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SOME PRACTICAL RESULTS ON A HIGH RESOLUTION SONAR SYSTEM

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1. INTRODUCTION

In an earlier paper [ref.1] the authors presented some practical results on the implementation of some high resolution direction finding (DF) algorithms on a transputer-based sonar system. The experiments were carried out in the water tank at the University which, although extremely useful, is relatively limited in size (9x5x2 m) and hence there were severe problems with multipath propagation. To avoid this cause of interference it was necessary to work within the near field of the array which increased the complexity of the calculations. However, the results obtained from these experiments demonstrated that the system was functioning satisfactorily and provided sufficient confidence to continue the work in an environment which more nearly simulates the normal operation of a sonar system.

The ultimate desire of this project is to test the algorithms under realistic sonar environments and the next step in this process was to move the system to a test site at a large nearby reservoir where the depth of water is of the order of 20-30 metres over a range of about 1 km. This of course improves the situation regarding the multipath but introduced other problems associated with a normal sonar environment:

a. The echo or signal level was reduced due to the increased ranges used and made the signal liable to corruption from noise.
b. Adverse weather conditions, in particular high winds and the concomitant waves, cause movement of the targets and the sources.

In this paper the results of some of the early experiments carried out at the reservoir are presented. The aim of these experiments was examine the performance of a number of high resolution algorithms in resolving the signals received from two hydrophone sources placed at a range of about 9 metres with a separation less than the nominal beamwidth of the receiving array. Experiments were carried out which involved varying the spacing between the two sources, the power of the sources and the number of snapshots, and studying the effects on the resolving power of the system, and the robustness of each of the algorithms.

2. DESCRIPTION OF THE EXPERIMENTAL SET-UP

A description of the sonar system used in the experiments was given in an earlier paper (ref. 2). For these experiments 10 elements of a 40kHz 15 element array were used. The array, together with a pan and tilt unit, was fitted at the bottom of a 12m triangular frame and deployed in the water close to the control tower of the reservoir. The frame was attached to the control tower but spaced about 1.5 metres away to allow free movement of the pan and tilt mechanism.

The array was mounted vertically since it was easier to mount and control the sources and targets vertically rather than horizontally. The vertical alignment of the array was ensured by means of mechanical stops fitted to the pan and tilt head.

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Ball hydrophones were used to provide the active sources and these were suspended from a long pole about 9 metres from the array and at a depth of approximately 11 metres (see Figure 1). A small weight was attached to the hydrophone/s to try to minimise movement while taking measurements. Initially one hydrophone was placed at the 0 degree direction relative to the receiving array by transmitting pulses continuously from it and monitoring the sum of the received signals from the end elements of the receiving array. In the first experiment the hydrophone was moved vertically up and down in steps of one metre across the sector and its position detected by using the Conventional Beam Forming (CBF) algorithm. In the subsequent experiments the first hydrophone was kept at the zero position and another hydrophone was placed above it. The vertical distance between the two hydrophones was set to 1.0, 0.75 and 0.5 metres which corresponds to 6.7, 5 and 3.5 degrees respectively.

The two hydrophones were fed from two separate power amplifiers. These amplifiers were driven by two pulse generator circuits working at slightly different frequencies around 40kHz. This difference in frequency is necessary to ensure that there is no correlation between the two sources. In the last experiment, which was to test the algorithms for sources which are correlated, the two hydrophones were fed from the same signal generator and amplifier.

3. POSSIBLE SIGNAL MULTIPATHS:

Figure 2 shows the possible signal multipaths. It can be seen from this figure that the reflection from the tower is the first to arrive after the main pulse from the direct path (about 2ms later). To avoid multipath interference (which will be considered in later experiments) the duration of the pulse used would have to be less than 2ms. However, because the cylindrical shape of the tower causes strong scattering and because the array is much less sensitive to signals arriving from the rear, this source of multipath is relatively small. It would therefore, have been possible to have used longer pulses than 2msec, but to be on the safe side, it was decided to use a 1.5ms pulse.

