Investigating jammer suppression with a 3-D staring array

J Liu*, A Balleri*, M Jahangir†, C Baker†

**Centre for Electronic Warfare, Information and Cyber, Cranfield University, Defence Academy of the UK Shrivenham, SN6 8LA, UK, a.balleri@cranfield.ac.uk*
†Aveillant Limited, UK {mohammed.jahangir, chris.baker}@aveillant.com

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Abstract

A 3-D staring radar operates by using a wide beam transmitter to illuminate the entire surveillance region and generates multiple receive beams using a 2-D static array that can be digitised at element level. The sensor achieves permanent search in all directions and harnesses the spatial, temporal and spectral domains to improve detection and discrimination of low observable, highly manoeuvrable targets in congested air space against strong non-stationary clutter. While the susceptibility of traditional scanning radars to jammers has been well researched, very little work has been carried out to assess the performance of 3-D staring radars in the presence of an interference source. In this paper, the response of a staring array radar to a jammer is modelled. Results are presented showing that by exploiting the persistent dwell time of the staring array, it is possible to achieve effective jammer suppression using null steering or similar techniques.

1 Introduction

Aveillant Ltd has built an L-band, single transmitter, multiple receiver, static array radar to provide wide-area, multi-beam surveillance of air and ground targets [1, 2]. The staring array architecture enables the sensor to form multiple independent reconfigurable narrow beams on receive that allow the radar to perform multiple simultaneous functions.

With no requirement for time-sharing and prioritisation, staring array radar can acquire and establish multiple tracks earlier and faster than other conventional scanning radar [3]. They can provide continuous monitoring and surveillance in the required search volume since they are continuously looking everywhere, all the time, unlike a scanning radar. This increases system update rate and improves tracking and imaging performance. In addition, staring array also provide a longer observation time required for Non-Cooperative Target Recognition (NCTR) without affecting other functions, and they are considered a “Lower” Probability of Intercept (LPI) radar due to the low gain transmit antenna [4].

The environment in which radars operate is inherently noisy due to the presence of unintended or hostile interference sources like navigation (e.g. GPS), communication (e.g. Radio), nearby radars or intentional jammers. All radars are susceptible to Electromagnetic Interference (EMI) and different radar architectures necessitate different Electronic Defence (ED) techniques for protection. While the susceptibility of traditional radars and adopted ED techniques have been well researched, the performance and impact of jamming sources on such a single-transmitter multiple-receiver digital phased array radar have not been investigated. Consequently, there are no ED techniques developed and implemented to improve resilience yet. Therefore, the performance of the Aveillant Holographic Radar in the presence of interferences needs to be investigated so as to develop an effective, simple and low-cost ED technique that can be easily implemented onto existing software architecture without affecting its commercial feasibility [1][5].

Of the 4 types of phased array architecture known today [6], both the Active Electronically Steered Array (AESA) radar [7][8][9] and Aveillant Holographic Radar [1][10] belong to the most advanced element-level digital architecture. The persistence dwell of the staring array may offer some unique advantages with regards to resilience to jammers. The paper presents results showing that jammer suppression can be obtained with a staring array using a combination of digital adaptive beamforming and phase monopulse. The solution is such that can be applied in post signal processing and does not require significant hardware modifications.

2 Simulation Model

2.1 Introduction

The simulation framework for studying the impact of an interference from a jammer is developed in MATLAB. It consists of firstly defining the 3-D co-ordinate frame-of-reference and modelling the receiver as a 2-D planar array. The received signal for the selected chirp transmitted waveform is synthesised so that beam forming, null steering and matched filtering can be tested. Whilst accuracy in range, bearing and estimated detected power are all relevant, the initial analysis has focused on range accuracy alone as this is sufficient to provide indicative performance. The interference source, in this paper, is modelled as an amplitude modulated jammer and results are presented for a couple of example scenarios. Finally, an Interference Suppression Approach is proposed and implemented to assess its effectiveness. The entire process can be grouped into three phases as shown in Figure 1.

