A radar network using FM radio broadcasters

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Abstract: Most current radar systems are monostatic i.e. the transmitter and receiver are co-located. However, when a target is illuminated by Electro-Magnetic radiation scattering occurs in all directions. Hence a single receiver can only intercept a very small portion of this energy and much of the signal and its information is lost. Netted (or multi static) topologies overcome this limitation and offer the potential to extend the capabilities and performance of current radar systems. In this paper, an introduction to the concept of netted radars is provided. An initial categorization of the types of possible radar networks is introduced. Additionally the ambiguity function is described for both monostatic and bistatic geometries and is used as the basis for calculating fundamental performance limitations of a passive system using FM broadcasters.

1. Introduction.

It is well known that when a target is illuminated by Electro-Magnetic radiation scattering occurs in all directions. Hence the single receiver of a monostatic radar system can only intercept a very small portion of this energy. Netted topologies overcome this limitation by using a number of transmitters and receivers and hence offer the potential to extend the capabilities and performance of current radar systems. In the most general case of a netted system, multiple transmitters and receivers are used and the echoes from the target in different directions are collected. In essence, with multiple transmitters and receivers one can have many perspectives of the same target and can exploit, in an optimum way, the scattered electromagnetic energy.

There are a number of advantages that this provides. For example spatial distribution of the nodes of the radar network enables the area to be surveyed and to be tailored according to the specific application. Additionally, it is possible to increase sensitivity, as more of the scattered energy (in the different directions) can be collected and hence detection performance can be improved. Target classification and recognition can also be enhanced. This is because the target is observed from different perspectives. Increased survivability and reliability is also achieved because of the 'silent' or passive operation of the receivers. These receivers can improve the location accuracy of possible jammers by fusing the information from the network nodes. Often monostatic radar systems do not have line of sight to a target and hence cannot provide detections. The likelihood of obtaining a line of sight is greatly improved in a network. Finally, if a single node is lost in the network it can still provide a level of (reduced) performance and the network is said to exhibit graceful degradation.

Finally, range and Doppler resolution are fundamentally important parameters in the design of any radar system as they govern the ability to distinguish between two or more targets by virtue of spatial or frequency differences. The nature of the transmitted waveform determines these properties which may be evaluated via the ambiguity function. In literature it has been proposed to use illuminators of opportunity [1] in order to form a radar network. In the case where FM broadcasters are used as the transmitters of the system, the waveform is not in the control of the radar designer.

2. Categorisation of radar networks.

The first aspect in this categorization is the transmitting and receiving options of the nodes in the network. There are three main categories: monostatic, bistatic and a combination of the two. In the multiple monostatic case, each radar system is transmitting a specific signal and receiving only the echo originating from its own station. An example of the multiple bistatic case is a network comprising one common emitter and N spatially separated receivers. Each transmitter-receiver pair is a bistatic radar. Lastly, a combination of these is possible, where in the most general case each node in the network has a transmitter and a receiver. Each receiver can accept echoes reflected from any transmission.

Another feature of multisite radars is topology. This concerns the location of the radar nodes comprising the overall system [2]. The radar network can be a ground based multisite radar system with fixed baselines. This does not imply that the system components cannot be relocated. It does however, make the point that a fixed configuration is important in that the relative positions of the nodes need to be known to a high degree of accuracy. If the ground nodes can move, the baselines change. This mobility introduces more degrees of freedom but also increases complexity (i.e. we still need to know where the nodes are and at what time). Another approach is to locate only the transmitters on an air or space platform and the receivers on the ground. This can be taken further with both the transmitting and the receiving stations located on a platform that is entirely airborne or space borne [3].

The last example implies a further degree of categorization: i.e. active and passive modes of operation. The active mode is used to locate non-cooperative targets. It’s also possible to have many spatially separated receivers collecting radiation emitted from other sources. This system is therefore operating in a passive mode. It should be noted that this type of operation is useful for locating jamming sources. Also, a combination of these two modes can be employed. Indeed the distinction between radar and ESM systems becomes very blurred.

