

A RECONFIGURABLE HYBRID COUPLER CIRCUIT FOR AGILE POLARISATION ANTENNA

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ABSTRACT

In this paper, we present a reconfigurable hybrid coupler suitable to feed any printed radiating element for full polarisation agility. The whole structure can alternatively radiate electromagnetic waves with orthogonal linear, right or left hand circular polarisation (CP) upon changing the state of the quasi-lumped hybrid coupler. A prototype is realized with a 0.762-mm-thick upper layer substrate and a 0.130-mm-thick feed layer substrate, both of the same dielectric material with a relative permittivity of $\epsilon_r=2.22$. Simulated and measured matching, insertion loss, axial ratio, gain and radiation pattern are presented.

1. INTRODUCTION

As mobile portable devices such as laptop computers acquire multi-mode wireless connectivity from both satellite-based and terrestrial-based transmitters, there is an increasing need for antennas having agile polarisation capabilities. We present here a reconfigurable hybrid coupler circuit which can be used as a reconfigurable patch antenna feeder.

Polarisation agility has already been demonstrated in [1-2], but the main limitations often come from the proximity between the active devices and the radiating element, resulting in high coupling effects. Our solution removes this problem because the antenna and the reconfigurable circuit can be designed separately and associated later.

In 1989, Fusco et al. reported [3] that a miniature -3dB hybrid can already be synthesized using some lumped components instead of the vertical printed branches of a traditional coupler (Fig.1).

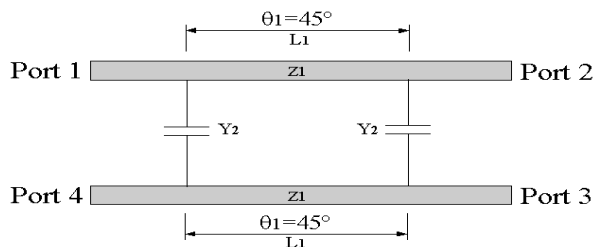


Figure 1. Quadrature quasi-lumped hybrid coupler

We propose here to use Micro Electro Mechanical Systems (MEMS) as bi-state capacitors in order to achieve different coupler circuit's behaviours. This reconfigurable hybrid can be used to feed a patch antenna via orthogonal slots etched in its ground plane as shown in Fig. 2. When the MEMS capacitors of the coupler are in the upper state, each slot is directly fed by a simple transmission line. By choosing which port of the coupler (Port 1 or 4) is excited using a MEMS Single Pole Dual Trough (SPDT), horizontal or vertical linearly polarised waves are generated. With the MEMS capacitors in down state, the coupler operates like a classical 3dB hybrid, i.e. the orthogonal modes of the patch are excited with a 90° phase difference resulting in a CP radiated wave. The right or left handed CP sense is then selected by simply changing which input of the coupler is fed with the SPDT.

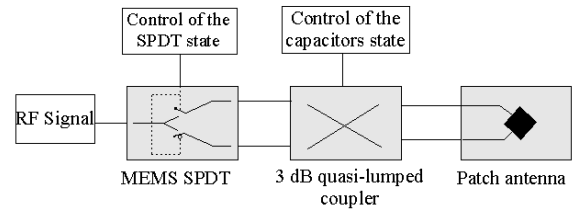


Figure 2. Topology of the structure

2. DESIGN OF THE HYBRID COUPLER

2.1 Theory and Design

The first step was to design a quasi-lumped hybrid coupler in microstrip technology at 5.85 GHz.

The conditions imposed for perfect matching, isolation, and coupling have been deduced from the method described in [4] with the even and odd mode equivalent circuits taken from [3]. They yield the following set of design equations:

$$Y_2 + j \tan(\beta L_1) Y_2^2 Z_1 = 0 \quad (1)$$

$$Y_c^2 = Y_2^2 \quad (2)$$

$$k = \frac{Y_1^2}{Y_2^2} \quad (3)$$

k is the power coupling ratio between ports 2 and 3 (Eq. 3) and Y_c is the characteristic admittance of the terminating network (Eq. 2). Then, Eq. 1 shows that the isolation condition can be obtained for three Y_2 values of the coupling element: null, inductive or capacitive.

For the capacitive coupled quasi-lumped hybrid with a 50Ω series line, the capacitance required (Eq. 1), to provide a 3 dB coupling at the center frequency of 5.85 GHz, is 0.568 pF.

