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# ELECTRONICALLY SWITCHED BEAM DISK-LOADED MONOPOLE ARRAY ANTENNA

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**Abstract**—A disk-loaded monopole array antenna with coplanar waveguide (CPW) feeding systems that has the capability of beam switching has been successfully demonstrated. The antenna utilises the advantages of CPW and the transmission line of input impedance equation and is integrated with RF/Microwave devices to enable beam switching in the elevated and azimuthal planes. The measured gain of the antenna in the direction of the open-circuited parasite element is in the range of 5.10 to 5.60 dBi. It has good input return loss at 2.45 GHz and produces useful gain in the direction of the open circuited element. The $E$- and $H$-plane patterns show that the beam can be steered by pin diodes switching.

## 1. INTRODUCTION

Antennas with electrically steerable beams are useful for modern communication applications, to reduce the power consumption through

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increased antenna gain and reduce multipath or interference. The beam switching or steering have been reported in [1–3] by utilizing the advantages of genetic algorithm to determine the optimum performance of the antenna. Whereas the antennas reported in [4–8] have demonstrated the concept of the antenna reconfiguration by introducing the parasitic elements. However, the antennas described have a fixed beam. The beam can be only switched by rotating the antenna manually. Effort has been made to steer the beam electronically as reported in [5] whereby the switching board was located underneath the ground plane. The antennas reported in [5–7] were fed by the coaxial cable.

One of the advantages of CPW is the integration with active devices. For example, PIN diodes and MEMs can be made simple and easy. Therefore, this benefit has attracted much attention from many researchers [9–12]. The CPW-fed antenna that has been reported in [8] has improved the gain and the radiation pattern of the antenna in [5]. However, the beam of the antenna is fixed at one direction. In this paper, the CPW-fed disk-loaded monopole array antenna is demonstrated with PIN diode switches. This work is motivated and inspired by the research done in [8].

## 2. BASIC PRINCIPLE OF SWITCHING SYSTEM

The interesting feature of this antenna is that the parasitic element configuration is controlled by a quarter wavelength CPW line. The parasite element (2) is short-circuited at one end of the CPW line whilst the other three (3–5) are open-circuited as shown in Figure 1. The details of the dimensions of the antenna are reported in [8]. By short and open circuiting at one end of the CPW line, it enables the parasite elements located at the other end of the CPW line to act as a

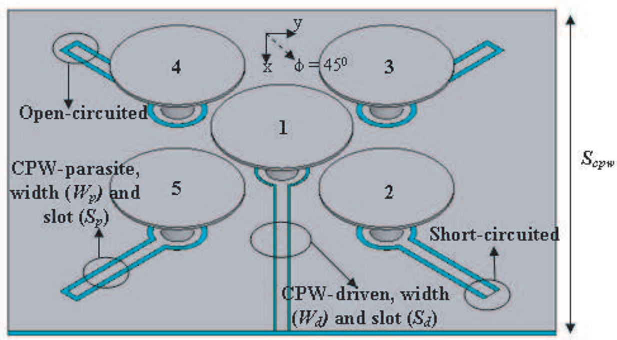



**Figure 1.** CPW-fed antenna for fixed beam.

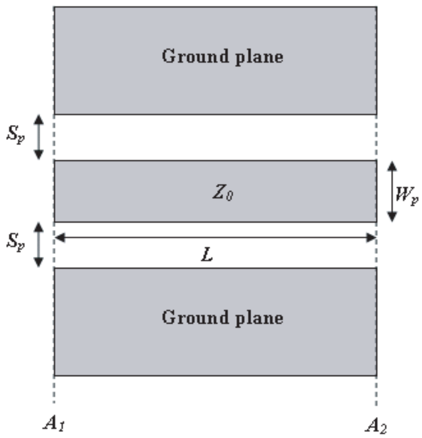



**Figure 2.** Top view of the parasitic CPW line.

director and reflector, respectively. This can be explained in detail by understanding the diagram shown in Figure 2 and the transmission line input impedance equation for a lossless line. In contrast, the parasite elements of the disk-loaded array fed by a coaxial cable perform as a director when it is directly open-circuited and vice versa [1].

