# PHARUS
## PHased ARray Universal SAR

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## Abstract
In the Netherlands, a polarimetric C-band aircraft SAR (Synthetic Aperture Radar) has been developed. The project is called PHARUS, an acronym for PHased ARray Universal SAR. This instrument serves remote sensing applications.
The antenna system contains 48 active modules (expandable to 96). A module is composed of a Transmit/Receive section, a dual polarized microstrip patch antenna and these parts are connected via a ratrace or hybrid ring. Every module can be replaced without disassembling a major part of the antenna.
The required scan range of the antenna is in azimuth +/- 20° and in elevation scan +/- 15°. With a center frequency of 5.3 GHz ($\lambda$ = 56 mm) this results in an element spacing of 41 by 44 mm which are also the cross section dimensions of the module. The necessary miniaturization is reached by using MMIC-technology extensively. For the radiator a microstrip patch antenna has been choosen for its flat and lightweight structure.
The cross-polarization of the microstrip patch antenna is reduced by feeding the two probes simultaneously. The ratrace, which is used as a splitter, has also other useful properties. Finally, for the internal calibration a monitoring channel is implemented.

## 1. Preface
The PHARUS project is carried out in a cooperation between the TNO Physics and Electronics Laboratory (TNO-FEL), the National Aerospace Laboratory (NLR) and the Delft University of Technology (DUT). TNO-FEL is the main contractor and is responsible for the project management. Financial support for the project is provided by the Ministry of Defence 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).

## 2. Introduction
The antenna system of the PHARUS SAR contains 48 active modules (expandable to 96). A module is composed of a Transmit/Receive section, a dual polarized microstrip patch antenna and both are connected via a ratrace or hybrid ring. Every module can be replaced without disassembling a major part of the antenna. The modules are connected to a combiner/splitter network with the RF-generators, Local Oscillators, Mixers, AD-converters etc. (see fig. 1).

