URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

2.45 GHz Pattern Reconfigurable Antenna for Wireless Sensor Network applications

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Abstract

The design and development of a new multi-directional switched beam antenna at 2.45 GHz for wireless sensor network applications is proposed in this paper. The beam of the antenna can be switched towards the boresight 0^0, at an angle of $\pm 80^0$ in both azimuth and elevation planes. The two ports when excited with a 90^0 phase difference lead to a circular polarisation in the beam directed towards the boresight. It is also worth noting that the resonance frequency of the antenna remains within the 2:1 VSWR bandwidth irrespective of the direction of the switched beam.

1. Introduction

Wireless sensor networks (WSN) consist of small, low power energy constrained devices used to monitor physical or environmental conditions. WSNs have applications in a vast range of different domains, scenarios, and disciplines. These include healthcare, industrial, environmental monitoring and structural health monitoring [1]. WSN nodes are usually equipped with omnidirectional antennas such as monopole and dipole antennas, consequently only a portion of the total radiated power directed at the receive node is effectively used, whereas the rest of the power is wasted. Therefore a node with a switched beam antenna could reconfigure the antenna radiation pattern to direct the beam towards the desired node. Directional antennas that can change patterns according to the location of the target sensors provide improvements over omnidirectional antennas in terms of the energy consumption, sensitivity of the receiver, and propagation range in WSN environments. Directive antennas integrated into WSN nodes in order to reduce energy consumption and extend node life have not been exhaustively explored yet. Some of the published work includes a reconfigurable antenna for WSN sink nodes capable of switching the beam from a conical pattern to a front-directional pattern [2]. However, the size of the antenna is large and presents no radiating beams in the azimuth direction. In [3], a four patch antenna is described, arranged on a cube-like shape, which directs the beam in the azimuth plane. However, the size of the structure is too large for its integration into WSN nodes.

Pattern reconfigurable antennas based on the Yagi-Uda principle have recently been addressed by many researchers. Some of the antenna designs based on this concept include a parasitic planar patch antenna capable of multi-directional pattern reconfiguration [4]. The antenna structure consists of a driven element surrounded by four parasitic elements that act either as reflector(s) or director(s) depending on the switching arrangement. Beam reconfiguration is achieved by using four PIN diode switches. A gain enhanced planar Yagi-Uda antenna with pattern reconfiguration is presented in [5]. The antenna offers three different states: two directional radiation patterns each in 20^0 and 170^0 and one omnidirectional radiation pattern. The pattern reconfiguration is achieved by alternately switching the driven and the reflector elements. A pattern reconfigurable microstrip antenna with parasitic elements is also reported in [6], the maximum radiation pattern tilt reported is 35^0.

In this paper, we have applied the principle of Yagi-Uda antenna for pattern reconfiguration. A microstrip patch antenna as the radiator with parasitic elements on each of the four sides of the patch acts as the reflector or the director depending on the ON/OFF states of the switches.

2. Antenna Design

A microstrip patch of size 27.6 mm x 27.6 mm is fabricated on one side of a FR4 substrate of dimension 80 mm x 80 mm that has a ground plane of size 34 mm x 34 mm on its other side. The dielectric constant and the thickness of the substrate is 4.3 and 1.6 mm respectively. Parasitic patches are fabricated on each of the four sides of the microstrip patch as shown in Figure 1. The spacing between the radiating element and the parasitic patch is 19.7 mm. The length of the parasitic elements can be lengthened or shortened. This is achieved by closing the gaps located on each parasitic arm. This can be done using RF switches. For proof of concept copper strips are used to realize the switches. The copper strips are used to switch the parasitic elements into reflector or director. The total length of each parasitic element is ($L_F + 2L_1 + 2d$) 38.6 mm.

The antenna is excited with two orthogonal feeds to obtain the pattern reconfigurations in different directions.

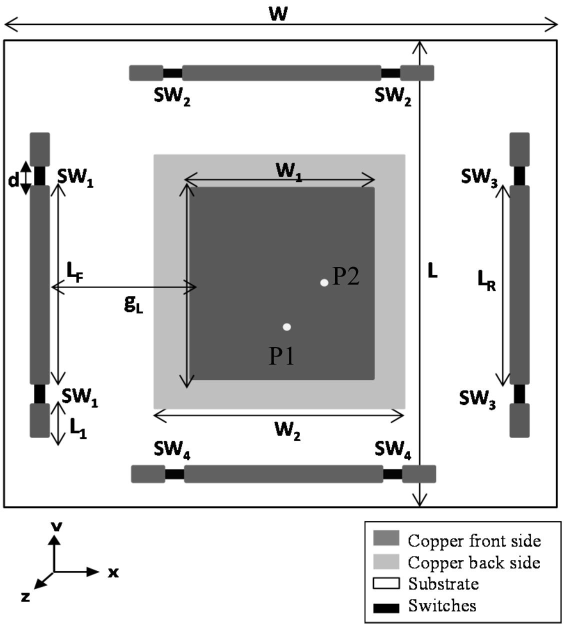


Figure 1. Geometry of the proposed antenna
(W_1 = 27.6 mm, $L_F = L_R$ = 27.6 mm, W = 80 mm, W_2 = 34 mm, g_L = 19.7 mm, L_1 = 3 mm, d= 2.5 mm, h = 1.6 mm, ε_r = 4.3)

The beam tilt is achieved for different switching conditions depending on the ports excitations. The antenna is simulated and optimised using CST microwave studio.

