

# Optimizing circular polarization within a beam of patch antenna elements

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**Abstract**— The paper presents the results of an investigation into patch antenna elements that would be capable of providing good circular polarization not only in the broadside direction, but also over a wide range of elevation angles.

**Keywords**— *lightweight antennas, circularly polarized antennas, microstrip antennas.*

## 1. Introduction

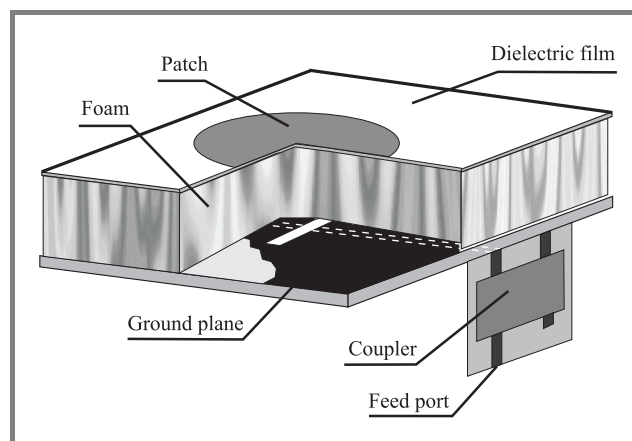
While many researchers have concentrated their studies on bandwidth widening techniques for microstrip antennas, there has been less concern paid to optimizing their polarization quality off the broadside direction. The increasing popularity of wireless services has brought about the designing of antennas capable of generating a high quality circular polarization not only in the broadside direction, but also over a broad angular range of beam, and is becoming a crucial issue. It is strongly advisable to provide such good circular polarization properties without sacrificing the antenna low profile – a property that is a primary advantage and is of paramount importance when undertaking application decisions.

In order to achieve the satisfaction of these requirements, we considered a number of antenna concepts, with a focus on shaping the antenna feed slots. Primary attention was also given to the patch shape, with parasitic elements in its proximity. Our research is being driven by the needs of two minisatellite missions. The first of them was completed successfully in October 2005 when SSETI-Express was launched and put into orbit, the second, ESEO, is scheduled for launch in 2008.

## 2. Methods of improving circular polarization in patch antennas

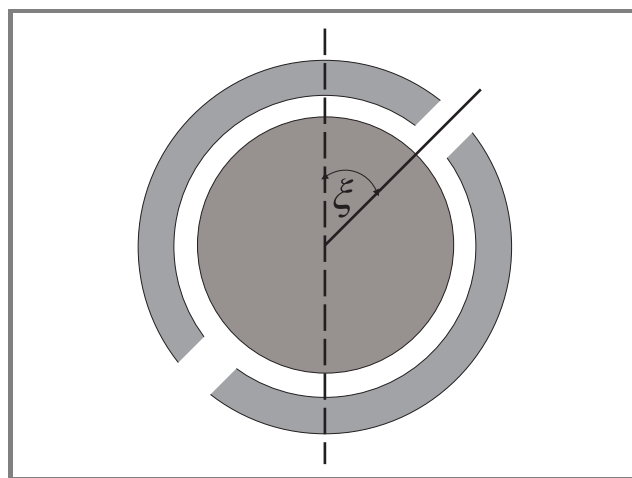
Figure 1 shows the general structure of the investigated antennas. It consists of a 31-mil thick microwave laminate bearing the ground and metal patch printed on the thin dielectric foil, which are separated by 10 mm thick dielectric foam. These values of substrate heights were selected in the course of lengthy simulations aiming at bandwidth broadening. The foam material features highly stable electrical parameters over a wide temperature range. In order to ensure broad impedance bandwidths, we designed our antennas using through-slot coupled transmission lines. Circular

polarization for these kinds of antennas can be achieved using either a single slot or a dual slot feed (due to space limitations, we abandoned the interest in feeds made with two pairs of coupling slots). We focused on a dual slot feed



**Fig. 1.** General structure of the investigated antennas.

because we believe it offers much better axial ratio (*AR*) values and a larger axial ratio bandwidth than the single feed method as far as we are capable of providing a high quality external polarizer. Both output signals of the polarizer must have an equal magnitude and differ by a  $90^\circ$  phase shift in the whole operating bandwidth. A three-strip coupler proved to be of the highest utility for such requirements. Typically, for a 2.4 GHz center frequency, it features phase variations within  $3^\circ$  in roughly a band of 1 GHz. Manufac-