The reflections from the surface and bottom will arrive at a much later time (7.9 and 9.8 ms respectively).

4. SUMMARY OF THE EXPERIMENTS

In the following, a summary of the experiments carried out at the reservoir are presented. The S/N ratio of the individual sources were measured by transmitting from the respective source and measuring the signal level received at the output of the first preamplifier stage on the receiver board having already measured the level of noise at this point when there was no signal present.

EXPERIMENT No. 1: A single source was moved vertically across the sector at intervals of 1metre and the conventional beam former was used to determine its direction.

EXPERIMENT NO. 2: Two sources spaced 6.7 degree apart at a distance of 9m from the array and each have a signal noise ration of 20dB.
Number of snapshots=15 and 30.

EXPERIMENT NO. 3: The condition as in experiment 2 but the spacing was 5 degrees. Number of snapshots=15 and 30.

EXPERIMENT NO. 4: As in experiment 2 but with the sources separated by 3.5 degrees. Number of snapshots=15, 30 and 50.

EXPERIMENT NO. 5: As in experiment 4 but with the S/N reduced to 5dB. Number of snapshots=15, 30 and 50.

5. PRACTICAL RESULTS

The results presented in this section were obtained on a practical sonar system although the conditions under which they were obtained were fairly well controlled. At a later stage the conditions will be relaxed in a controlled manner to move towards the more realistic sonar environment.

In Figures 3 to 6 we observe a series of results for two equal amplitude sources with different separations, different numbers of snapshots and different signal/noise ratios. Four algorithms are evaluated in each figure

1. The Conventional Beamformer (CBF).
2. The Capon Estimator (CAPON).
3. The Music Algorithm (MUSIC).
4. Minimum Norm Method (MNM).

For more details of these algorithms see for instance ref. 3. The array used had ten elements spaced at one wavelength so that the conventional beamwidth is approximately 5.6 degrees.

In figure 3 (a) and (b) the spacing of the two sources is 6.7 degrees and thus even the conventional beamformer is able to separate the sources. The other methods all perform considerably better however. The Capon estimator should estimate the level of the signals as well as the position but it should be noticed that for 15 snapshots there is a difference between the two estimates. In figure 3 (b) with 30 snapshots the estimates are much better.

In Figures 4 (a) and (b) the source separation is 5 degrees and the CBF now fails to separate them.

Figures 5 (a) (b) and (c) are for a source separation of 3.5 degrees and with 20db S/N. All three high resolution methods are still separating the sources.

However in figure 6(a) where the S/N has been reduced to 5db none of the methods are successful with only 15 snapshots. With 30 snapshots (figure 6(b)) we see that the MUSIC and MNM are able to separate the sources successfully, and with 50 snapshots the Capon method is managing to separate the sources.

6. CONCLUSIONS

The performance of a number of high resolution algorithms has been tested under well controlled conditions at a reservoir. The performance of the algorithms was as expected taking into account that each set of data was only a single trial and some statistical variation will be present, particularly when the number of snapshots was relatively low.

The experiments will be extended to move nearer the practical sonar environment and to include the performance under multipath conditions.

7. REFERENCES

[1]. Rafik, T. A. and Griffiths, J.W.R. " High Resolution Sonar DF System ", Proc. Of the Institute of Acoustics on Sonar Signal Processing, Vol. 11, Pt. 8, Loughborough University of Technology, Loughborough, 1989.

[2]. Rafik, T. A. and Griffiths, J.W.R. " An Experimental Sonar System Using Transputers ", Underwater Acoustic Data Processing, NATO ASI Series, Vol. 161, Kluwer Academic Publishers, Canada, 1988.

[3]. Griffiths, J.W.R. " A Tutorial on Sensor Array Processing " Ibid.

