Dual Antenna Array for Radiolocation of RCIED Trigger

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***Abstract*— We describe a dual-antenna design for use in radiolocation of remote controlled improvised explosive device (IED) triggers in the 136-174 MHz frequency band. Each antenna array consists of 8 dipole-fed corner reflector antennas mounted in a circular array, radiating mainly in azimuth and elevation planes respectively. Received signal from the two arrays are downconverted to baseband using an RF front end and passed onto an FPGA for further processing. The FPGA implements an amplitude comparison algorithm to estimate the direction of arrival of the signal and returns the co-ordinates (θ, ϕ). We have simulated and studied the error performance of antenna as a function of angle and distance to the antenna.**

Keywords—Dual circular antenna, Direction-finding, Amplitude comparison, Direction of arrival

I. Introduction

Radiolocation of remote-controlled improvised explosive device (RCIED) trigger is a ubiquitous problem in modern warfare. In the simplest form, trigger location consists of listening onto the radio signal at appropriate frequencies either by scanning a highly-directional antenna or an antenna array and estimating the angle of arrival (AOA) of the signal. There are various techniques to locate the presence of a malicious signal in the remote area but many of these fail to locate the RCIED transmitter itself. This is due to the fact the signal emitted from an RCIED trigger is active only for a time interval of 2-3 milliseconds making acquisition and tracking difficult.

In this work, we describe the design of a dual-antenna array to estimate AOA from an RCIED in the 136-174MHz frequency range. Our design is suitable for those systems in which the IEDs are triggered using wireless signals. Due to two antenna arrays, each radiating in orthogonal planes, we are able to estimate the AOA in both azimuth and elevation angle coordinates. The AOA is estimated by using an amplitude comparison algorithm [1], implemented on an FPGA (Xilinx V5). The algorithm allows estimation of location of trigger to within 1^0 of resolution. Due to the high-speed FPGA, the total computation time of the algorithm is 50 µs which in turn

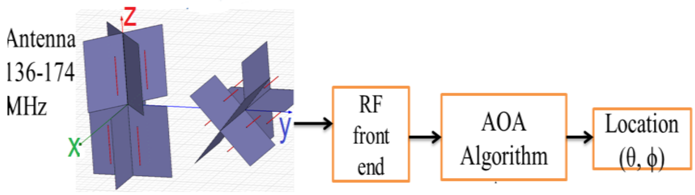

Figure 1. RCIED Detection Block Diagram

enables tracking of the RCIED trigger or locate multiple RCIED triggers in quick succession.

II. ANTENNA DESIGN

The antenna should be capable of detecting RCIED trigger located in a superposition of azimuth and elevation planes at a frequency range of 136-174MHz. We propose the use of two circular arrays of 8 dipole-fed corner reflector antennas. Signal received by the two arrays are processed simultaneously inside the FPGA to find out the angles of arrival (θ, ϕ). A block diagram of our system is shown in Fig.1.

We use amplitude comparison algorithm to estimate the angle of arrival signal. That is based on rotated lobe theorem [2] of identical directional antennas placed in such a way its 3 dB bandwidth overlap. We placed all 8 identical antennas at 45^0 shifted angles to each other in circular array. Gain pattern of the antenna array is obtained by repeating the gain pattern of the single-antenna at intervals of $N \times 45^0$, where N=0, 1. . , 7.

Due to the overlapping of gain pattern of antennas in the array, part of the RF signal impinging on one antenna, say A_1, also strikes the neighboring antennas, say A_2, as shown in Fig. 2. We divide the received power of both the antennas and compare the ratio with pre-calculated gain ratios of antennas in its overlap region. The pre-calculated gain ratios are stored in a lookup table in the FPGA memory to speed up the calculations. The direction of arrival corresponds to the particular coordinates (θ, ϕ), for which the ratio of the measured gain power matches with the pre-calculated gain ratio.

$$R = \frac{P_2}{P_1} = \frac{G_2(\theta,\emptyset)}{G_1(45-\theta,\emptyset)}.$$

