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# EMISAR: C- AND L-BAND POLARIMETRIC AND INTERFEROMETRIC SAR

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## ABSTRACT

EMISAR is a C- and L-band fully polarimetric (i.e. 4 complex channel per frequency) synthetic aperture radar designed for remote sensing with high demands for resolution (2 m), polarization discrimination, and absolute radiometric and polarimetric calibration. The present installation has one 3-axes stabilized antenna (C- or L-band) and two flush mounted C-band antennas providing the system with cross track and repeat track interferometric capabilities.

## INTRODUCTION

Electromagnetics Institute (EMI) began operating its C-band, vertically polarized, Synthetic Aperture Radar (SAR) in 1989. The radar has a 100 MHz bandwidth and an 80 km range. A full swath, full resolution real-time processor was completed in 1992. The C-band system has since been upgraded to fully polarimetric capability, and the first test flights took place in the fall of 1993. An additional L-band system with full polarimetric capability and the same resolution and image quality was completed and tested early 1995. The system was upgraded to interferometric capability in 1995 and the work on perfecting the installation and the processing software is ongoing.

The major application of the system is data acquisition for the research of the Danish Center for Remote Sensing (DCRS) which has been established at EMI with funding from the Danish National Research Foundation. The upgrade to polarimetry has been supported by the Joint Research Centre (JRC) of the European Community with the intention that EMI will operate the polarimetric SAR for JRC in connection with the intended EARSEC (European Airborne Remote Sensing Capabilities) campaigns. During 1994 and 1995 the SAR system has been used to acquire polarimetric data for EMAC (European Multi-sensor Airborne Campaigns) organized and sponsored by ESA [1].

## SAR SYSTEM RADAR HARDWARE

The SAR consists of an airborne system (the SAR sensor including 2 sensors with antennas), and a ground segment (the off-line processing facility). Figure 1 gives an overview of the complete system while Table 1 summarizes the more important performance parameters of the sensor.

## AIRCRAFT

The EMISAR is operated on a Gulfstream G-3 aircraft of the Royal Danish Air Force (RDAF). The G-3 is a twin engine jet, with a 6000 km range. The radar is usually operated at an altitude of 41,000 ft. but lower altitudes are used in some modes.

The size, weight, and power consumption allows the complete dual frequency system to be transferred to a smaller jet aircraft of the size of a Falcon 20 but the large range and high ceiling of the G-3 has advantages with regard to data acquisitions at distant sites and flexibility in imaging geometry. The G-3 can reach most sites in Europe, carry out the mapping, and return to the home base within one or two days.

The aircraft flight director gets its navigation information from an inertial navigation system and thus has a limited accuracy which is sufficient for normal flights. The SAR control computer gets navigation information from the aircraft P-code GPS receiver and emulates an instrument landing system (ILS) receiver which is connected to the aircraft flight director computer. In this way the actual flight track during mapping can be kept within a few meters of the desired track.

## ANTENNA POD INSTALLATION

A polarimetric antenna system and the radar INU are installed in a pod mounted below the fuselage, which facilitates rapid system installation and dismount. The pod installation includes a 3-axes stabilized antenna that allows zero Doppler

Table 1. EMISAR performance parameters

Frequency	5.3 GHz	1.25 GHz
Polarization	Polarimetric	Polarimetric
Antenna cross polarization	< -30 dB	< -35 dB
Azimuth ambiguity	< -30 dB	< -30 dB
Resolution in slant range	2, 4 or 8 m	2, 4 or 8 m
Resolution in azimuth	2, 4 or 8 m	2, 4 or 8 m
Swath width	12 or 24 km	12 or 24 km
Range (at noise equivalent $\sigma_{ON} < -20$ dB)	Max. 80 km	Max. 64 km
PSLR (In azimuth only at good flight conditions)	30 dB	25 dB
ISLR (In azimuth only at good flight conditions)	25 dB	25 dB
Intrinsic cross-talk terms	< -30 dB	< -35 dB
Calibrated cross-talk terms	< -35 dB	TBD

