PHARS: A C-BAND AIRBORNE SAR

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ABSTRACT

For the study of microwave scattering of vegetation, forests, sea and other targets ground-based and airborne scatterometers and a digital SLAR system (X-band) are used since many years in The Netherlands. All these systems are absolutely calibrated. The experience gained with building radar remote sensing systems led to the development of a polarimetric C-band aircraft SAR. Before this system can be build a number of technological problems have to be solved. This is done in several theoretical and practical studies. In one of these preparatory studies a SAR testbed will be constructed, to test parts of the technology that will be used in the final system and to gain experience with airborne SAR in general. After an overview of the PHARUS project, the results reached so far with the design and realization of the SAR testbed will be described.

PREFACE

The PHARUS project is carried out in a cooperation between the Physics and Electronics Laboratory of TNO (FEL-TNO), the National Aerospace Laboratory NLR and the Delft University of Technology, Telecommunication and Remote Sensing Laboratory.
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INTRODUCTION

Ground-based scatterometry in The Netherlands has proven to be essential in studying the scattering of microwaves by vegetation and sea. The results of ground-based measurements were among others used for the development of suitable models and for the design of a digital and calibrated airborne X-band SLAR system. Among others the multitemporal crop classification could be demonstrated with this system (1).

There are however some limitations set to the ground-based measurements. In the first place the possible number of test fields is limited, therefore the statistical spread of the radarsignature for different fields with the same crop type cannot be investigated. Secondly the illuminated area is relatively small and in some cases even too small, which leads to differences in scatter values between ground-based and airborne measurements. In the third place ground-based scatterometers use normally only X-band or higher frequencies. The

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mentioned limitations led in the 1980's to the design and the use of the DUTSCAT (Delft University of Technology SCATterometer) system (2). The DUTSCAT is an airborne scatterometer system operating at six frequencies simultaneously between 1 and 18 GHz. The data sets from this system form the basis for the knowledge that is necessary to evaluate new applications in the field of remote sensing. Apart from studying the behavior of targets as a function of frequency or angle of incidence, the polarization dependence can be studied, which becomes of growing importance as the interest in polarimetry increases.
The next step is the development of an airborne polarimetric SAR system in the C-band, called PHARUS (PHased ARray Universal SAR). The choice of the parameters for this system are based on the experience gained with the previous programs. This means that special attention will be paid to the data accuracy. In the end the system will have to deliver radarbackscattermaps: calibrated images with a high level of geometric and radiometric accuracy. The frequency used for the PHARUS is the same as for the ERS-1 satellite. The "universal" aspect of the PHARUS system is found in its twofold application: both military and civil programs in The Netherlands will benefit from it.

The PHARUS project consists of two phases: a definition phase and a realization phase. In the definition phase studies are carried out on antennatechnology and aircraft motion measurement and compensation. Furthermore a SAR testbed is constructed. This relatively simple SAR system will be used to study in detail the problems and the design of the final PHARUS system, which will be realized in 1991-1993.

THE PHARUS PROJECT

A few years ago the three institutes mentioned in the preface developed a plan to design and build a polarimetric airborne C-band SAR system of a novel design, meant as a replacement for the current SLAR system. It took about two years to raise the necessary funding. This can be seen in figure 1. As a result the system will be completed much later than originally expected.

The plans for the PHARUS system are based on the experience that was built up with the previously described systems. The choice for C-band was based on the development of the ESA ERS satellite program (3). However, the initial hope to have the system operational simultaneously with the ERS-1 seems to be unrealistic. The SAR testbed PHARS will be flying simultaneously with the ERS-1 now, but PHARS is not meant to be an operational system.

Figure 1 shows a block diagram of the PHARUS project. The project consists of two phases, a definition phase and a realization phase. The definition phase is intended to increase our knowledge on SAR and to develop the critical technology that will be used in the final system. In figure 1 it can be seen that three preparatory studies will be carried out before the actual PHARUS system is designed. These studies are considered to be essential for a proper design of the PHARUS.

Upon completion of the preparatory studies enough experience will have been built up to design the polarimetric PHARUS system. This system will be realized in the period 1991-1993. Simultaneously a flexible software package for SAR processing called PASAR (Preprocessing of Airborne SAR data) will be developed. Apart from the necessary SAR processing, this software package shall perform geometric and radiometric corrections. The experience that was built up with the processing software for the present SLAR system will form the basis for PASAR.

