Fundamental Aspects of Netted Radar Systems

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ABSTRACT

Netted radar has a number of inherent advantages that make it attractive for further evaluation. However, it also entails additional complexity and cost. It is therefore important that its true performance potential is established so that the most effective application areas can be determined. Central to this is an understanding of performance metrics normally associated with monostatic radar. These are sensitivity, coverage, range and Doppler resolution, range and Doppler ambiguity, side-lobes etc. In this paper we describe the development of a simulation environment in which all these metrics can be evaluated. It is shown how netted radar differed from its monostatic counterpart in some very basic ways. In particular, in many cases the netted radar becomes a near field sensor requiring significantly different forms of processing. Results of the simulations for sensitivity, coverage etc as a function of network radar parameters including network topology will be given.

1.0 INTRODUCTION

Netted radar employs several spatially separated transmitters and receivers. This topology offers some inherent advantages over the traditional monostatic or bistatic radar, where a single transmitter and receiver are collocated for the former, and are often spatially separated by a distance comparable to the target distance for the later [1] [2].

An advantage of netted radar is the ability to optimize the coverage area. Owing to the use of multiple transmitting and receiving stations, the geometry of the netted radar can be tailored to meet the needs of specific requirements. Combined with suitable data fusion algorithms, extension of the coverage area in a given direction is achievable. Another advantage is the increase of system sensitivity. Due to the additional use of radar transmitters, the received signal power will be augmented, leading to an increase in overall signal to noise ratio (SNR), and consequently system sensitivity. In netted radar cases, the target is observed from multiple perspectives rather than from a single direction. This makes better use of the scattered energy. Target classification and recognition can be improved due to the more information retrieved from different perspectives. Also, the survivability and reliability are improved significantly in netted radar systems. The loss of one or even several stations may not be completely fatal and leads to the concept of graceful degradation, because there are still some other stations working properly. Additionally, the passive operation of receiving stations makes netted radar less vulnerable to physical attacks.

Recent development in relevant technologies such as multi-channel antennas with electronic beam steering, high speed digital processors and computers, transmission lines with high capacity, and precise synchronization systems, give rise to the possible implementation of low cost, coherent, and stable netted radar systems.

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2.0 NETTED RADAR SENSITIVITY

2.1 Background

Radar sensitivity is perhaps the most important parameter used to evaluate the performance of radar systems. It indicates the radar's ability to detect the presence of a target. It is expressed as the received signal to noise ratio, calculated by radar range equation. Normally the minimum acceptable signal to noise ratio can be calculated when both the required probability of detection and the probability of false alarm are given. Radar sensitivity is affected by many parameters, including radar factors, such as transmitted power, antenna gain, transmitted wavelength, etc, which can be managed by radar designers, and other factors, such as target cross section, target distance from radar receivers, etc, which cannot be chosen.

2.2 Monostatic and Bistatic Radar Sensitivity

Monostatic sensitivity can be calculated according to the conventionally used monostatic radar equation [3]. Monostatic and sensitivity plots are shown in Fig. 1 in both two dimensional and three dimensional spaces. In this simulation, the transmitted power is 6 kw and the detection threshold is set as 13db. It is assumed that the target cross section does not change with look angles. Monostatic and bistatic radar sensitivity plots are shown in Fig. 1 and Fig. 2, respectively. Fig. 1 shows that monostatic radar gives a spherical coverage area in three dimensional space, whereas a circular area in two dimensions. This is resulted from the isotropic transmission of radiated energy. Fig. 2 shows that for bistatic radar system, the coverage in the ground plane is elongated, while it is reduced in the third dimension of height.

