EVALUATION AND ANALYSIS OF ARRAY ANTENNAS FOR PASSIVE COHERENT LOCATION SYSTEMS

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ABSTRACT

For a radar receiver to be more effective, engineers need to increase their knowledge of antenna. coverage and resolution. However, passive receiver systems are a relatively uncommon with more interest having been placed in signal processing rather than antenna design. Since passive radar systems typically exploit commercial TV or FM broadcasts, traditional Yagi antennas had been acceptable, since these are generally used for a television broadcast reception. This paper pursues a host of alternative array systems for the purpose of enhancing the direction of arrival ability in passive radar systems.

INTRODUCTION

Radio Detection and Ranging *(Radar)*, is a well known technique for detecting distant objects based on radio waves reflected from their surfaces. *Monostatic Radar* operates by radiating energy into space and detecting the echo signal reflected from an object back to the same location [i]. *Bistatic Radar* is similar except that the transmitter and the receiver are at two separate locations, with either or both of these locations changing with time [ii]. When two or more receiving sites with common spatial coverage are employed, and data from objects in the common coverage area are combined at a central location, the system is called *Multistatic Radar* [iii]. *Passive Radar*, on the other hand, uses a transmitter of opportunity, possibly another radar, to detect and locate objects near the transmitting or receiving site. The trendy *Passive Coherent Location (PCL)* can be classified as a form of passive bistatic radar, bistatic radar net, or multistatic radar, which uses commercial broadcast signals such as television (TV) or Frequency Modulation (FM) signals. The basic configuration of passive radar is illustrated in Figure 1.

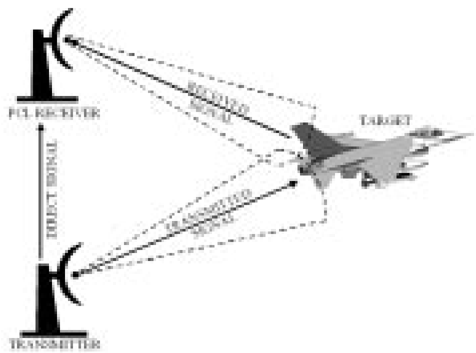

Figure 1: Basic Passive Radar Geometry

PROBLEM

The two fundamental parameters for an antenna design which are directly concerned with the effectiveness of any receiver system are coverage and angular resolution. To understand the effect of an antenna on bistatic receiver coverage, it would be appropriate to look at the bistatic radar range equation. The radar range equation for a bistatic case [iii] is:

$$(R_T R_R)_{max} = \left[\frac{P_T G_T G_R \lambda^2 \sigma_B F_T F_R}{(4\pi)^3 k T_S B_n (S/N)_{min} L_T L_R} \right]^{1/2} = \kappa \quad (1)$$

where, R_T = transmitter-to-target range, R_R = receiver-to-target range, P_T = transmitter power output, G_T = transmitting antenna power gain, G_R = receiving antenna power gain, λ = wavelength, σ_B = bistatic radar target cross section, F_T = pattern propagation factor for transmitter-to-target path, F_R = pattern propagation factor for receiver-to-target path, k = Boltzmann s constant, T_S = receiving system noise temperature B_n = noise bandwidth of receiver s predetection filter, sufficient to pass all spectral components of the transmitted signal, $(S/N)_{min}$= signal-to-noise power ratio required for detection, L_T = transmitting system loss (>1) not included in other parameters, L_R = receiving system loss (>1) not included in other parameters, κ = bistatic maximum range product.

From this equation we conclude that the receiver antenna gain is proportional to the square of range which defines the coverage. In the conventional radar case, this dependency is twice that of the bistatic case [iv]. Because of this dependency, the receiver antenna gain is considered essential for a better bistatic radar coverage area.
For the passive radar case the received power can be represented as

$$P_R = P_T + P_{L1} + G_T + P_{L2} + G_R \tag{2}$$

where, P_R = Received power, P_T = Transmitter power, P_{L1} = Path loss (transmitter to target), G_T = Gain of target, P_{L2} = Path loss (target to receiver), G_R = Gain of the receiver.

