PHARUS: AIRBORNE SAR DEVELOPMENT IN THE NETHERLANDS

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ABSTRACT

The PHARUS project (PHARUS stands for Phased Array Universal SAR) aims for a polarimetric C-band aircraft SAR, that will be finalized in 1994. The system will make use of a phased array antenna with solid state amplifiers. The project consists of two phases, a definition phase and a realization phase. The definition phase was intended to increase the knowledge on airborne SAR systems and to develop the critical technology that is used in the final system. As part of this phase a C-band SAR testbed called PHARS was developed, which made its first testflight in november 1990. The testbed is based on the concept of a wide beamwidth antenna, rigidly fixed to the aircraft. Pulse compression and a high PRF ensure sufficient sensitivity in this system, which is equipped with a 160 Watt peak pulse solid state transmitter. The processing is done off-line.

In the current realization phase the polarimetric PHARUS system is being developed. Its design is similar but more advanced when compared to the PHARS testbed. The system will make use of a phased array dual polarised patch antenna and will be equipped with solid state amplifiers and MMIC vector modulators. The number of microwave modules is increased (48 for PHARUS versus 8 in PHARS).

The paper focuses on the design of these SAR systems and on the results obtained sofar with the PHARS testbed. A performance evaluation of this system using corner reflectors was part of the testprogram. PHARS was also operated during the ERS-1 CAL/VAL campaign in Norway in November 1991.

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, Laboratory for Telecommunication and Remote Sensing Technology. Financial support for the project is provided by the Ministry of Defense and

by the Netherlands Remote Sensing Board (BCRS). The program management on behalf of these partners is carried out by the Netherlands Agency for Aerospace Programs (NIVR).

INTRODUCTION

The PHARUS project started in 1988 as a Netherlands national project, after preparatory studies in the previous years [1, 2]. PHARUS is an acronym for PHased ARray Universal SAR, where SAR stands for Synthetic Aperture Radar. The initiative for this project came from the remote sensing community, which in the years before performed extensive studies using an X-band SLAR and groundbased and airborne scatterometers. Furthermore international campaigns offered data from various systems.

An important factor in the development of radar systems is the frequency choice. Though initially a preparatory study aimed for a detailed analysis of pro's and con's of possible frequencies and polarizations, the final choice was based on the ERS family, ESA's remote sensing satellites for the nineties. There the C-band (5.3 GHz, wavelength 5.6 cm) was selected. The frequency analysis in the preparatory study was limited to an analysis of what could be expected from a C-band radar for remote sensing applications.

The complete PHARUS project consists of two parts, a definition study and a realization phase. The definition study was meant to solve the problems that were encountered in the preparatory study and to gain experience with SAR technology and with airborne SAR problems. The realization phase will profit from the gained experience and will lead to a straightforward development of a polarimetric SAR system.

In the definition study three separate studies were carried out. The antenna technology study was mainly focused on the theory and design of patch antennae, including polarimetric designs for the PHARUS system. The second study was focused on motion compensation. Using a raw SAR data computer simulator, the motion compensation requirements could be well defined. An experimental verification was performed with the SAR testbed, developed in the third study. The testbed (PHARS, a simple SAR system for experimental and verification purposes) is described in this paper. In the third study attention was also paid to the development of SAR processing algorithms, including so-called autofocus algorithms, which determine the aircraft trajectory from the radar data. These schemes were necessary to enable a comparison with the results of the motion compensation study and to determine whether the achieved motion compensation quality could meet the desired standards. This paper also discusses the results obtained from a testflight with the PHARS system. In this part both the radar performance and the motion compensation system performance are evaluated.

The results of the three studies were used in a pre-design of the PHARUS system. The pre-design is currently developed into the detailed design of PHARUS. The status of this phase is discussed here, focusing on the system specifications and on some design aspects.
The definition study PHARUS was started in the first half of 1988 and ended early 1991. The completion of the studies was rewarded with a successful testflight of the PHARS SAR

testbed on 8 November 1990. The realization phase started in April 1991 and aims at a first testflight with the polarimetric system in 1994.

