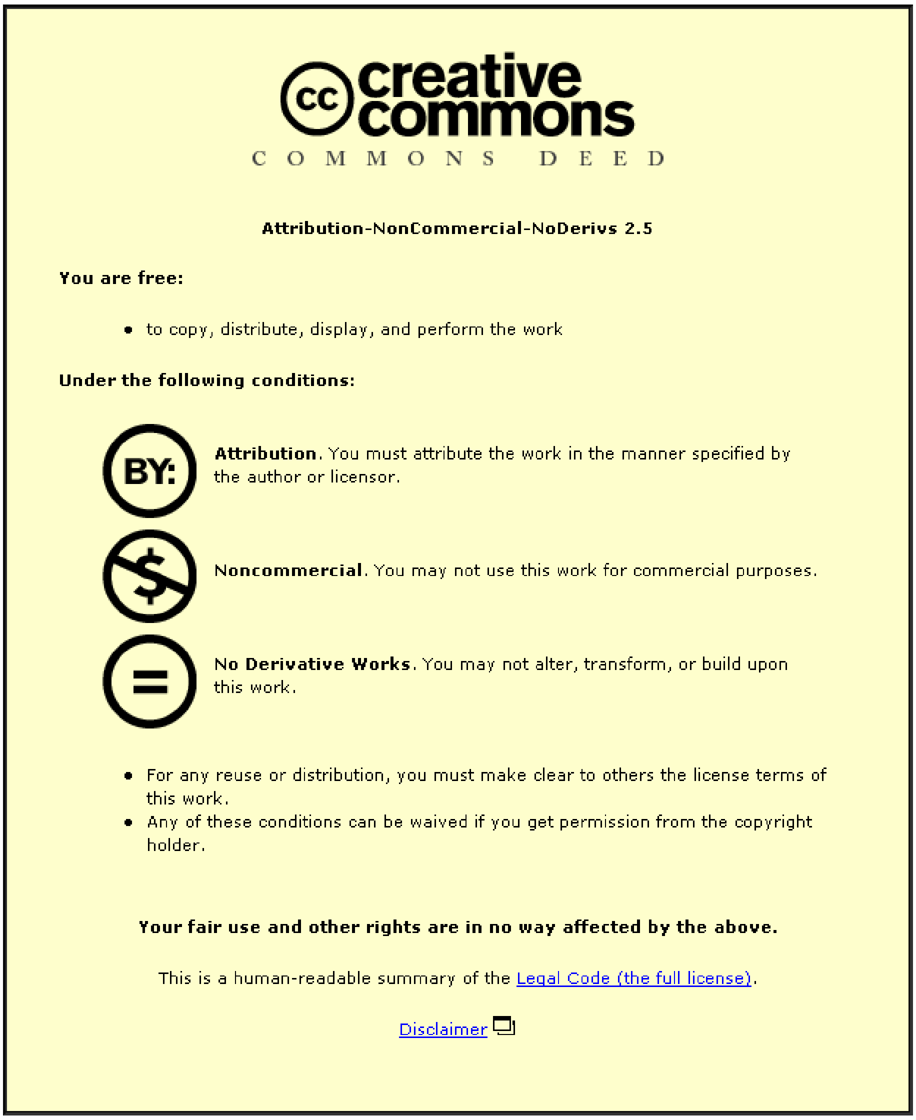


RECONFIGURABLE ANTENNA USING PHOTOCONDUCTING SWITCHES

C. J. Panagamuwa and J. C. Vardaxoglou

Department of Electronic and Electrical Engineering
Loughborough University
Loughborough, Leicestershire, LE11 3TU, England

This paper presents a design for an optically reconfigurable printed dipole antenna. A wideband coplanar waveguide (CPW) to coplanar stripline (CPS) transition is used to feed the balanced printed dipole. Two silicon photo switches are placed on small gaps in both dipole arms equidistant from the centre feed. Light from two infra-red laser diodes channelled through fibre optic cables is applied to the switches. With the gaps in the dipole bridged, the antenna resonates at a lower frequency. Measured return loss results that compare well to the simulated values are also presented, showing a frequency shift of nearly 40%. The change in bore-sight gain along with radiation patterns are also presented.