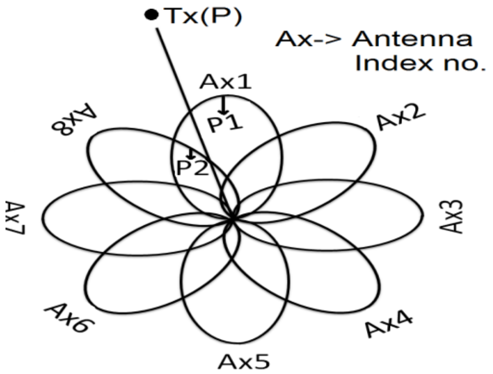

Fig. 2. Gain of individual 8 identical antennas placed in a circular array

For the amplitude comparison algorithm to be efficient, the design should be such that all antennas in both the arrays are highly directive and the radiation pattern of adjacent antennas should overlap. While the dipole antenna is the most suited choice for operation in the VHF band, radiation pattern of the dipole is not directive. To obtain high directivity, we use reflectors at 90 degree. But due to the use of reflectors, gain pattern of adjacent antennas do not overlap. To solve this problem, we design the circular array in two parts, each part consisting of four antennas. Both parts are arranged such that the adjacent antenna radiation patterns overlap.

The first circular array radiates in the azimuth plane and is used to estimate AOA over the entire 360^0 range. The second circular array radiates in the elevation plane and is used to estimate the AOA in the entire 180^0 range. The radiation pattern of both the circular arrays is shown in Fig.3.

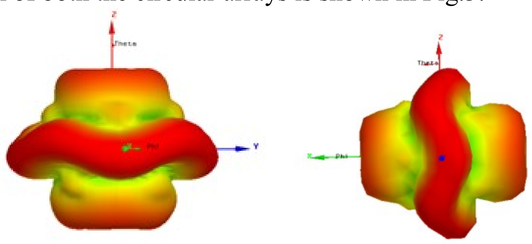

Figure 3. Radiation pattern of dual-antenna circular array.

For simulation, we assume both circular arrays have Gaussian current and field distribution and all antennas in circular arrays operate independently. To verify this assumption, we calculate the coupling between all antennas. The coupling inside one array is -40dB and cross-coupling between the two arrays is approximately -40dB, when distance between the two arrays is greater than 2m.

Fig.4(a) shows a plot of the gain pattern of the antennas excited individuly. All antennas in circular array are placed at multiple of 45^0 , staring from 0^0.

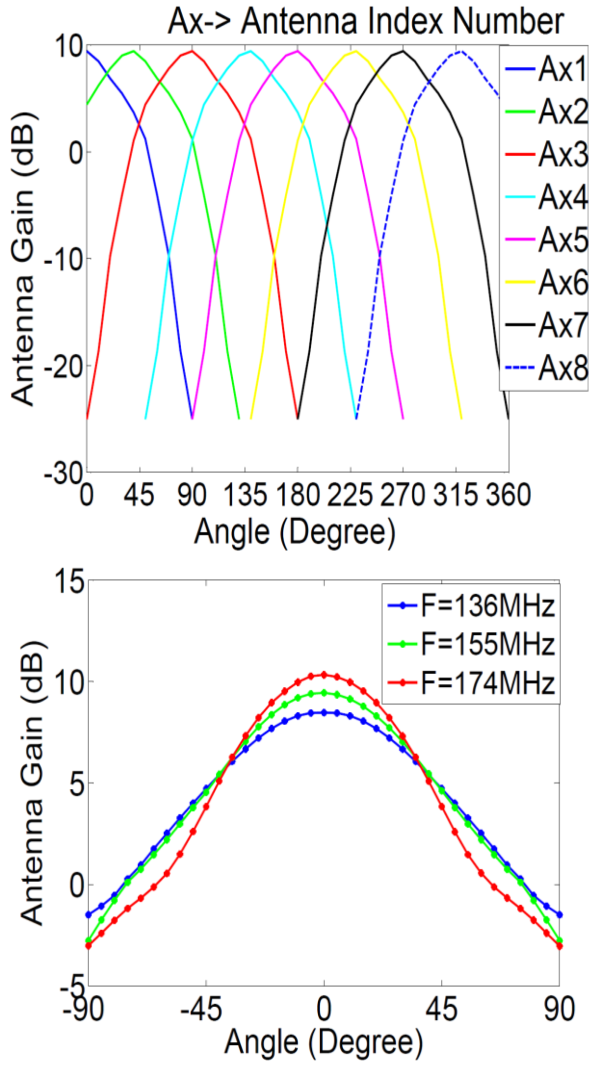

Figure 4 (a) Gain pattern of all the antennas (b) gain pattern at different frequencies.