THE SAR TESTBED PHARS

In one of the preparatory studies a SAR testbed has been constructed. The testbed was necessary to study general problems of aircraft SAR and to study the coherent integration processes which in the end determine the system sensitivity. 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 modern technology for the PHARUS system. In Table 1 some key parameters of the PHARS are given. Figure 1 (left) shows the full blockdiagram of the system.

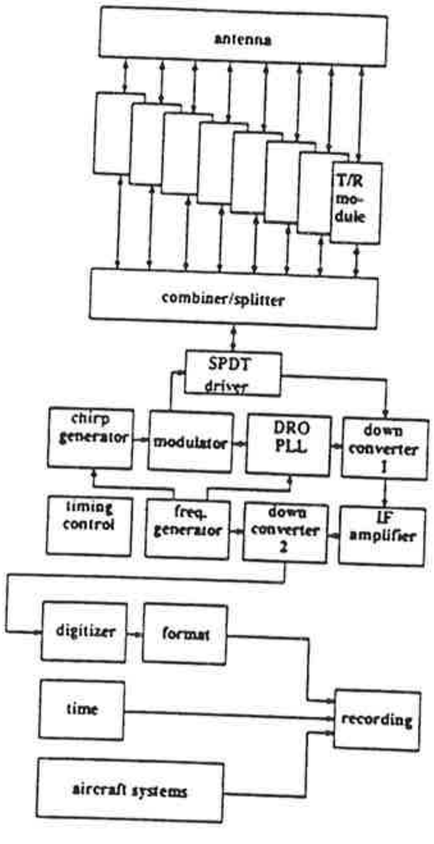
Radar type	Coherent pulse radar
RF frequency	5.25 GHz (C-band)
PRF	3500 Hz
Waveform type	linear FM (no amplitude modulation)
Pulse length	12.8 ms before and 32 ns after pulse compression
Total peak transmit power	160 Watt
Range	3 - 14 km
Antenna	8 elements antenna with 2 patches each
Polarization	vertical
Azimuth beamwidth	9 ° (two way)
Azimuth presumming factor	16
Azimuth scan angle	-12 to +12 degrees (1° steps)
Elevation beamwidth	35 ° (two way)
Elevation pointing angle	mech. fixed at 20, 30 or 40° (depression angle)
Resolution	4.8 m in range 1 m single look in azimuth
Sampling freq. in range	87.5 MHz (A/D conversion), 4096 * 8 bit
Data storage rate	8.2 Mbit/s
Airplane	NLR Metro
Altitude	3 - 6 km
Speed	100 m/s
Position and motion registration	IRS, ARA

Table 1. Specifications of PHARS

A single patch antenna is used for transmission and reception. This antenna is fixed to the aircraft (no gimbaling system). The beam can be steered in 1° steps 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 antenna consists of eight rows of two elements each. The two elements are connected by a transmission line and radiate equally to narrow the vertical antenna beamwidth to approximately 35° 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 modules are mounted on the backside of the antenna. They measure 4 x 13 cm^2 and are produced in stripline technology on Aluminumoxide 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 off immediately afterwards to reduce the consumed electrical power and to reduce to noise leakage from the power stage into the low-noise amplifier. 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.

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.