3. Results and Discussions

The simulated reflection coefficient of the antenna for different switching conditions port excitation is shown in Figure 2. It is observed that the antenna resonates at 2.45 GHz irrespective of the mode of excitation or the switching conditions. The simulated and measured return loss for the antenna as well as the port isolation with excitation of 90^0 phase difference is shown in Figure 3. It is observed that an isolation of more than 30 dB is obtained between port 1 and port 2.

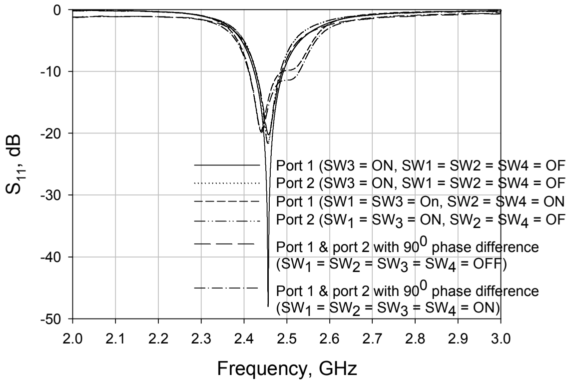


Figure 2. Simulated reflection coefficient of the antenna for different switching conditions

When the centre microtrip patch is excited with two orthogonal feeds of equal amplitude and with a relative phase shift of 90^0, the antenna acts as a bidirectional end-fire radiator simultaneously in both azimuthal and elevation planes with a null in the boresight, when all the switches SW_1, SW_2, SW_3 and SW_4 are in the ON state and also as a circularly polarised bore-sight radiator when all the switches are in the OFF state. Figure 4 shows the radiation pattern for different switching conditions. LHCP and RHCP can be obtained by properly selecting the phase of excitation of the ports. The directive gain of the antenna when switched to the boresight mode is 5.04 dBi and the radiation efficiency is 64 %. When all the switches are ON, the maximum directive gain obtained is 3.3 dBi and the radiation efficiency is 73 %.

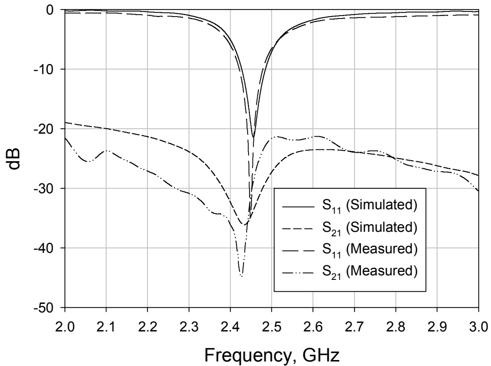
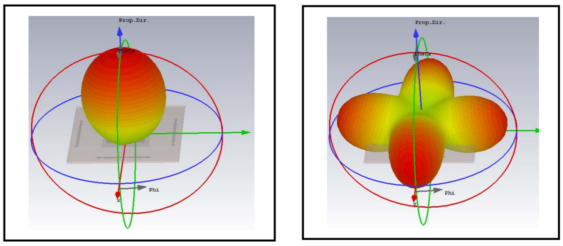
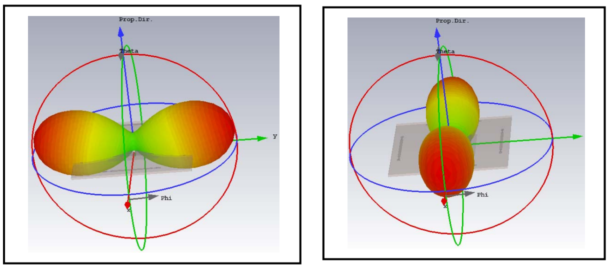


Figure 3. Simulated and measured reflection coefficient |S11| and port isolation |S21|



(a) (b)

