D(\theta) = \frac{\sin(N \cdot \pi \cdot d \cdot \sin(\theta)/\lambda)}{N \cdot \sin(\pi \cdot d \cdot \sin(\theta)/\lambda)} \tag{2}$$

When $\pi d \sin(\theta) = 0, \pm 2\pi, \pm 4\pi \cdots$ the beam will have its maximum values. Using the parameters of this array : d = 23 mm, λ= 8.5 mm the beam pattern will have maximum values at $\theta = 0°, \pm 21.8°, \pm 47.8°$.

We need to modify this equation to take into account the directivity of the individual elements. According to the product theorem [2], the beam pattern of the array of directional elements array will be the product of the beam pattern of an identical array of nondirectional elements and the beam pattern of an individual element.

Thus the beam pattern of the array will be given by:

$$P(\theta) = D(\theta) \times S(\theta) \tag{3}$$

4. DIGITAL RECEIVER SYSTEM

The digital receiver system had been designed and made originally for processing the output from a 15/16 element array for investigating the use of high resolution algorithms in a sonar system [4,5]. It is based on an analog input circuit using quadrature sampling (I and Q) followed by analog/digital conversion, and is used in this experiment for processing the data.

5. PRACTICAL MEASUREMENTS

Fig. 3 shows the geometry of the array and sources used in the measurement. The distance between the array and the two sources is 7.8 m whilst the separation between the two uncorrelated sources is varied in different scenarios. Three sets of data were recorded under each source separation corresponding to cases when the two sources were present individually and the case when the two sources were both present.

The radius of the transducer used in the array is 17 mm and the theoretical beam pattern for one element was calculated from equation 1. The measured beampattern is compared to this in Fig. 4. The beam width of one element can be seen to be about 15 degree at 40 kHz.

The beam pattern of the whole array was measured by two methods electronically and by mechanical scanning. In the first method the data received from the stationary array is processed by the digital receiver to produce an electronically scanned waveform as is seen in Fig. 5. The theoretical curve derived from equation 2 is also shown. In the second method the array was mechanically scanned under computer drive by the beam plotter and the resulting beam pattern is shown in Fig. 6. The appropriate theoretical curve was obtained from equation 3. It can be seen that the beam width of the whole array is about 1.4 degree at 40 kHz.

Fig.7 shows the CBF and MUSIC spectra obtained from received real data. Three source separations were considered : 150 mm, 200 mm, and 400 mm which were about 1.1, 1.5, and 2.9 degree respectively. Under each separation, two sources were measured individually as shown in figures 7(a), 7(c), and 7(e), and the corresponding spectra when two sources were present were given in figures 7(b), 7(d), and 7(f).

The recorded data was also applied to several other algorithms which include IMP (Incremental Multi-stage Parameter estimator), WSF (Weighted Subspace Fitting), and ML (Maximum Likelihood). For detailed discussion of these methods, [6,7,8] are recommended. The results obtained using these methods are presented in Table 1.

6. CONCLUSIONS

In Fig.3, we find that the theoretical result and the measured result of the beam pattern of one element are very similar.

In Fig.4, the theoretical result and measured result of the beam former of the array are also similar. It should be noticed that measuring the beam pattern by electronic steering produces diffraction secondaries since the beam pattern of the individually elements does not come into effect.

In Fig.5, the theoretical result differs slightly from the measured result of the beam pattern of the air array. There are two large sidelobes beside the mainlobe which are higher than the theoretical result. There are a number of possible causes of this effect the most likely of which is that the source was not at a sufficient distance for the far-field approximation to apply.

Figure 7 and Table 1 show the results of implementing several high resolution algorithms in resolving two sources in open air. When the source separation was less than one beamwidth, the conventional beamformer failed to resolve the two sources while high resolution algorithms including MUSIC, IMP, WSF, and ML gave an indication of two separate sources. As the source separation increased, the conventional beamformer began to show two separate peaks in the spectrum as expected. The three other high resolution methods tried also gave good and consistent estimates.