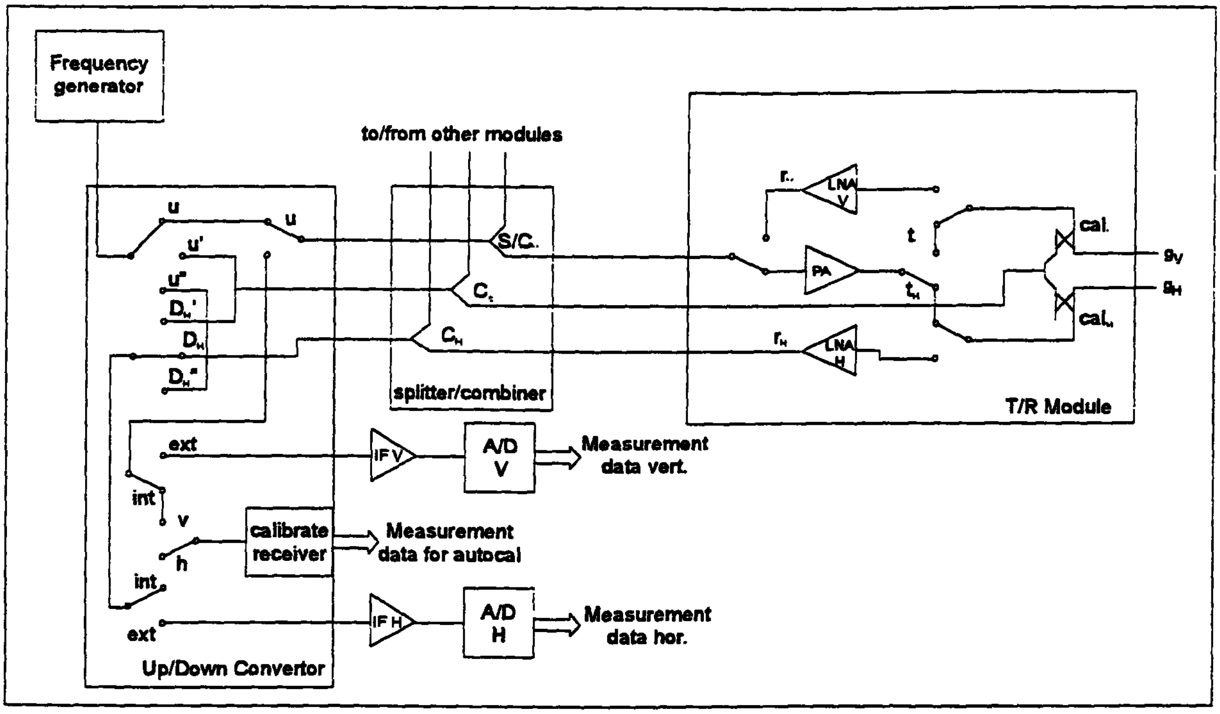


Fig. 1 Simplified block diagram of the PHARUS system

The radiation pattern of an electronically steerable phased array antenna is determined by the amplitude and phase characteristics of the feeding signals of each of the radiation elements. In a polarimetric active phased array with one T/R-module for each individual radiator the calibration is very complicated. To assure an optimal performance of the system, correction mechanisms and Look Up Tables (LUT's) have been implemented at several levels.

## 3. T/R Module

The T/R-module contains two vector modulators (4 bit amplitude control, 7 bit phase control) , a 20 W (peak) solid state Power Amplifier (PA) and two Low Noise Amplifiers (LNA). In the transmit-mode, the PA is connected via a diode switch to either the horizontal or vertical port of the ratrace and patch antenna. In the receive mode, both polarizations are received and recorded simultaneously. A separate calibration channel is implemented for monitoring the actual behavior of the module (see fig. 2). Digital timing and control circuits control the microwave switches for receive and transmit mode. The total gain of a T/R-module in transmit mode is about 55 dB. To increase the efficiency and avoid oscillations the PA's are switched off after the transmit time. The LNA's are turned on, and the microwave switches and vector modulators are activated for the receive mode of the radar.
To keep the module within the mentioned cross-section dimensions, MMIC-technology has been used extensively. Some of the realized dimensions: the vector modulators measure 2 x 3 mm each, the LNA's are 20 x 10 mm each and the PA is 75 x 40 mm. The PA can not be reduced further at the moment as the end-stage transistors determine the size. The total length of the module is 157 mm (6 inch). Mechanically the T/R modules are designed as a sandwich structure. At the top layer, the microwave circuits are located, in the middle the analog distribution printed circuit boards, and at the bottom the digital circuits can be found. By using this sandwich construction a very compact T/R-module has been realized.

The behavior of the Vector Modulators is linearized by implementing a Look Up Table for each Vector Modulator. The non-linearity has been measured and fitted to a third order 2-dimensional polynomial in I and Q. This is a correction on component level.
The transfer characteristics of the T/R-modules have been made equal to a passive reference module by implementing another Look Up Table. Each module has been measured separately in an anechoic box in both transmit and receive mode. In this way, the modules are interchangeable. This is a correction on module level.