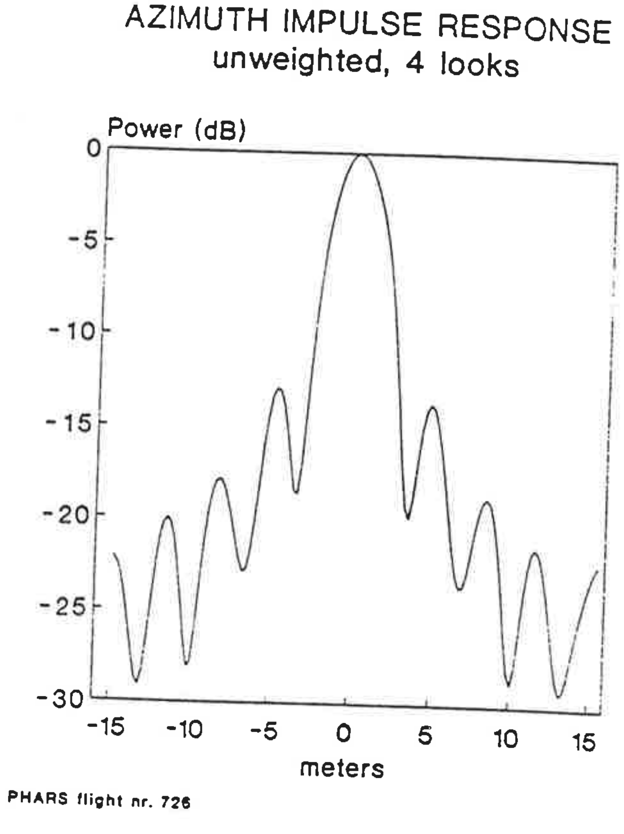


Figure 1. Left: blockdiagram of the complete PHARS system.
Right: Corner reflector azimuth response of PHARS.

The detector circuit is rather straightforward: the microwave signal is downconverted to 300 MHz, the 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 within the dynamic range of the A/D converter.

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 of -50 to +50 Hz. This bandwidth can be 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 real time 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 correspond to the edges of the antenna beam.

The PHARS digitizer and presummer also contain a monitor and AGC section. The raw SAR signal is not suited as a monitor signal. By performing partial correlation on the raw data a SLAR like A-scope signal can be constructed. This signal is used to monitor the system and to set, after some additional processing, the radar receiver gain. The gain setting is done before an actual measurement. The gain is fixed during the measurement. There is no onboard SAR processing for the testbed.

The aircraft available to the project is a Swearingen Metro II, a twin engine business plane, used as a laboratory aircraft by the NLR. It will take both the PHARS and the PHARUS at altitudes up to 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.

RESULTS OF THE PHARS FLIGHTS

On 8 November 1990 a testflight with the PHARS system was performed. The test flight resulted in good quality data over a mixed sea/urban/rural area in the surrounding of The Hague in The Netherlands. A second track was directed over some corner reflectors which were deployed in the Flevopolder on a field with short grass.

To measure the image quality the corner reflector responses in the Flevopolder scene were analyzed. The data was corrected for aircraft motion with aid of the Inertial Reference System onboard the aircraft and a Firebrand Attitude Reference Assembly close to the antenna. In azimuth the data was processed to four unweighted (50% overlapping) looks. Fig. 1 (right) shows the azimuth response of a corner reflector. The plot is an interpolation by a factor of 4 from the calculated datapoints, which occurred every 1 meter. So the actual azimuth sampling has been increased to 0.25 m. The resolution turns out to be close to 3 meter, as was expected. The sidelobe levels and their symmetry reveal that a complete correction is achieved. The plot strongly resembles the theoretically expected sin x/x.

The range resolution was also tested. From the corner reflector response the resolution turned out to be 5.1 meter as opposed to a theoretical value of 4.8 meter. The difference is most probably caused by bandwidth or phase effects in the radar, leading to an extra, uncompensated weighting function.

After the testflights it was decided to participate in the ERS-1 calibration/validation campaign held at the end of 1991in the Norwegian Sea. The analysis of these data is still in progress. A recent image of the North Sea locks and the steelworks near IJmuiden is shown in figure 2. This 3 meter azimuth resolution image contains 4 looks.

Figure 2. PHARS image near IJmuiden. Image dimensions: 3 x 6 km.

REALIZATION OF PHARUS

In this section the predesign of the PHARUS system is described. It serves as a starting point for the development of the PHARUS system in the realization phase of the project. The technical properties of the proposed system should be regarded as design goals.