The PHARUS project is reaching the end of the definition phase, but it is still to early to give detailed specifications for the system. They will be fixed during the design phase. The plans are heading for a polarimetric SAR with user selectable values for resolution (1.5 - 10 meter), swath (near range, far range or wide swath with reduced resolution) and recorded polarizations (one, two or four polarizations). The frequency will most probably be the same as used for the PHARS: C-band (5.3 GHz). It is expected that the system will be operational by the end of 1993.

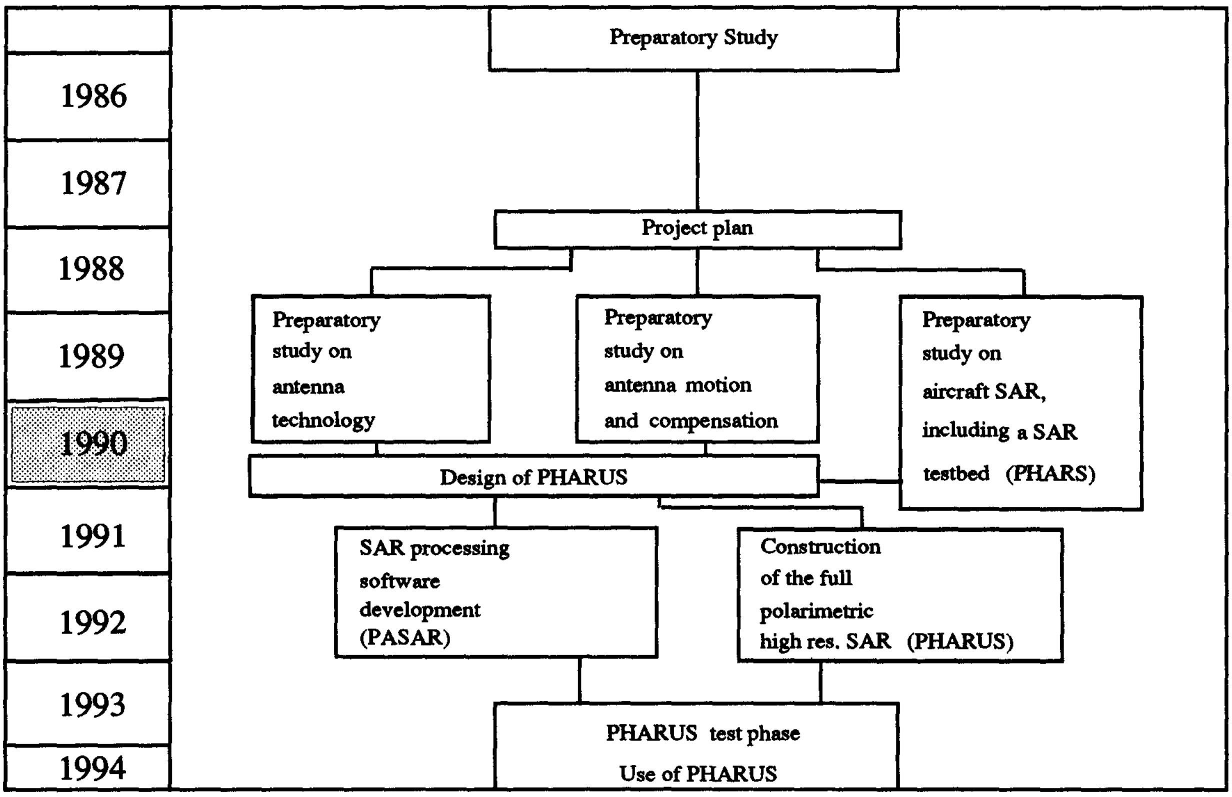

Figure 1. Block diagram of the PHARUS project.