The transmission line equation when lossless, $\alpha = 0$, is:

$$Z_{A_2} = Z_0 \left( \frac{Z_{A_1} + jZ_0 \tan \beta L}{Z_0 + jZ_{A_1} \tan \beta L} \right) \tag{1}$$

where $\alpha$ is the attenuation (loss term); $\beta$ is the propagation constant $(2\pi/\lambda)$; $Z_o$ is the characteristic impedance and normally $50\,\Omega$; $L$ is a length; $Z_{A1}$ and $Z_{A2}$ are the impedance at point $A_1$ and $A_2$. For a length, $L$, equal to a $\lambda/4$, the input impedance equation can be simplified as:

$$Z_{A_2} = \frac{Z_0^2}{Z_{A_1}} \tag{2}$$

Assume that the base of the parasite element is located at point $A_2$. When one end of the CPW line ($A_1$) is short-circuited, the impedance ($Z_{A1}$) is $0\,\Omega$. By substituting $0\,\Omega$ in Equation (2), the impedance at point $A_2$ is infinity. Fundamentally, when the impedance is very big or infinity, there is no current flow through the impedance. This enables the parasite monopole element to act as a director. Thus, in order to be a reflector, the $Z_{A1}$ impedance should be infinity or open-circuited. The length, $L$, of CPW strip for the parasite element is about a quarter wavelength, $\lambda_z/4$, equal to approximately 22.69 mm.

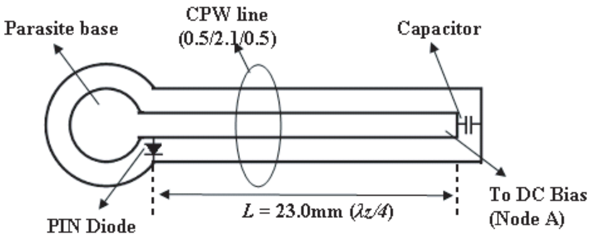



**Figure 3.** The diagram of CPW line of the parasite elements.

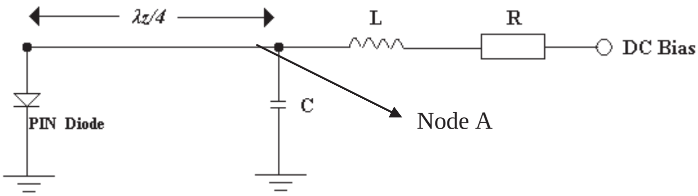



**Figure 4.** Circuit diagram of the complete circuit.

This basic principle can be applied to the antenna structure as shown in Figure 3. Practically, the surface mount capacitor and PIN diode switch can be used to short- and open-circuit the CPW line to provide high impedance at the base of the parasite monopole, providing an open circuited condition and vice versa. Figure 4 shows the circuit diagram of the principle.

From both figures, the capacitor is placed at the end of the CPW line which is close to the ground plane. From the microwave point of view, by placing the capacitor at such place, it acts as a short-circuit and routes the current to the ground plane. In contrast, it performs as an open-circuit for DC bias, and this helps to avoid the DC current from being short-circuited. In this case, the CPW line is always short-circuited, and the parasite element is in open-circuited mode or acts as a director. The PIN diode switch is applied to change the parasites to be a short circuited element. This can be done by putting the PIN diode switch about a quarter wavelength away from the capacitor. It can be seen from the figure that the location of PIN diode is close to the parasite base. The configuration of the parasite element can be altered by providing enough current to the PIN diode switches. For instance, as the parasite element is currently a director, by switching the diode on, the current will flow through the switch to the ground and change the parasite to be a reflector.

## 3. SWITCHING ANTENNA DESIGN

The basic idea has been validated by the measurement. Figure 5 shows the disk-loaded monopole array antenna integrated with RF/Microwave devices. The inductors are used to stop the microwave current from flowing to the DC bias source and are connected to the switching board via feed-through wires.