**Fig. 2.** One of the patches in the investigated antennas.

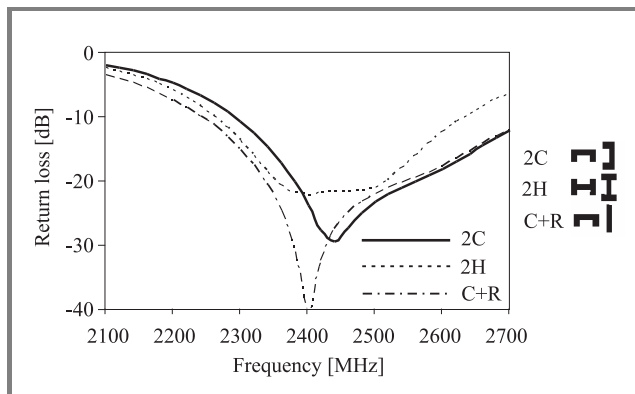
tured on a thin dielectric membrane, it does not contribute much to the weight and volume of the antenna and can be perfectly integrated with its structure. The methods of development for such couplers are described by Sachse and Sawicki [3].

Our investigation focused on determining the most advantageous shape of the slots and the geometry of their arrangement to be used. We compared a wide range of possible dimensions and shapes for the coupled slots [1]; the shape of the slots in a pair may be different, or the slots may be of identical shape and dimensions.

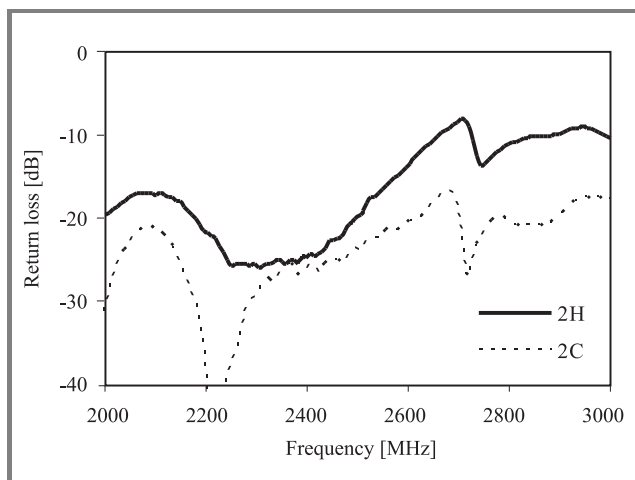
In order to improve the axial ratio over the broad angle of a main beam, we decided to use parasitic elements in the proximity of the patch, usually produced as a copper strip divided into two or four sectors (Fig. 2).

### 3. Discussion of results

In our analysis of printed, dielectric antennas, we used Ensemble of Ansoft. Several antenna models were manufactured and measured. Figure 3 presents the calculated



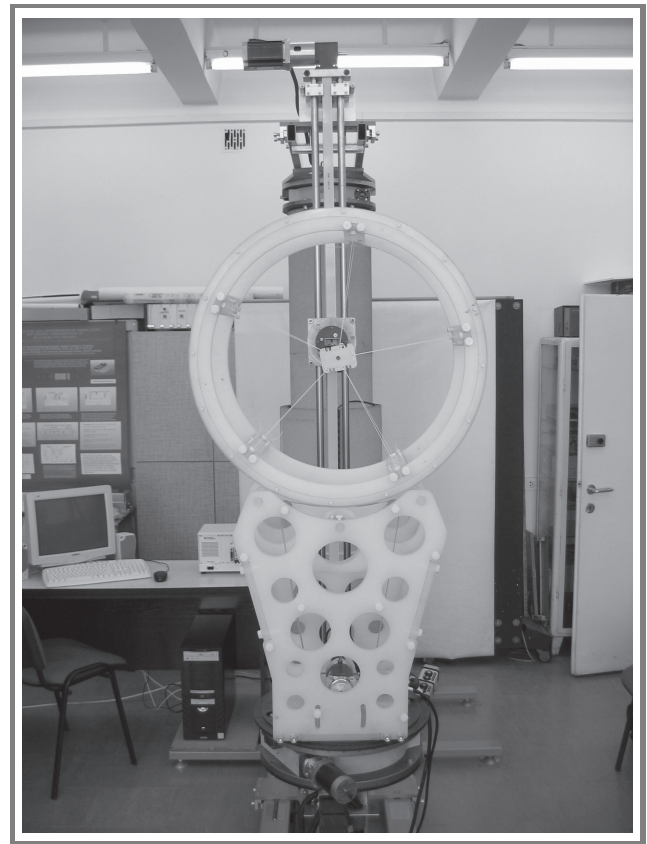
**Fig. 3.** Simulated return loss characteristics for antennas fed with a various pairs of slots (2C, 2H, C+R).



