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A New X-band Experimental Airborne Radar for SAR and GMTI

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Abstract

Defence Research and Development Canada – Ottawa has developed a new multifunction X-band wideband experimental airborne radar (XWEAR). The system consists of a high peak, high average power transmitter, a digital waveform generator, two wideband 8-bit analog to digital conversion channels for SAR/ISAR data collection and two narrowband 14-bit analog to digital conversion channels for GMTI radar data collection. The antenna is horizontally polarized and a novel multimode feed horn is used to derive two azimuthally displaced phase centers. The new radar maximizes the use of an existing digital scan converter as a controller, and commercially available components including the transmitter, A/D converters and computer boards. The timing circuitry, waveform generator, single and dual-channel receivers are custom built. The radar was designed to support research into SAR imaging of fixed and moving targets (ocean and land), time-frequency analysis of moving targets, clutter suppression for GMTI radar, ocean surveillance for small target detection and long-range surface surveillance, and tracking of land and ocean targets. Highlights of the data collection capabilities of the instrument include a swath width 16K points wide in the single channel SAR modes, 8K points wide in the two channel integrated SAR-GMTI modes and 4K points wide in the GMTI surveillance modes. The digitized data are recorded on a RAID at rates up to 65 MBytes/second. Motion measurements consisting of data from an EGI mounted near the centre of gravity of the aircraft and a strap-down inertial measurement unit mounted on the antenna are recorded coincidentally with the raw radar data. The PPI display of the maritime modes operates in real-time and is used to select maritime targets or regions for seaspot (ISAR) data acquisition. When acquiring data in the land environment in the landspot, stripmap and GMTI modes, target coordinates are entered manually. Recorded data are processed post-flight to produce the SAR and GMTI products. Currently, all processors are Matlab based, and a SAR ground processing facility with a real-time kernel has been developed. This paper discusses the architecture of the radar, its modes of operation with respect to data collection capabilities, and presents results from its high resolution stripmap, landspot, seaspot and GMTI modes from trials in July 2003.

1 Introduction

The DRDC Ottawa airborne experimental radar is an air to surface sensor that can record large volumes of data for investigations into wideband SAR, ISAR, GMTI and maritime surveillance. Specifically, the multimode experimental radar is being used to collect data for research into SAR imaging techniques for fixed and moving targets, time-frequency analysis of ocean and ground moving targets, space-time adaptive processing for application to GMTI, investigations into the electromagnetic backscatter properties of the ocean surface, generation of signatures for feature extraction and automatic target recognition studies, and analysis of the utility of wide bandwidth systems against electronic countermeasures. X-band, because of its relative immunity to tropospheric effects, allows operation in the maritime environment to ranges of 200 nmi. The multimode radar is installed on a Convair 580 aircraft which is operated by the Institute for Aerospace Research and has been flight trialed in all of its modes.

The architecture of the experimental radar is described along with its most salient system level and data collection capability characteristics. Within the following, emphasis is placed on the SAR and GMTI modes. For the SAR modes, preliminary imagery of both land and ships are presented. For the GMTI modes, early results from the wide area surveillance (WAS) GMTI are presented.

DRDC Ottawa SL 2004-036

2 SAR/GMTI System Design

A block diagram of the radar system architecture is shown in figure 1. The Data Scan Controller (DSC) is a digital scan converter designed for the AN/APS-506 maritime search radar that has been modified to allow SAR and GMTI control. The antenna servo and power supply are also taken from the AN/APS-506. The Raytheon transmitter is capable of transmitting 50 KWatt pulses of up to 30 µs duration with a maximum duty cycle of 1%. The navigation subsystem consists of a Litton LR-86 Inertial Measurement Unit (IMU) mounted near the Antenna Phase Centre (APC) and a Honeywell H-764G Embedded Global Positioning/Inertial Navigation System (EGI) mounted near the centre of gravity of the aircraft. The Receiver-Exciter Processor (RXP) is a new subsystem central to the experimental radar.