In this equation, a parameter we can easily control is the antenna gain. Increasing the gain of the antenna will automatically increase the received power, which will increase the range of the system respectively.
The angular resolution is another important parameter for a radar receiver, and of course for a passive bistatic system. Resolution [iv] i.e. the ability to recognize closely spaced objects is directly related to the electrical size of an antenna In other words, the larger the electrical size, the better the resolution of that antenna. Of course the size of the radar antenna measured in wavelengths is inversely proportional to its beamwidth and hence determines the radar s angular resolution.

As stated previously, for a radar receiver to be more effective, engineers need to increase their knowledge of coverage and resolution. But passive receiver systems are uncommon and more effort has been placed in signal processing rather than antenna design. Traditional television broadcast type Yagi antennas were used, since passive systems exploit commercial TV or FM broadcasts. As we know, using more elements in an *array antenna* design, will increase the gain or narrow the main beam, which will help improve the performance.

In passive systems, the Directional Of Arrival (DOA) estimation in azimuth has always been the a major focus for engineers. DOA estimation is done by different techniques, such as Conventional Beam Forming (CBF), Multiple Signal Characterization (MUSIC) or Analytical Constant Modulus Algorithm (ACMA). For these DOA estimation techniques, interferometry is the common method to acquire the incoming signal. Of course. since interferometry depends on the difference of incoming signals, the receiver should have at least two channels. By using an array antenna, the number of receiver channels can be increased and thus will provide more accurate DOA results.

In addition to the obvious result of increasing the number of the array elements (increasing the electrical size of the antenna) causing the main beam to narrow, resulting in increased angular resolution, this will allow engineers to take advantage of the DOA estimation techniques such as MUSIC or ACMA. Furthermore, using an arrays will afford the use of some array attributes such as sidelobe reduction techniques, super directivity, etc., which will result in even better performance. Also, the increased number of channels will acquire more information about the received signal, which will improve the precision within the receiver system.

METHODOLOGY

There are several variables that directly have an effect on the objective functions that will be mentioned in this section. Several variables that can be exercised in NECWin Plus, which was the main antenna software used for this work, can be categorized as: Element Shape, Element Material, Element Spacing, Sub Arrays, Media, Sidelobe Level, and Diameter.

In this work, array antenna designs are analysed and are evaluated for passive systems with regard to DOA estimation in azimuth. Different element configurations and spacings, and the various excitation phases and amplitudes of the individual elements will be examined in a typical linear array antenna designs. The effect of changing variables- such as length and the diameter of the elements, element materials, different element shapes, different media, etc.- while designing a linear array antenna will be studied thoroughly.

A passive radar system has requirements of the antenna design. Some typical desirable features are:

- √ *Broadband* - i.e. we want this antenna to exploit FM frequency emissions that are from 88MHz to 108MHz,
- √ *High Gain or Directivity* — since the peak power of a passive system is noticeably low compared to typical radar peak power, we need the antenna to have higher gain to overcome this handicap,
- √ *Low Sidelobes*,
- √ *Low cost* — since one of the intended side benefits of a passive system is its low cost, designers usually prefer to build a low cost antenna within the receiver system.

For the antenna array, and for the structure as a whole it should be:

- √ *Able to steer nulls at jammers, interferers, direct breakthrough from the transmitter,*
- √ *Able to make accurate measurements*,
- √ *Covert* - i.e. we don't want to be obvious as to what frequencies we are using or which transmitters we are exploiting. Possibly a radome can solve this problem; or hiding the receiver antenna in existing buildings can achieve this. In that case we could use very large antennas, including vertical apertures.

Under these constraints and after studying current antenna designs, phased array antennas, are analysed for a possible passive radar system. In this work, the configuration is fixed horizontal, linear since the area of interest is DOA estimation in the azimuth. Initially, only equally spaced elements are studied for array structures. However, because Sidelobe Level (SLL) Reduction is an important issue for passive systems, array designs with non-uniformly excited elements will be of significance as well. Since broadside arrays are most desired phased for this application, only broadside arrays were studied.

CONCLUSION

There are many advantages of using an array antenna for a passive radar system. However, because the array antenna for such a system theoretically functions as *a receiver only phased array antenna*, there are some slight differences. Considering these important and useful advantages, using array antennas for passive radar systems instead of traditional Yagi Uda antennas is an obvious engineering advantage.

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