7. REFERENCES

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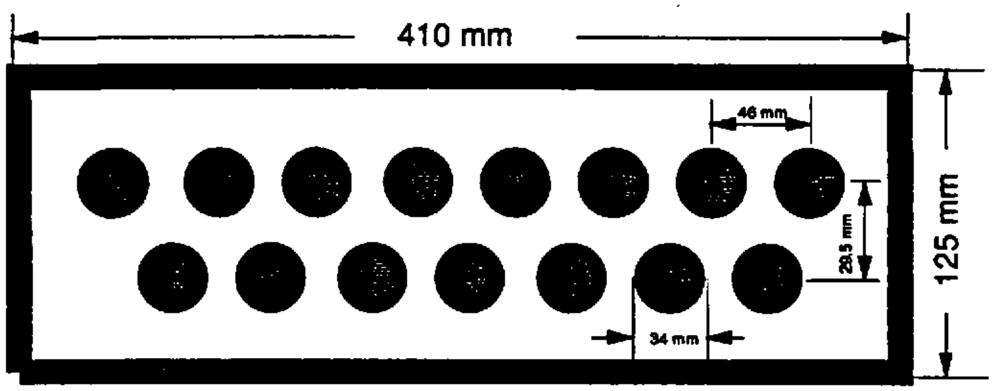