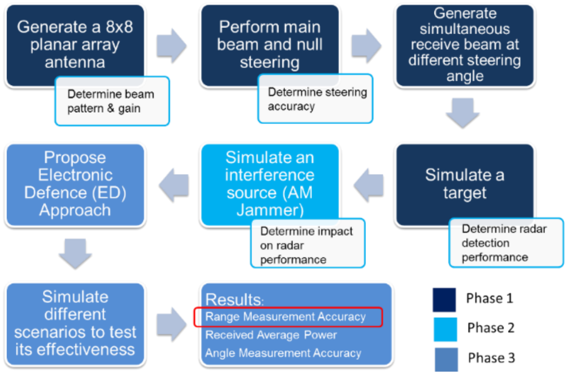

Figure 1 Test and simulation process

2.2 Staring array geometry

The Aveillant staring radar is represented in MATLAB as an 8x8 planar array oriented along the x-z plane with the y-axis aligned along the array centre, as shown in Figure 2. The array centre is at Cartesian co-ordinate (0, 0, 0) with default boresight perpendicular to the x-z plane, emanating from the centre. The maximum steering angle is $\pm 45^{o}$. A target (or jammer) can be placed at any polar coordinates represented as (range, azimuth, elevation).

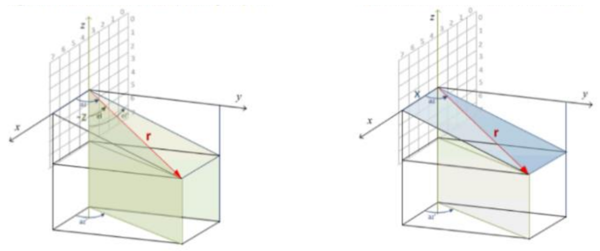

Figure 2 The Aveillant reference frame for the receiver array

2.3 Simulation Scenarios

Two scenarios were modelled and tested: (a) a moving target with a fixed position jammer, and (b) a fixed position target and jammer as illustrated in Figure 3. The interference source is an AM continuously emitting jammer with a modulating frequency of 20 kHz and either fixed or variable output power. The transmit waveform is a narrow band chirp with 2 MHz bandwidth.

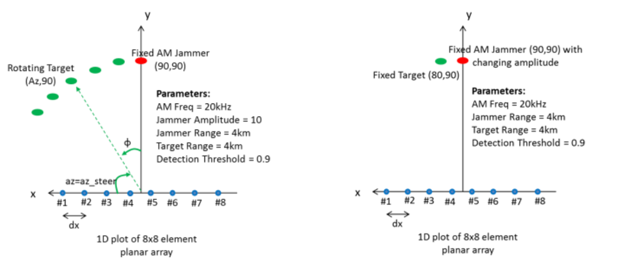

Figure 3 Simulation scenarios, Target (green), Jammer (red)

2.4 Proposed interference suppression approach

An interference suppression approach that combines Phase Monopulse with null steering is proposed. Phase Monopulse is a fine Direction Finding (DF) technique that compares measured phases over spatially separated antennas to refine an angular position estimate. The 2-D receiver array is divided into two quadrants as illustrated in Figure 4. The array data is used to form two separate beams centred on the initial coarse angle (main beam) estimate of the candidate detection. Using the refined monopulse angle estimate, the digital beam forming can be adjusted to steer a null in the direction of the jammer in order to suppress the interfering signal.

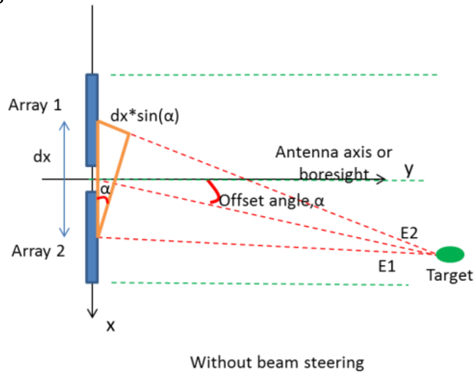

Figure 4 Top-Down View: Phase Comparison Monopulse antenna

Phase Monopulse can be realistically performed for the first time with minimum trade-offs by exploiting the static phased array nature of the staring radar and digital beamforming. First, the radar relatively long dwell time allows most interference sources to be identified. Second, the multiple staring and simultaneous beams generated by the array enable the radar to determine the coarse direction of the interference source. This is a pre-requisite for application of the Phase Monopulse technique. Third, the “multistatic” architecture, whereby only an omnidirectional transmitter is used alongside digital beamforming in receive, makes it easier to produce different quadrants and hence generate separate digital receive beams for the Phase Monopulse through a simple software modification.

Once the exact angle of the jammer is identified, azimuth and elevation null steering can be performed. This is done by phase shifting until beam pattern nulls are coincident with the position of the jammer direction, as illustrated in Figure 5. While adaptive Digital Beam Forming (DBF) is conceptually similar to null steering to a certain extent, null steering is used here in this case as it is simpler and will not compromise the speed and cost when added-on to the existing radar software.