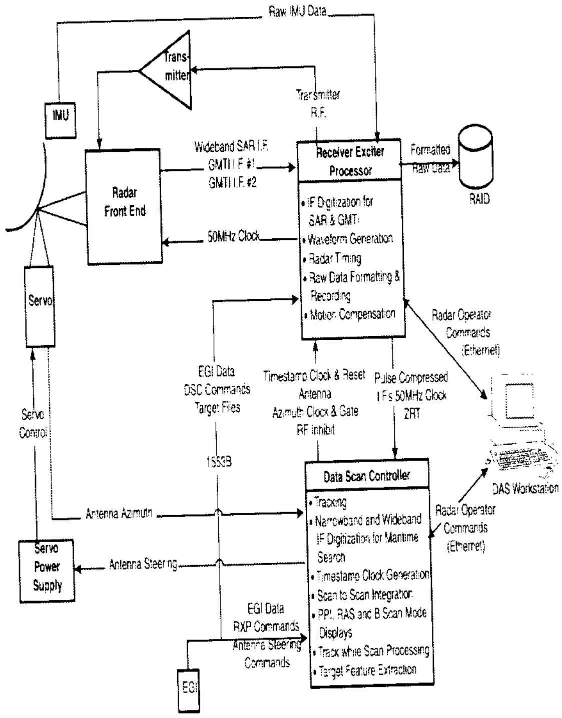


Figure 1: SAR/GMTI Radar Architecture

The functionality of the RXP is derived from a blend of hardware and software functions. Hardware dependent functions comprise waveform generation, radar system timing, radar up/down conversion and analog-to-digital conversion. Software dependent functions include system control, targeting, navigation, motion compensation and radar system timing control, radar data recording and the operator interface for coherent radar data acquisition. The radar system timing circuitry and radar front end are custom to this radar. All timing and local oscillator signals for waveform generation, radar up-conversion, radar down-conversion and signal digitisation are derived from the RXP's low phase noise reference clock. An arbitrary waveform generator is employed to generate highly precise linear frequency modulated waveforms of various bandwidths, from files containing digital waveform descriptions, to modulate the Intermediate Frequency (IF) signal. The RXP up-converts this IF waveform to the transmitter Radio Frequency (RF) of 9.75 GHz. The system's spurious free dynamic range exceeds 45 and 65 dB for the widest bandwidth SAR modes and the narrow band WAS-GMTI modes, respectively. The RXP receives the EGI data as well as target position information data from the DSC via a 1553B interface. A custom interface brings the IMU data into the RXP. The RXP timestamp clock and reset are derived from the DSC. In the receiver, the RF echo is mixed with a local oscillator of 9.25 GHz to produce a down-converted signal at an IF of 500 MHz. Eight bit analog to digital conversion is performed on the IF signal at rates up to two GHz in the SAR modes and to 14 bits/channel at maximum rates of 100 MHz in the WAS-GMTI modes. The RXP sends the digitised IF data to the 144 GByte Redundant Array of Inexpensive Disks (RAID) for recording at rates up to 65 MBytes/second.

A summary of the characteristics of the radar is given in table 1. Table 2 summarizes the characteristics of the data collection modes. In the single channel modes, 32768 eight-bit samples at IF are digitized per PRI. For each channel in the two-channel SAR modes, 16384 eight-bit samples at IF are digitised. In the two-channel GMTI modes, 8192 14-bit samples at IF are digitized per PRI. Seaspot is a spotlight SAR imaging mode in which the radar illuminates an ocean target such as a ship. Landspot is the conventional spotlight mode for imaging of land (fixed) targets. Table 2 summarizes the range resolutions that are supported. The range resolutions listed assume no degradation in the main-lobe response due to window weightings imposed on the pulse compression filter.

