Study into ESM and PCR Convergence

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Abstract

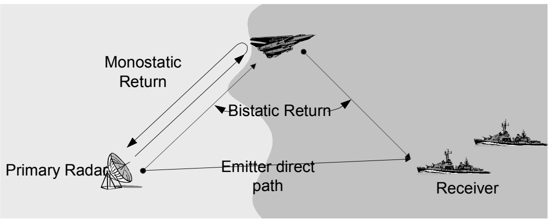
This paper presents year-one results from a three-year programme studying Passive Coherent Radar & Electronic Support Measures convergence. In particular the work has concentrated on using a ship-borne R-ESM system in the PCR role, that is to detect targets by receiving a bistatic return when they are illuminated from sources such as Air Traffic Control Radars.

Keywords: Passive Coherent Radar, Electronic Support Measures, Simulink

Introduction

Electronic Support Measures (ESM) and emerging Passive Covert Radar (PCR) systems both operate in the same environment, albeit for different purposes. This work has studied utilising an existing ESM system in the PCR role, that is to covertly detect and subsequently track targets from their bistatic return when illuminated by a non-cooperative source.

A naval scenario was chosen with either a land based or naval source, represented by the Watchman Air Traffic Control (ATC) and commercial Bridgemaster Radars respectively.



This choice was made for two key reasons:

- Typical naval R-ESM systems can be heavier and more bulky than (say) man-portable systems, and are therefore likely to be technology limited rather than environment limited.
- As ships tend to operate in groups, the Time Difference Of Arrival (TDOA) technique can be evaluated.

In order to be of relevance, only technology that is currently in-service, or likely to be available in the short to medium term is considered. Also, this work has not considered aspects of ESM operation such as throughput and emitter classification, assuming these will be part of the ESM systems' normal operation.

In order to evaluate such a combined ESM/PCR system, a complex baseband simulator was created to accurately represent each part of the scenario (e.g. source, target, environment etc). The specification for each section was derived through a series of study activities into current ESM and PCR systems including signal processing aspects. A separate study was undertaken to show that the technology represented was available in the timescales required for the system to be relevant.

To validate the simulation, a series of limited tests was undertaken at Southampton International Airport.

Study Output

To define the simulator and verify that the systems modelled would be available in the short to medium term, three studies were undertaken and are summarised below.

ESM System & Radar Source Specification

This document specified the ESM system modelled, and was agreed between various

DTC members before proceeding. The main areas covered were the Source, Target, Receiver Architecture (i.e. the RF receiver chain of the ESM system) and any positioning methods used although results from these are not included here due to space constraints. It also specified terrain clutter responses although these have not been included in the simulator at this stage. The outcome is summarised below:

Subsystem	**Option**	**Description**
Source	ATC radar	Watchman pulse-doppler Radar.
	Marine radar	Bridgemaster incoherent pulse Radar. S & X-band
Env'rnmt	Sea & land clutter	
Target	RCS of approx. 0 to 10dBsm	
Receiver Architecture	D-IFM[1]	Sensitivity: -65dBm Dynamic Range: 60dB BW: 40MHz
	Digital	Sensitivity: -85dBm Dynamic Range: 70dB BW: 1MHz – 40MHz[2]
	C'lised[1]	Sensitivity: -85dBm DR: 70dB (12 bit) BW: 20MHz
	Super-het	Sensitivity: -90dBm DR: 90dB (16 bit) BW: 20MHz

Review Of ESM/PCR Antenna, Synchronisation And ADC Technology

The main conclusion was that the requirements for the technologies outlined above could be met either by existing equipment, modified existing equipment or, for the digital receiver, components likely to be available in the short term. Therefore, the systems are relevant for near or medium term use.

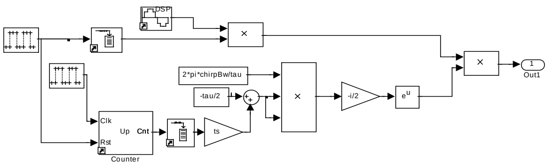
PCR Technology Review

This study concluded that PCR systems are effectively 'coming of age' due to rapid advances in compute power and other allied technologies and highlighted a number of operational possibilities.

The report also studied the signal processing used for PCR systems and concluded that cross-correlation was the most widely used technique.