THE SAR TESTBED PHARS

In the third preparatory study a SAR testbed is under construction. The testbed is necessary to study general problems of aircraft SAR and to study the coherent integration processes which in the end determine the system sensitivity. Finally the testbed can be used to determine the antenna motions from the radarsignal. The results will be compared with motion measurements taken from other sensors, like an inertial navigation system, gyro's and accelerometers. This forms an important input for the final choice on a motion compensation system. Since calibration of a radar equipped with an active array antenna is difficult to perform, several calibration schemes will be tested in the PHARS. In table 1 some key parameters of the PHARS are given. On one hand this testbed can be considered as a simple

SAR system, with a limited range, on the other hand it is a state of the art technology testbed, designed to test modem technology for the PHARUS system.

Radar type	Coherent pulse radar
Frequency	5.3 GHz
PRF	3500 Hz
Pulse width	32 ns (4.8 m) after compression, 12.8 μs before compression
Peak power	160 W
Range	6 - 13.7 km
Antenna	one 8 x 4 element patch antenna
Polarization	VV
Sampling	87.5 MHz, 8 bit offset IF, 4096 samples
Azimuth presumming	16 times
Resolution	4.8 m in range, 6 m (4-6 looks) or 1 m single look in azimuth

Table 1: Specifications of PHARS.

The antenna consists of eight rows of four elements each. The four elements are connected by transmission lines and radiate equally to narrow the vertical antenna beamwidth to approximately 24° as desired. Most of the microwave electronics is concentrated in the T/R modules. The eight radiating sections of the antenna are each connected to a module. The eight microwave transmit/receive modules are mounted on the backside of the antenna. One module measures 4 x 13 cm^2 and is produced in stripline technology on Aluminiumoxide substrate. The modules contain a two stage FET power amplifier, a low-noise amplifier, a limiter, a 4 bit phase shifter and two SPDT switches, to actuate either the receive or the transmit channel. The power transistors are switched on just before transmission of the pulse and switched of immediately afterwards to reduce the consumed electrical power and to reduce to noise leakage from the power stage into the low-noise amplifier. The noise figure of the receiver chain is 1.3 dB.

A power splitter/combiner network connects the eight modules with the frequency generator and detector. The frequency generator uses a dielectric resonator oscillator (DRO) to generate the microwave carrier. The DRO is phase locked to a crystal oscillator. The 5.3 GHz signal is modulated by a single side band modulator with a digital generated linear FM chirp of 31 MHz bandwidth

The detector circuit is rather straight forward: the microwave signal is downconverted to 350 MHz, the IF frequency. This rather high frequency is chosen, because the final PHARUS system will use an increased bandwidth of approximately 100 MHz, necessitating a high IF frequency. The output of the IF section is mixed to an offset frequency of 21 MHz and then A/D converted in 8 bits, with a sampling rate of 87.5 MHz. An amplifier-attenuator pair in the IF section is used to bring the received signals into the dynamic range of the A/D converter. A single patch antenna is used for transmission and reception. This antenna is fixed to the aircraft (no mechanical motion compensation). The beam can be steered in coarse steps of 3.5° to compensate for the average drift angle. The horizontal beamwidth of the antenna is wide enough to eliminate the influence of aircraft yaw, once the beam is corrected according to the average drift angle of the aircraft, which may vary between -12° and +12°.

The use of distributed power generation with transistors instead of a central TWT yields in a much smaller than usual peak power in both the PHARS testbed and the final PHARUS system. Each transistor power amplifier in the PHARS delivers 20 Watts, resulting in a total transmitted power of 160 Watts. System sensitivity is realized by the use of a high PRF (3500 Hz) and a large pulse compression ratio of 400. In the PHARUS system the peak power will be increased to approximately 2 kW and possibly the pulse compression ratio will also be further increased.
The range lines are produced at a rate of 3500 Hz, being the radar PRF. The associated data stream is much too large to store on magnetic tape. The indicated 4 look azimuth resolution of 6 meter corresponds to a dopplerband between -50 and +50 Hz. This bandwidth can de sampled by the recording system at a maximum value of 218 Hz. To reduce the range line frequency of 3500 Hz to a 218 Hz sampling rate and to filter out the doppler components outside the band of interest, a Finite Impulse Response (FIR) filter is used as a weighted presummer. In addition the antenna azimuth pattern further reduces the amplitudes of the high doppler frequencies, because they come from targets that are at the edge of the antenna beamwidth.