An important aspect in netted radars is coherency. Information extraction in coherent networks is enhanced significantly when compared to non-coherent systems. Temporal coherence, which may be achieved with GPS time transfer or via an atomic clock, will be examined in a later paper.

A final discrimination of netted radar systems is in terms of the distributed aspects of radar signal processing characteristics. The main categories are centralized and decentralized (distributed) processing for netted systems. There are several parameters to be taken into account when examining the distribution characteristics [4]: the sensitivity and the robustness of the network and the grouping of the measurements from each radar system. Sensitivity of the system is related to the communication capacity capabilities of the network. The more data (i.e. energy) that can be sent, the better the overall sensitivity and the more centralized the system. This though, requires wideband transmission which may be prohibitively expensive. Alternatively each radar can perform some pre-processing of the data before transmitting to the central station. These results are sent to the central station for fusion, where the final processing and decision making is carried out. This is decentralized processing.

3. Ambiguity function.

The ambiguity function has been widely recognized as a very important tool for radar signal design and for quantitatively assessing the performance of a system in terms of range and Doppler ambiguities and range and Doppler resolution. It is formed from the output of a matched filter in the receiver. The input signal is a copy of the transmitted one but shifted in the frequency domain due to the Doppler Effect. Thus the output is:

$$X(\tau,\nu)=\int_{-\infty}^{\infty}u(t)u^{*}(t-\tau)e^{j2\pi\nu t}dt \qquad (1)$$

where $u(t)$ is the complex envelope of the transmitted signal, τ is the expected delay of the original signal and ν is its Doppler shift. The ambiguity function is defined as $\left|X(\tau,\nu)\right|^{2}$.

The original formulation of the ambiguity function was calculated by Woodward [5]. Here we introduce the ambiguity function for monostatic radar to indicate the features that must be preserved in a netted formulation. Figure 1 illustrates typical properties of a monostatic ambiguity function.

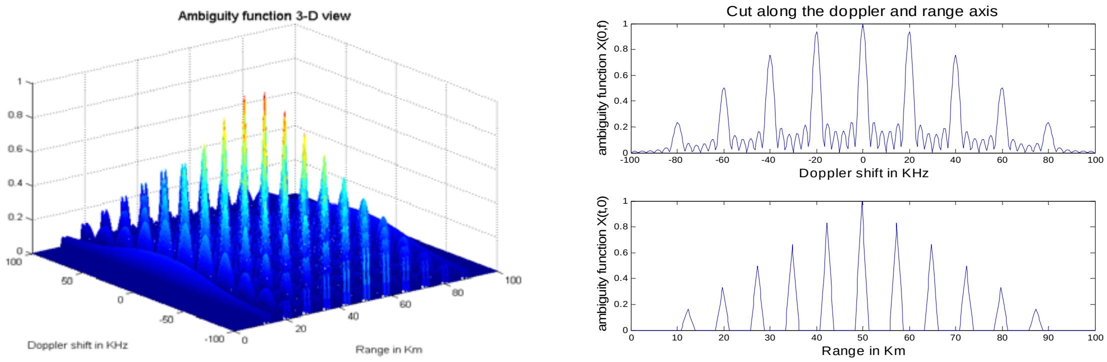
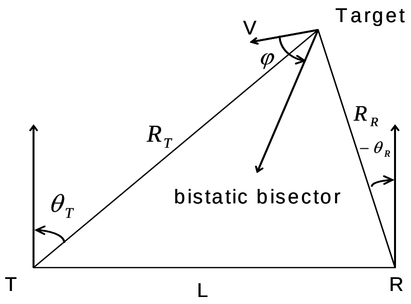


Figure 1: Stepped frequency pulse train (10µs pulse duration). 3-D plot and cut along the Doppler and Range axis. Stationary target at 50km.