<sup>1</sup> Electromagnetics Institute (EMI, TUD) changed name per 1.1.96 to Dept. for Electromagnetic Systems (EMI, DTU)

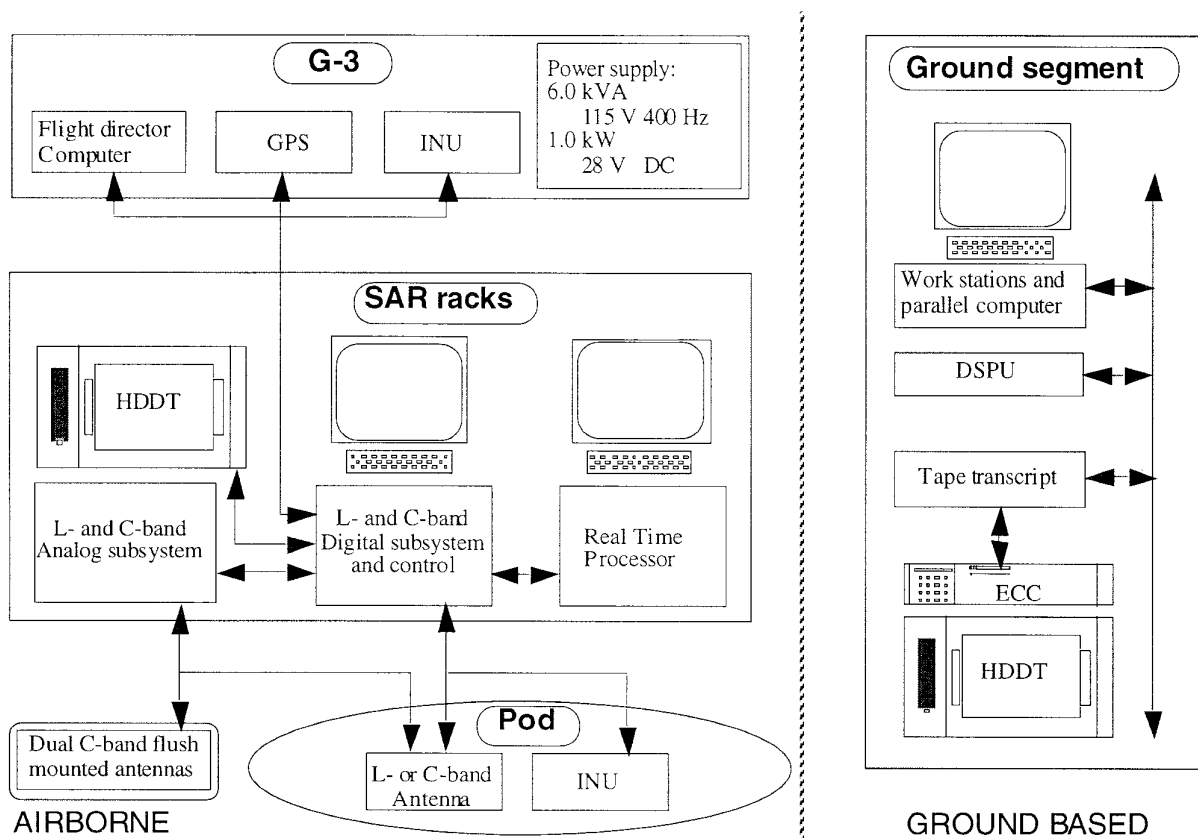


Figure 1. EMISAR C- and L-band SAR system overview with airborne and ground based segments.

mapping. However, the present pod has only room for one antenna, i.e. either L- or C-band. The radar electronics has been designed for simultaneous L- and C-band operation.

#### DUAL FREQUENCY AND INTERFEROMETRY

In 1995 one RDAF Gulfstream aircraft was augmented with two flush mounted antennas primarily intended for interferometric SAR applications. However, both antennas are fully polarimetric thus this installation offers a possibility for simultaneous dual frequency operation, although not at zero Doppler. The data rate needed for the squinted operation with the present hardware does not permit full resolution/swath dual frequency operation with full polarimetry.