Table 1: Radar System Parameters

Pulse Length	5 µs in all modes except Search II which is 10 µs with a fixed 5 MHz signal that randomly frequency hops over a 500 MHz range
Peak Power	50 kwatts
Carrier Frequency	9.75 GHz
Polarization	Transmit&Receive – Horizontal
Antenna	42" width, 2.4° azimuth beamwidth, 4.0° elevation beamwidth

Table 2: Radar Data Collection Modes

Mode	PRF (Hz)	Range Resolution (m)	IF Samples per range line/ quantization (bits)
Search I (300 RPM)	2000	0.3	32,768 / 8
Search II (6 RPM)	500	30	16,384 / 8
Search III (6 RPM)	500	0.3	32,768 / 8
Search IV (60 RPM)	400	0.3	32,768 / 8
Single Channel Stripmap	100 to 1375	<1, 1.3	32,768 / 8
Single Channel Landspot	100 to 1375	<1, 1.3	32,768 / 8
Single Channel Seaspot	500	<1, 1.3	32,768 / 8
Two Channel Stripmap (SAR-GMTI)	100 to 1375	<1, 1.3	2x16,384 / 14
Two Channel Landspot (SAR-GMTI)	100 to 1375	<1, 1.3	2x16,384 / 14
Two Channel Seaspot	500	<1, 1.3	2x16,384 / 14
WAS-GMTI (1.6, 6 RPM)	2000	5, 10	2x8,192 / 14

3 Early Results

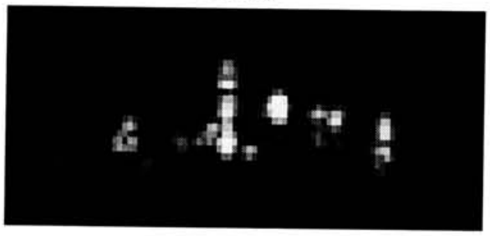
3.1 SAR

Figure 1: Landspot SAR image of DRDC Ottawa

Figure 1 is a one metre resolution Landspot image of part of DRDC Ottawa. Distributed about the bottom left of the image is a field of reflector antennas. The visible structures are mostly small outbuildings and parked vehicles.

Seaspot SAR is hybrid SAR/ISAR ship imaging. It involves the imaging of a target from a moving platform that has its own components of motion. The seaspot algorithm performs range compression and tracking in the range direction (multiple targets are tracked and corrected). In the cross-range (Doppler) direction, the target is often undergoing complex rotational motions. Time-frequency analysis allows the time and frequency information to be viewed simultaneously. A short-time Fourier Transform (duration around 100 ms) is used to provide good time domain resolution while avoiding distortion of the frequency spectrum. Heavy overlapping (around 50%) of the time domain windows is used to recover as much information as possible on the target. The seaspot algorithm is capable of performing an assessment of the collected data and selecting the subset which is optimal in both length and location for forming an image of the target. It does this by optimising cost functions as a function of target location in Doppler. The Doppler domain data is then corrected to allow coherent subaperture processing to be used to integrate the data in azimuth and form the final image. The orientation of the image projection plane of the resulting image is generally unknown. However, previous studies, where vessels have been instrumented to measure their motion while simultaneously being imaged, have shown correspondance between the image orientation as derived from the vessel motion and the seaspot imagery [1,2].

Figure 2 presents seaspot images of targets of opportunity. Figure 2a is a small craft and figure 2b is an unknown merchant vessel. Both ships were imaged off the east coast of Canada.