1. Introduction

With the increase in demand for multiband antennas in recent years, reconfigurable active antennas have become an attractive option. A single reconfigurable antenna has the possibility of switching to all the required frequencies, thus eliminating the needed for complicated wideband and multiband antenna solutions.

CPW and CPS have many advantages in RF circuit design. For example, they allow the easy placement of shunt and series passive and active devices, and have no need for via-holes to connect to the ground plane. Tilley *et al.* [1] presented a CPW-fed CPS dipole antenna with a wideband balun, which was later modified by Kolsrud *et al.* [2] to include varactor diodes for frequency tuning. Many designs have been proposed in the past that use the variable reactance property of varactor diodes, but these are normally accompanied by biasing lines and high biasing voltages [3, 4]. PIN diodes in reconfigurable antennas have also gained in popularity, as they require lower biasing voltages [5]. All these designs still require biasing lines to be attached to the antenna. As the fibre optic cables have no metallic elements, they have the advantage of being electromagnetically transparent and so do not interfere with the radiation patterns of the antenna [6]. Here we have investigated the effect of the switches on the design of the antenna (balanced feed has been maintained throughout) with a view to achieving the maximum possible frequency shift.

2. Silicon Switches

The switches on the antenna are diced from wafers of high resistivity (ρ) silicon ($\rho > 6000\ \Omega\cdot$cm). When illuminated by light, silicon changes from an insulator state to a near conducting state by creating an electron-hole plasma. The photons incident upon the silicon must have enough energy to promote electrons from the valence to the conduction band. Light in the near infra-red range is ideal for this process as it strikes a balance between the absorption coefficient and the light penetration depth, which are inversely proportional to each other and related to the wavelength of the light. Light delivery on silicon wafers for generation and switching of frequency selective surface (FSS) arrays has been extensively studied by Vardaxoglou [7 - 9]. Here, we adapt a similar model regarding the properties of silicon under optical illumination perpendicular to the direction of travel of the microwave signal.

3. Dipole antenna

The schematic of the dipole antenna is shown in Figure 1(a). It is printed on 1.17mm thick TLY-5® substrate that has a dielectric constant (ε_r) of 2.2. There is no ground plane on the underside of the printed dipole, allowing the antenna to radiate above and below the substrate. The antenna is fed at the CPW using a 50Ω SMA connector. The CPW is an unbalanced transmission line but since the dipole is a balanced antenna, a transformation of the input signal is required. The circular balun is used to convert the unbalanced CPW to a balanced CPS [10]. The balun is based on a CPW to slotline T-junction shown in Figure 1(b). If output 2 is terminated in an open circuit, there is a complete transfer of current from the CPW to the slotline leaving at output 1. Current in the centre feed of the CPW flows directly onto the top half of the slotline and the backward currents on the ground planes of the CPW combine through the bond wire to form the current on the bottom half of the slotline, thus transforming the CPW mode to a slotline mode. Finally, reducing the width of the slotline creates the CPS. In the antenna structure, the circular stub acts as an open circuit with a non uniform impedance, giving a greater bandwidth match. Simulations of two back-to-back transitions show an insertion loss better than 1.5dB in the switching range of the dipole antenna.

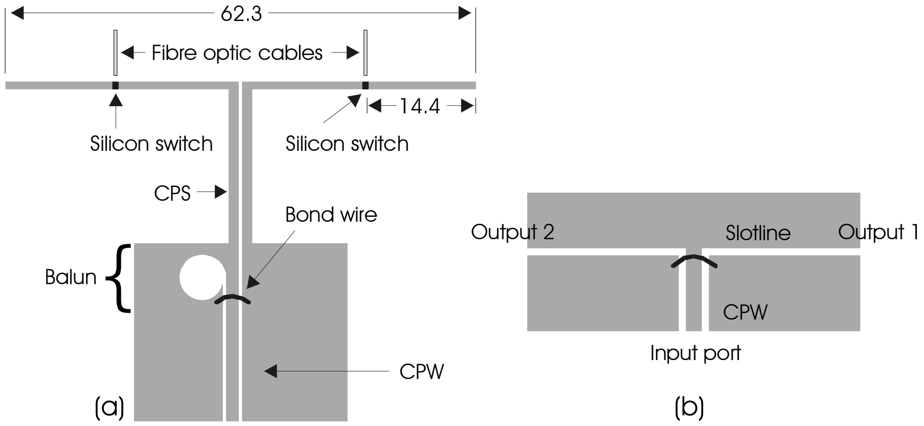


Figure 1 - (a) Optically reconfigurable CPS dipole antenna (dimensions given in millimetres) (b) CPW-Slotline T-junction