The antenna has the same configuration as the reference in which the driven element (1) is encircled by four parasite elements (2–5). The switches are located at the base of the parasite elements. The PIN diode switches used in this project were Agilent HSMP-3890. To provide the same configuration as in [8], three switches should be on whilst one is off. The CPW impedance to the fed monopole is chosen to be 50 Ω to give good input match, and this was also chosen for all elements for convenience. The antenna dimensions are given in Table 1.

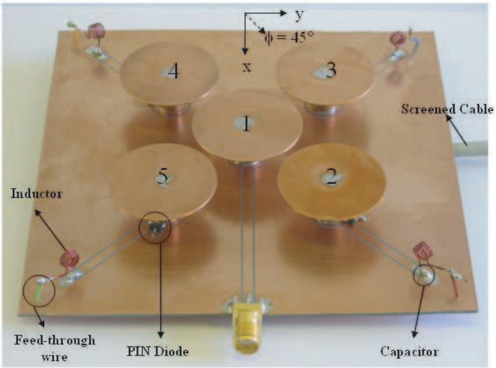



**Figure 5.** Integrated disk-loaded CPW antenna made for 2.45 GHz.

**Table 1.** Dimensions of switching antenna.

| Components | Unit (mm) |
|---|---|
| CPW ground plane size, $S_{cpw}$ | 100 × 100 |
| CPW line width of driven and parasite (width, $W$) | 2.10 |
| CPW line slot of driven and parasite (slot, $S$) | 0.50 |
| Driven disk radius, $R_d$ | 13.00 |
| Parasite disk radius, $R_p$ | 12.35 |
| Height of elements, $h$ | 10.60 |
| Driven and parasite cylindrical rod radius, $R_{cd}$ | 3.00 |
| Distance between driven and parasite | 27.00 |

## 4. RESULTS

The antenna results shown are based on the antenna configurations in which three PIN diodes are switched on while the remaining is switched off as shown in Figure 6. The PIN diode identification numbers, such as PIN diode No. 2 is referred to the parasite numbers (2–5) used in Figure 5. Figure 7 illustrates the input return loss of the antenna for all four configurations. It can be seen that this antenna has a good reflection coefficient at 2.45 GHz for all four configurations.

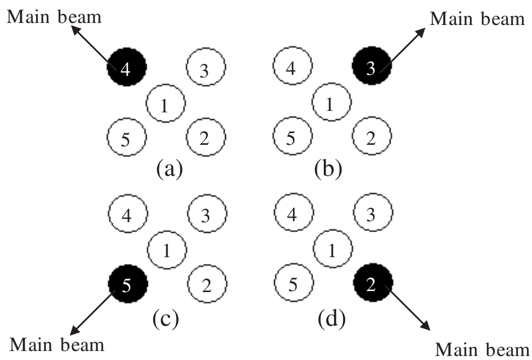



**Figure 6.** The configurations of the antenna. Black circle is when the diode was switched OFF, whilst other three were switched ON: (a) PIN diode No. 4 was switched OFF; (b) PIN diode No. 3 was switched OFF; (c) PIN diode No. 5 was switched OFF and (d) PIN Diode No. 2 was switched OFF. White circle in the middle is the driven element.

