Polarisation-Reconfigurable Patch Antenna

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INTRODUCTION

Polarization diversity can be an issue in effectively addressing the multipath-fading effects in modern wireless communication systems. Traditional indoor microwave communication systems as Wireless Local Area Network (WLAN) use linearly polarised waves, but in [1], it was already shown that Circular Polarisation (CP) could marginally reduce fade levels by 7dB and up to 11 dB. Thus, to achieve fully compatible communication systems, antennas with agile polarisation capabilities are needed.

Several kinds of antenna architectures can be found in the literature. Schaubert et al. [2] proposed an antenna solution to switch between two linear and two circular polarizations. Each specific polarisation was obtained by shortening some parts of a patch antenna by using pin-diodes. However, in this [2], a complex biasing network was necessary to control the active components inserted between the top patch and the ground plane. Some solutions with pin diodes mounted on the patch itself have also been proposed [3-5]. Due to the use of PIN diodes, only discrete commutations between linear and circular polarisation are possible and no further tuning possibilities exist. Vidmar et al. [6] demonstrated in 2006 additional polarisation agility using varactor diodes mounted directly on a patch antenna. However, due to the proximity between the active devices, these structures are complex for modelling and suffer from a degradation of their radiation patterns.

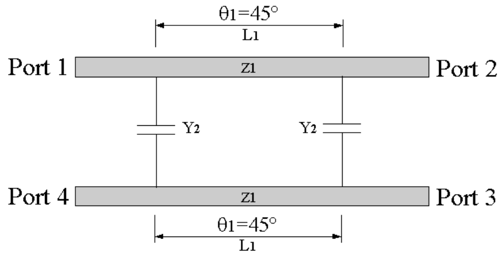
In this paper we propose here to overcome these problems by designing separately the antenna and the reconfigurable circuit and associate them in a second step. The feeding structure of the antenna consists in a quasi-lumped tunable hybrid coupler. Thanks to the use of varactor diodes, the coupler characteristics can switch from a -3 dB hybrid circuit to uncoupled parallel transmission lines. Furthermore, the use of these diodes offers new tuning opportunities like any mismatch corrections.

DESIGN OF A RECONFIGURABLE HYBRID COUPLER

In 1989, Fusco et al. [7] reported that a reduced size -3dB coupler could already be synthesized using some lumped components instead of the two vertical branches of a traditional hybrid (Fig. 1). To design a reconfigurable four-port network, the idea is to substitute the fixed lumped capacitors of the previous design by varactor diodes to get some tuning capabilities. In this configuration, the biasing circuit may be simple thanks to the fact that for continuous bias voltages, the two horizontal transmission lines can be considered as electrically disconnected. The design equations of this reconfigurable hybrid can be found in [7]. Assuming that the electrical length of the horizontal lines provides a 45° phase shift and the impedance Z_1 is equal to Z_c (characteristic impedance of the horizontal lines), Eq. 1 allows calculating the capacitance needed to provide a perfect matching, a perfect isolation and a perfect -3 dB coupling [8].

$$C = \frac{1}{2\pi f Z_1} \qquad \text{(Eq. 1)}$$

For a center frequency of 3.5 GHz and a Z_c =50Ω for the series line, the capacitance required is 0.909 pF. To confirm this assumption, a first prototype operating at 3.5 GHz was designed and fabricated in microstrip technology on a 0.13mm-thick duroid substrate (ε_r =2.22, tan δ= 0.001). GaAs Flip-Chip varactor diodes from M/A-com having a capacitance ranging from 0.15 pF to 1.1 pF were selected [9]. All the simulations were performed with the help of the electromagnetic planar solver Agilent Momentum [10]. A picture of the fabricated prototype is presented in Fig. 2.