The dipole resonates when its length is equal to $\lambda_{eff}/2$ where λ_{eff} is the effective wavelength. λ_{eff} is given by $\lambda_0/\sqrt{\varepsilon_{eff}}$ where λ_0 is the wavelength in free-space and ε_{eff} is the effective dielectric constant. Although the effects of dielectric loading cannot be ignored, the absence of a ground plane under the antenna reduces the value of ε_{eff} close to 1.2. The dipole is printed with two gaps, each one 14.4mm from the end of each arm. 1mm x 1mm x 0.3mm silicon dice are then placed over the gaps and are held in place using silver loaded epoxy, which ensures good contact between the copper and silicon. Two 980nm lasers operating at 200mW (maximum output) are coupled to two glass fibre optic cables, which are then angled over the silicon wafers using plastic clamps. When both switches are turned off, the silicon acts as an insulator and so the dipole resonates at its shorter length of 33.5mm. When both lasers are on, the silicon starts to conduct and the gaps are bridged, increasing the dipole arm lengths to 62.3mm and hence reducing the resonance frequency. Work previously carried out on switching microstrip transmission lines by Chauraya *et al* [11] showed by designing a suitable capacitance across the gap, an isolation in the OFF state of typically 15 dB at 2.4GHz could be achieved. By comparing simulated switched transmission lines with measured results, plasma properties were characterised for simulating switches on antennas in Micro-Stripes™. The simulation package also allowed easy optimisation of the feed structure and balun.

4. Results

Measured return loss results compare well with those obtained from simulations and are shown in Figure 2 along with measured bore-sight gain. In addition to these standard modes of operation, each side of the dipole was switched on individually and measurements taken. These two modes of operation were also simulated in Micro-Stripes and the results shown in Figure 3.

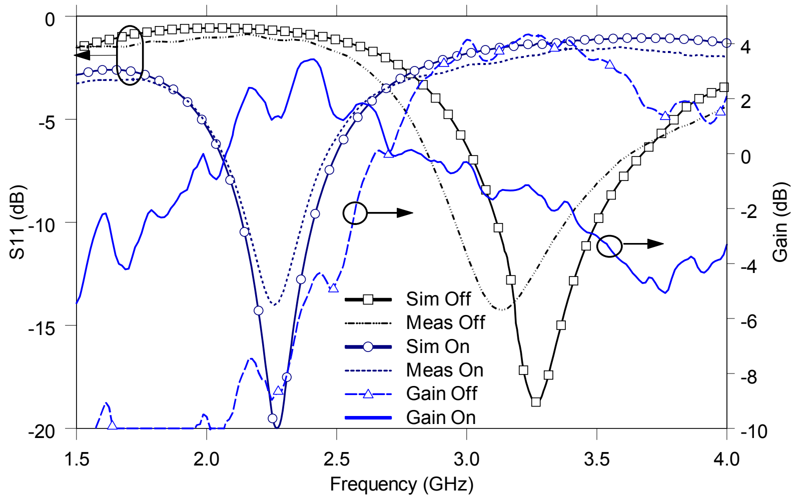


Figure 2 – Measured and Simulated return loss with gain measurements for both switches on and off

Previous work using a similar dipole [6] has shown that in the on state, the dipole behaves very similar to a full length dipole (62.3mm long) in terms of resonance frequency and gain. Experiments have shown that increasing the plasma density increases the gain very close to the level expected from a full length dipole. Further increase in optical power saturates the silicon as the electron-hole recombination processes become more pronounced, and so no further noticeable increase in gain is observed. The resonance of a shorter length dipole (33.5mm) is slightly higher than that of a switched dipole in the off state. This is due to the capacitive loading effect introduced by the silicon dice, because without the silicon fixed in place, the dipole behaves like a 33.5mm long dipole. A thorough investigation was carried out to establish the maximum frequency shift while the match was kept below –10dB. Positioning the switches closer to the antenna feed improves the shift but at the expense of the return loss. The optimum distance for each switch from the ends of the dipole was 14.4mm.