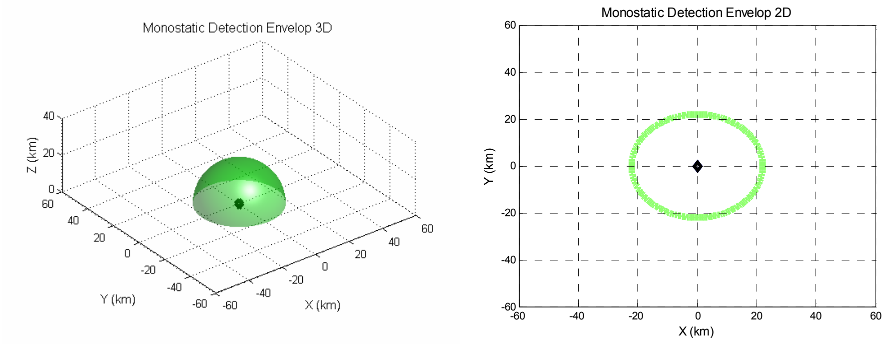

Figure 1: 3D & 2D Monostatic radar sensitivity

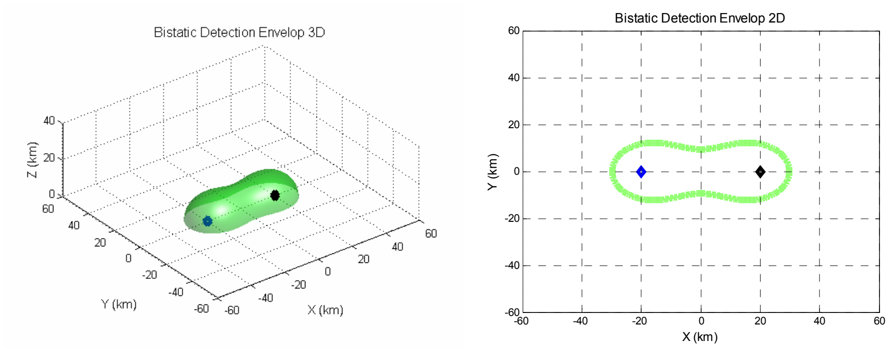

Figure 2: 3D & 2D Bistatic radar sensitivity

2.3 Netted Radar Sensitivity

The netted version of radar equation is developed based on the bistatic radar equation. Fully coherent radar networks are considered, which means the radars comprising the network have a common and highly precise knowledge of time and space. The whole network is composed of m transmitters and n receivers. It is assumed that the radar network is well synchronized such that each receiver is able to receive and process echoes scattered from target due to any transmitter in the network. The total netted radar sensitivity is calculated by summing up returns from every bistatic pairs, which is given by:

$$SNR_{netted} = \sum_{i=1}^{m} \sum_{j=1}^{n} \frac{P_{ti} G_{ti} G_{rj} \sigma_{ij} \lambda_i^2}{(4\pi)^3 k T_s B_i R_{ti}^2 R_{rj}^2 L_{ij}} \tag{1}$$

where
P_{ti} = i th transmitted power
G_{ti} = i th transmitter gain
G_{rj} = j th receiver gain
σ_{ij} = radar cross section (RCS) of the target for i th transmitter j th receiver
λ_i = i th transmitted wavelength
T_s = receiving system noise temperature
B_i = bandwidth of the matched filter for the i th transmitted waveform
L_{ij} = system loss for i th transmitter, j th receiver
R_{ti} = distance from i th transmitter to target
R_{rj} = distance from target to j th receiver

Netted radar sensitivity simulations were then carried out. The radar network is composed of three transmitters and three receivers. The total transmitted power of 6kw is evenly distributed among all three transmitters. All the other key parameters remain the same as previous examples. Netted radar sensitivity plots with varying system geometries are shown in Fig. 3 and Fig. 4 respectively. In Fig. 3, the three transmitter-receiver pairs are dispersed. The coverage area in the first two dimensions is greatly expanded, compared with the monostatic case, because in this netted radar case there are more receivers accepting the reflected echoes. It is shown that netted radar uses the transmitted power more effectively than monostatic radar. In Fig. 4, all the transmitters and receivers are fully dispersed. This gives a further enlarged coverage area in the first two dimensions, and at the same time, the coverage in the third dimension of height is reduced compared with the case shown in Fig. 3, because the total transmitted energies are the same.