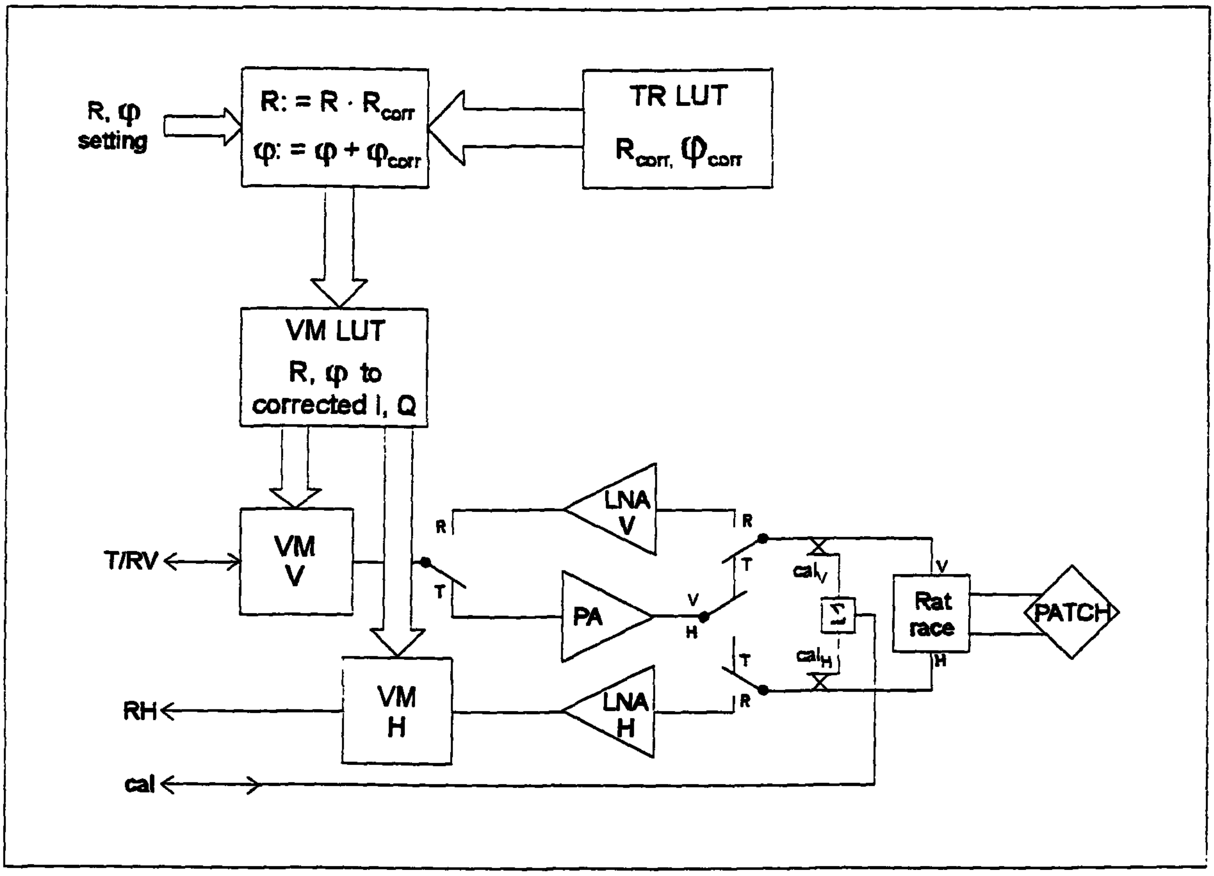


Fig. 2 Simplified block diagram of the T/R-module

## 4. The Patch Antenna

The radiator is a lightweight structure. For a good polarimetric operation a polarization decoupling of at least 20 dB is required. Polarization decoupling means the difference between the co- and cross-polar patterns at any angle in the -3 dB beam region (+/- 45°) in any plane. In practice this means that the cross-polarization level (defined as the difference between the max. values of the co- and cross-polar patterns) should be at least -23 dB in the beam region. Such a cross-polar performance was only reported for subarrays. However, this technique is not applicable in this case due to the scan requirements. The solution is to use two feed probes and excite them both for each polarization. Both feed get the same amplitude but the signals are in phase for one polarization and in anti-phase for the other orthogonal polarization. In this way, the fields are always a combination of the TMxy ± TMyx modes. Cavity Model analysis learns that the higher order modes have now a negligible influence (below 40 dB). Also the combination of TM01 + TM10 gives a better cross-polarization performance in comparison to just one of them on it self [Ref. 1]. The coupling between the probes has no influence on the cross-polar radiation anymore. Since the patch is a passive device, the coupling is identical (S12 = S21) so the fields caused by this coupling are again TMxy ± TMyx combinations.

The Cavity Model is not very reliable for higher angular values. Besides that, for radar in general and Remote Sensing in particular, the two-way performance (transmit*receive) is important. The main beam region is most important, the rest is not illuminated. Fig. 3 shows some measured results of the diagonal plane of a single patch. As is well-known, this is the most critical plane for cross-polar radiation. The patch is square and made of 1.58 mm thick Duroid substrate.