Fig.1 The diagram of the air array

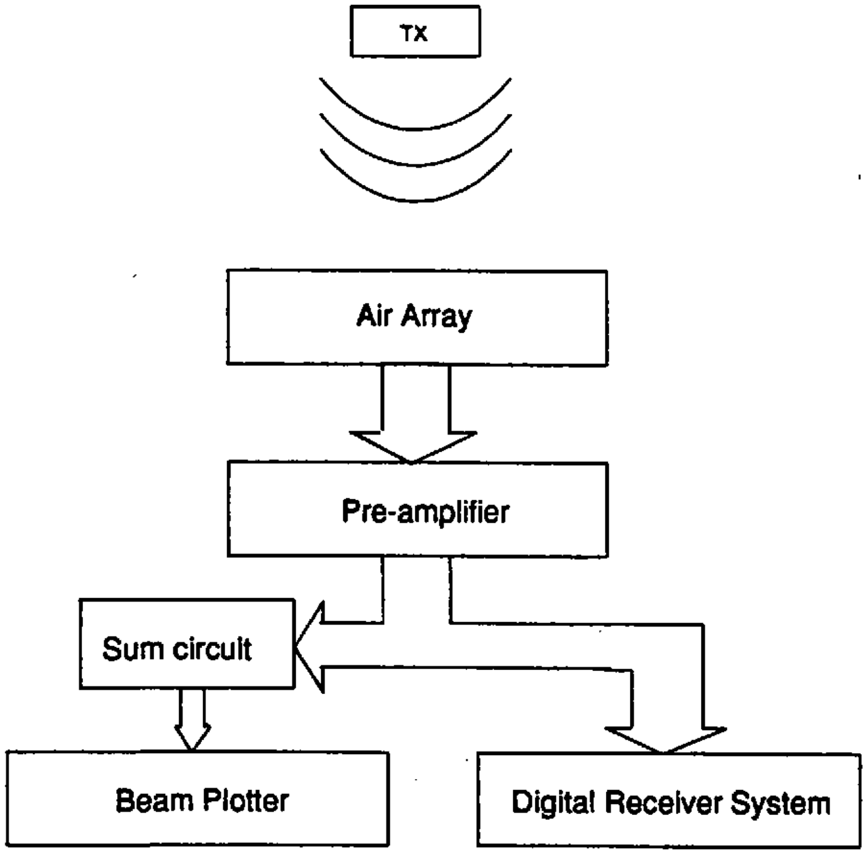

Fig.2 The diagram of the measurement system

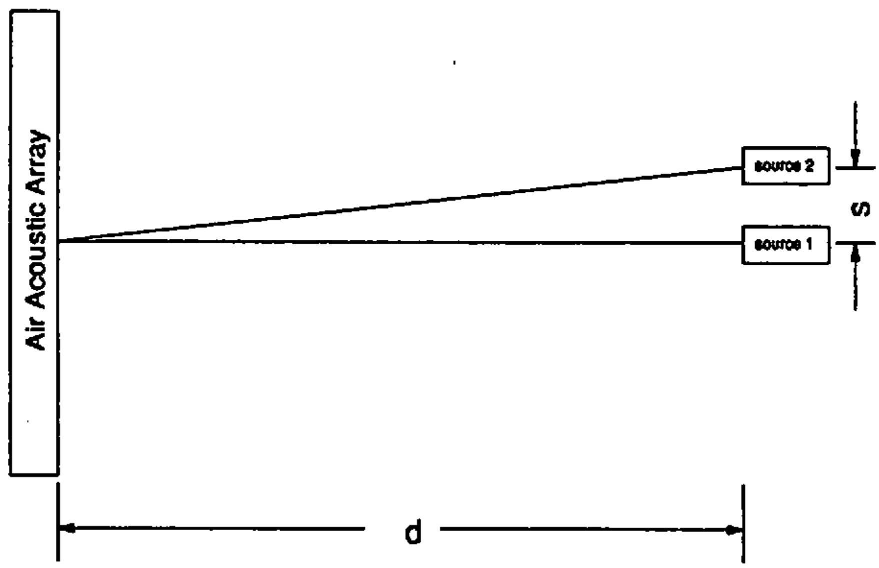

Fig.3 The geometry of the measurement environment

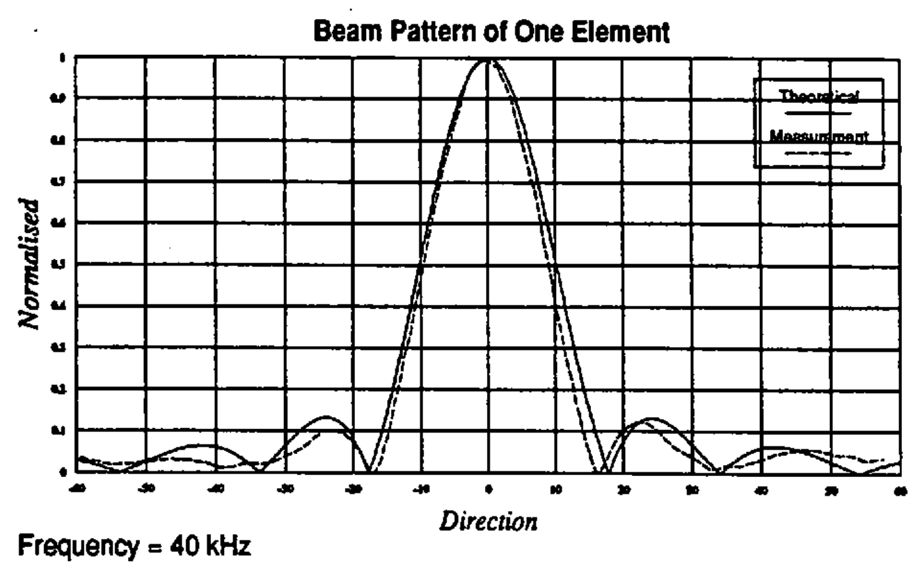

Fig.4 The theoretical and measured beam pattern of one element

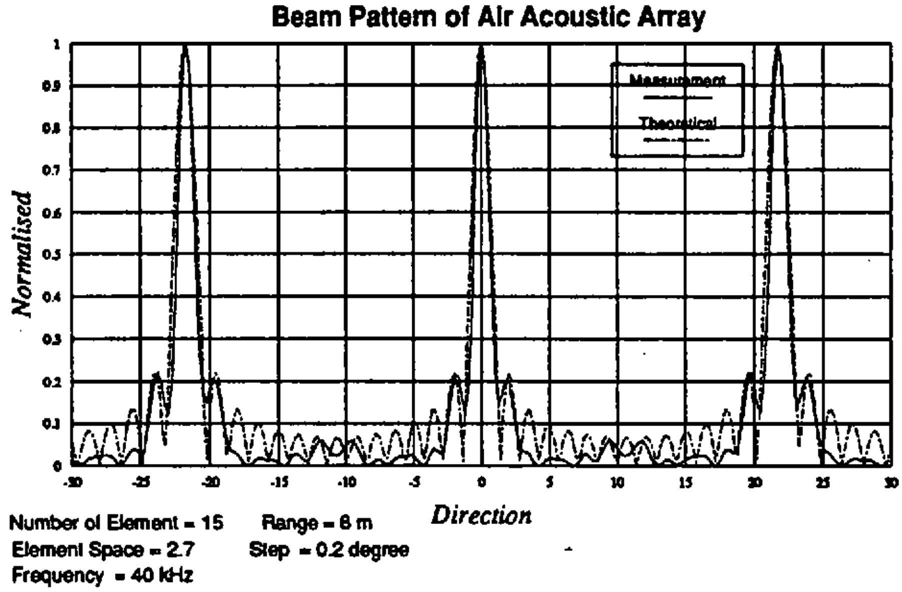

Fig.5 The theoretical and measured beam pattern of the acoustic array in air using electronic steering