Assuming that the electrical length of the series horizontal lines provides a 45° phase shift and also that the impedance Z_1 is equal to Z_c , it is then possible to determine the value of the S_{11} and S_{21} parameters (Eq. 4 and Eq. 5).

$$S_{11} = \frac{Y_2 + 2jY_2^2}{1 + 4Y_2 + j(1 + 2Y_2^2)} \quad (4)$$

$$S_{21} = \frac{\sqrt{2} + 2j\sqrt{2}Y_2 + j\sqrt{2}*(1 + Y_2^2)}{2*Y_2 + j(2 + 4Y_2 + 2Y_2^2)} \quad (5)$$

In down state, MEMS capacitors are set to provide $Y_2 = jY_1$. An input signal at Port 1 is then equally divided between Ports 2 and 3 with a quadrature phase shift. In the upper state, the resulting capacitance of the MEMS is minimum. Capacitance Ratio superior to 60 between upper state and down state has already been demonstrated [5]. If we consider that $|Y_2|$ is equal to $jY_1/20$, S_{21} is found to be -0.034dB from Eq. 4 (at 5.85GHz). Then, the hybrid circuit appears as two uncoupled parallel $\lambda/8$ transmission lines and all of the power injected into Port 1 is transmitted to Port 2.

2.2 Fabrication and measurements

As a proof-of-concept, a first prototype operating at 5.85 GHz was designed and fabricated in microstrip technology on a 0.13mm-thick duroid substrate ($\epsilon_r = 2.22$). In this structure, capacitor chips were used instead of on-state MEMS components. Off-state MEMS were modelled by removing the capacitors. Accu-P thin-Film technology chips having a 0.5 pF value in 0201 package from AVX company were selected [6]. All the simulations were performed with the help of the electromagnetic planar solver Agilent Momentum [7]. A picture of the fabricated prototype is presented in Fig. 3. The feeding signal is evenly divided between Port 2 and 3 (Fig. 4) and a quadrature phase shift is observed. The return loss at Port1 and the Port 4-to-1 isolation are both better than -20dB . The bandwidth for insertion loss, power division and quadrature phase is suitable to feed a patch antenna. Simulated and measured curves are in a good agreement.

The simulated and measured S-parameters without any capacitors are presented in Fig. 5. Good isolation levels are obtained between Port 1-3 and 1-4 while the Port 1-2 2 2 insertion loss is always better than -0.3dB .