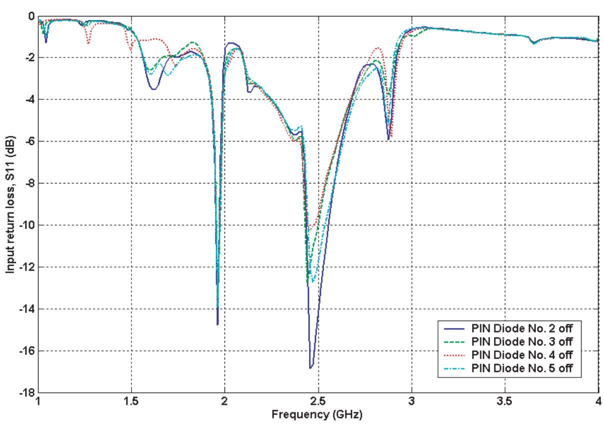
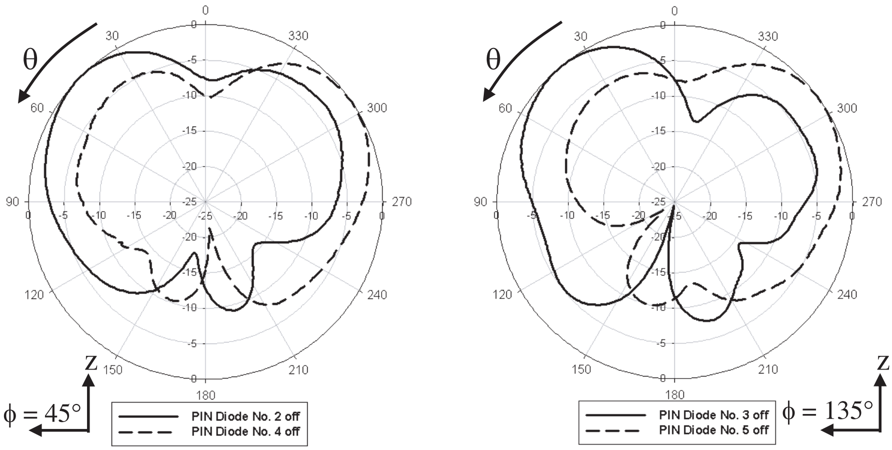



**Figure 7.** Measured input return loss against frequency for all four configurations. (Inset shows which diode was off; other three were all on).




(a) E-Plane (dB) at ϕ = 45° (b) E-Plane (dB) at ϕ = 135°

**Figure 8.** Measured normalized $E$-plane antenna radiation patterns. Frequency = 2.45 GHz.

**Table 2.** Antenna measured gains at the main beam direction.

| **Positions** | **Main beam measured gain (dBi)** | **Opposite beam measured gain (dBi)** |
|---|---|---|
| Pin Diode No. 2 off | 5.10 | 0.70 |
| Pin Diode No. 3 off | 5.50 | 1.10 |
| Pin Diode No. 4 off | 5.50 | 1.00 |
| Pin Diode No. 5 off | 5.60 | −0.30 |

The $E$-plane patterns as shown in Figures 8(a) and 8(b) clearly demonstrate that the main beam direction is determined by the PIN diode state. The gains of the antenna at different positions are given in Table 2. By comparing these results with the results of the reference antenna, these patterns are much better because they produce lower gain at the opposite position. The gain in back of the reference antenna is 4.90 dBi.

Figures 9(a) and 9(b) show the $H$-plane patterns of the antenna. The average of front-to-back ratio is about 5 dB. In general, the results show that the beam of the antenna can be switched by implementing PIN diode switches.