The main peak of the ambiguity function corresponds to the resolution of the system in terms of range and Doppler. The additional peaks correspond to potential ambiguities, resulting in confusion at choosing the correct range of the target and its velocity.

The next step is to examine the bistatic configuration. This analysis is based on [6] and stresses the importance of target location in determining the shape of the bistatic ambiguity function. Figure 2 illustrates a typical bistatic geometry and the bistatic ambiguity function.



$$X(T,\omega_D)=\int_{-\infty}^{\infty} u(t)u^*\big(T(R,\theta_R,L)-t\big)e^{j\omega_D(R,\theta_R,L,V,\varphi)t}\,dt \tag{2}$$

Figure 2: Bistatic topology and bistatic ambiguity function.

The results from calculating (2) for a number of possible geometries are presented in Figure 3.

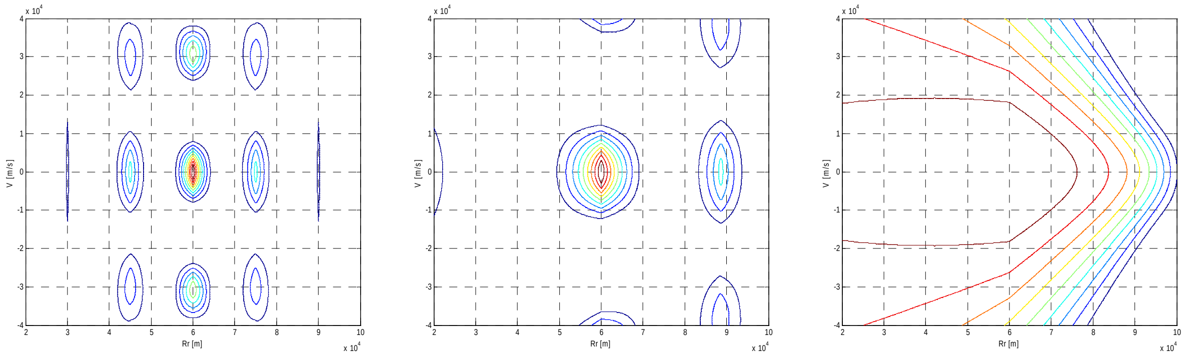


Figure 3: Coherent pulse train. L=100km (a) θ_r=90^0 (b) θ_r=-45^0 (c) θ_r=-90^0.

It is evident that target's location is crucial for determining the output of the matched filter. For case (a), the bistatic system is responding in the same way as a monostatic one. Decreasing θ_r (b) though results in inferior resolution in range and Doppler. Especially in the case where the target lies in the transmitter-receiver baseline (c), the information extraction is impossible. This will also be a characteristic of netted radar systems and must be catered for in any mathematical formulation and in the design of real systems.

4. FM broadcasters.

As stated before, the waveform of the radio signal determines the range and Doppler resolution of the system. In a particular case we used the FM broadcaster in Alexandra Palace and placed the receiver in UCL. Afterwards we simulated the change of the resolution for this bistatic geometry, comparing it with the case of monostatic system (the receiver co-located with the transmitter). Figure 4 presents the changes in range resolution as a function of the target position. Values from 0.66 to 1 correspond to resolution of up to one and a half that of a monostatic system. Values from 0.33 to 0.66 correspond to resolution of one and a half up to three times that of a monostatic case. This shows that there are significant areas where the resolution is severely degraded, especially close to the baseline.

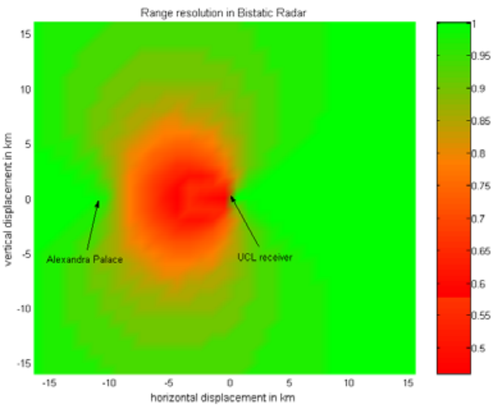


Figure 4: Range resolution degradation with one Tx.