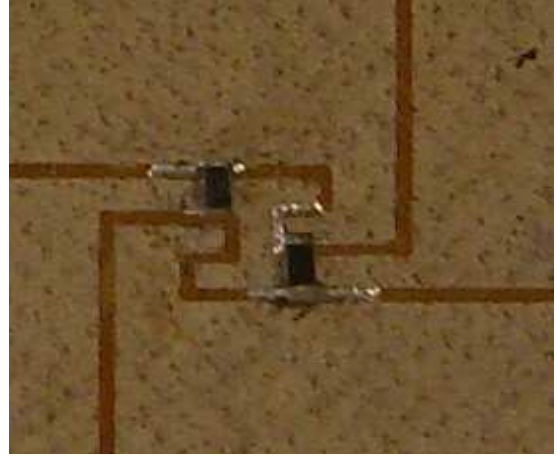


Figure 3. Picture of the capacitive hybrid coupler

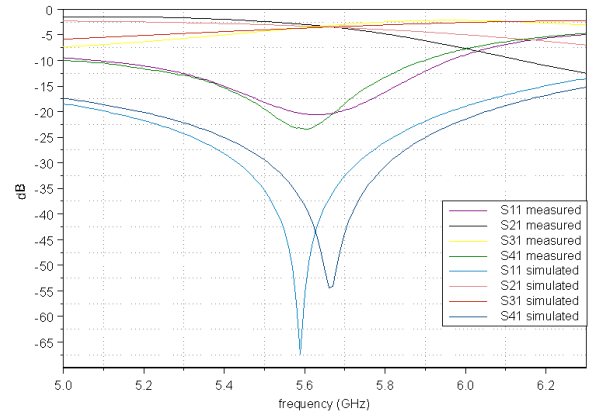


Figure 4. Simulated and measured S-parameters of the coupler with the capacitors

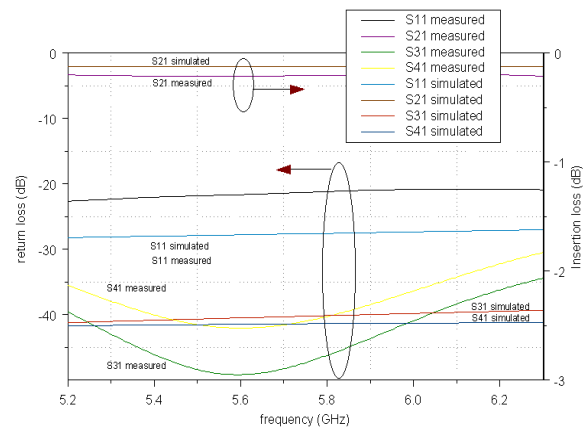


Figure 5. Simulated and measured S-parameters of the coupler without capacitors

3. DESIGN OF THE RADIATING ELEMENT

The second step was to design a radiating element with two orthogonal excitations. We used the same technique as the one shown in [8]. A patch antenna is printed on a first substrate and fed by two orthogonal slots etched in its ground plane (Fig. 6). These slots are electromagnetically coupled to the outputs of the microstrip quasi-lumped hybrid coupler.

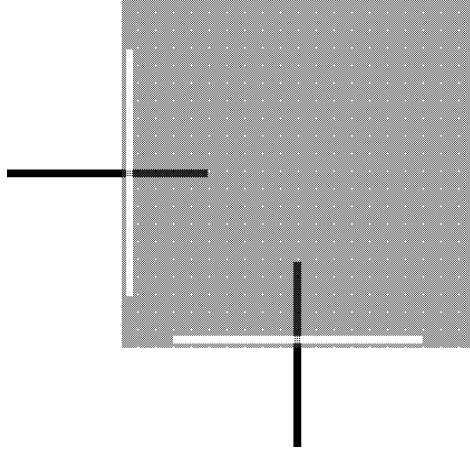


Figure 6. Top view of the antenna with the square patch in grey, microstrip lines in black and slots in white

To verify the theoretical predictions, 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 material having a relative permittivity of $\epsilon_r = 2.22$ (Fig. 7).

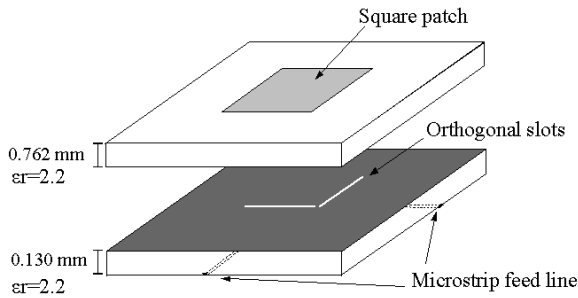


Figure 7. Multi-layer view of the antenna

The matching and the insertion loss between the feeding ports are presented in Fig. 8. A measured -10dB bandwidth of 2.7% (156MHz) is found and the insertion loss at 5.85 GHz is less than 20 dB. A gain of 5.2 dBi was measured at 5.85 GHz.

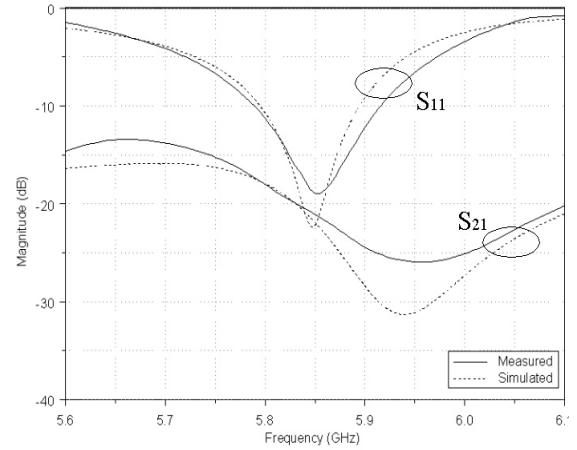


Figure 8. Matching and insertion loss between the feeding ports of the antenna

4. AGILE POLARISATION ANTENNA

The third step was to carefully associate the quasi-lumped hybrid coupler and the dual-fed antenna. The coupler has been placed on the substrate to exactly provide the same electrical delay seen from each of its outputs (Fig. 9).