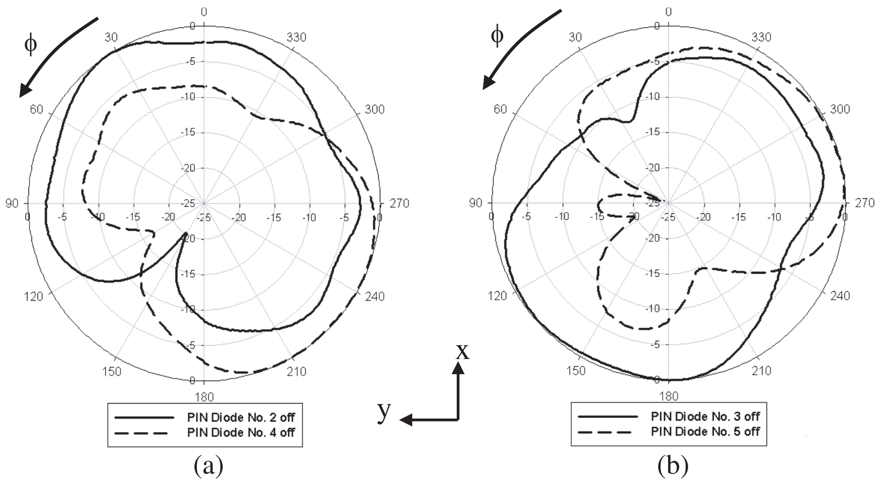



**Figure 9.** Measured normalized $H$-plane antenna radiation patterns. Frequency = 2.45 GHz.

## 5. CONCLUSION

A switched beam disk-loaded parasitic monopole antenna array with coplanar waveguide (CPW) feeding systems with integrated PIN diode switches has been demonstrated. The measured gain of the antenna in the direction of the open-circuited parasite element is in the range of 5.10 to 5.60 dBi. The antenna utilises the advantages of CPW and is integrated with RF/Microwave devices to enable beam switching in the elevation and azimuthal planes. It has good input return loss at 2.45 GHz and produces useful gain in the direction of the open circuited element. The $E$- and $H$-plane patterns show that the beam can be steered by PIN diodes switching. Thus, this kind of antenna can operate as a pattern diversity antenna for on-body diversity measurements for various channels.

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## REFERENCES

1. Ares-Pena, F. J., G. Franceschetti, and J. A. Rodriguez, "A simple alternative for beam reconfiguration of array antennas," *Progress*

*In Electromagnetics Research*, PIER 88, 227–240, 2008.

2. Mitilineos, S. A., S. A. Papagianni, C. A. Verikaki, and C. N. Capsalis, "Design of switched beam planar arrays using the method of genetic algorithms," *Progress In Electromagnetics Research*, PIER 46, 105–126, 2004.
3. Sotirio, A. I., P. K. Varlamos, P. T. Trakadas, and C. N. Capsalis, "Performance of a six-beam switched parasitic planar array under one path rayleigh fading environment," *Progress In Electromagnetics Research*, PIER 62, 89–106, 2006.
4. Varlamos, P. K. and C. N. Capsalis, "Electronic beam steering using switched parasitic smart antenna arrays," *Progress In Electromagnetics Research*, PIER 36, 101–119, 2002.
5. Kamarudin, M. R. and P. S. Hall, "Switched beam array antenna with parasitic element," *Progress In Electromagnetics Research B*, Vol. 13, 187–201, 2009.
6. Schlub, R. and D. V. Thiel, "Switched parasitic antenna on a finite ground plane with conductive sleeve," *IEEE Transaction on Antennas and Propagation*, Vol. 52, No. 5, 1343–1347, May 2004.
7. Kawakami, H. and T. Ohira, "Electrically steerable passive array radiator (ESPAR) antennas," *IEEE Antennas and Propagation Magazine*, Vol. 47, No. 2, 43–49, April 2005.
8. Kamarudin, M. R., P. S. Hall, F. Colombel, and M. Himdi, "CPW-Fed switchable top disk-loaded monopole array antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 11–12, 1631–1638, 2009.
9. Jaw, J.-L., F.-S. Chen, and D.-S. Chen, "Compact dualband CPW-fed slotted patch antenna for 2.4/5 GHz wlan operation," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 14–15, 1947–1955, 2009.
10. Chen, J., G. Fu, G.-D. Wu, and S.-X. Gong, "Compact graded central feeder line CPW-fed broadband," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 14–15, 2089–2097, 2009.
11. Jiao, J.-J., G. Zhao, F.-S. Zhang, H.-W. Yuan, and Y.-C. Jiao, "A broadband CPW-fed T-shape slot antenna," *Progress In Electromagnetics Research*, PIER 76, 237–242, 2007.
12. Soltani, S., M. N. Azarmanesh, and P. Lofti, "Design of band notched CPW-fed monopole antenna using two symmetric parasitic elements for UWB applications," *Journal of Electromagnetic Waves and Applications*, No. 11–12, Vol. 23, 1407–1416, 2009.