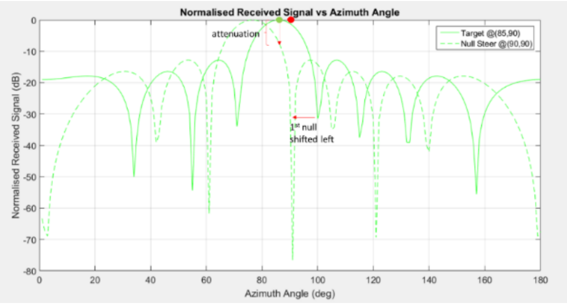

Figure 5 Jammer suppression concept after null steer

3 Results and analysis

This section presents the results from each of the three phases of the synthesis. Phase 1 is the modelling of the basic operation of digital beam forming and null steering. Phase 2 involves combining the target and jammer signals and finally phase 3 includes the results of the interference suppression.

3.1 Digital beam forming and characterisation (Phase 1)

Figure 6 plots the azimuth broadside beam response generated for the 8x8 array. The 3dB beamwidth of the main lobe is 12.7^{o} (±6.3^{o}).

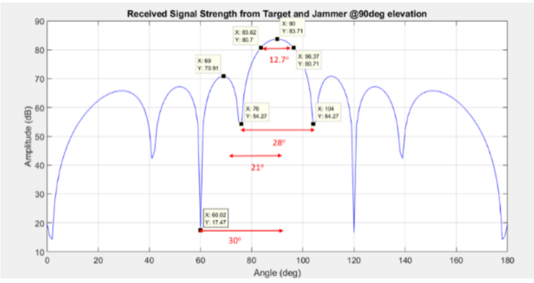

Figure 6 8x8 Planar array beam pattern

Digital beam steering is demonstrated by varying the phase shifts in azimuth while keeping the elevation fixed. The beam response for a target is simulated that is located at a range of 4 km and placed at an azimuth of 110°. Figure 7 shows that the simulated signal peak appears at the correct range of 4 km and at the steering angle of 110°. The plot on the right-hand side shows the resulting array pattern when the beam is steered so that the first null of the beam is on the target. Although not shown here beam steering can be performed in 2-D with respect to both azimuth and elevation. Furthermore, the developed software tool can generate outputs for multiple simultaneous beams that are steered in different directions to represent a full 2-D staring array.

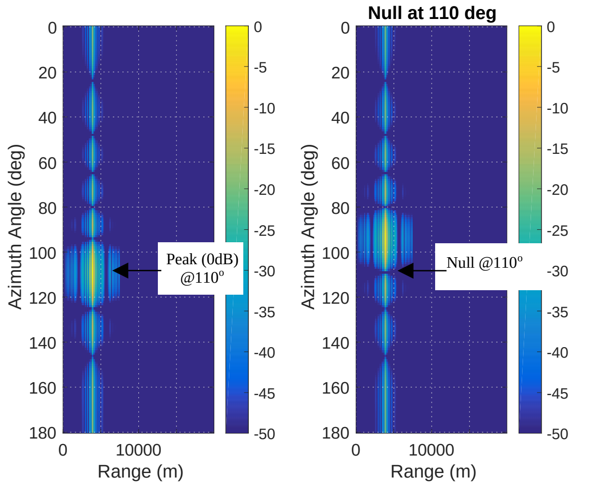

Figure 7 Placement of main beam and null at different steering angle (Azimuth, 90^{o})

The exact estimate of the target range is obtained from the matched filter output. Figure 8 shows the matched filter response obtained for a target that is located at 4 km from the radar.

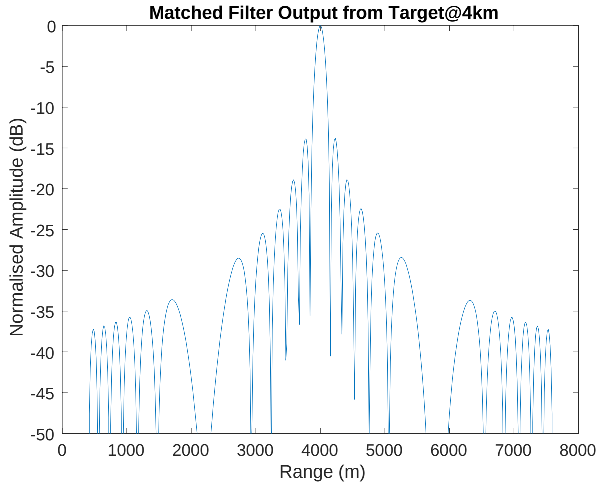

Figure 8 Range detection after Matched Filtering using a Chirp waveform with Target at 4km

3.2 Interference jammer simulation (Phase 2)

The presence of a jammer that is in close proximity of the target will alter the received signal. Figure 9 shows the response with a jammer that is at the same range as the target but offset by 5^{o} in azimuth. It can be seen that the jammer is distorting the matched filter output, resulting in multiple peaks that lead to ambiguities in the range estimate. In this situation, electronic defence techniques will be useful in mitigating the effects of the jammer.