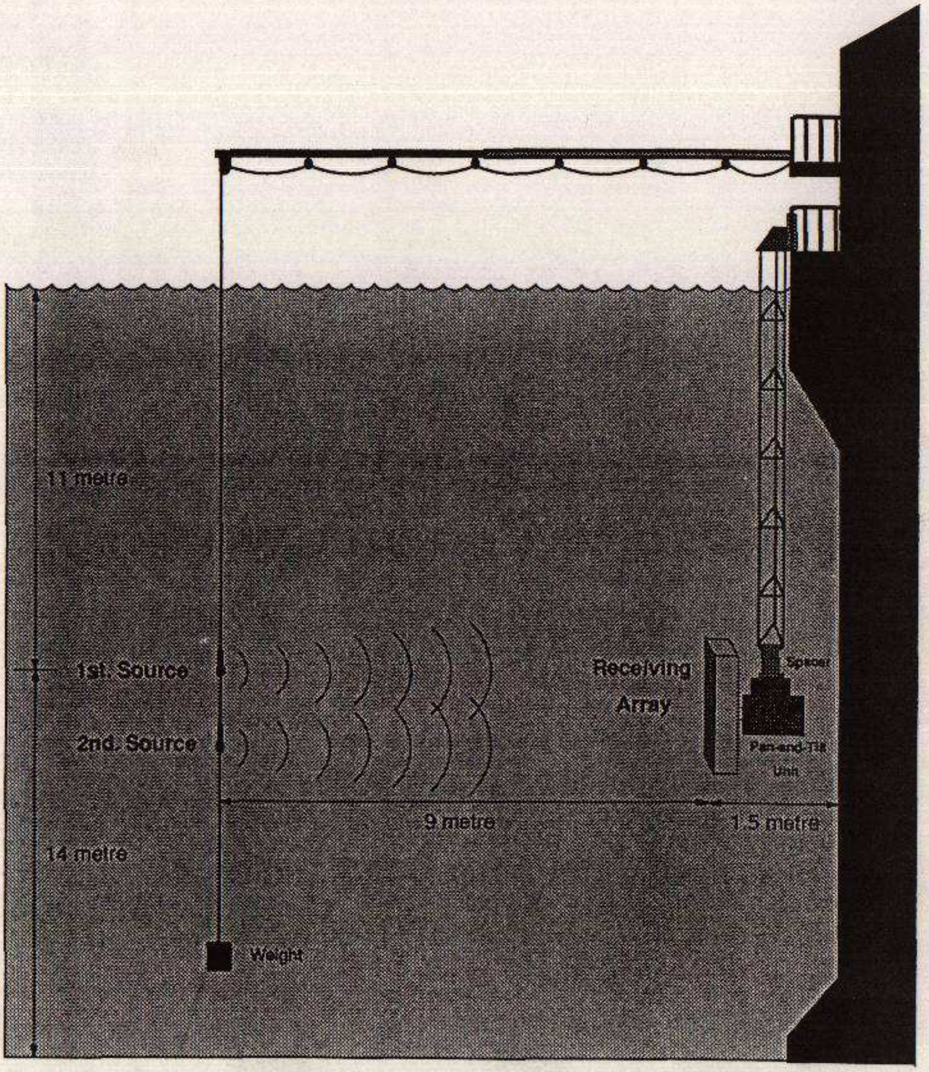

Figure 1: The Experimental Set-up.

