

# Design of an Airborne Dual-Polarized Triple Stacked Patch Antenna for Broadband SAR Applications in P-Band

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**Short Abstract—** The development of a P-band antenna for airborne SAR application is presented. Wide band operation, static electrical antenna beam pointing and small size were key parameters of this antenna array design. First results are shown.

**Keywords-** wide band; airborne SAR; patch array antenna; dual polarization; low cross-pol-level;

## I. INTRODUCTION

Considerable interest has developed recently in wide bandwidth, fully polarimetric, fine resolution synthetic aperture radar (SAR) systems, operating at VHF/UHF bands. The combination of low frequency and high bandwidth creates a variety of applications. These systems appear to be extremely useful for the detection of targets concealed by foliage and/or camouflage, detection of buried objects, forestry applications and archeological and geological exploration.

In 1994 DLR's well-known airborne experimental synthetic aperture radar system, named E-SAR, was upgraded by a first P-band subsystem. Up to now a moderate bandwidth of 50 MHz restricted this frequency band to medium resolution radar applications. Severe RFI problems at the original centre frequency of 450 MHz asked for extensive filtering methods for obtaining an acceptable image quality.

Driven by these constraints, a new fully polarized fine resolution P-band subsystem was developed at DLR's Microwaves and Radar Institute. The configuration of the P-band equipment, as well as the design of key hardware components, like front-end, high power amplifier and the new dual polarized patch array antenna is described. A bandwidth of more than 28% is achieved at a lower centre frequency, corresponding to a range resolution better than 2.1m. Measurements of system gain, cross polarization suppression, system sensitivity and some antenna parameters are shown.

## II. ANTENNA

The small size of the aircraft, a Dornier Do 228-212, gives one of the major restrictions for antenna design in the meter wavelength domain.

Common methods to enhance the bandwidth of microstrip antenna elements are established e.g.: aperture-coupling [1], stacked-patch configuration [2], matching network [3] and the proper choice of substrates [4]. In this case all these options are used together to increase bandwidth, because of the requirement of mounting the antenna at the small aircraft.

The optimal width of the antenna would be about 200cm. On the other side the width of the cabin of the airplane is only 150cm. On that account the antenna has to consist of dielectric material of  $\epsilon_r \gg 1$  to scale down the antennas overall dimensions at least to the cabin's size.

High cross-polarization isolation is a major requirement for the use of the new P-band antenna in polarimetric SAR applications. Additional information of the targets can be obtained by analyzing their behavior in changing polarization angle during reflection process. Antennas cross polarization isolation should be better than 25dB. For a properly designed microstrip element the level of cross polarization level is usually 20dB below the co polarization level [5]. Therefore a suited group configuration has to give better cross polarization isolation than a single element and at the same time proper side lobe suppression [6].

For full polarimetric measurements the beam shape in both polarizations should be equitable and point in the same direction, in the case of P-band antenna  $\Theta_0 = 42^\circ$  off boreside. The array consists of 16 elements in a 4 x 4 configuration. Centre frequency is 350MHz.

The distance,  $d$ , between two elements in the array has to be smaller 50cm, see (1), to prevent grating lobes. The antenna will be mounted under the fuselage of a Dornier Do 228 and the suppression of received signals from opposite swath has to be as good as possible.

$$\frac{d}{\lambda} < \frac{1}{1 + \sin|\theta_{0\max}|} \quad (1)$$

Cause of the overall dimensions the antenna array is mechanically divided into four subgroups. Otherwise the substrate materials were not available. The materials used were FR 4 glass fiber and "Roofmate", a Styrofoam. Styrofoam boards consist of extruded polystyrene foam. The extrusion process produces a uniform structure of small closed cells. It is

highly resistant to water absorption. The boards are very resistant to the passage of water vapour and are unaffected by repeated freeze/thaw cycles. By its characteristic it will not change its size if air pressure varies.

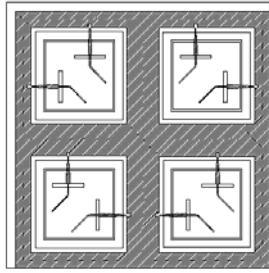


Figure 1. Rear side of one field with 4 radiating elements and feeding lines.