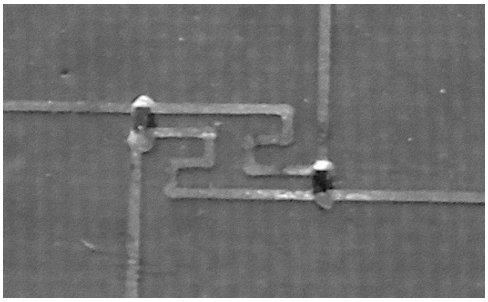


Fig. 1 Quadrature quasi-lumped hybrid coupler

Fig. 2 Photograph of the quasi-lumped tunable coupler

We measured this hybrid circuit at 3.5 GHz for several reverse voltages V_r from 0V to 15V. The magnitude and the phase of the S_{ij} parameters are presented in Fig.3. It can be seen that for capacitances lower than 0.2pF (V_r >11V), the four-port network can be considered as two uncoupled parallel transmission lines. For a capacitance of 0.920 pF (V_r=0.96V), the system operates like a 3-dB hybrid coupler. If we tune the bias voltage around this centre value, it is possible to obtain a non-symmetric hybrid coupler with good matching.In Figure 4, we present the simulated and measured S-parameters versus frequency of the circuit when Vr=0.96V (3-dB hybrid mode). Simulated and measured curves are in a good agreement. The feeding signal is evenly divided between Port 2 and 3. The return loss at Port 1 and the Port 4-to-1 isolation are both better than -25dB. With a reverse voltage equal to 15V (uncoupled line mode), good isolation levels are obtained between Port 1-3 and 1-4 as well as a good match (Fig. 5). The insertion loss between Port1-2 is -0.45dB at 3.5 GHz.

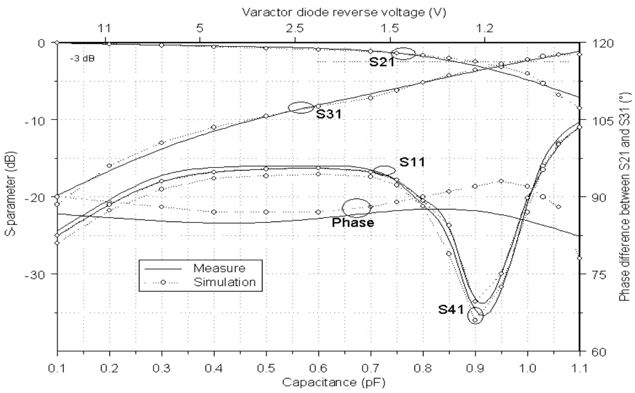


Fig. 3 Simulated and measured magnitude and phase of the S_{ij} parameters of the reconfigurable hybrid versus capacitance (or voltage)

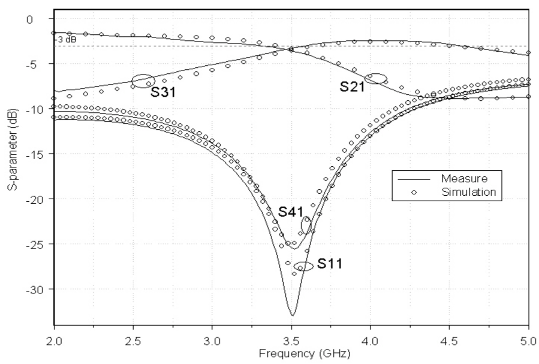


Fig. 4 Simulated and measured S_{ij} parameters of the circuit for a reverse voltage of 0.94V.

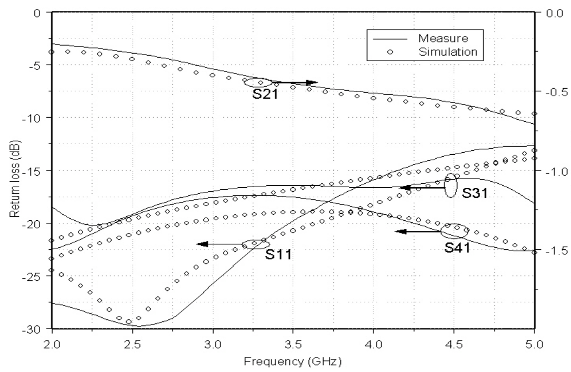


Fig. 5 Simulated and measured S_{ij} parameters of the circuit for a reverse voltage of 15V.

AGILE POLARISATION ANTENNA

This tunable hybrid can be used to feed a patch antenna via orthogonal slots etched in its ground plane. Fig.6 shows a possible topology of the whole structure. For a capacitance down to 0.15 pF, the patch will be excited to radiate linearly-polarized waves. Especially, by choosing which port of the coupler (Port 1 or 4) is excited when using a Single Pole Dual Trough (SPDT) device, horizontal or vertical linearly polarised waves could be generated.

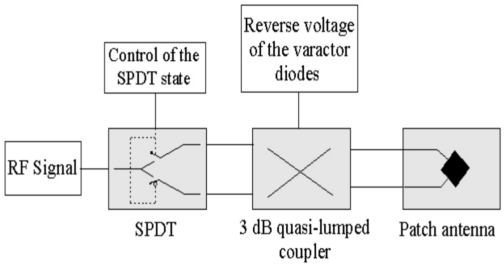


Fig. 6 Topology of the structure.

When the coupler behaves like a classical hybrid (0.909 pF capacitance values), the orthogonal modes of the patch are excited via the slots with a 90° phase difference which results in a CP radiated wave [11]. The right or left handed CP sense is then selected by simply changing which input of the coupler is fed with the SPDT. In this way, this antenna-system is capable of providing full reconfigurability in terms of the polarization of the radiated waves and that, simply by changing the DC bias of both the SPDT switch and the two varactor diodes. The method to design a dual-fed radiating patch via slots in its ground plane was already explained in [8, 11]. Here, our work was to carefully associate the previously designed quasi-lumped hybrid coupler and a patch antenna resonating at 3.5 GHz (Fig. 7).