The flush mounted installation presently has a physical baseline of 1.1 m and topographic mapping (aiming at producing digital elevation models) with this system has already been demonstrated [2]. The complete installation, having one antenna in the pod and two flush mounted antennas, also has the capability of along track interferometry although that feature has not yet been tested.

The system has been extended to support repeat track interferometry (RTI) but this mode is still under development. Very accurate track geometry is possible by the SAR control computer emulating an ILS receiver making actual tracks deviate only a few meter from the desired. Very high resolution

topographic mapping and change detection are possible although the method does require a challenging off-line processing [3].

#### ANTENNAS

The antenna for C-band is a dual polarized 32x7 element microstrip antenna designed to approximate a modified cosec-squared elevation radiation pattern for optimum illumination of the ground. The design has achieved high polarization discrimination, [4], [5].

The L-band antenna is a dual polarized 8x2 element microstrip antenna with even better high polarization discrimination. In order to obtain the required bandwidth the elements are stacked microstrip patches [6].

The antenna designs have furthermore been optimized to improve the system azimuth sidelobe performance [7]. Some of the more important antenna parameters are listed for both frequencies in Table 1.

The antenna attitude is automatically controlled. The antenna depression is set-up before each mapping to give the appropriate illumination of the target area. The aircraft attitude is measured by an inertial navigation unit (INU) located next to the antenna, and the antenna pointing is continuously updated to compensate for aircraft motion during mapping.

## THE SENSORS

The two sensors, one for C-band and one for L-band are identical except for the microwave subsystems.

Digitally generated modulation waveforms are converted to an I, Q pair of baseband signals which are upconverted, amplified, and then guided to the antennas. The signals received by the antennas are amplified and downconverted to an I, Q pair of baseband signals. The analog subsystems are temperature regulated to assure high stability.

The I, Q baseband signals are digitized to 8 bit samples at 100 Mhz and the received baseband signals is range pre-filtering (if reduced bandwidth and wider swath has been requested), double buffered, first order motion compensated, and azimuth pre-filtered and decimated to the requested pixel spacing. The pre-processed data are sent to the high density digital tape recorder (HDDT) which has sufficient capacity for the necessary ancillary information plus the output of both sensors at 1.5 m pixel spacing (240 Mbit/s). The data are also sent to the real time processor, [8], [9], which performs the SAR processing at full swath and resolution of one channel (although with some limitations at L-band and for squinted data).

The HDDT can accept all 8 channels at 1.5 m pixel spacing which is sufficient only when the signals are recorded at zero Doppler (a limitation of the existing azimuth pre-filter). With the present installation one sensor will use the flush mounted antennas and thus simultaneous dual frequency polarimetric operation is not yet supported at the highest resolution with a full swath.

## ABSOLUTE CALIBRATION

The SAR system has been designed and thoroughly tested to provide absolute radiometrically and polarimetrically calibrated data. This is accomplished by 1) having a very stable system, 2) performing internal calibration of this system immediately before and after each data take, and 3) by performing an absolute calibration at each mission using external standards.

EMISAR employs a unique internal calibration system which greatly relieves the dependence on external calibration targets: by measuring system parameters via internal signal loops just before and after mapping a scene, a calibrated image can be generated assuming knowledge and stability of a few passive components [10], [11], [12].

The internal calibration procedure comprises channel amplitude- and phase-imbalance correction, absolute radiometric calibration, and it has a potential for range delay calibration, STC calibration, and noise estimation, as well. Furthermore, the built-in calibration paths allow the pulse-based procedure to calibrate almost the complete system, including both the transmitter and the receiver, but not the antenna.