The array consists of 16 elements, each with three stacked microstrip patch resonators. They are aperture coupled to a microstrip line with an impedance matching line section. The amplitude taper and phase shift for each element is formed by a network of discrete power dividers and coaxial lines of different length.

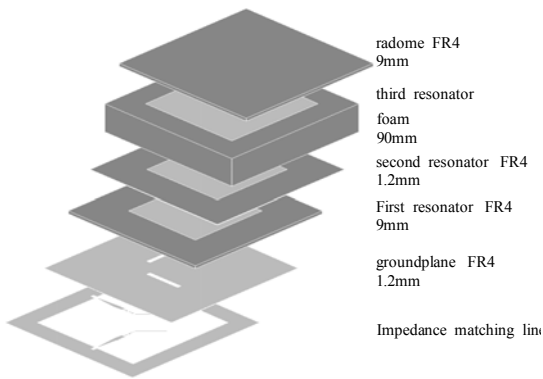


Figure 2. Structure of the substrates of one antenna element.

In Figure 2 the internal structure of one single antenna element is shown. Five dielectric layers form a 10.92cm thick composite. Three quadratic copper areas with increasing edge length inside form the resonators. The coupling apertures in the ground plane are of rectangular shape and located under the first patch to excite dual linear polarization. Measurements of input reflection are shown in Figure 3.

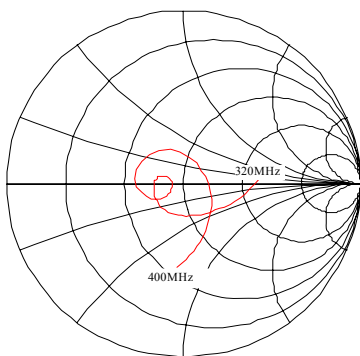


Figure 3. Reflection of a single element in the environment of the full array.

	length	width
resonator 3	239mm	239mm
resonator 2	194mm	194mm
resonator 1	185mm	185mm
slot	85mm	9mm

Table 1 Resonator and slot dimensions

Four elements are put together to a subgroup on one composite. With an element spacing of 35cm the group measures 70cm squared. Four subgroups are mounted on an aluminium frame and represent the complete radiating part of the antenna. This frame is used to assemble the subgroups and connect them to the aircraft's fuselage. It also assures that the distance between the microstrip matching lines as well as the coupling slots and the metallic bottom of the cabin is about 1/4 of a wavelength. The second part of the antenna, the network, in particular a plate carrying the power dividers for both polarizations, is attached to this frame.

The side looking property, a requirement for SAR application, is excited by the coaxial cable network. 125° degree phase shift from row to row results in a 42° degree off-nadir shift of the main beam of the antenna. Together with the arrangement of the feeding positions of the single antenna elements with respect to each other, good cross-polarization isolation is achieved [6].

		flight direction direction of view						
		→	↑					
+	*	+	+	*	+	*	330° phase offset	
+	+	*	*	*	*	+		220° phase offset
+	*	*	*	+	+	*		
*	*	*	*	+	+	+		110° phase offset
*	*	*	*	+	+	*	0° phase offset	

\* reference phase  
+ reference phase +180° degree

Table 2 Port plan with phase offset and port distribution for each element. Rear view.

The port distribution described in the paper: "Cross-Polarization and Sidelobe Suppression in Dual Linear Polarization Antenna Arrays" [6], as configuration "E" provides good results, even for this small group. The influence of phase shift over the antenna group was not investigated in this paper. To prevent proper cross-polarization isolation two antennas are excited from opposite edges, with respect to the network the signals merge in with another 180° degree phase shift, so the cross portion is nullified.

Because of the small element spacing, the coupling between adjacent elements within the array is very strong, so standard amplitude taper routines become not successful. During far-field measurements the power dividing network was optimized. Far field measurements show good results of the antenna for both polarizations. Voltage standing wave ratio is better 1.6 over the whole frequency range of 100MHz, corresponding to 28% bandwidth. Antenna gain is 10dBi, cross

polarization level on average is -24dB. In Figure 4 an exemplary far-field diagram at 350MHz is plotted.