**Fig. 4.** Measured return loss characteristics for CP antennas fed with 2H and 2C slot pairs.

return loss characteristics for three shapes of slots. When the slots are in a T arrangement, there are some difficulties in reaching equal impedance matches on two feed ports. In most cases, the impedance bandwidth of one port is wider than the other. These differences can be minimized if designed carefully. When the slots are in an L arrangement, these problems do not occur. The return loss characteristics, shown in Fig. 4, were measured for assembled CP antenna models (Fig. 1). The measured 20 dB bandwidth was about 600 MHz for the dual C-slot feed (2C), and 300 MHz for both 2H slot and C+R feeds.

One of the conditions for generating an excellent circular polarization is the high isolation between the orthogonal ports. A remarkable increase in the degree of isolation can be obtained when the slots are in a T arrangement [2], especially when one of the slots is pushed a little to the side of the symmetry axis of the patch. Owing to the T arrangement, the isolation between the ports was increased by 12 dB in all cases. Thus, we had no problems achieving isolation better than 30 dB. However, it is difficult to obtain a compact feed line arrangement. The calculated isolation between the ports in the 2C case slightly exceeds 30 dB in the band. The calculated isolation values for 2H and C+R feed ranged between 22 and 30 dB. Measured characteristics were consistent with the calculated ones. The isolation was only frequency dependent to a small degree.



**Fig. 5.** The in-house developed measurement system in the microwave laboratory at the Institute of Telecommunications, Teleinformatics, and Acoustics, Wrocław University of Technology.

Most of electromagnetic computer tools and measurement systems are capable of determining axial ratio characteristics only in some cut-planes (usually in two orthogonal planes  $\varphi = 0^\circ$  and  $\varphi = 90^\circ$ ). In our research, we had to examine the axial ratio within the whole forward hemisphere. This has become possible with the measurement system shown in Fig. 5, developed in-house in our microwave laboratory.

Figure 6 presents the measured values of the axial ratio (in dB) within the forward hemisphere at 2400 MHz for a dual C-slot CP antenna. In the broadside direction ( $\Theta = 0^\circ$ ), the measured axial ratio was 0.6 dB. The parameters of these antennas were additionally measured in Saab Ericsson Space antenna laboratories, where their excellent polarization quality was confirmed. Identical antennas were