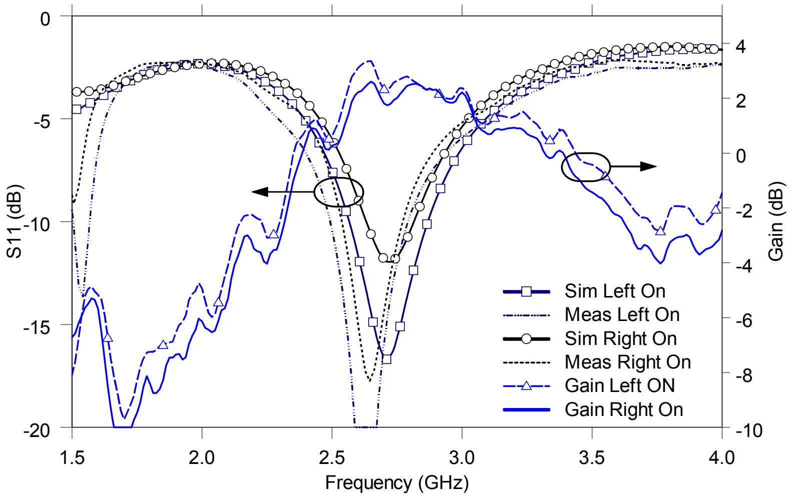
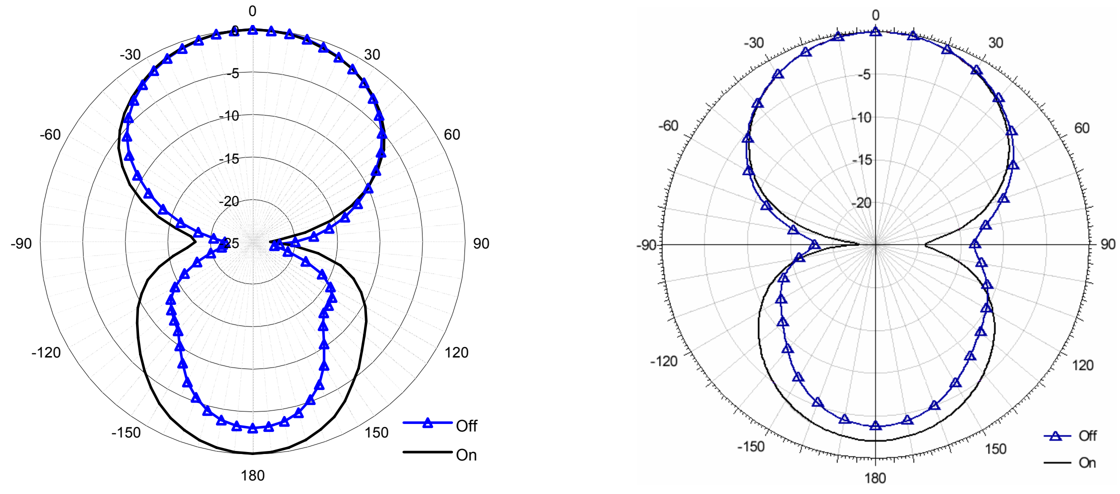


Figure 3 – Measured and Simulated return loss with gain measurements for right switches on and left switch on