(a)

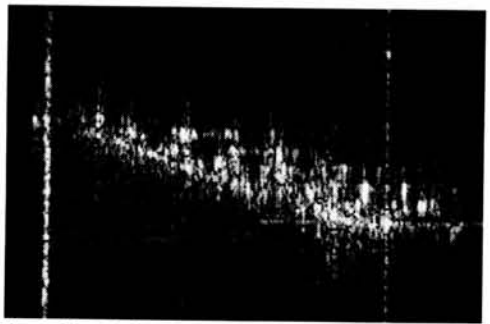


Figure 2: (a) Small vessel, (b) Large merchant vessel

3.2 GMTI

The GMTI radar system operates in two basic modes: SAR-GMTI and WAS-GMTI. Both modes are two channel modes in which the two receivers are fed by outputs from a reflector antenna. The SAR-GMTI mode is capable of finer resolutions than the WAS-GMTI. A novel multiple phase centre reflector antenna was designed for the GMTI modes of operation [3]. The feedhorn of the reflector antenna allows the TE11 and TM01 modes of propagation to be excited simultaneously. Two physically separated phase centers are then achieved by combining these transverse electro-magnetic modes in software using appropriate complex combinations of weights. The antenna is large enough compared to the wavelength such that the phase centre is unique to within a constant phase beamwidth of approximately 5° [4].
Figure 3 shows the display from the existing matlab-based GMTI processor, called the GMTI eXploratory Processory (GMTIXP). Currently GMTIXP works on WAS-GMTI data with a scan rate of 6 rpm. Figure 3 shows a Doppler Beam Sharpened (DBS) image overlaid on a map from an existing database. The red dots are the GMTI reports from the processor. They are generally seen to coincide with the roadways. GMTIXP allows the operator to investigate various pre-Doppler and post-Doppler STAP-based algorithms. Figure 4 illustrates typical responses from a datacube of GMTI data. Note the fast moving target is passed through without attenuation while the clutter is attenuated by about 40 dB.

4 Summary and Outlook

The SAR and GMTI modes of the multimode radar were successfully flight tested in July 2003. Imagery from the flight testing of the land and ship imaging SAR modes were presented as well as results from the WAS-GMTI mode.
Ongoing flight trials are planned to further evaluate the air-to-land surveillance modes, the two-channel SAR-GMTI modes, ground moving target imaging, feature extraction from ground moving targets, automatic target recognition, the ECM susceptibility of the radar, and its potential for electronic counter-counter measures. In the maritime surveillance modes of operation, the advantages of using coherent processing, as well as scan-to-scan processing, to detect slow-moving low observable targets as well as fast-incoming-attack-craft are also being examined.
Currently, the experimental radar is being modified to allow the imaging of extremely wide swaths at fine resolutions, to enable bistatic SAR experiments, and to allow an image-while-search capability which will be embedded in a coherent maritime processing mode.

5 Literature

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[4] Olver, A.D., Clarricoats, P.J.B., Kishk, A.A. and L. Shafai: 'Microwave Horns and Feeds', IEE, London, UK, 1994

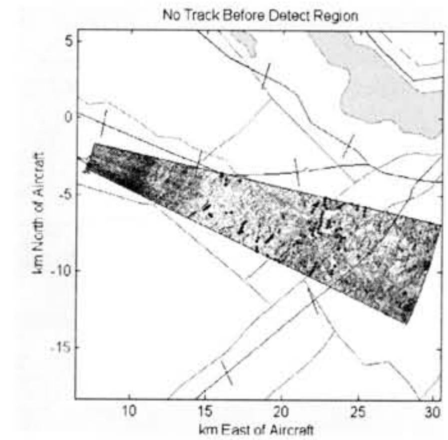

Figure 3: GMTIXP display showing GMTI contacts & DBS imagery with map underlay

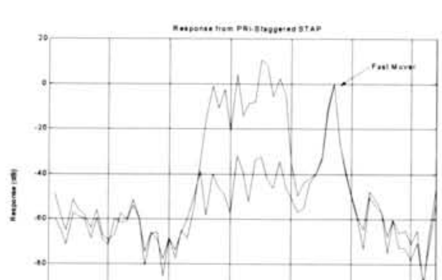

Figure 4: Doppler Response from a post-Doppler STAP algorithm (lower curve) and pulse Doppler processing (upper curve)

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