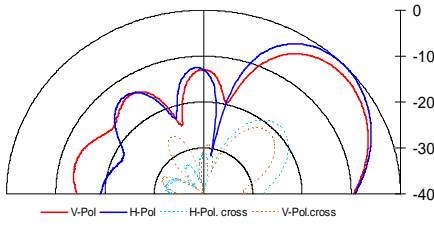


Figure 4. Far field diagram for h- and v- polarisation at 350MHz.



Figure 5. Antenna mounted on DLR's Dornier DO 228-212.

The antenna is protected against mechanical stress of wind, rain and ice with the help of a wind deflector. It is made of glass fiber and covers the antenna at their side walls. Figure 5 shows the antenna together with its wind deflector mounted under the Do 228-212.

### III. FRONT-END DESIGN

A new front-end configuration was necessary caused by the new centre frequency and the extra in bandwidth.

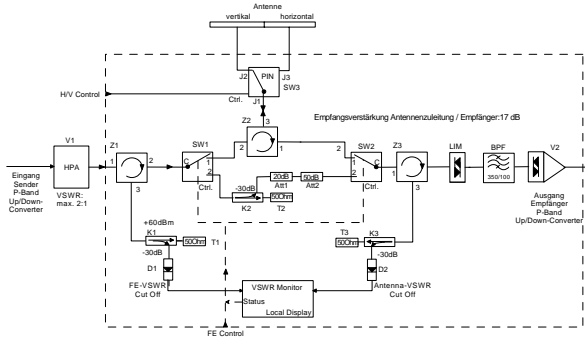


Figure 6. P-band front-end design

Some interesting features are integrated into the P-band front-end. First of all there is a VSWR monitoring unit which is able to shut down the high power transmitter amplifier immediately if the reflected power is higher than a certain threshold. An internal loopback for testing and calibrating the transmit / receive path is also integrated. By switching off the antenna a complete characterization of the P-band subsystem for calibration or test is possible. Polarization switch and transmit / receive controller are integrated. The overall receiver gain is 87dB at a noise figure of 2.9, isolation between the channels for H and V polarization is better than 75dB.

### IV. FIRST SAR-IMAGE

After the process of airworthiness certification the new hardware inside and outside the airplane was tested in flight. During this flight SAR-data were recorded and the first results are presented here.

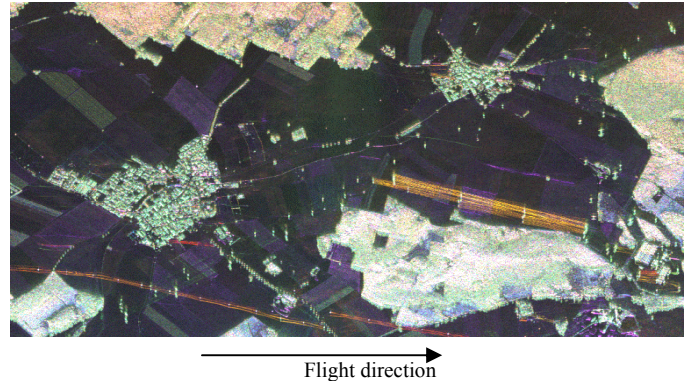


Figure 7. Colour composite SAR image (red : HH ; green : HV ; blue : VV). Oberbrunn, Germany.

The raw data was processed in a 4 look mode and thus the image shows a resolution of 2.1 x 4.0 meters (range x azimuth). It is a small sector of a SAR image of one of our calibration sites near Oberpfaffenhofen, Germany, shown in Figure 7. It's a colored composite of the backscatter intensities in H-, V- and the cross-polarization channel. The image shows forested areas as well as farmland and two small villages. High-voltage power lines, aligned in flight direction, are visible in HH polarization. The raw data was processed without any filtering in frequency domain and shows an enhancement in image quality in relation to the former P-band subsystem. In a single look image resolution in azimuth is 1.8m. In range direction 2.1m is reached.

### V. CONCLUSION

The performance of the P-band subsystem as a part of the E-SAR system is increased in relation to the former subsystem design. Improvement in bandwidth together with a lower centre frequency yields a better image quality with higher range resolution and less RFI disturbances.

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