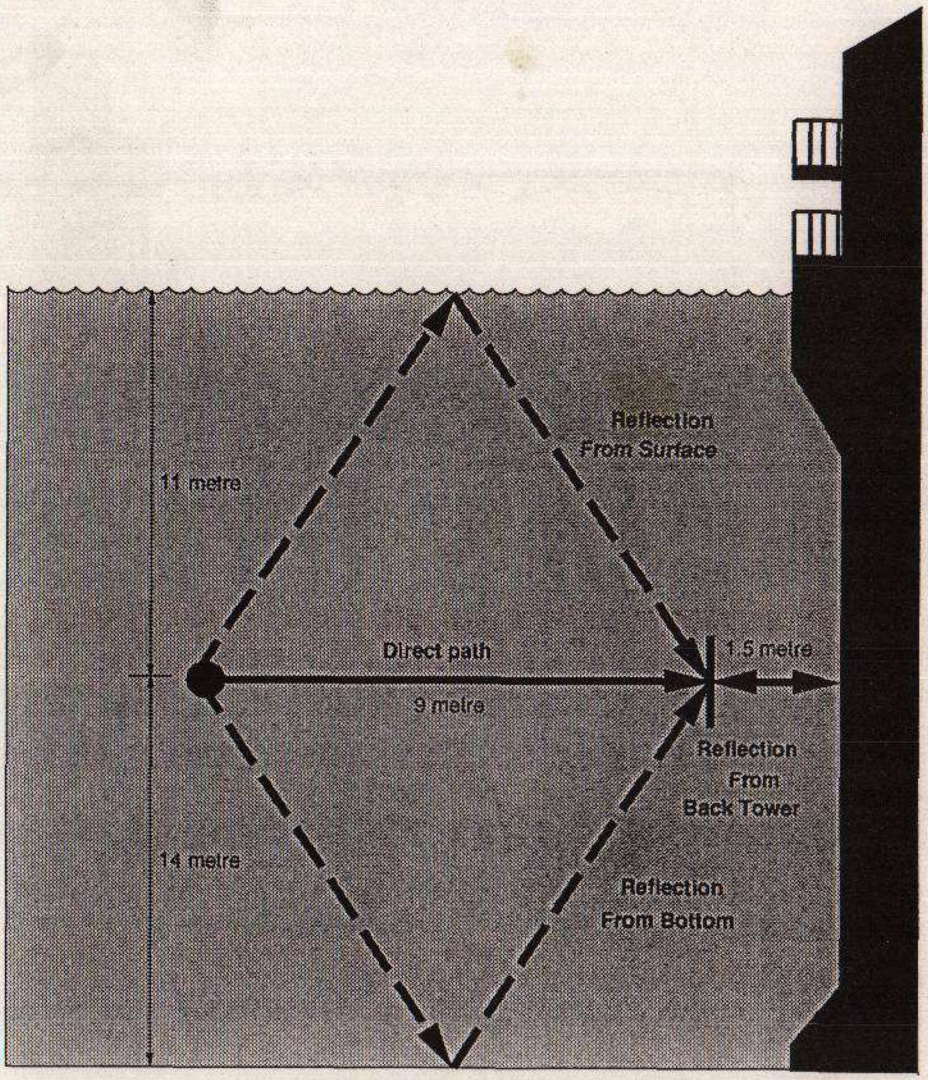

Figure 2: The Possible Signal Multipaths.