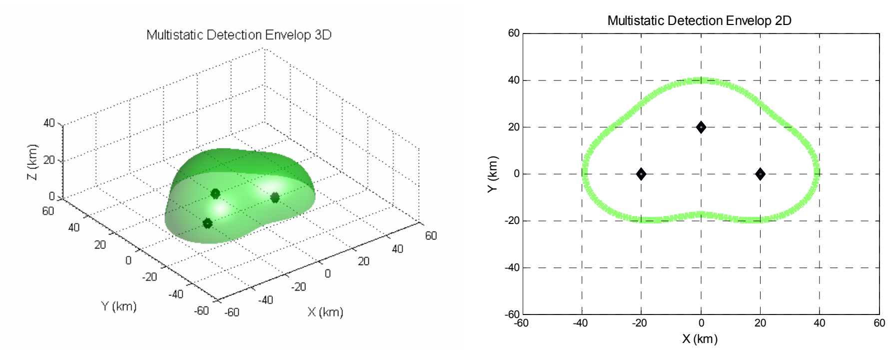

Figure 3: 3D & 2D Netted radar sensitivity-dispersed transmitters & receivers

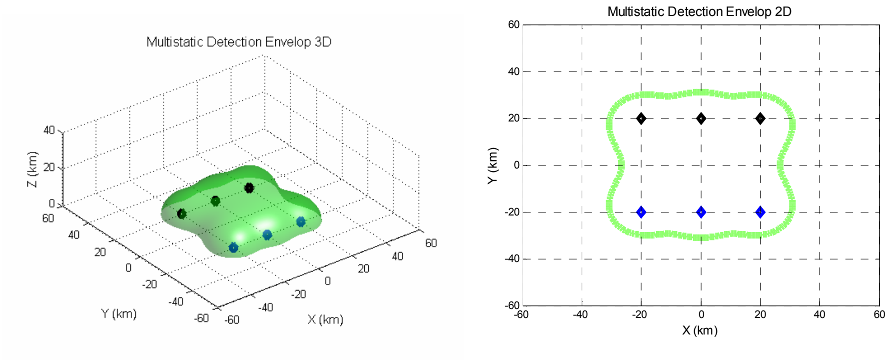

Figure 4: 3D & 2D Netted radar sensitivity-fully dispersed transmitters & receivers

3.0 THE NETTED RADAR AMBIGUITY FUNCTION

3.1 Background

It is widely recognised that the ambiguity function is an important tool to evaluate radar performance in terms of target resolution and clutter rejection. The concept of ambiguity function was firstly defined by Woodward. It can be seen as the absolute value of the envelope of the output of a matched filter when the input to the filter is a Doppler shifted version of the original transmitted signal, to which the filter is matched [4][5]. If *u (t)* is the complex envelop of the transmitted signal, the ambiguity function is calculated by:

$$|\chi(\tau, f)| = \left| \int_{-\infty}^{+\infty} u(t) u^*(t-\tau) e^{j2\pi ft} dt \right| \tag{2}$$

Monostatic radar ambiguity is fairly well developed, and a variety of examples can be found in literature [6]. Bistatic radar ambiguity is developed by Tsao et al.[7].

3.2 Monostatic and Bistatic Radar Ambiguity Function

Monostatic and bistatic radar ambiguity function examples are shown in this section for comparison with netted radar cases. The signal used for ambiguity function simulation is a coherent pulse train consisting of three rectangular pulses with 40 µs pulse length, 100 µs period, and carrier frequency ω_c =3×10^8 rad/s. The target is 60 km away from the receiver with 600 m/s velocity.

Fig. 5 shows the monostatic radar ambiguity function plots, where a sharp main peak appears around the centre of plot, giving good resolutions in both range and velocity domains. Fig. 6 and Fig. 7 show the bastatic radar ambiguity function with different system geometries. The baseline length for this bistatic radar is 100 km. Fig. 6 shows that, when the target is far from the bistatic baseline, the ambiguity diagrams, and therefore, resolutions in both range and velocity domains are not very different from the monostatic counterpart, but when the target is close to the bistatic baseline, both range and velocity resolutions are degraded dramatically. This is shown in Fig. 7. From the above simulations, it is not hard to see that the bistatic radar geometry has a great influence on the shape of bistatic ambiguity function.