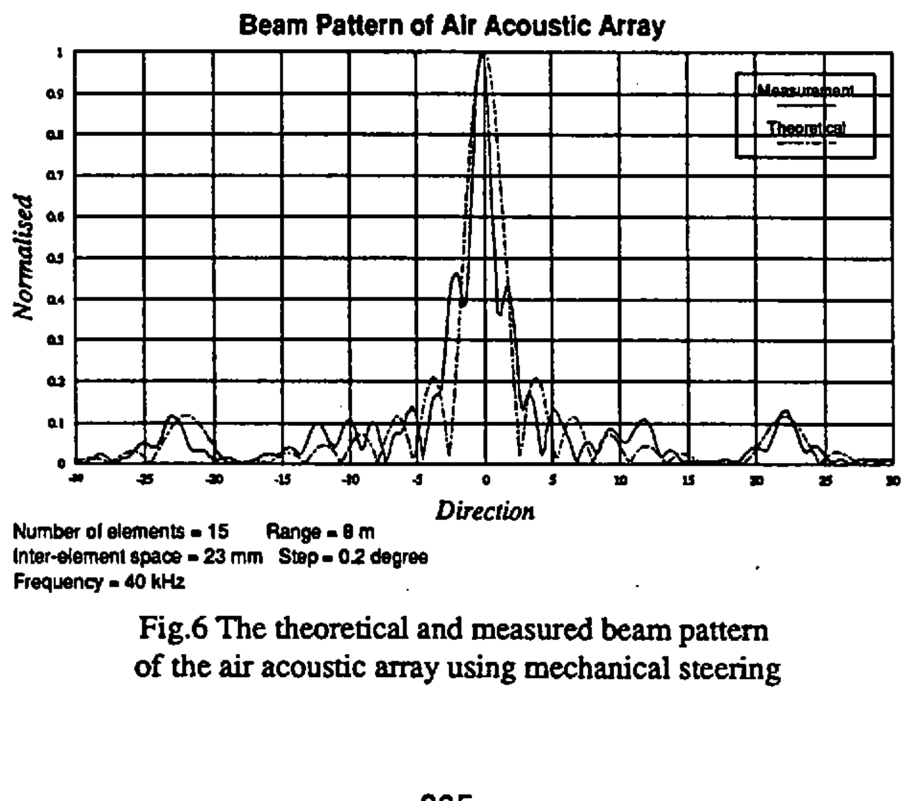

Fig.6 The theoretical and measured beam pattern of the air acoustic array using mechanical steering

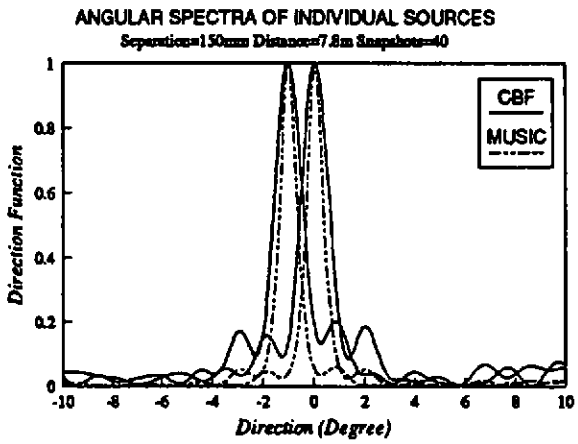

Fig.7(a)

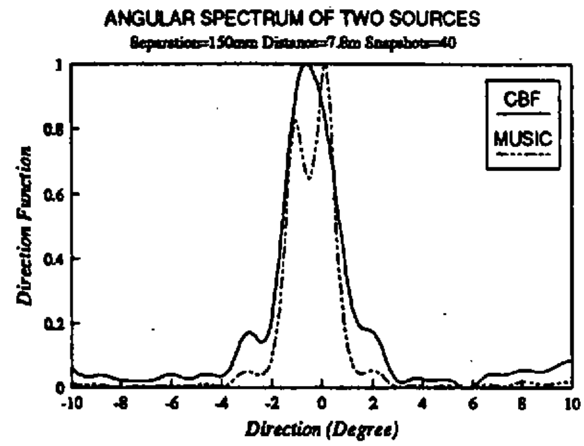

Fig.7(b)