The PHARS digitizer and presummer also consist of a monitor and AGC section. The raw SAR signal is not suited as a monitor signal due to the phase information. By performing partial correlation on the raw data a SLAR like signal can be constructed. This signal is used to monitor the system. These signals are also used after some additional processing to set the radar receiver gain. The gain setting is done before an actual measurement. The gain is fixed during the measurement. The digital data remaining after azimuth presumming with a factor of 16 will be recorded on an airborne instrumentation recorder with HDDR. Similar recording systems are also used for recording of the SLAR and DUTSCAT data. Apart from the azimuth presumming there is no onboard processing for the testbed. In figure 2 a block diagram of the testbed is shown.

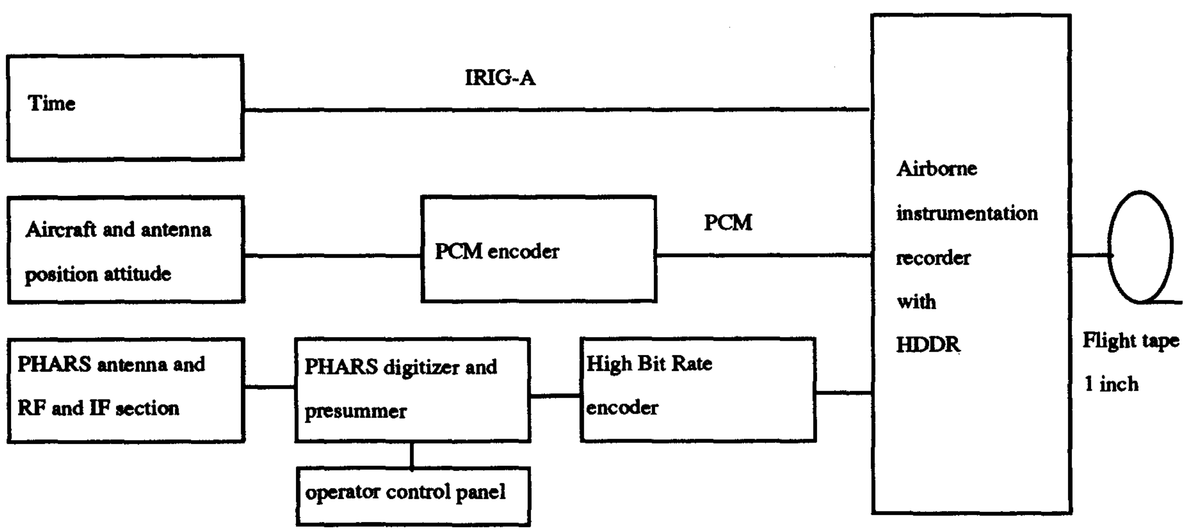

Figure 2. Block diagram of the PHARS airborne system.

Besides the digital output of the digitizer and presummer, aircraft attitude, antenna attitude and timing data are recorded. By getting down as much data as possible, very flexible experiments are enabled with the system at the cost of long processing times. This is not a major disadvantage since the amount of data that will be gathered with the testbed is small anyway. Afterall the testbed PHARS is not an operational system.

The aircraft that will be used in the project is a Swearingen Metro II, a twin engine business plane, and in use as a laboratory aircraft by the NLR. It will be the platform for the PHARS and the PHARUS at an altitude of 6000 meter with a speed of approximately 100 m/s. The aircraft is equipped with various sensors to acquire aircraft attitude and position. Among others an inertial navigation system, using lasergyro's is available.

CONCLUSIONS

Bearing in mind the experience in remote sensing, build up over more than ten years, a polarimetric SAR system is designed in The Netherlands. The project is carried out in two steps. In this paper the first step, consisting of the preparatory studies including a SAR testbed, is described in detail. This SAR system has limited capabilities, but will serve the purpose of acquiring experience with aircraft SAR and its technology. The system is built up with state of the art technology. Remarkable features are the fixed antenna and the low peak power, generated by solid state devices. The solid state technology reduces the dimensions of the radar considerably and avoids the use of potentially dangerous high voltage power supplies for TWT's. The use of MMIC's in the PHARUS is investigated in the preparatory study on antenna technology. Application of MMIC's would further reduce the dimensions of the radar system.

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