Antenna Characterisation for Amplitude Comparison in Electronic Warfare Systems

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Abstract

Radar warning receivers listen for pulses from radars of interest. The angle of arrival of each pulse is needed for pulse processing and location purposes. It can be accurately calculated using phase comparison, but this method is often impractical and expensive. This paper describes the authors attempts to use the less accurate method of amplitude comparison to provide adequate accuracy for use in a novel low cost radar warning receiver.

Introduction

The Radar is regarded as perhaps the biggest advance in remote sensing since the invention of the telescope [1]. Consequently since then methods have been sought to impair radar performance and to turn radar operation into a weakness. Such activity is referred to as electronic warfare (EW) and plays a major part in modern warfare. An ideal radar has enough transmit power to be able to illuminate targets at the desired operating range, enough resolution to be able to separate targets of interest and is able to measure both the range and velocity of those targets. These requirements place constraints on the type of signal a radar can emit and thereby provide a useful set of characteristics an eavesdropper can use to identify a radar.

Such listening devices fall into two categories, radar warning receivers (RWR) and Electronic Support measures (ESM). RWRs are the simpler of the two and perform a platform protection role. They warn the operator of the presence of a radar of interest and may be able to indicate if they are being tracked by the radar. As an example RWRs are often fitted to military jets and are used to warn of the presence of enemy air defences, whether they are being tracked by the defences and whether an anti-aircraft missile has been launched in their direction. ESMs are more sophisticated in that they can provide all of the functionality of a RWR but also the ability to detect unexpected and characterise previously unknown radars. Their role is primarily intelligence gathering rather than protection.

As the exact nature and location of the radars of interest is not known in advance, RWR and ESM systems have to listen across the entire radar band and have antennas that can receive emissions from all directions. A radar pulse characteriser is able to measure the characteristics of individual radar pulses such as their width or frequency but some important data can only be inferred such as pulses repetition frequency and angle of arrival. The more data that can be gathered, the more exactly the radar can be characterised.

Angle of arrival (AOA) is often used as the key parameter for deinterleaving the received pulses. That is attributing a received pulse to the pulse train of one emitter rather than another. If it is known that two pulses have come from the same direction, the chances have improved that they have come from the same source. Once the pulse trains have been separated it is much easier to identify the emitter. There are two techniques commonly used to calculate angle of arrival, both of which rely upon comparing how the same pulse was received by multiple antennas. If the antennas are phase matched and are situated a known distance apart, phase comparison can be used. This technique has an accuracy of less than 1 degree but is less commonly used. As well as being more expensive it requires the siting of three or more antennas at multiple points around the platform. Expensive protection is fitted to expensive platforms which normally have a long service life. This makes it very hard to fit to existing high value platforms which were not designed around such antennas, and platforms such as jets with strict aerodynamic constraints. The comparatively inexpensive option is amplitude comparison which is normally quoted as having a 10 degree error [3]. It requires single antennas placed at multiple points on the platform and uses the known antenna gain patterns to calculate the AOA of the pulse.

Teledyne Defence Ltd has developed a new RWR/ESM system called Phobos. Phobos was designed to challenge the accepted view of the role of RWR and ESM systems by being significantly smaller, lighter, lower power and lower cost than anything currently available. This allows it to be fitted to lower cost platforms and to be used in new ways. This paper describes the authors' work to characterise the antennas on a prototype Phobos system to allow the measurement of angle of arrival accuracy.

System Description

The Phobos prototype consists of a RR017 [2] pulse characteriser, processing board, digital compass, GPS and 4 antennas. The prototype is shown in Figure 1 with the lid removed. The RR017 is the device connected to the four antennas and rests on top of the computer. The RR017 has four ports but only two active channels. The two active channels are switched around the four ports to provide full 360 degree azimuth coverage. When a pulse is detected, the RR017 sends to the processing board a pulse descriptor word (PDW) which contains a variety of information including width and frequency of the pulse and the amplitude measurements from each channel. The processing board then passes the pulse descriptor words through an algorithm which performs both the deinterleaving and the identification step. For pulses of interest the AOA then needs to be calculated, duplicates removed and the resulting data passed to the operator.