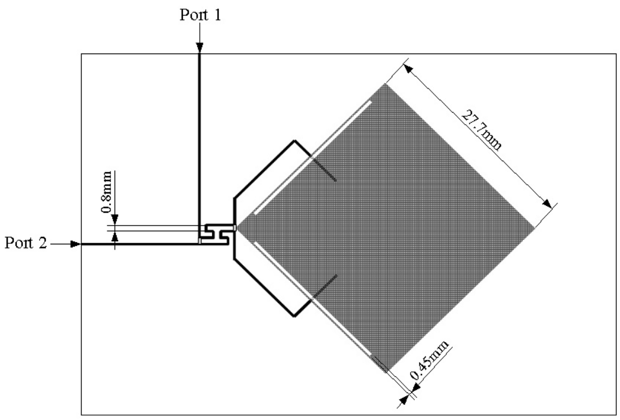


Fig. 7 Top view of the antenna with the patch in grey, the microstrip hybrid coupler in black and the slots in white.

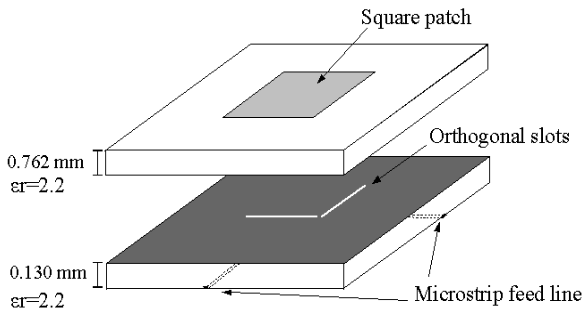


Fig. 8 3D view of the antenna-system

As a proof-of-concept, a prototype was realized with a 0.762-mm-thick substrate as the upper layer and a 0.130-mm-thick substrate as the feeding layer, both of the same Duroid material with a relative permittivity of ε_r =2.22 (Fig. 8).

CP axial ratio (Vr = 0.96V) and cross-polar levels (Vr = 15V) are presented in Fig.9 in the broadside direction of the antenna. In CP mode, the 3dB axial ratio bandwidth is 3.8% (134MHz) whereas the cross-polar level in the linear mode is always superior to 19 dB.

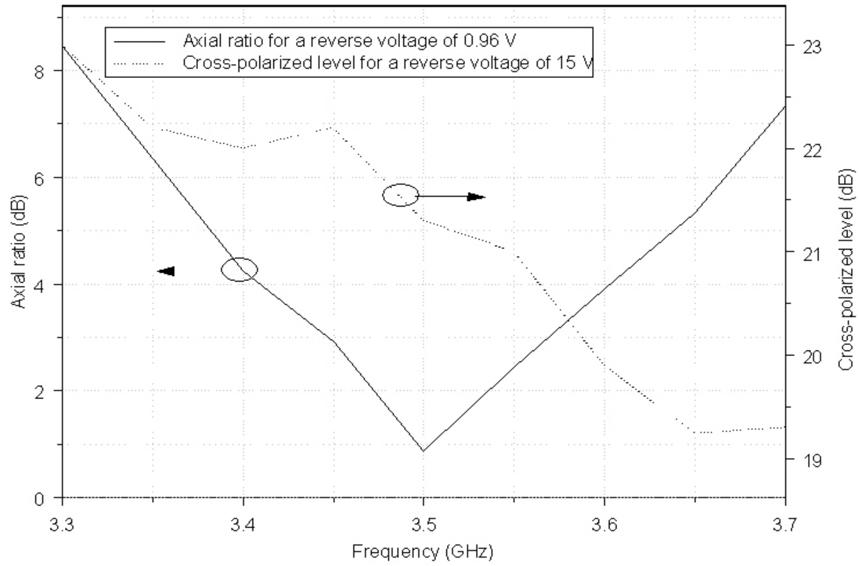


Fig. 9 Axial ratio and cross-polar levels of the antenna-system versus frequency

CONCLUSION

A tunable hybrid coupler was successfully designed to feed an antenna for full polarisation capabilities. The proposed solution has the advantages of separating the active devices from the radiating element and thus avoiding any unwanted coupling effects. Also, it provides a full set of polarization states by simply changing the DC bias of both a SPDT and two varactor diodes. The feasibility of the concept was fully demonstrated and validated by S_{ij} parameters and radiation pattern measurements.

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