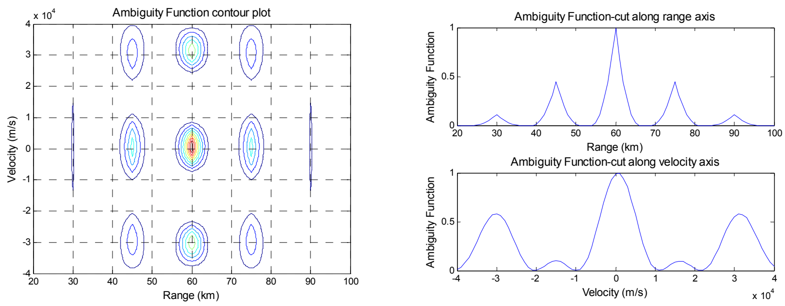

Figure 5: Monostatic radar ambiguity function

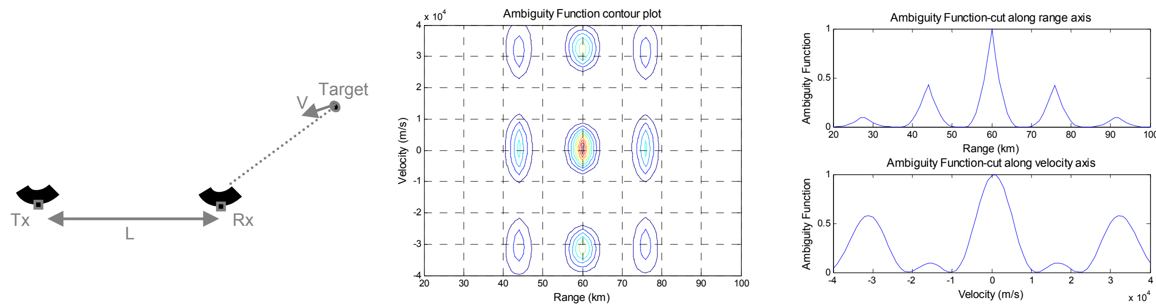

Figure 6: Bistatic radar ambiguity function-target far from baseline

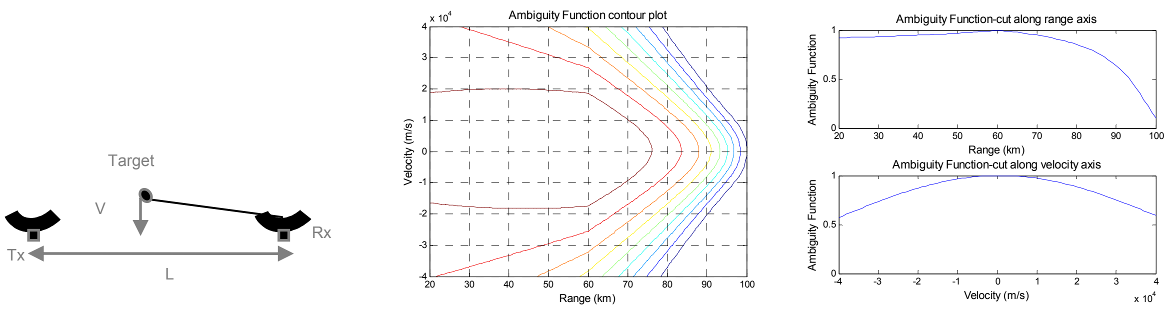

Figure 7: Bistatic radar ambiguity function-target close to baseline

3.3 The Netted Radar Ambiguity Function

Here the netted radar ambiguity function is formulated based on the bistiatic radar ambiguity calculation. It is assumed that the radar network is composed of N transmitters and one single receiver, such that it is easy to choose the receiver as the common reference point. In this case the radar network comprised N bistatic pairs. The analysis is based on the matched filter processing at the receiver. There are some important assumptions for the formulation of netted radar ambiguity function. Firstly, the target is slowly fluctuating and its scattering properties do not change with the look angles. Secondly, the transmitted signals are the same and the filter is matched to the original transmitted signal. A very important assumption is that the network is coherent. This implies that the echoes arriving at different time instances can be processed jointly. Similar to the bistatic radar ambiguity analysis, the netted radar ambiguity is developed by the following three steps:

- To calculate bistatic ambiguity function for each transmitter-receiver pair (2).

- To calculate weighting factor according to received signal intensity.

$$P_{ri} = \frac{P_{ti}G_{ti}G_r\lambda^2\sigma}{(4\pi)^3(R_{ti}R_r)^2}, i = 1,2...N \tag{3}$$

$$w_i = \frac{P_{ri}}{Max(P_{ri})} \tag{4}$$

- To formulate netted radar ambiguity function using the results form previous calculations:

$$\chi_{netted} = \left|\sum_{i=1}^{N} w_i \chi_i\right|^2 \tag{5}$$

A three dimensional netted radar model is developed for a comprehensive understanding of netted radar ambiguity performance. It is assumed that the fixed transmitters and receiver are located in one plane and the target is moving in another plane which is parallel to the transmitter-receiver plane. The three dimensional netted radar topology used for the netted radar ambiguity analysis in the rest of this paper is shown in Fig. 8.