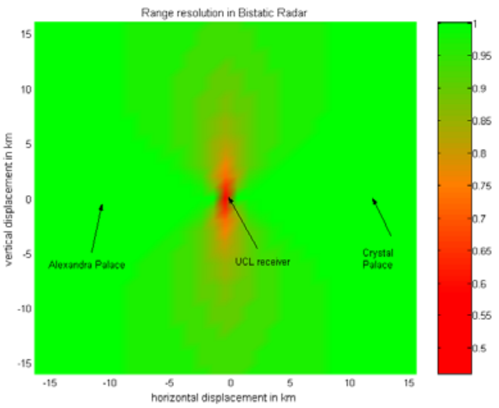


Figure 5: Range resolution degradation with two Tx.

This would seem to be a significant limitation of this approach. However, it should be borne in mind that it is quite likely that multiple transmitters will be exploited and their spatial spread will alter the simple bistatic case considered above. Figure 5 shows an extension to this simple case. Here the transmitter at Crystal Palace had been added to our example system. The geometry has been adjusted from the true case to make the second transmitter lie along the baseline (which is quite close to the actual geometry). For simplicity the same frequency of operation and waveform properties are assumed for both Alexander Palace and Crystal Palace transmissions. Figure 5 shows that the area from 0.66 to 1 is now extended and the regions of 'no-go' are very limited. This illustrates two important points. The first is that multiple transmitter sites can be used to improve the overall range resolution performance. The second is that this performance is still very much governed by the location of the additional broadcasters and is a function of the angles made by the multiple baselines. Figures 6, 7 show similar behaviour for Doppler resolution. Note here, though, that the degradation in resolution is much more severe and the addition of the second transmitter has correspondingly greater benefit.

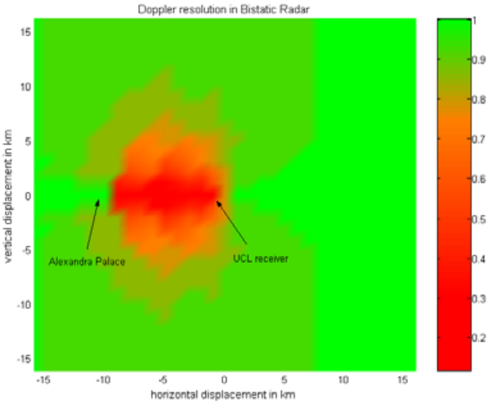


Figure 6: Doppler resolution degradation with one Tx.

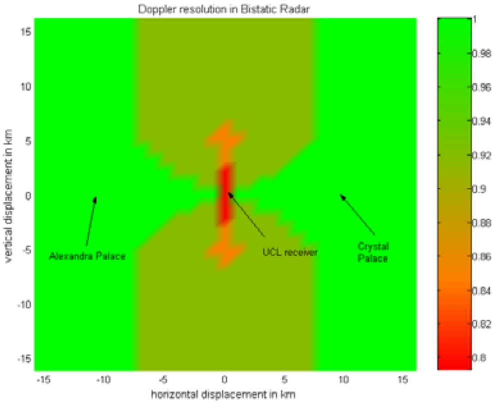


Figure 7: Doppler resolution degradation with two Tx.

5. Conclusions.

In this paper we have reviewed netted radar outlining the performance advantages. The different types of possible networks have been identified and a set of categorisations was developed. We have also highlighted the utility of the ambiguity function as a tool for determining ambiguity and resolution properties in range and Doppler. This is greatly complicated in the case of netted radar with target position influencing the ambiguity behaviour. Finally the case of using FM broadcasters as illuminators of opportunity was examined, indicating the importance of their location on the system's resolution.

Acknowledgments.

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