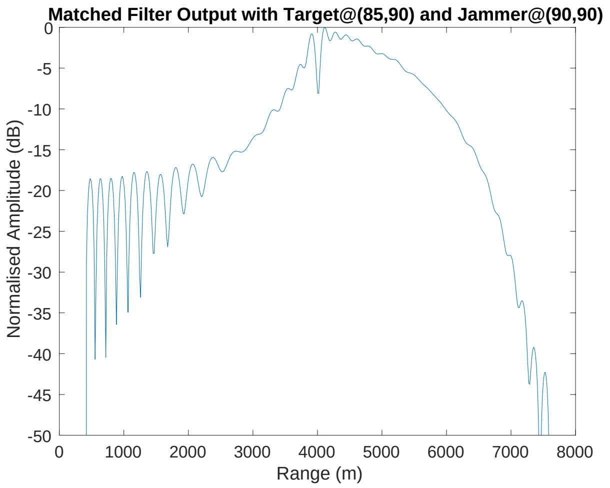

Figure 9 Matched Filter output waveform of Target (85°, 90°) in presence of Fixed Jammer (90°, 90°)

3.3 Interference suppression approach (Phase 3)

Section 2.4 outlined the proposed interference suppression approach that consisted of a monopulse angle refinement followed by null steering. Phase monopulse is evaluated by plotting the expected angular accuracy as a function of the relative offset from boresight as shown in Figure 10. Figure 10 shows that after the monopulse the angular accuracy is in the region of ±0.1°. Note also that the azimuth accuracy gradually worsens the further away from broadside. This is because the SNR drops due to broadening of the beams away from boreside which has a direct impact on angular accuracy. Nevertheless, the angular accuracy of the estimate of the jammer location is vastly improved with respect to the antenna beamwidth using the phase monopulse.

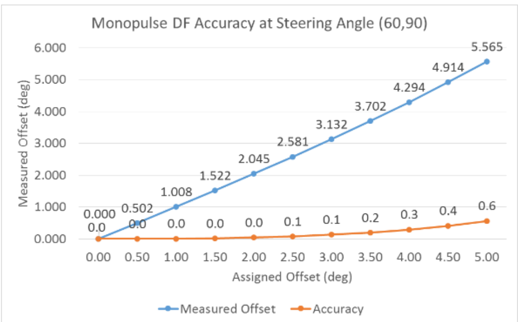

Figure 10 Monopulse accuracy at different offset angle with initial steering angle at (60°, 90°)

Using the improved angular estimate and digital beam forming the first null is steered in the direction of the jammer and the result for one of the scenarios where the target angular position is varying is examined first. Figure 11 is a snapshot for when the target is offset by 5° in azimuth from the jammer. Here the target is correctly located in range. We can examine how the jammer suppression approach performs if the target is moved in azimuth relative to the jammer position. Figure 12 shows the estimated range for a fixed jammer at an azimuth of 90° and target azimuth varying from 90° to 60°. Without suppression, the correct range is only recovered once the target is separated by more than 12° in azimuth from the jammer. This is the case where the target is moved to an adjacent azimuth beam from that of the jammer. However, with suppression the target can be correctly located except for when the target and jammer are co-located. This significantly enhances the ability to detect and correctly locate the target in the presence of an interference jammer.

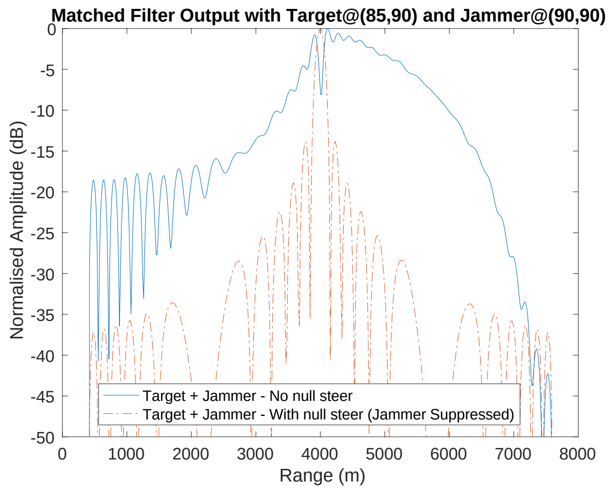

Figure 11 Matched Filter output with and without null steering for a Target at (85°, 90°) and Jammer at (90°, 90°) with amplitude 10. Both Target and Jammer at 4km range.