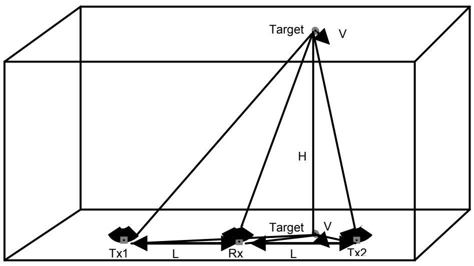

Figure 8: 3D netted radar system geometry

A vectorial approach is used to calculate the two important parameters, delay and Doppler, which are used for ambiguity function calculation.

$$\tau = \frac{\left|\overrightarrow{R_t}\right| + \left|\overrightarrow{R_r}\right|}{c} \tag{6}$$

$$\begin{aligned} f_b &= \frac{1}{\lambda}\left[\frac{d}{dt}(\overrightarrow{R_t} + \overrightarrow{R_r})\right] \\ &= \frac{1}{\lambda}\left[\frac{\overrightarrow{R_t}\cdot\overrightarrow{V}}{\left|\overrightarrow{R_t}\right|} + \frac{\overrightarrow{R_r}\cdot\overrightarrow{V}}{\left|\overrightarrow{R_r}\right|}\right] \end{aligned} \tag{7}$$

where $\vec{V}$ is the target velocity vector, and $\vec{R}_t$ and $\vec{R}_r$ are target to transmitter range vector and target to receiver range vector, respectively.

In the first group of simulation, the baseline is 10 km long; the target is 6 km away from the receiver for the two dimensional geometry with 600 m/s velocity. Fig. 9 shows the two dimensional ambiguity diagrams, while Fig. 10 and Fig. 11 shows three dimensional ambiguity diagrams with a target height of 20 km and 4 km, respectively. Three dimensional examples with different target heights are presented to observe the effect of varying target height on the form of netted radar ambiguity properties.

Fig. 9 illustrates that in the two dimensional netted radar cases, when the target is close to a bistatic baseline, the system resolution in both range and velocity domains deteriorates dramatically. The netted radar system is not capable of resolving target parameters. In Fig. 10, the target is far from the transmitter-receiver plane. Both range and velocity resolutions are improved greatly. However, if the target is not far enough from the transmitter-receiver plane, the improvement is not satisfactory. This is shown in figure Fig. 11. In other words, in three dimensional netted radar cases, the target should be far enough from the transmitter-receiver plane to achieve satisfactory improvement in range and velocity resolution.

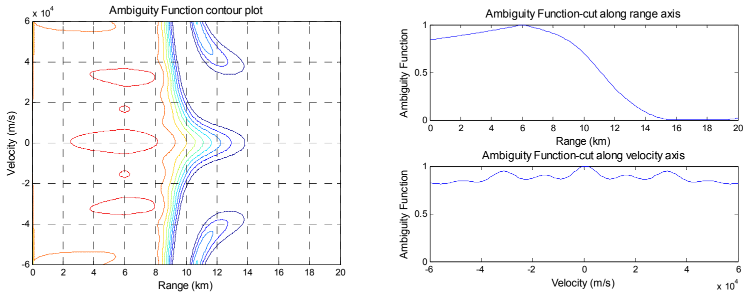

Figure 9: 2D netted radar ambiguity function

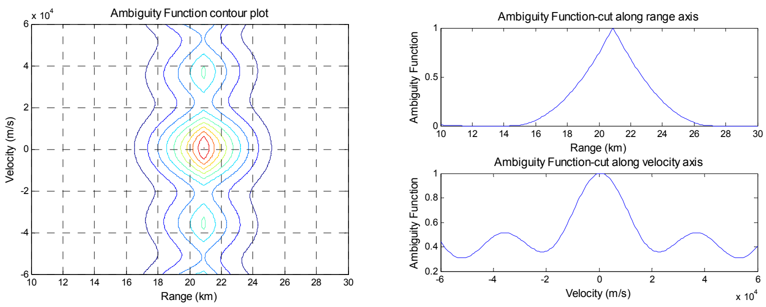

Figure 10: 3D netted radar ambiguity function-H=20km

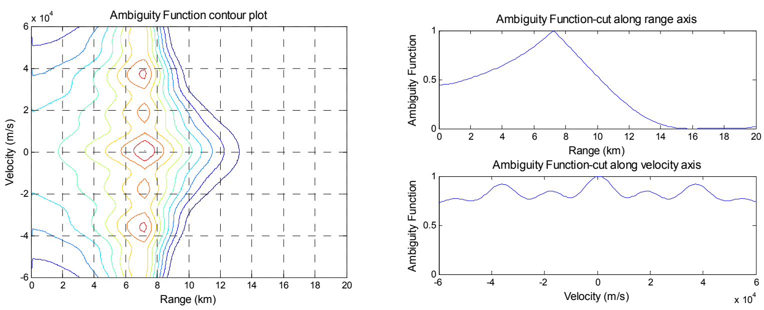

Figure 11: 3D netted radar ambiguity function-H=4km

The following examples show the ambiguity function diagrams of the netted radar with a long baseline, where the baseline length is 100 km, which is 10 times greater than the former examples. In this case, the target is 60 km away from the receiver for the two dimensional case.