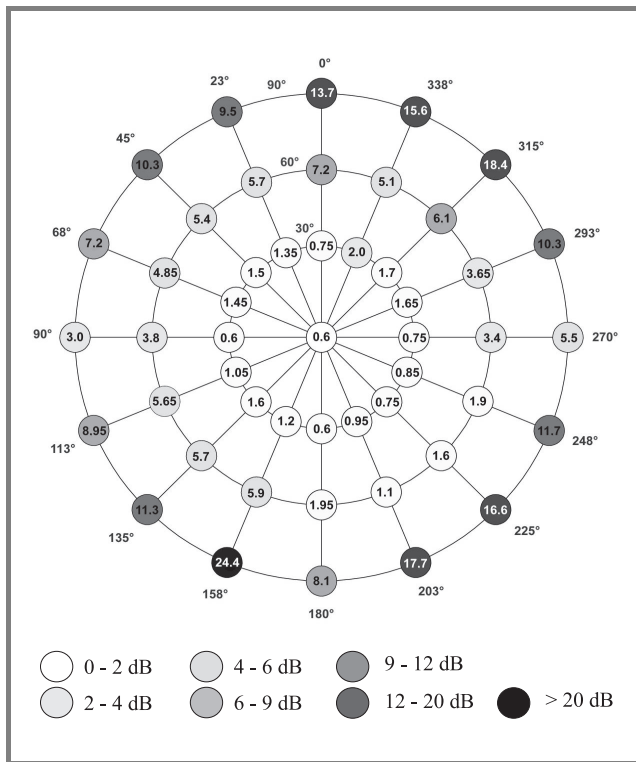


Fig. 6. The measured values of the axial ratio (in dB) of the 2C antenna at 2400 MHz in the forward hemisphere.

used onboard the SSETI-Express minisatellite. For the other two introduced antenna models, we obtained the axial ratio values 1.34 dB and 2.36 dB at the broadside for 2H-slot and C+R slots (Fig. 7), respectively.

However, the greatest interest was in providing a good degree of circular polarization in a possible wide angular range in the forward hemisphere of the radiation pattern. A great impact on this parameter was the shape and arrangement of the feed slots. The T arrangement, which significantly improves the isolation between the feed line ports, raises concerns in regard to symmetry. One of the slots must be pushed a little to the side of the symmetry axis of the patch. This leads to some asymmetry in

the radiation pattern and in the CP quality of the antennas, which considerably differentiates the values of the axial ratio between the cut-planes. While there are excellent values at one cut-plane across the hemisphere, we should expect poorer axial ratio values at high elevation

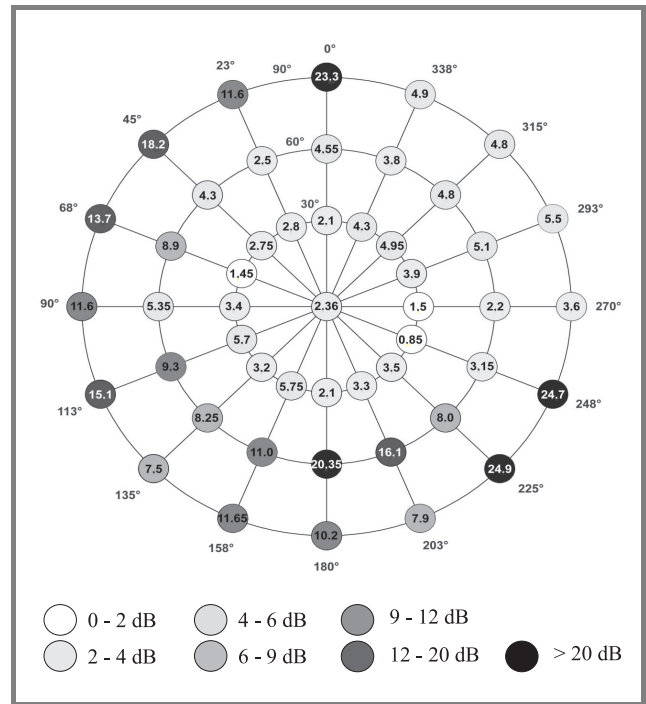
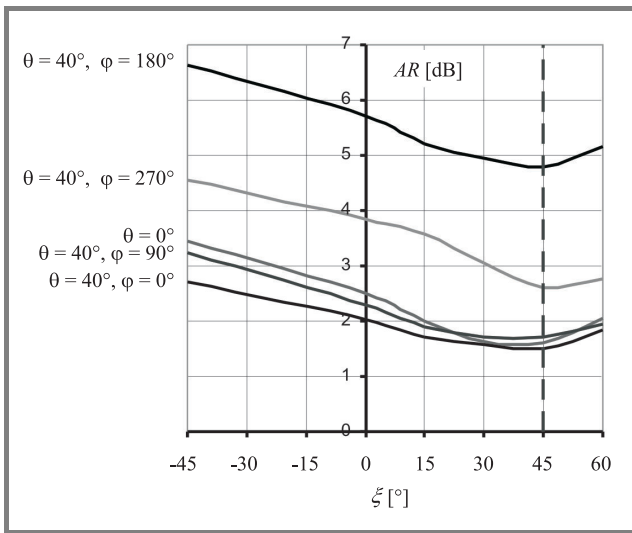


Fig. 7. The measured values of the axial ratio (in dB) of the C+R antenna at 2400 MHz in the forward hemisphere.