The Angle of arrival is calculated in a very simple manner. It is assumed that the only reason for a variation in amplitude between the two channels is due to the difference in antenna gain caused by antenna variation and orientation. Once the antennas have been characterised, the AOA can then be calculated. The antenna gain patterns at 3GHz are shown in Figure 2.

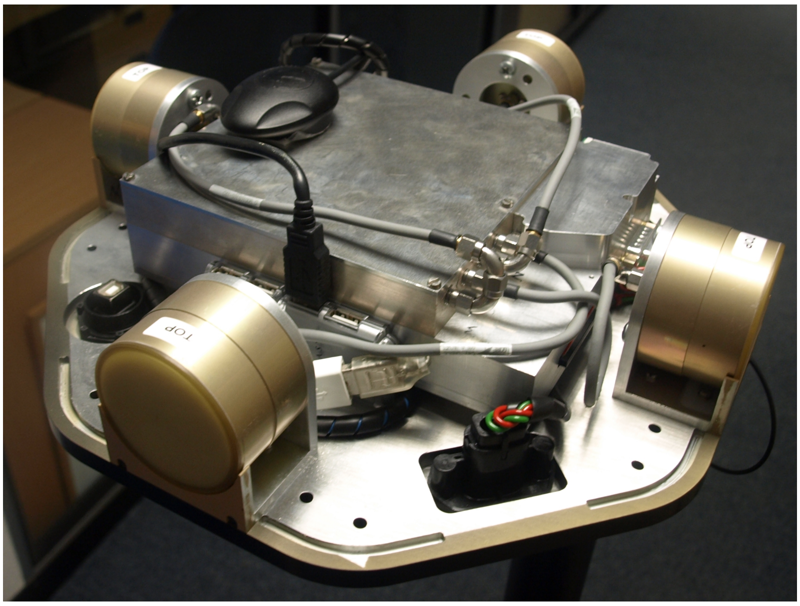

Figure 1: Phobos Prototype

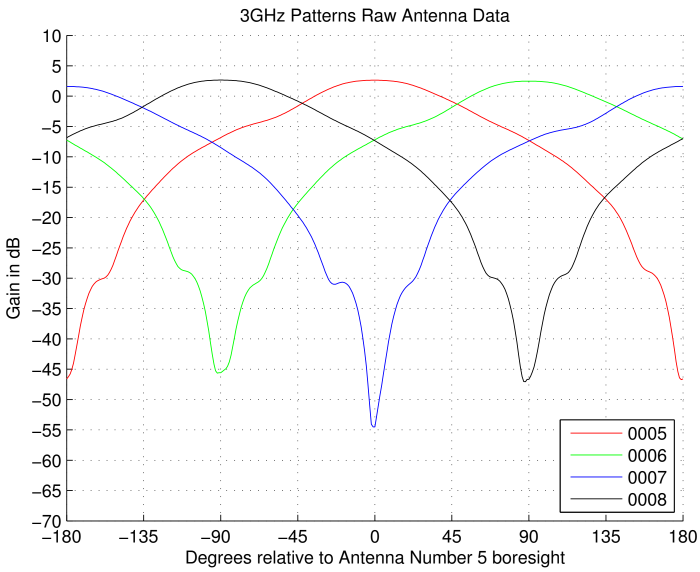

Figure 2: Antenna Gain Patterns

Gain difference tables are calculated for the antennas for each degree in GHz steps across the operating band using the known antenna characterisations. The results for 3GHz are are shown in Figure 3