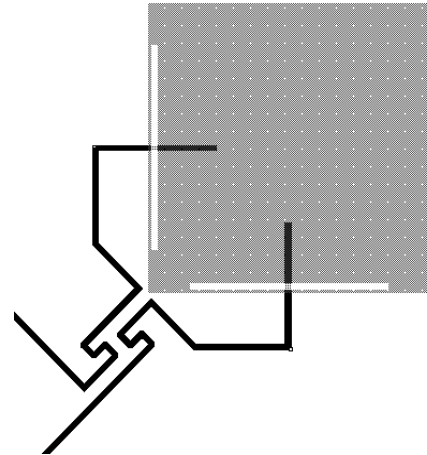


Figure 9. Top view of the antenna with the patch in grey, hybrid coupler in black and slots in white.

The matching and the insertion loss for the structure with capacitors are presented in Fig. 10. The frequency bandwidth is limited by S_{21} and is found to be 2.5% (146 MHz for a -13dB bandwidth). This limitation comes from the antenna's excitation and not from the hybrid coupler. The results without capacitors are shown in Fig. 11. Good agreement is found between predicted and measured S_{11} and S_{21} . The results are very similar to Fig. 8, showing that the hybrid without capacitance appears like a structure with uncoupled transmission lines.

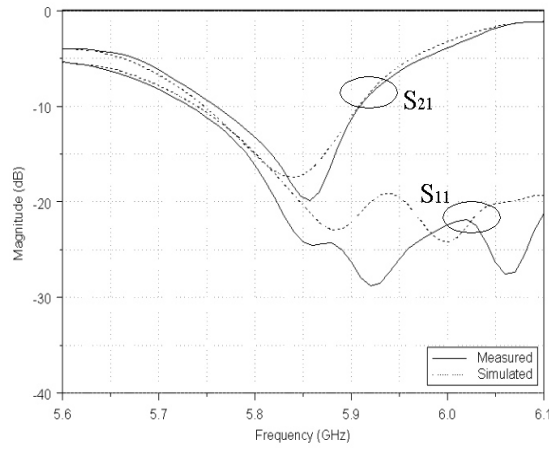


Figure 10. Matching and insertion loss between both ports of the antenna with capacitors

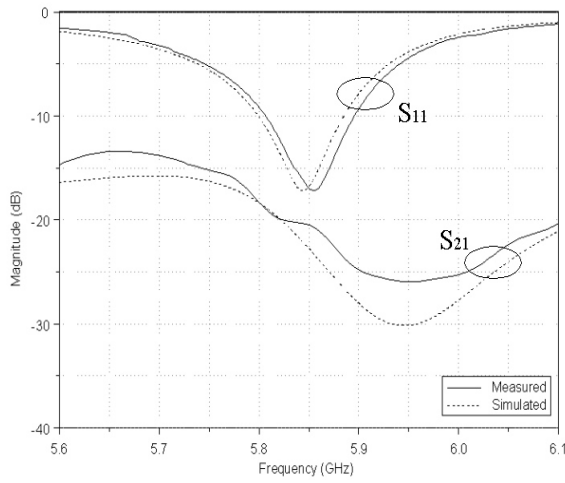


Figure 11. Matching and insertion loss between both ports of the antenna without capacitors

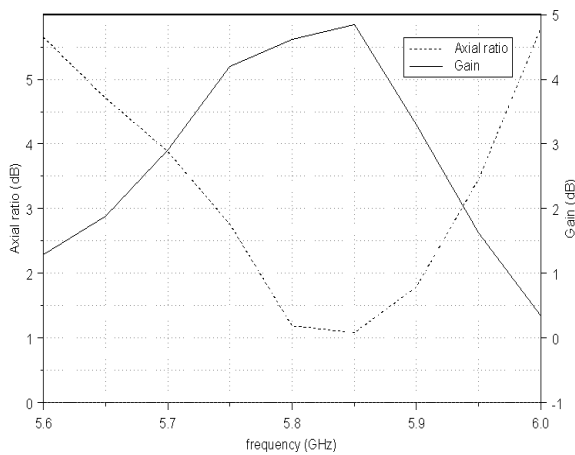


Figure 12. Axial ratio and gain versus frequency for the antenna with capacitors

CP axial ratio in broadside direction is shown in Fig.12 and Fig. 13. For the system with the capacitors, the 3 dB axial ratio bandwidth is 3.3% (198 MHz). The measured maximum gain in the normal direction of the antenna is also presented in this figure. The gain is still limited by the thin microstrip lines of the coupler that induce non negligible ohmic losses. Without the capacitors, the cross-polarized level is superior to 15dB on a 3.6% (210 MHz) bandwidth. A linearly polarized wave was expected. This is in agreement with the theory. A maximum gain of 5 dB is measured at 5.85 GHz.