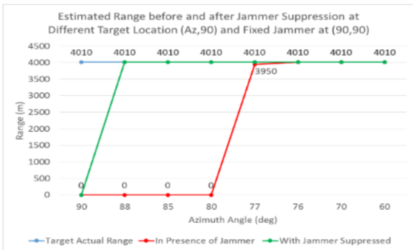

Figure 12 True and estimated range for Target at different azimuth with and without Jammer suppression.

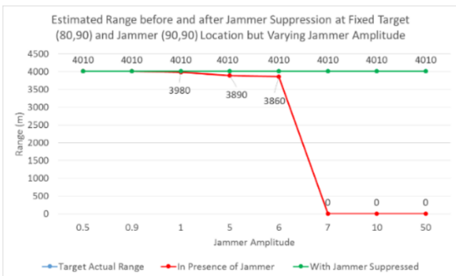

Figure 13 Estimated range for a Fixed Target and Jammer with varying strength

A similar assessment of the range estimation accuracy where the jammer strength is varied against a fixed target and jammer position is shown in Figure 13. It can be seen that, as expected, for very low jammer power no detrimental effects are observed on the estimated range accuracy. However, inaccuracies will start to occur when the jammer power increases until the Signal to Interference Ratio (SIR) becomes so low that the target is no longer detected. However, measurement accuracy recovers once the jammer is suppressed.

3.4 Discussion

A likely consequence of null steering is that the main lobe peak can be unintentionally shifted hence attenuating the target return. This is illustrated in Figure 14 whereby the target falls onto the sidelobe when the first null is steered onto a jammer. One way to overcome this is to select the optimal null that minimises the shift required through a defined mathematical relationship. For example, instead of using the first null, the second null can be shifted. Second, null steering has limited flexibility in countering > 1 interference source.
However, a key application is in the use of retrospective processing to re-establish the target track when it is lost. When a target track is lost, the staring radar can use this technique to nullify interferences on both current data but also past history and thereby recovering the target over a much longer time span. Alternatively, this can be used to suppress clutter around small targets so as to accentuate their key features for tracking, discrimination or micro-Doppler processing. For such scenarios whereby clutter is close to the target, a small shift in beam pattern can significantly amplify the target return.

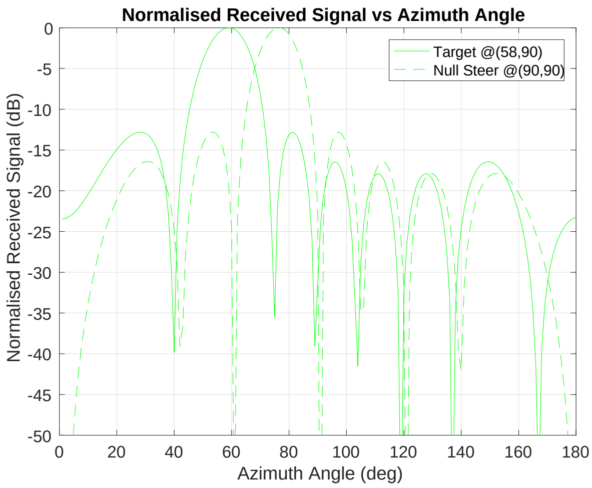

Figure 14 Worst case Target attenuation when Target at (58^o, 90^o) and Jammer at (90^o, 90^o) separation is >28^o before and after null steering

4 Conclusion

The response of a 2-D staring array to interference jamming has been investigated. An interference suppression approach is proposed that combines phase monopulse with null steering. Simulations have demonstrated that while AM jammers can affect detection and the range measurement accuracy they can accurately be located to an accuracy of ±0.1^o using phase monopulse and then effectively suppressed by null steering. Of note, this technique is simple and thus can be expeditiously and efficiently implemented in software to improve resilience without compromising affordability. However, its optimal performance occurs when target and jammer are near to one another. This electronic defence technique can be applied in retrospective processing or for clutter suppression around small target so as to accentuate its features.
This paper has highlighted some of the benefits that staring array can offer with respect to scanning radars and has helped identify future possible research avenues. In addition to array based nulling, for example, with a staring array more pulses can be integrated to improve weighting estimation and continual refinement of the weights can be achieved without having to look away from the target.

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