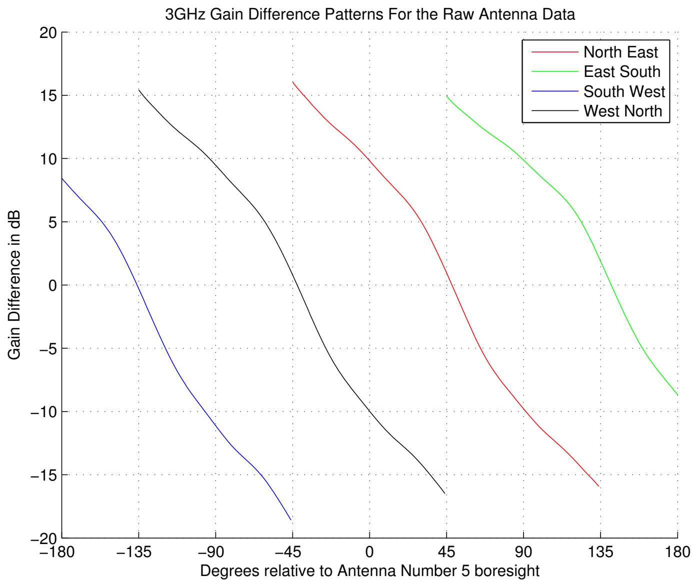

Figure 3: Antenna Gain Difference

and over each ninety degree region of interest or quadrant the result is an approximation of a straight line. So to find the AOA in a quadrant two searches are started one from each end of the antenna difference table for that quadrant. If both searches find a match within the match tolerance and difference between the two AOA values is within the AOA tolerance a match is declared and the average of the two AOA values used.

Antenna Characterisation

The Antennas were supplied with amplitude and phase performance data. This allowed for a rough calibration for initial development work and as a reference for the system characterisation. The amplitude response is shown in Figure 2. The response for the four antennas although measured in isolation has been overlaid to aid comparison. The curves for each antenna are very similar, but shoulders can be seen for all antennas approximately eighty degrees either side of each antennas bore sight. The effects of these shoulders can be seen in the gain difference plots shown in Figure 3. The shoulders seen in Figure 2 now correspond to flatter sections on the difference curve which leads to greater error as the flatter curve the greater the number of degrees of error each dB of amplitude error equates to.

Absolute amplitude measurement error within the RR017 will not cause error in the AOA calculations as long as both channels are in error to the same extent. The amplitude tracking error for most situations is expected to be less than 0.5 dB based on the current RR017 build standard. This allows the AOA calculation error to be predicted assuming amplitude tracking error is the only component. The results for the antennas in isolation are shown in Figure 4.

Variation with the lids

First attempts in an anechoic chamber to measure how the antennas performed once they were housed in the unit produced awful results. If the amplitude response for each antenna is not monotonic for the two ninety degree regions either side of boresight there maybe multiple places on the curve that correspond to the same amplitude difference. We supposed that the problems were due to scattering and reflection from the various metal parts within the unit. The unit contains a GPS receiver so must have a