A 3-axes stabilized antenna has been chosen for both frequencies (the flush mounted antennas are not used for polarimetric calibrated modes) to avoid the calibration uncertainty otherwise caused by temporal variation of the antenna pointing error. The antenna is pointed perpendicular to the desired

track to permit zero Doppler processing. The antennas which are not included in the internal calibration loops have been calibrated to an accuracy of 0.1 dB on the directivity and 0.2 dB on the absolute gain by using the ESA-TUD Spherical Near-Field Antenna Test Facility [13]. The cross polarization terms of the antenna gains have not been included in the calibration.

To facilitate the absolute (external) calibration, a calibration test site (with 3 trihedral and 4 dihedral corner reflectors) has been established in cooperation with Research Centre Foulum which is also collaborating with DCRS on research in mapping soil and plants. This site is mapped on all missions and a very significant number of calibration data sets are available.

The results obtained for the 3 dB resolution, the peak side lobe ratio (PSLR) and the integrated side lobe ratio (ISLR) using the co-polar trihedral responses are summarized in Table 2.

The calibration stability has been examined based on a three day campaign where first two C-band calibration scenes were acquired, then four L-band scenes, and finally two additional C-band scenes, i.e. the antenna was dis-mounted and re-mounted between the two C-band missions. Using internal calibration only, the standard deviations of the absolute calibration and the channel imbalance was calculated, Table 3. Obviously a single external calibration per mission suffice.

For absolute calibration and channel imbalance correction, the internal calibration is complemented by corrections derived from external calibration results. These corrections are small and vary little from mission to mission. They were determined in an initial calibration experiment, and on most missions they are checked and adjusted if necessary by external calibration.

Cross-talk calibration may be carried out using distributed targets for which the true co- and cross-polarized returns are uncorrelated. This requirement is met by natural targets with azimuthal symmetry. Unlike most other algorithms, the Quegan algorithm [15] is non-iterative, and since it has previ-

Table 2. L-band and C-band impulse response statistics based on 2.0 m trihedrals (average  $\pm$  standard deviation).

L-band	azimuth	range
3 dB resolution (m)	$2.05 \pm 0.02$	$1.98 \pm 0.02$
PSLR (dB)	$-25.2 \pm 2.0$	$-25.8 \pm 1.3$
ISLR (dB)	$-25.1 \pm 2.4$	$-22.8 \pm 1.7$

C-band	azimuth	range
3 dB resolution (m)	$1.97 \pm 0.01$	$2.09 \pm 0.01$
PSLR (dB)	$-31.9 \pm 2.4$	$-30.9 \pm 2.1$
ISLR (dB)	$-30.8 \pm 0.8$	$-29.0 \pm 1.2$

Table 3. Standard deviation of residual calibration errors after internal calibration.

Frequency	TX imbal- ance	RX imbal- ance	Absolute cal.
L-band	0.12 dB 1.1°	0.20 dB 2.2°	0.51 dB
C-band	0.07 dB 1.2°	0.14 dB 1.6°	0.05 dB

ously shown good results for AIRSAR data, it has been used - in an enhanced version providing 4 channels - to estimate the rather small residual cross-talk from the EMISAR data [1]. Recent results seem to question that natural targets in general can be assumed to have sufficient azimuthal symmetry. Therefore EMISAR data, considering their low intrinsic cross talk (Table 1), are usually not cross-talk corrected.

#### PROCESSING CAPACITY

The processing of SAR data to quality images used to be a very time consuming task for standard computers. However, with 3 of today's fast RISC work stations with adequate RAM the computer capacity for processing polarimetric SAR data is in excess of 1000 fully polarimetric (i.e. 4 channels, 12 by 12 km, 2 by 2 m resolution) scenes a year. With the recent acquisition of a parallel computer facility the computer capacity is not the problem.

However, bottlenecks during HDDT transcription, lack of automated set-up in parts of the processing chain and output product generation presently limits the actual throughput to a somewhat lower number. The HDDT reliability is a weak link. Presently the actual processing throughput is around 10 polarimetric scenes per week. Work on automating the entire processing chain is in progress and further improvements of the capacity is expected during the summer of 1996.

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