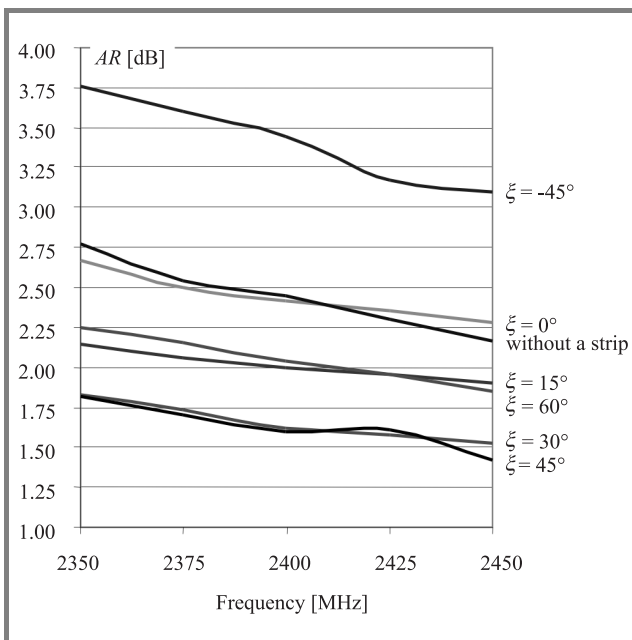
angles in the other principal cut-plane. Only with 2C and 2H antenna types, AR has taken the values below 2 dB in the broad angular range of the main beam. We observed that the 2C antenna features favorable AR values within at least  $60^\circ$  of the elevation angle ( $\theta$ ). In some cut-planes at elevation angles close to endfire, the circular polarization quality can deteriorate abruptly and actually become linear polarization within the narrow angular step (AR drop by more than 10 dB). Even with the best 2C type antennas, this drawback occurs at two diagonal cut-planes.

Our investigations have shown that in some cases, the polarization quality of the antenna can be significantly improved when a conductive parasitic strip partitioned into two or four sectors surrounds its patch. We have found that the axial ratio values may considerably depend on the angular orientation of the gaps between the sectors of the strip in respect to the feed slots ( $\xi$  angle shown in Fig. 2).

This claim is substantiated by plots (Figs. 8 and 9) showing the results of the simulations carried out for the antenna feed with two rectangular slots. In all considered directions ( $\theta = 0^\circ$ ), ( $\theta = 40^\circ, \varphi = 0^\circ$ ), ( $\theta = 40^\circ, \varphi = 90^\circ$ ), etc., the AR value was the lowest for  $\xi \in \{30^\circ, 40^\circ\}$ .



**Fig. 8.** Simulated values of the axial ratio in specified directions of the antenna as a function of angular orientation of the gaps between the strip sectors.



**Fig. 9.** Simulated values of the axial ratio for the different angular orientation of gaps between the strip sectors and for the patch without the strip in the operating band of the antenna.

In Fig. 9, the axial ratio of the antennas with patches surrounded by a strip (for varying  $\xi$ ) are compared with patches without a strip in the 2350 MHz to 2450 MHz frequency band.

## 4. Conclusions

High quality of circular polarization over a broad angle of an antenna beam has been achieved with low profile microstrip patches. One of the antennas we had devel-

oped is characterized with favorable values ( $< 6$  dB) of the axial ratio in some cut-planes even from  $\theta = -90^\circ$  to  $\theta = +90^\circ$ . Good polarization properties have been shown in the large range of the forward hemisphere with a few other microstrip patch designs. The prerequisites of good polarization properties are compact forms of coupling slots used in the element feed (i.e., C), their careful arrangement under the patch (i.e., T geometry) and the use of parasitic, small conductive shapes in the proximity of an antenna patch. The axial ratio values are then likely to match those known from bulkier shapes and volumes, and until now, widely used antenna elements (e.g., helix).

The patches optimized and presented in this paper are to be used mostly in space communication, polarimetric radar and in radio interfaces of wireless services.

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