In an active phased array SAR system as considered in this study, the number of microwave modules determines both the transmitted power and the antennagain. Each module can be connected to only one patch antenna, if the low cross polarization design of the antenna study is followed. The system will be realized with a limited number of high power modules. In the design a number of 48 modules was chosen, rendering over 700 Watt transmitted power when the individual modules deliver maximally 20 Watt, like the PHARS modules. A low sidelobe tapering of the aperture is taken into account here and clearly reduces the maximum transmitted power. The antenna will be configured as 2 x 24 elements (elevation x azimuth).

The selected configuration will enable a resolution of 4, 8 or 16 meter over ranges up to 26 km in the single polarization mode. In dual and quad polarization (polarimetric) mode, the range is reduced to appr. 14 km, due to S/N restrictions. The swathwidth varies with mode and resolution between 2.5 and 18 km. The number of looks varies from 3 to 20. The large amount of data to be stored forms a bottleneck here in several modes.

A module is composed of a Transmit/Receive (T/R) module and a microstrip patch antenna connected via a ratrace or hybrid ring. Any module can be replaced without disassembling a major part of the antenna. The modules are connected to a combiner/splitter network with the RF-generator, Local Oscillators, mixers, AD-converters etc.

The antenna shall have an azimuth scan range of +/- 20° and an elevation scan range of +/- 15°. With a center frequency of 5.3 GHz (l = 56 mm) this results in an element spacing of respectively 41 and 44 mm. These are also the cross-section dimensions of the T/R-module. The necessary miniaturization is reached by using MMIC-technology where ever possible. The T/R-module contains two vectormodulators (4 bit amplitude control, 7 bit phase shifter), a 20W (peak) Power Amplifier (PA) and two Low Noise Amplifiers (LNA). In the transmit mode, the PA is connected by a diode switch to either the horizontal or the vertical channel, in the receive mode both channels are active and recorded simultaneously.

For a good polarimetric operation of the microstrip patch antenna a polarization decoupling of at least 20 dB is required in any plane, even under scan conditions. A single, dual polarized element with such performance was not known to the authors. In the antenna study of the definiton phase a solution was developed. A ratrace (also called hybrid ring) connected symmetrically to the patch appeared to meet the requirements and solved some other problems. Figure 3 shows the setup. Using one port of the ratrace, the two patch connectors will receive their signals in phase, the other port results in anti-phase feeding. On the patch this yields two orthogonal fields. The ratrace isolates the ports connected to the T/R-module on a natural way and the same applies for the two connectors to the patch. Finally, a third port on the ratrace which is isolated from the patch connectors is used to implement a calibration channel. In the transmit mode a small part is coupled out (about -

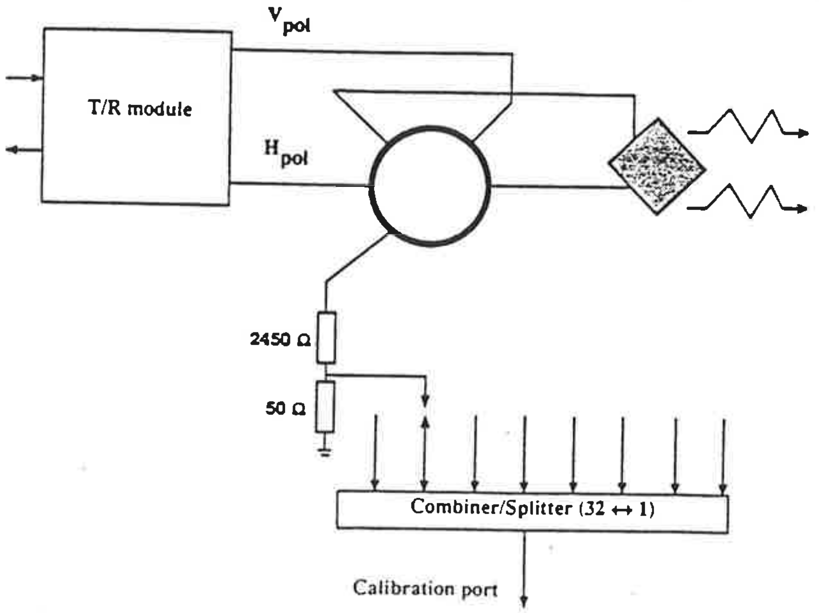


Figure 3. Dual channel patch antenna connection to the T/R module in PHARUS.