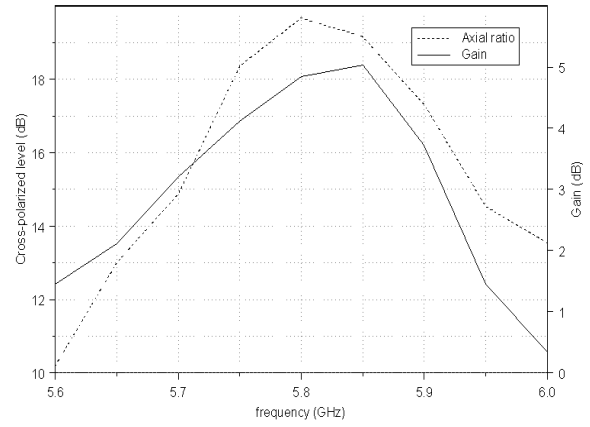


Figure 13. Cross-polarized level and gain versus frequency for the antenna without capacitors

The measurements of the x-z plane RHCP far-field radiation pattern are shown in Fig. 14 with the capacitor and in Fig. 15 without them. With the antenna configured for CP, the axial ratio of the antenna is less than 3 dB over an angular region of $-78^\circ < \theta < 58^\circ$ around the zenith. The pattern shape of the antenna without capacitors shows a highly linear radiation with an axial ratio always greater than 13 dB.

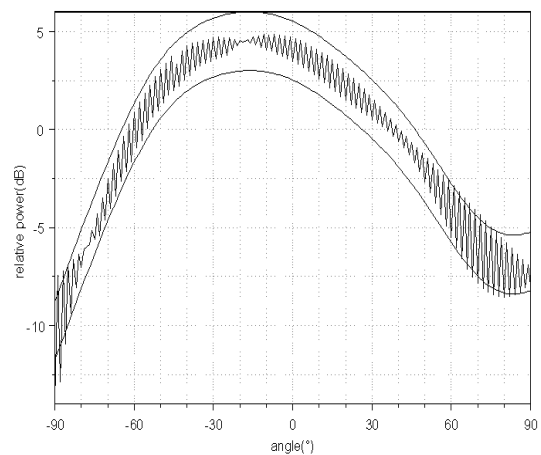


Figure 14. Measured CP radiation patterns of the antenna with capacitors at 5.85 GHz

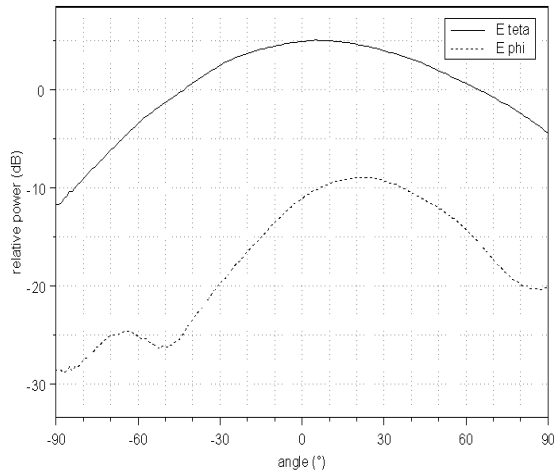


Figure 15. Measured radiation patterns of the antenna without capacitors at 5.85 GHz

5. CONCLUSION

A reconfigurable hybrid coupler was successfully designed to feed an antenna for full radiated polarisation capabilities. Linear and circular polarisation has been achieved with a gain better than 4.85 dBi. The proposed solution separates the active devices from the radiating element avoiding any coupling problems. The feasibility of the concept was fully demonstrated. The next development will consist of direct integration of the MEMS devices as bi-state capacitors into the feeding circuit.

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