Simulator Overview

To calculate the powers received from the bistatic reflections accurately, including various signal processing options for target detection and the receiver architecture, the commercial Simulink package was chosen. Simulink is a powerful graphical-block based language, which can incorporate 'C', MATLAB or other code. By way of example, the Watchman source is represented by the following model:



It has been chosen to allow four detector models, two for each source:

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[1] The channelised and Digital Instantaneous Frequency Measurement (D-IFM) receivers were not considered for modelling as the superheterodyne and digital systems offered better/similar performance.

[2] This bandwidth depends upon the application. For example, if the output is directly Fourier Transformed, then the bin bandwidth may only be ~1MHz. However, for this application the full 40MHz is used.

Source	**Detectors**
Bridgemaster	Square-law
	Cross-Correlation
Watchman	Pulse Compression
	Moving Target Indicator (MTI)

These are summarised thus:

- *Square-law*: Power-level detector (diode).
- *Cross-Correlation*: Local copy of a pulse is correlated against received signal. Trades improved sensitivity for poorer time resolution as correlated peaks are twice the width of uncorrelated peaks
- *Pulse Compression*: Matched filtering of chirp signal allowing processing gain along with ability to separate closely spaced targets
- *MTI*: An addition to pulse compression allowing suppression of clutter. However, as processing is non-cooperative, issues regarding the reference to process against exist

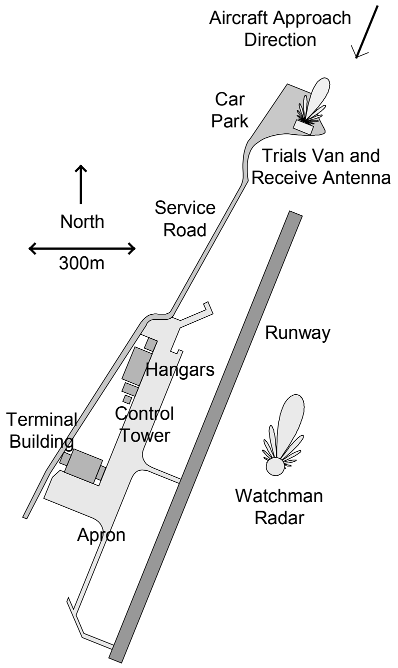
Accurate antenna patterns were implemented for both Watchman and Bridgemaster (including S- and X-band variants) in azimuth and elevation.

Measurements Setup

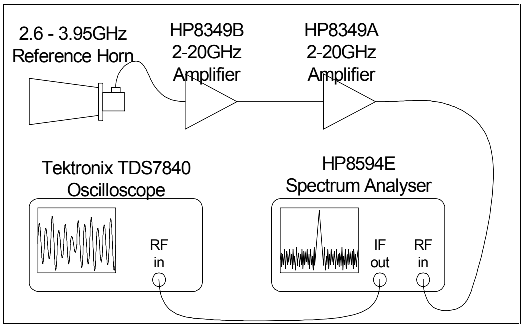
In order to verify the simulation work, a limited series of measurements was undertaken at Southampton International Airport, using the local Watchman Radar as a source. This arrangement has a number of advantages:

- The source parameters for Watchman could be confirmed
- The rate of aircraft arrivals at Southampton airport was sufficiently low that it could be ensured that data was gathered for just a single aircraft at a time
- Visual confirmation of the presence and type of aircraft was possible

The layout of the airport and setup is shown below.



The trials were conducted over a two day period using off-the-shelf test gear thus:



Simulation Results

The goal of this project has been to evaluate an ESM receiver in the role of a PCR. As such, the simulations have been targeted towards calculating the distances over which targets could be detected given one of the sources, receiver architectures and signal processing options previously outlined. This has lead to results being calculated for a range of target positions with a static transmitter/receiver geometry, and source directed such as to give maximum reflected power (i.e. pointing towards the target).

Two scenarios were studied; one with a 20NM transmitter / receiver separation and a second with 40NM separation. For brevity, only 20NM results are presented here.

Bridgemaster Results

The Bridgemaster Radar S- and X-band options were both implemented, along with pulse width, power level and Pulse Repetition Frequency options. Again for brevity, only S-band maximum power & 1μs pulse length results are shown here. The X-band results are similar as the increase in antenna gain offsets the higher free-space loss.