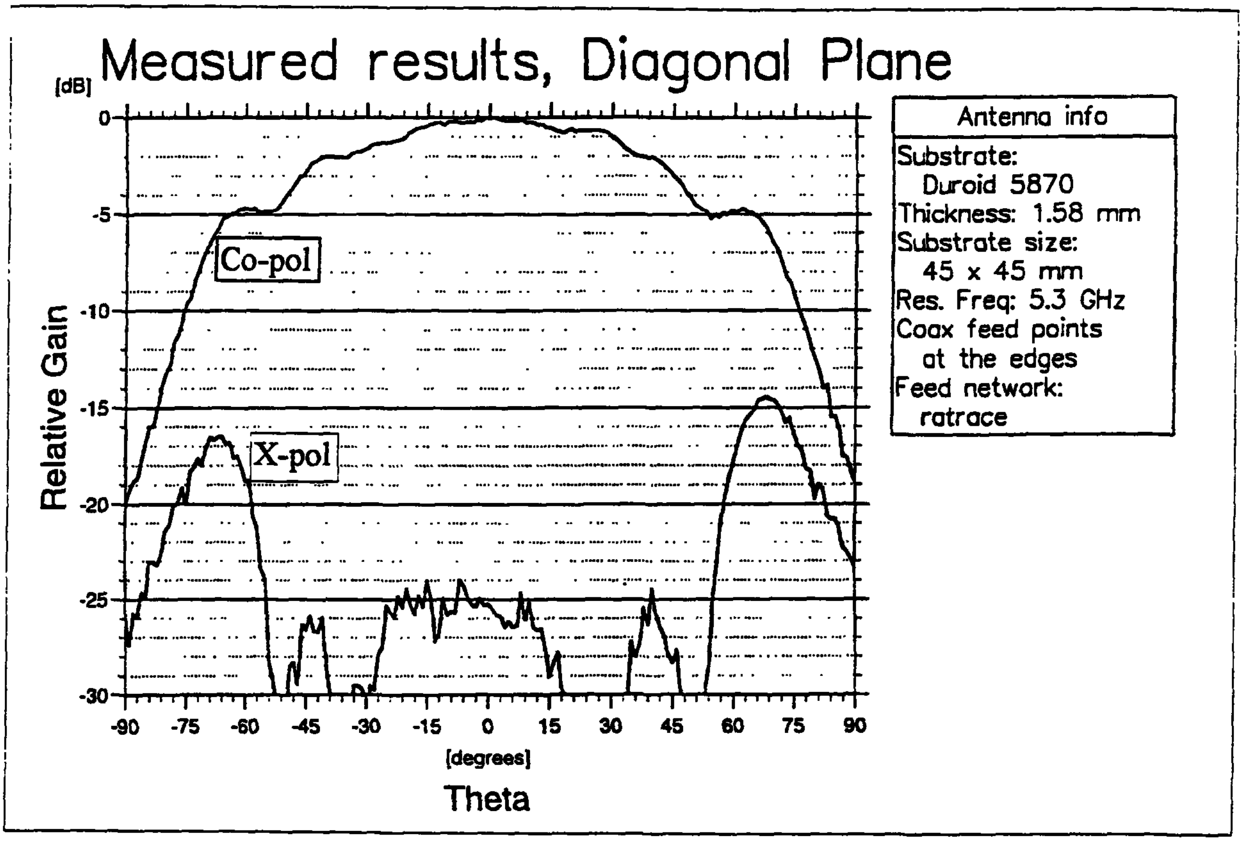


Fig. 3 Measured pattern of a square patch with in-phase feeding

## 5. Ratrace

The in-phase and anti-phase feeding of the patch can be realized by a so called ratrace or hybrid ring. This element has several other useful properties. The ports, connected to the T/R-module are mutual isolated so an additional circulator is not required. An isolation of more than 30 dB is not hard to realize in this way. The antenna ports are also mutual isolated which means that the ratrace does not give any additional polarization coupling. Another problem which can be solved is the matching problem. By using two coaxial probes for the patch antennas it is impossible to connect them both to the 50 Ohm points of the patch. Their spacing is then less than the coax diameter. Besides that, feeding at the edge is optimal to suppress cross-polarization. But on these edge points the impedance of the patch antenna is quite high (almost 300 Ohm). The use of impedance transformation lines on the same substrate as the patch spoils the cross-polarization. Multilayer structures are in this case not applicable. For mechanical stability reasons Duroid on a quarter inch thick aluminum ground plane is preferred. The solution to this problem was found in using a 100 Ohm coax line as a quarter wavelength transformer through the aluminum. This reduces the impedance to about 37 Ohm. The final match to 50 Ohm is done with the ratrace. The ratrace, made on a ceramic substrate, takes less than 18x18 mm.

## 6 Antenna Measurement and Alignment

The complete PHARUS antenna has been measured at the TNO-FEL Near Field Antenna Range. By means of a backtransformation technique the excitation coefficients of all the modules are determined from the measurement. The amplitude and phase settings of the T/R-modules have been adjusted and the antenna has been measured again to verify the settings or to make a further adjustment. In this iterative way all the elements got a nearly identical excitation. The procedure has been repeated for all 4 modes (Transmit and Receive, Horizontal and Vertical polarization). The actual setting of the T/R-module is monitored through the calibration channel of each module. The final setting is stored in a so called α-LUT. During flight the actual setting of the modules is monitored again and adjusted to the values of the α-LUT. This procedure is called autocalibration. This is a correction on system level.