Fig. 4(b) shows the gain pattern of an individual antenna at frequencies 136, 155, and 174 MHz. Due to change in frequency, beamwidth of the antenna changes which in turn introduces errors in AOA.

We calculate error at different frequencies by placing one transittter in space at $\theta=50^0$ and $\Phi=140^0$ with respect to the origin. By applying the amplitude comparsion algorithm we find the error in θ and Φ. Fig. 5(a) shows the transmitter position in between both circular array. The antennas receiving first and second maximum power is shown in Fig. 5(b).

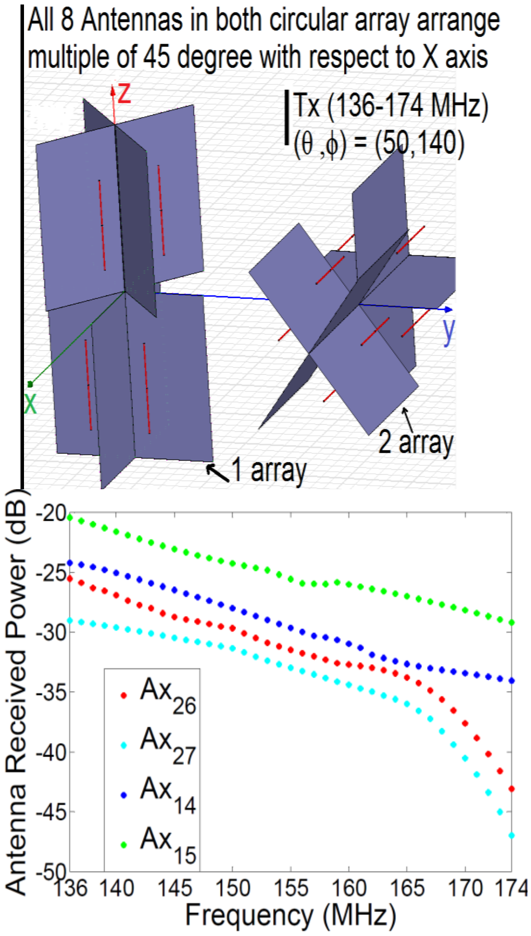

Figure 5. (a) Both arrays receive signal from transmitter (b) **Antennas receiving first and second maximum power from both arrays.**

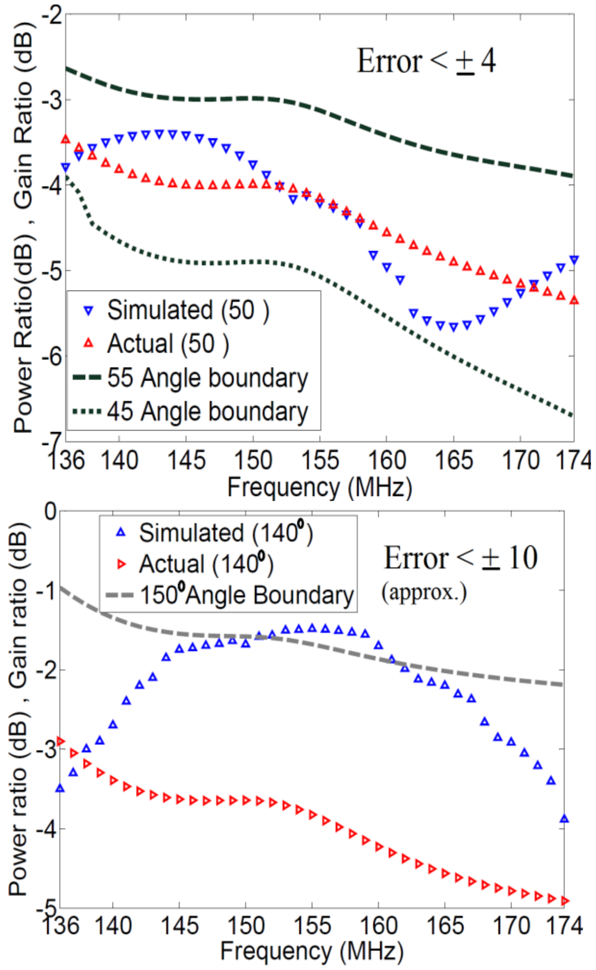

Figure 6. (a) Error in θ calculated from second array (b) Error in Φ calculated by first circular array.