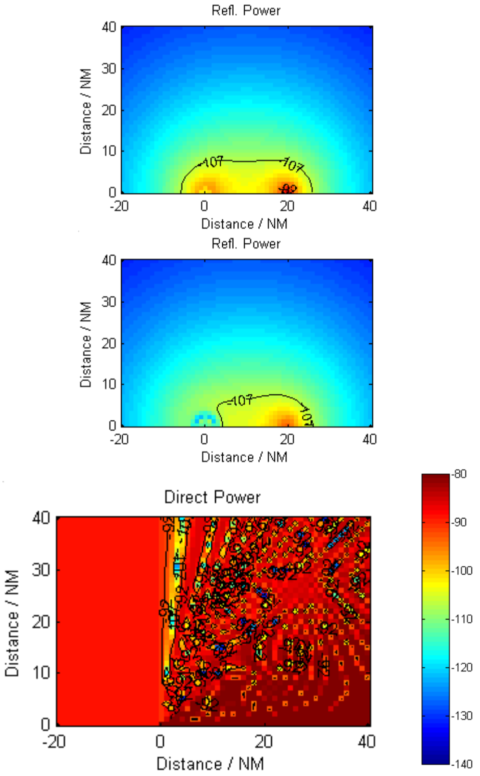
A key result is sensitivity which, in the absence of dynamic range and pulse separation issues, will govern maximum range. Values for this, which show the minimum detectable power level at the output of the antenna, are shown below. Results for two typical ESM receiver architectures are given:

- The superhet receiver, representing a tuned, narrowband receiver typically used in a hand-off situation. A 16-bit ADC is assumed.
- A digital receiver, giving a ~100% Probability Of Intercept by using a bank of splitters/digitisers to capture the entire bandwidth simultaneously. A 12-bit ADC is assumed.

Receiver	**Detector**	**Sensitivity / dBm**
Superhet.	Square-Law	-92
	Cross-corr	-107
Digital	Square-Law	-80
	Cross-corr	-94

As expected, the wide-open architecture and lower dynamic range of the digital receiver offers poorer sensitivity than the superhet. Also, the processing gain achieved through correlation is evident compared to the square-law detector.

Graphs showing the power received at the base of the antenna port in dBm are shown below. A receiving gain of 10dBi and RCS of 10dBsm was used, with the target at 3,000 feet height (left) and 10,000 feet (right). Contour lines are set to -92dBm & -107dBm representing the sensitivity of the superhet receiver with the two detectors.



All results are calculated for the source pointing towards the target. The top result, 'reflected power', is for the source → target → receiver path, whereas the bottom result, 'direct power', is the direct source to receiver path and is independent of target height.

These show a number of features:

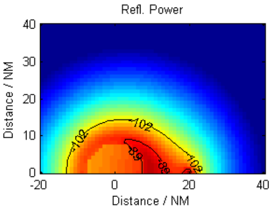
- Little difference with aircraft height, reflecting the broad elevation pattern of Bridgemaster
- Variation in the direct power due to gain pattern and fixed sidelobe level behind the antenna
- Useful range severely limited due to low received powers reflected from the target

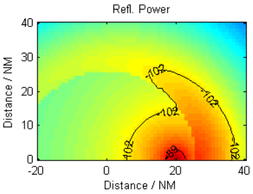
Watchman Results

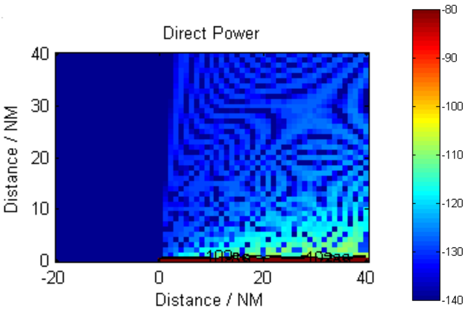
The Watchman Radar with its chirp source allows for a pulse compression matched filter and subsequent MTI filtering to cancel targets that show a steady phase across a given pulse train (i.e. clutter). The MTI filter will *not* add further processing gain however, and so the FAR data is shown for pulse compression only and MTI results are not shown. MTI is discussed in the experimental verification section where severe clutter proved a limiting factor.