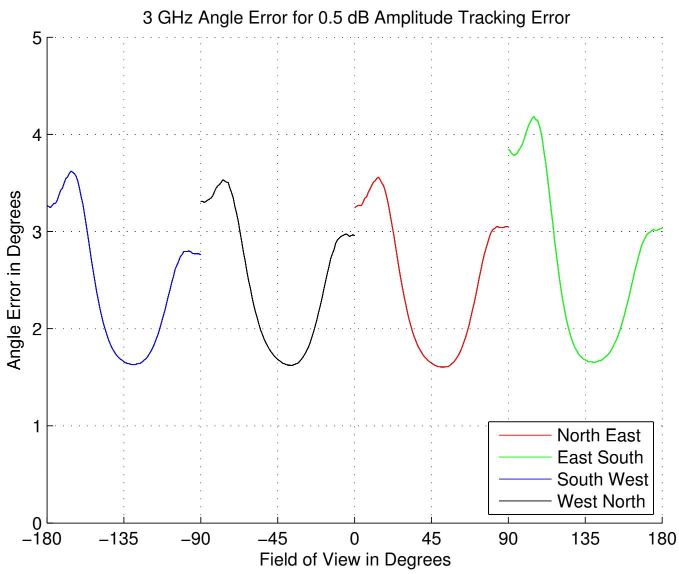

Figure 4: AOA Calculation Error for the Antennas in isolation at 3GHZ

reasonably unobstructed view of the sky. To allow this the unit had a nylon lid. So to try and eliminate scattering and reflection the sides of the lid were covered with copper tape. This was only of marginal if any benefit. The measurements were then repeated with no lid at all and although still unusable this produced a better result than the first two lids. An aluminium lid was the next trial, knowing that the GPS would then have to be repositioned, which produced good results. The results for all four lids can

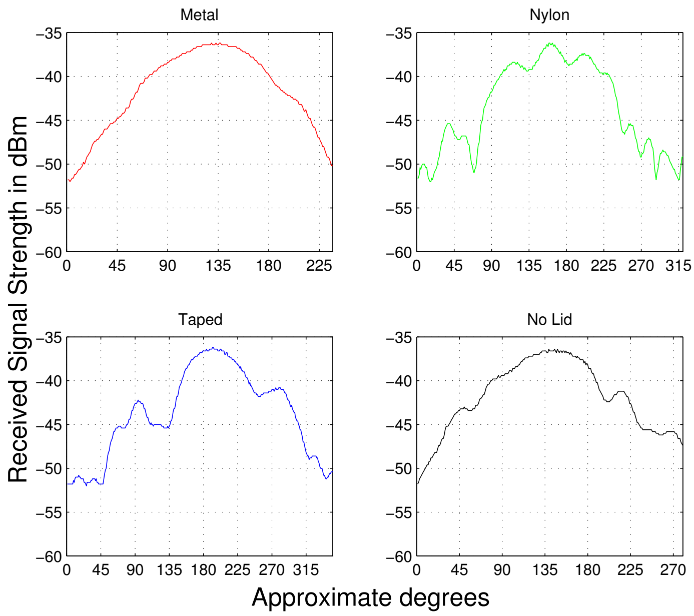

Figure 5: Amplitude measurements taken at 3 GHz with different lids

be seen in Figure 5. A full characterisation was then attempted using the metal lid.

Results

The amplitude response for the system with the metal lid

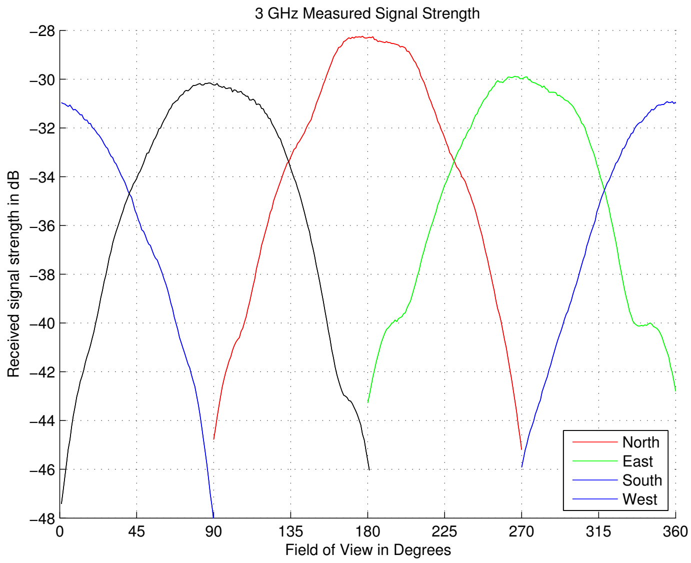

Figure 6: System Amplitude measurement at 3 GHz

can be seen in Figure 6. The result is similar to before, but large shoulders can be seen on the East antenna's section of the plot. Figure 7 the gain difference plot