40 dB) and can be used for monitoring. In the receive mode a signal can be injected to check both receive channels. Mutual coupling of other patches and modules is of no influence because the calibration port is isolated from the radiator.

The two channels of the received analog radar data are digitized at a maximum speed of 100 MHz in 8 bits. The resulting high bitstream cannot be handled by single channel digital circuitry. Therefore the data is split up and treated in parallel. Four presummers are available to process the data of one, two or four channels (polarimetric mode). To comply with these varying needs, the data streams can be configured as necessary in a matrix switch. After presumming the data rate is reduced, but still high and pulse compression will be applied on board. The limits of the current data recording unit forces us to compress the data as much as possible, especially in the polarimetric mode, which is very demanding on data rate.

CONCLUSIONS

A description is given of the SAR testbed PHARS, which was developed in The Netherlands as part of the PHARUS airborne SAR program. After the successfull completion of PHARS in 1990, the testflights showed that the system operated well. In the meantime PHARS was operated during the ERS-1 CAL/VAL campaign in Norway.

The design of the PHARUS polarimetric SAR, based on the experience with PHARS has just been finalized. The system will use a dual polarized microstrip patch antenna with 48 radiators (expandable to 96). A novel design using a ratrace ensures a low cross polarization level in the antenna and opens the possibility for an accurate internal calibration system. The values for resolution (4/8/16 meter, 3-20 looks) in both azimuth and range are user selectable. Likewise the number of polarizations (1/2/4) can be chosen. The latter value leads to polarimetric observations. The system will have an active phased array antenna, which can be steered in one axis, to compensate aircraft yaw and drift. It is expected that the system will be ready for its first testflight early 1994.