Receiver	Sensitivity / dBm
Superhet	-102
Digital	-89

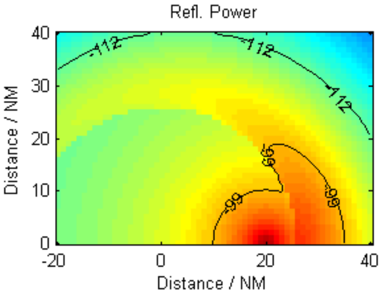
These values are worse than for Bridgemaster, reflecting the different signal processing used. However, the increased gain from Watchman and squinted cosec^2 pattern leads to improved performance, especially at higher altitudes.







To provide an increase in target detection range, a higher gain receive antenna could be used. The result for a 20dBi antenna is shown below.



This shows detection is possible over the bulk of the area shown.

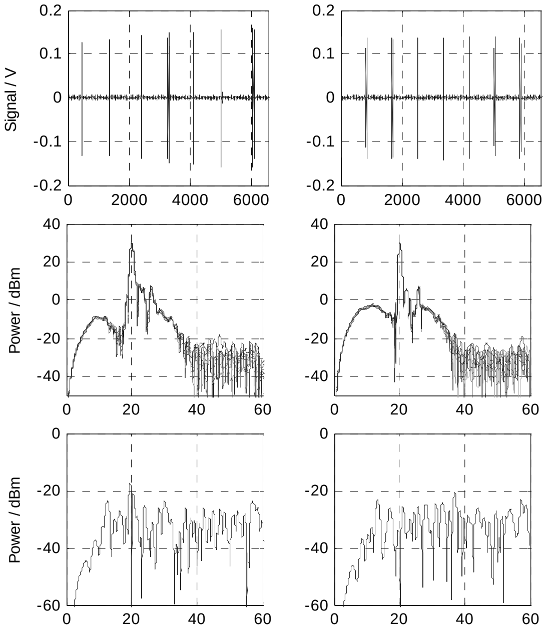
Experimental Verification

The goal of the experiments is to valid the simulation. This is deemed successful if the measurements & simulation show agreement with realistic parameters.

As outlined, tests were undertaken at Southampton Airport using the Watchman Radar as a source. A scenario can be established in the simulator to replicate the geometry and measurement setup used, including the 8 bit ADC in the DSO and noise figures of the wideband amplifiers. It is also necessary to introduce clutter objects, representing the goods yard and warehouses at Eastleigh Railway depot.

Given this scenario it is possible to directly compare measured and simulated data, as shown below with measured data on the left and simulated on the right showing a clear correlation.

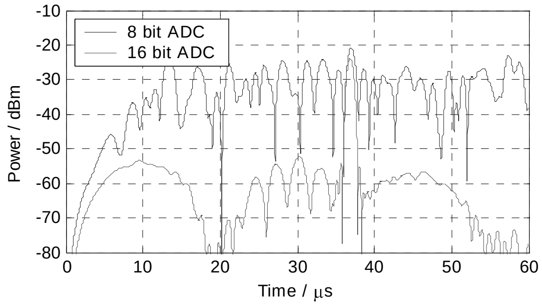
The results show a raw pulse train, single pulse after matched filtering and MTI processing on previous pulse. All x-axes show time in μs.



These show similar results between

simulation and measurement, verifying the simulator as required. More quantitative analysis of the measurements is not possible as the exact clutter distribution around the measurement location is not known.

An important issue in these results is that they show dynamic range to be a limiting factor. For example, the following result shows simulations for 8 & 16 bit ADC's. Note the results are scaled and the target is at ~37μs.



This shows clear target detection for the higher dynamic range receiver with identical noise levels between simulations.

Conclusions & Further Work

This work has considered the convergence of PCR & ESM systems. In particular, the work has concentrated on using a ship-borne R-ESM system to detect targets by receiving a bistatic return when they are illuminated from non-coperative Radars. To evaluate this, a series of simulations have been created for a variety of scenarios including realistic receiver architectures and signal processing options.

The simulation has been verified against a series of tests undertaken at Southampton International Airport. These show very similar results from simulation and measurement.

The simulation results show that targets can be detected over an approximate 15NM range around the receiver assuming the source is 20NM away and a target height of 10,000 feet, target RCS of 10dBsm and receiver antenna gain of 10dBi with the Watchman source. The results are considerably poorer when using the Bridgemaster marine Radar. If the receiver gain is increased to 20dBi, targets can be detected over a range of over 40NM which offers a useful operational ability.

Further work in this area is intended to include more Radar sources, more accurate simulation of components and further measurements with a higher dynamic range receiver.

Acknowledgements

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References

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