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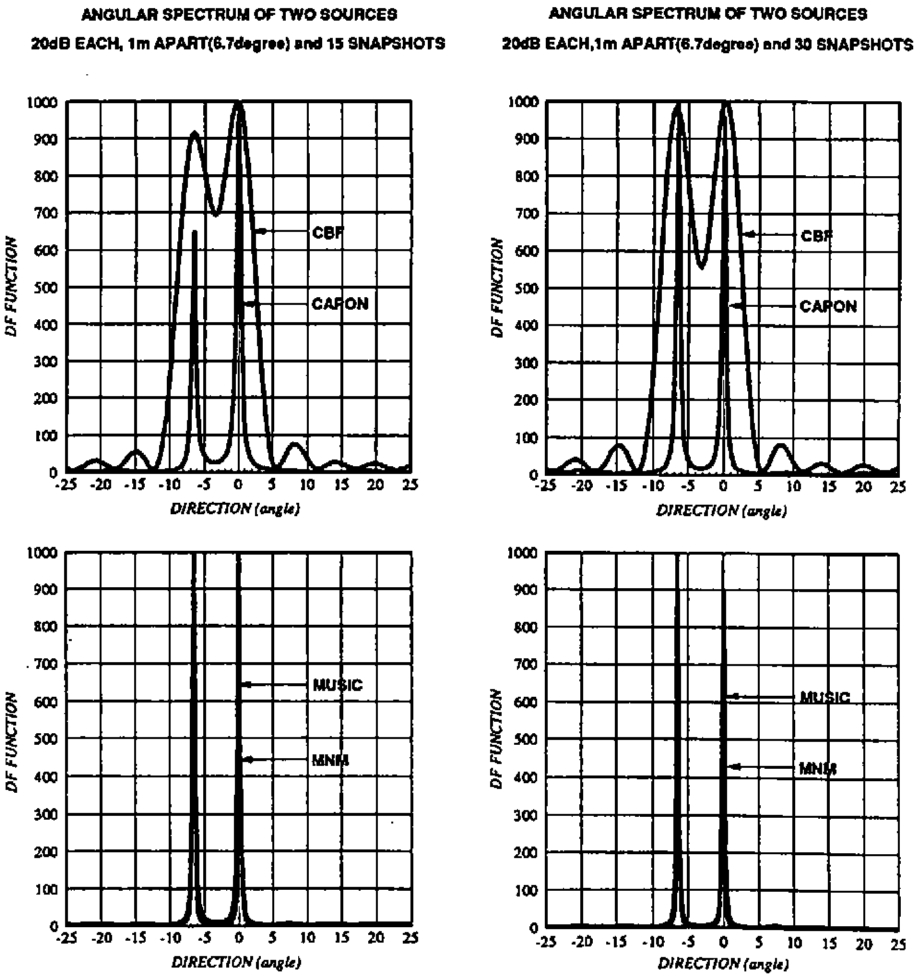