Fig. 12 shows the degradation in range and velocity for the two dimensional netted radar case. Fig. 13 shows the three dimensional ambiguity diagrams with a target height of 20 km. It is observed that, although the absolute value of target height is big enough, satisfactory improvement of range and velocity resolution is still not achievable. This is because the relative value of target height is still not big enough; i. e. the target height to baseline length ratio is not big enough.

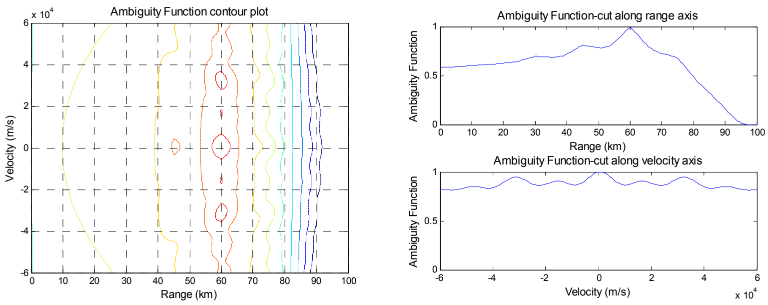

Figure 12: 2D netted radar ambiguity function-long baseline

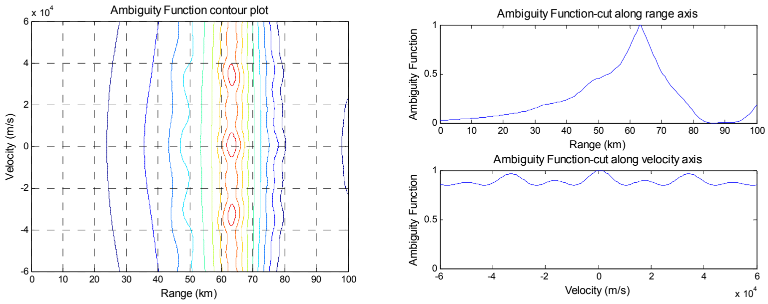

Figure 13: 3D netted radar ambiguity function-long baseline

4.0 CONCLUSIONS

Two important aspects of netted radar systems have been investigated in this paper. They are sensitivity and ambiguity. Mathematical model and simulation results have been shown in both two dimensional and three dimensional spaces.

It has been shown that netted radar sensitivity is not only dependent on radar parameters, but also on system geometry. Netted radar offers more flexible arrangement of system geometry than traditional monostatic systems, leading to the possibility of configuring radar nodes to form a satisfactory coverage area. It has also been demonstrated that the degradation of range and Doppler resolution shown in the two dimensional netted radar cases can be reduced in three dimensional netted radar cases, when appropriated system configuration is selected. The target height to baseline ratio plays an important role in three dimensional netted radar ambiguity performance and short baselines perform better than long baselines. As a result, it is possible to change netted radar parameters to achieve satisfactory range and Doppler resolution.

5.0 ACKNOWLEDGEMENT

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6.0 REFERENCES

[1] V. Chernyak: 'Fundamentals of Multisite Radar Systems', Gordon and Breach Scientific Publishers, 1998

[2] C. J. Baker, A. L. Hume: 'Netted Radar Sensing', IEEE Aerospace and Electronic Systems Magazine, Vol. 18, Issue 2, pp3-6, Feb. 2003

[3] S. Kingsley, S. Quegan: 'Understanding Radar System', McGraw-Hill Book Company Europe, 1992

[4] N. Levanon: 'Radar Principles', Wiley, 1998

[5] P. M., Woodward: 'Probability and Information Theory, with applications to Radar', Pergamon, New York, 1953

[6] N. Levanon, E. Mozeson: 'Radar Signals', wiley, 2004

[7] T. Tsao, et al: 'Ambiguity Function for a Bistatic Radar', IEEE Transactions on Aerospace and Electronic Systems, Vol. 33, Issue 3, pp 1041-1051, July 1997