## 7. External Calibration

The aim of a Remote Sensing Radar is to determine the $\sigma_{xy}$ from the received and recorded power. In the radar equation

$$P_{rec} = P_{tr} \cdot G_{tr} \cdot G_{rec} \cdot \frac{\lambda^2}{(4\pi)^2} \cdot \frac{\sigma_{xy}}{R^4} \tag{1}$$

the known variables are $P_{rec}$, R (from the delay time) and λ. The unknown variables are $P_{tr}$, $G_{tr}$ and $G_{rec}$. These variables are subject to drift and aging of components, mutual coupling etc. The uncertainty can be eliminated by additional measurements of the transmit chain, the receive chain and source alone (see fig. 1). These measurements are described as (C stands for a constant):

| | |
|---|---|
| $P_{syscal,trans} = C_{tr} \cdot P_{tr} \cdot G_{tr}$ | by sampling after PA's via cal. channels |
| $P_{syscal,rec} = C_{rec} \cdot P_{tr} \cdot G_{rec}$ | by injecting before LNA's via cal. channels |
| $P_{syscal,\ source} = C_{src} \cdot P_{tr}$ | by bypassing the active antenna |

The unknowns in the radar equation (1) are eliminated by:

$$\frac{P_{meas} \cdot P_{syscal,source}}{P_{syscal,trans} \cdot P_{syscal,rec}} = C_{syscal} \cdot \sigma_{xy} \tag{2}$$

$C_{syscal}$ is the absolute calibration function which has to be determined once by external calibration. The External Calibration uses both active polarimetric transponders and passive corner reflectors. The cross-talk between the H- and V-channels is also determined in this way. A more elaborate description of the calibration can be found in ref. 2.

## 8. Conclusions

By using a high degree of MMIC integration it is possible to miniaturize the active components of a phased array radar. By also integrating the microstrip patch antenna into the module a completely modular set-up of the system is obtained. Every module can be replaced in case of malfunctioning without disassembling a major part of the radar or even recalibrating the array antenna. The single patch antenna is dual polarized with a improved cross-polarization performance by using symmetrical feeding. A ratrace turns out to be a very useful feeding network since it solves several problems at the same time. To assure optimal performance and to make the system immune to aging and drift, correction mechanisms at several levels have been implemented. PHARUS is operational since February 1996 and the first results look very promising.

## 9. References


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