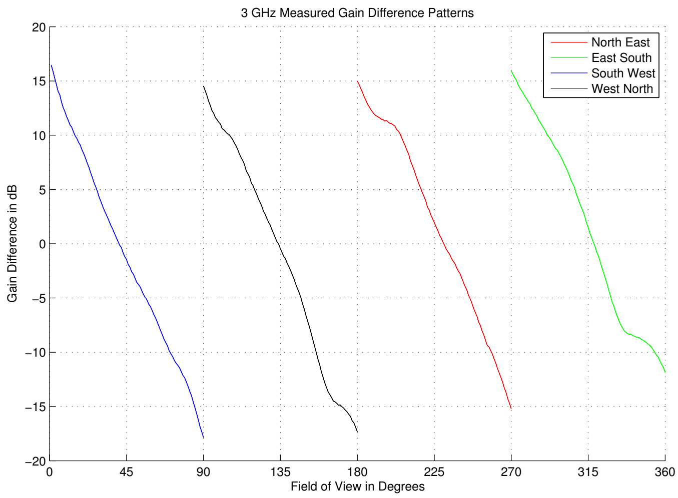

Figure 7: System Gain Difference at 3GHz

shows the effect of the shoulders more clearly, with almost flat sections in 3 of the four quadrants. The resulting angle error plot

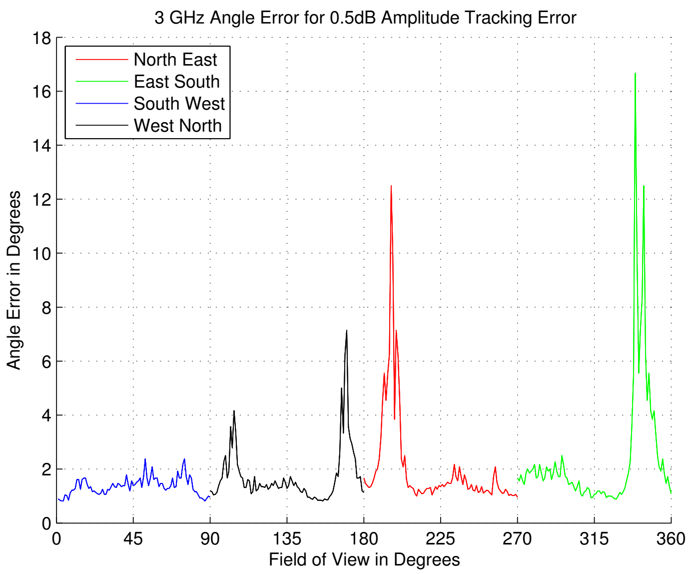

Figure 8: System Angle Error for a 0.5 dB Tracking Error at 3 GHz

is shown in Figure 8. Large spikes are shown which correspond to each flat spot on the gain difference plot. The error is less than three degrees for most of the field of view with an average of 1.88 and a worst case of almost seventeen degrees.

Conclusions

The purpose of this exercise was to better understand the process of AOA calculation and to provide a indication of the performance of a production unit. The design for the housing has been changed to take advantage of what was learnt when trialing the different lids. The production units will have an aluminium side with the antennas placed in aluminium holders to improve the shielding around them and to minimise internal reflection and scattering. The test equipment has been augmented with higher power signal sources and antennas for testing the higher frequencies to compensate for path loss in the test chamber.

Further work

This work does not take into account the noise floor of the RR017 pulse characteriser. When the received signal strength on the weaker of the two channels is below the RR017's sensitivity, there is the potential for erroneous results as the apparent signal strength difference will be less than the actual difference. This is especially important when the emitter is not in the quadrant currently being observed. One channel may have a valid measure and the other is in the noise.

The performance of the current build standard of RR017s is significantly better than the one used in the Phobos prototype. Once the amplitude tracking error for the new units has been measured there maybe new information that could be taken advantage of. For example if it is shown to be strongly temperature dependant, temperature information could be used to set the tolerances used in the AOA matching search. As the gain difference curve is monotonic, the AOA matching search could also be improved by using a faster search, such as a binary search in place of the linear search.

Acknowledgments

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