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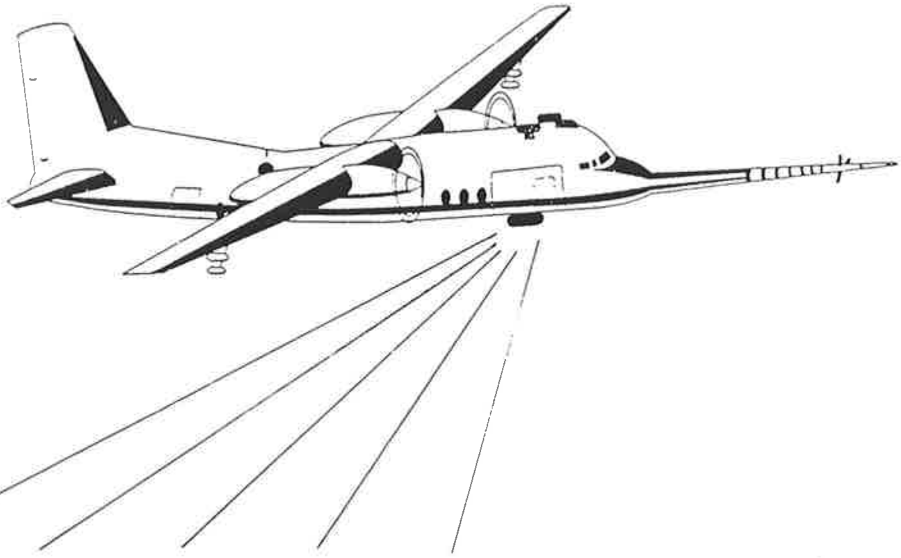
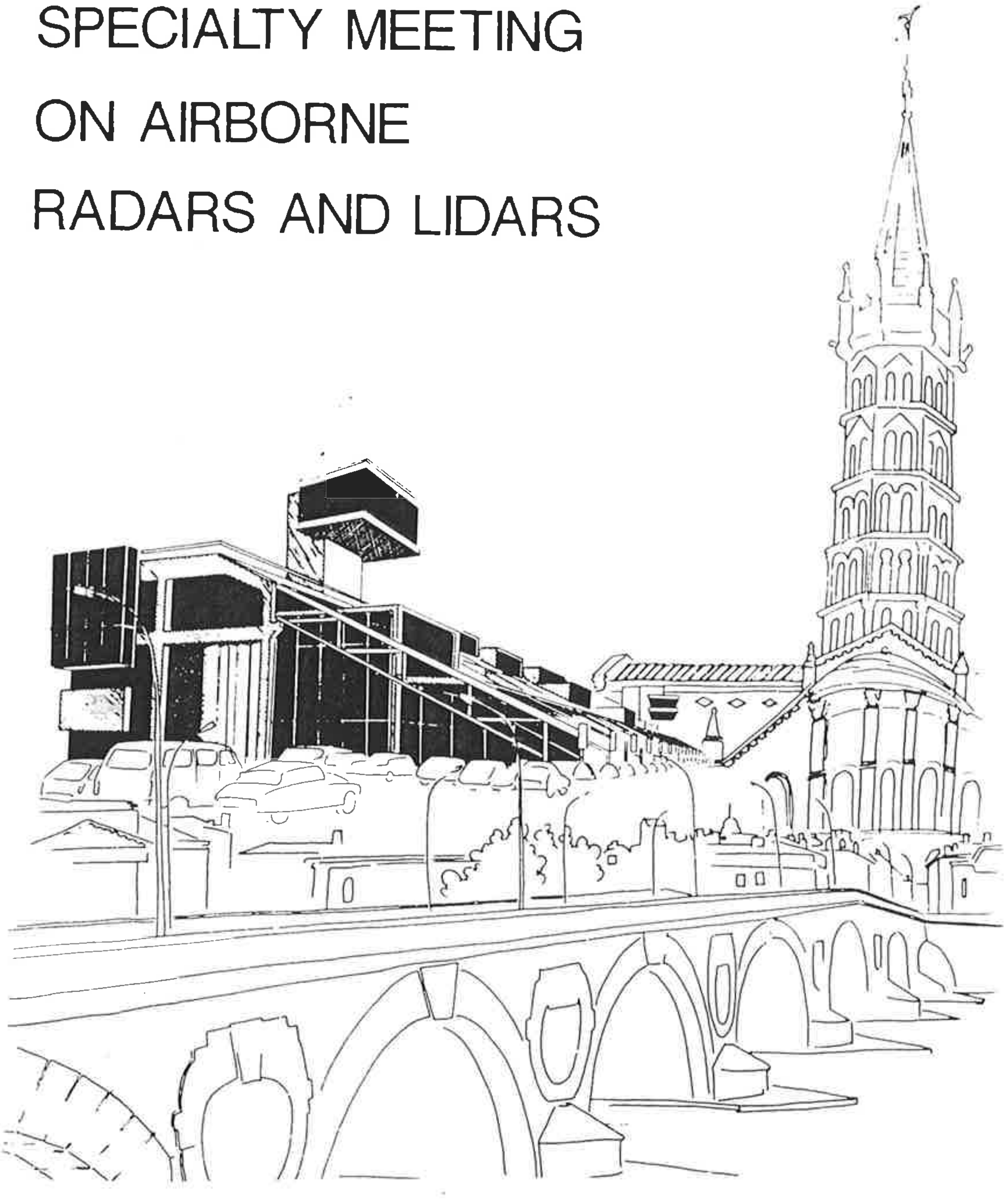


SPECIALTY MEETING ON AIRBORNE RADARS AND LIDARS



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