Figure 3

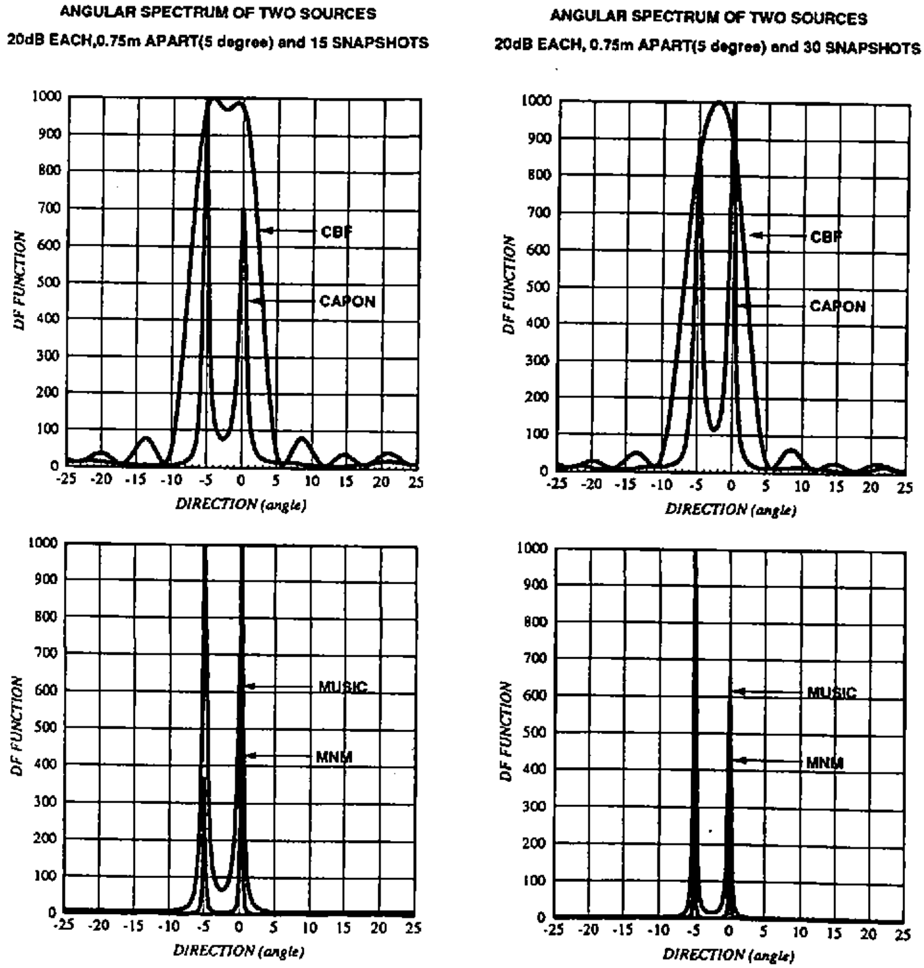
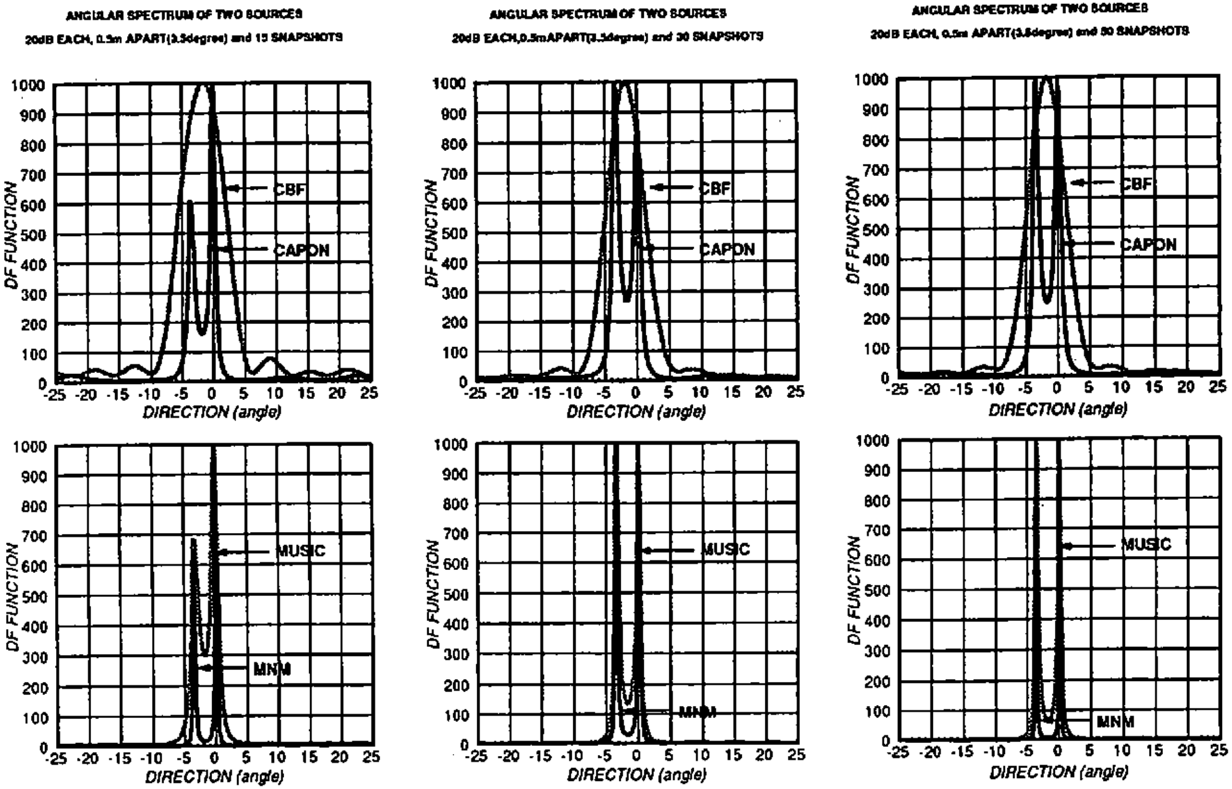