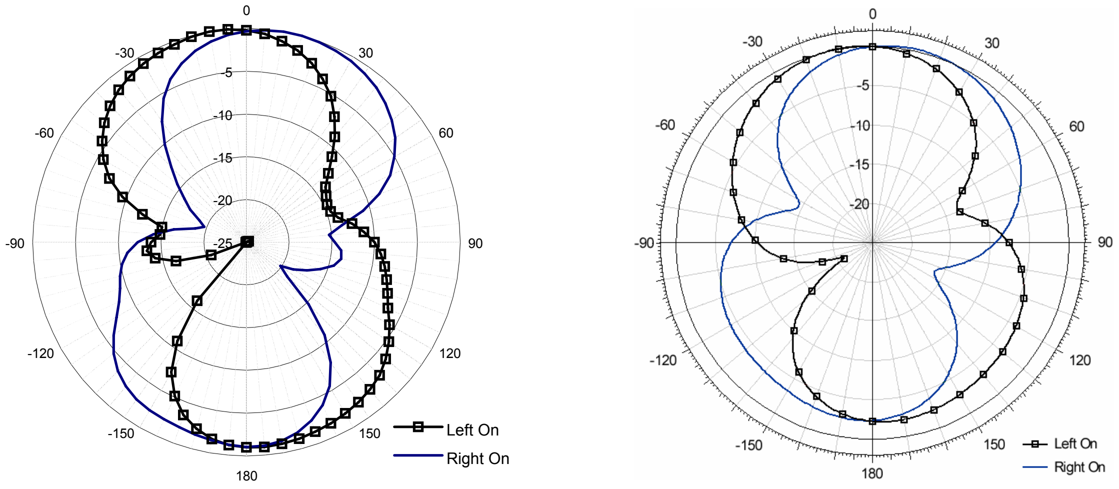
From both switches on to both switches off, the resonant frequency shifts from 2.26GHz to 3.15GHz. This is a shift of 39.4%. When only the right switch is on the antenna resonates at 2.65GHz and with just the left switch on, it resonates at 2.63GHz. These are frequency shifts of 17.3% and 16.4% respectively from the on state. The –10dB bandwidth is 9.5% for the on and 13.4% for the off states. For right switch on and left switch on, the –10dB bandwidths are 8.8% and 11.3% respectively. There is a clear shift in antenna gain as it switches from both on to both off, with gain changing from 2.9dBi to 4dBi. The ripples on the measurements are attributed to the limitations of the anechoic chamber. The difference in gain at 2.26GHz and at 3.15GHz between both on and both off states are about 10dBi and 5.3dBi respectively. When only one switch is used, the antenna resonates in between the other two extremes and this is also reflected in the gain maxima. The gain here is about 2.7dBi.



(a) **(b)**

Figure 4 – (a) Measured and (b) simulated E-Plane radiation patterns for the printed antenna with both switches on and both switches off

The measured and simulated E-plane radiation patterns for all four operational states are shown in Figures 4 and 5. There is good correlation between measured and simulated patterns. When both switches are on or off, the patterns conform well to the typical figure-of-eight patterns expected from a standard half wavelength dipole and they all have very wide beam widths. Comparing both switches on with both switches off, the forward E-plane pattern shapes are very similar indicating that the activation of the switches are not having a detrimental effect on the radiation patterns. The slight change in the reverse pattern is due to interaction with the CPW ground plane, which seems to be more pronounced at higher frequencies. When switching on each arm individually, there is a noticeable shift of about 10-15 degrees in the maximum gain direction. Making the left arm longer than the right by activating the left switch only causes the beam to shift left of centre and vice versa. However, since the patterns are still broad beam, the bore-sight gains are always above 2.5dBi.



(a) **(b)**

Figure 5 – (a) Measured and (b) simulated E-Plane radiation patterns for the printed antenna with left switch on and right switch on

5. Conclusion

An optically reconfigurable CPW-fed CPS dipole antenna has been successfully designed and tested. A frequency shift of 39.4% is achieved from both switches on to both switches off. The antenna exhibits ideal forward E-plane radiation patterns and good bore-sight gain during both switches on and both switches off operation. In addition, switching on of just one switch results in a resonance in the middle of the two extremes and is accompanied by a gain of 2.7dBi. Therefore, the antenna can be switched from 2.26GHz to 2.63GHz to 3.15GHz, all the while maintaining good match and gain. In fact, using the different switching combinations, a –7dB or better S11 with a gain better than 1dBi can be achieved from 2.1GHz through to 3.6GHz. No adverse effects due to fiber optic cables or the silicon wafers were observed.

Acknowledgements

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