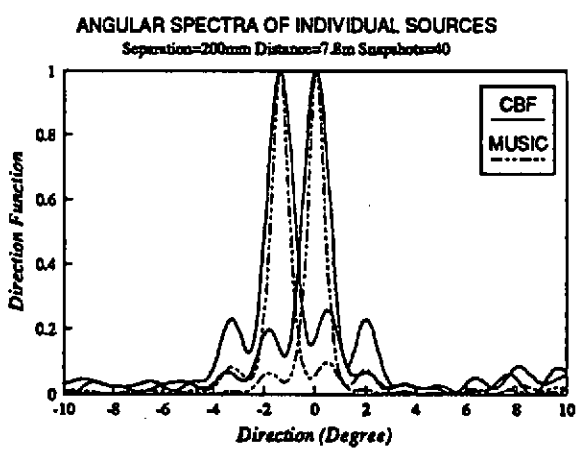

Fig.7(c)

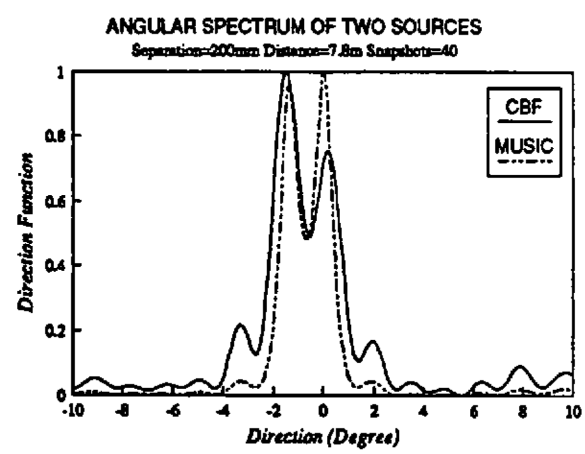

Fig.7(d)

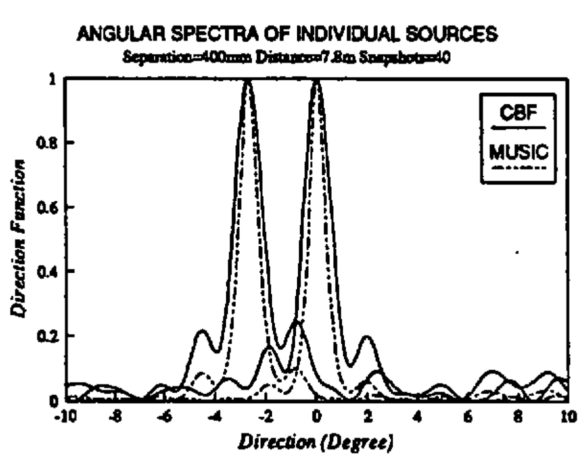

Fig.7(e)

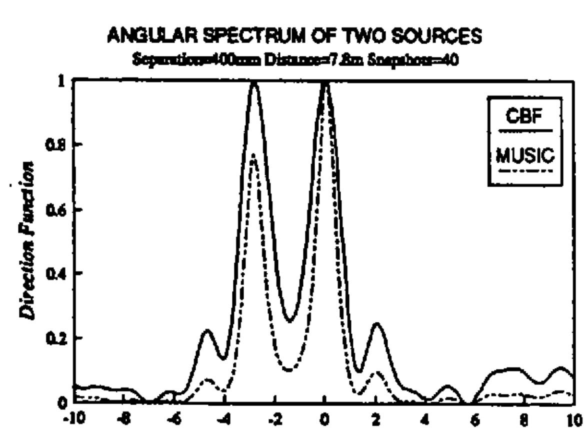

Fig.7(f)

Table 1.

Results obtained from different algorithms (in degree)

Source Separation	Source State	Algorithms				
		CBF	MUSIC	IMP	WSF	ML
150 mm	1# ON 2# OFF	0.1	0.1	0.1	0.07	0.07
	1# OFF 2# ON	-1.0	-1.0	-1.0	-0.99	-0.99
	1# ON 2# ON	-0.6	0.1 -1.0	0.1 -0.9	0.10 -0.90	0.11 -0.90
200 mm	1# ON 2# OFF	0.1	0.1	0.1	0.06	0.07
	1# OFF 2# ON	-1.4	-1.4	-1.4	-1.36	-1.36
	1# ON 2# ON	0.2 -1.5	0 -1.4	0 -1.3	-0.01 -1.32	-0.00 -1.32
400 mm	1# ON 2# OFF	0.1	0	0.1	0.06	0.06
	1# OFF 2# ON	-2.7	-2.7	-2.7	-2.66	-2.66
	1# ON 2# ON	0.1 -2.8	0.1 -2.8	0.1 -2.8	0.15 -2.83	0.14 -2.83