In Fig. 6(a) and (b), we show the simulated ratio of antenna power and the estimated gain ratio of antennas from the radiation pattern. We can estimate the errors in θ and Φ.

Figs. 7(a) and (b) show the error in estimation of AOA [3] for the case when antennas receive signal from same plane as its radiation pattern and when antennas receive signal from a plane perpendicular to its radiation pattern. As expected, error is higher in the second case compared to the first.

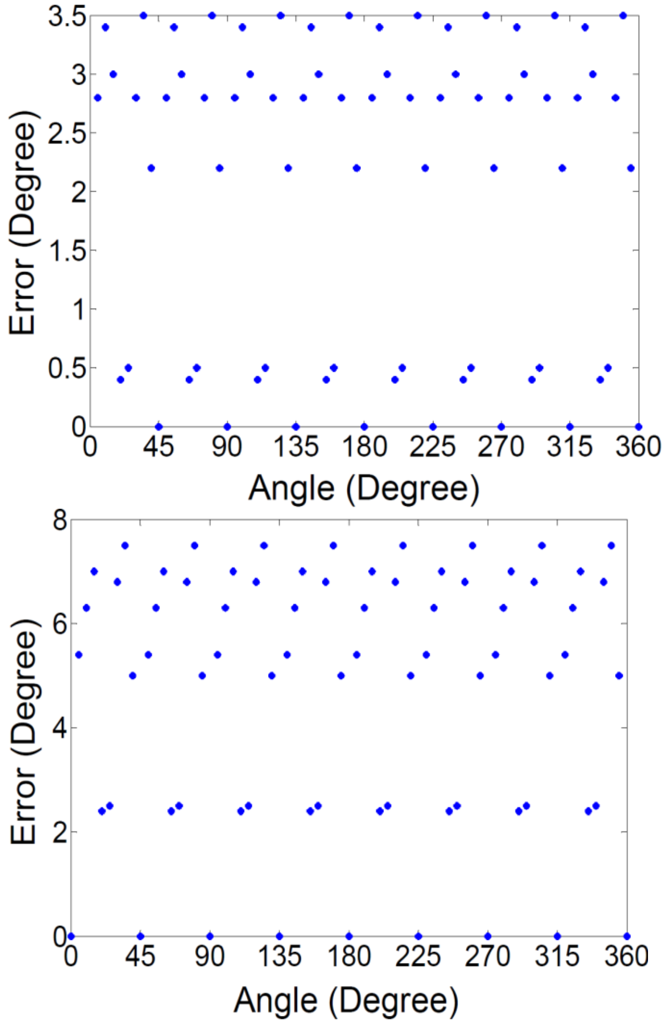

Figure 7. Error in AOA when transmitter is located in the (a) same plane as the radiation plane of antennas (b) plane perpendicular to the radiation plane of the antennas.

This is due to the mismatch between distance between the antennas to its adjacent antennas from the transmitter end as 4 antennas are placed up and the remaining 4 antennas are placed below.

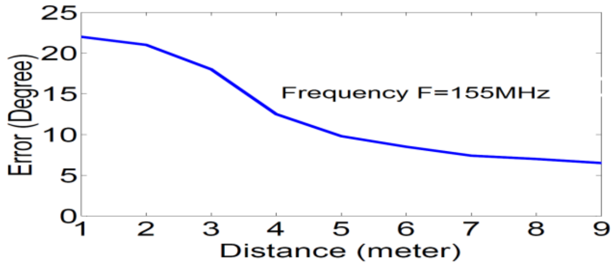

Figure 8. Error due to placing of the transmitter in the direction perpendicular to radiation pattern of the antenna.

Fig. 8 shows that error decreases as distance from the transmitter increases. This is due to the fact that at larger distances, the upper and lower antennas are almost equidistant from the target.

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