ANGULAR SPECTRUM OF TWO SOURCES
20dB EACH,0.75m APART(5 degree) and 15 SNAPSHOTS
ANGULAR SPECTRUM OF TWO SOURCES
20dB EACH, 0.75m APART(5 degree) and 30 SNAPSHOTS
DF FUNCTION
DIRECTION (angle)
CBF
CAPON
MUSIC
MNM

Figure 4


ANGULAR SPECTRUM OF TWO SOURCES
20dB EACH, 0.5m APART(3.3degree) and 15 SNAPSHOTS
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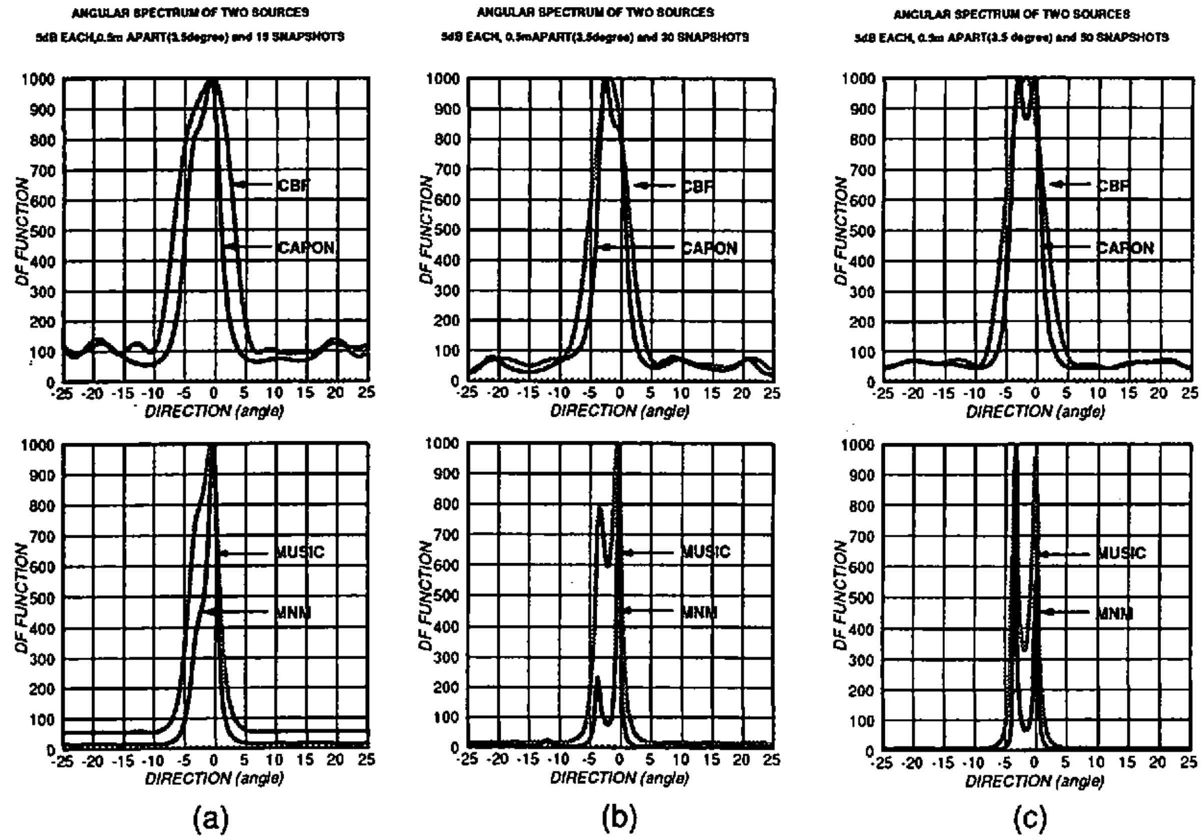
20dB EACH, 0.5m APART(3.3degree) and 50 SNAPSHOTS
DF FUNCTION
DIRECTION (angle)
CBF
CAPON
MUSIC
MNM

(a) (b) (c)

Figure 5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DF FUNCTION
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CBF
CAPON
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MNM
(a)
(b)
(c)

Figure 6