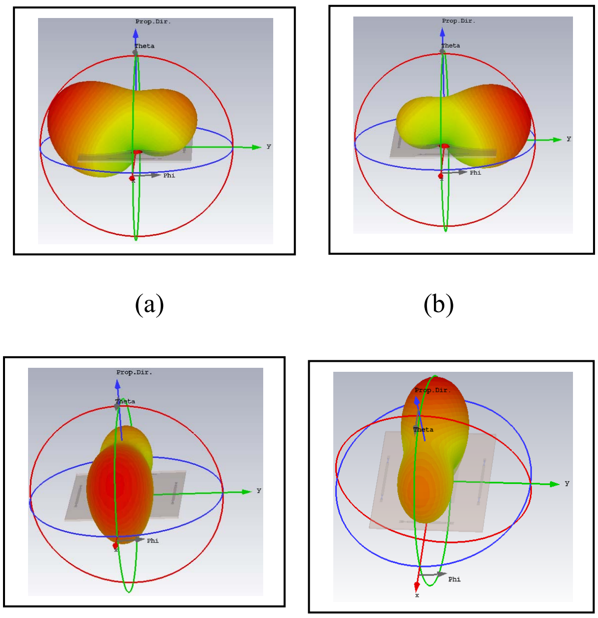
Figure 4. 3D radiation pattern (a) $SW_1 = SW_2 = SW_3 = SW_4$ = OFF (b) $SW_1 = SW_2 = SW_3 = SW_4$ = ON



(a) (b)

Figure 5. 3D radiation pattern (a) $SW_1 = SW_3$ = ON, $SW_2 = SW_4$ = OFF (b) $SW_1 = SW_3$ = OFF, $SW_2 = SW_4$ = ON

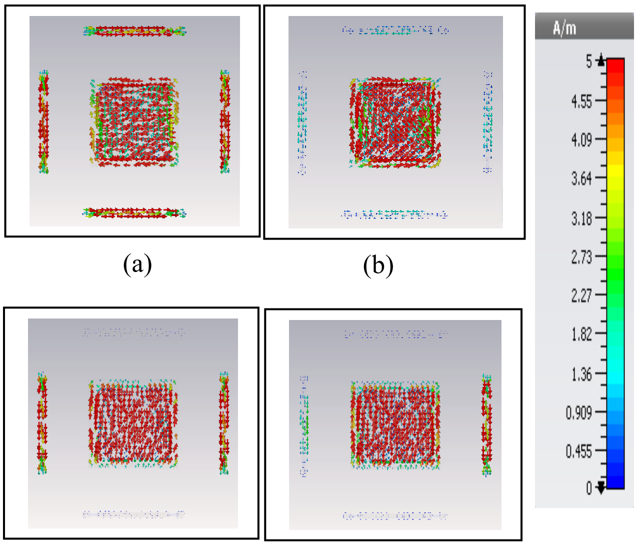
Figure 5(a) shows the radiation pattern of the antenna when port 1 is excited and switches SW_1 and SW_3 are in the ON state and switches SW_2 and SW_3 are in the OFF state. Figure 5(b) shows the radiation pattern of the antenna when port 2 is excited and switches SW_2 and SW_4 are in the ON state and SW_1 and SW_3 are OFF. The directive gain of the antenna in this mode is 5 dBi and the radiation efficiency is 64%.



(a) (b)

(c) (d)

Figure 6. 3D radiation pattern (a) SW_3 = ON, $SW_1 = SW_2 = SW_4$ = OFF (b) SW_1 = ON, $SW_2 = SW_3 = SW_4$ = OFF (c) SW_2 = ON, $SW_1 = SW_3 = SW_4$ = OFF (d) SW_4 = ON, $SW_1 = SW_2 = SW_3$ = OFF



(a) (b)

(c) (d)

Figure 7. Surface current distribution (a) $SW_1 = SW_2 = SW_3 = SW_3$ = ON (b) $SW_1 = SW_2 = SW_3 = SW_4$ = OFF (b) $SW_1 = SW_3$ = ON, $SW_2 = SW_4$ = OFF (d) SW_3 = ON, $SW_1 = SW_2 = SW_4$ = OFF

Figure 6 depicts the three dimensional radiation pattern of the antenna when port 1 is excited. It is observed that the switches in any of the arms when it is ON acts as a reflector and directs the beam in the opposite direction at an angle of 80^0 from boresight. The directive gain and the radiation efficiency of the antenna in each of these cases are 4.89 dBi and 68 % respectively irrespective of the direction of the switched beam. The surface current distribution of the antenna at 2.45 GHz for different switching conditions is shown in Figure 7. It can be seen from Figure 7(a) that maximum currents flows on the patch as well as on the arms when the antenna is excited with two orthogonal ports with a phase difference of 90^0 between them and that all the switches are in the ON state. The antenna radiates in four directions as shown in Figure 4 (b). Similarly, when all the switches are in the OFF state, the maximum current confines to the centre radiator hence the antenna radiates in the boresight direction as shown in Figure 4(a). Figure 7(c) shows the surface current distribution when port 1 is considered and switches SW_1 and SW_3 are in the ON state. The antenna radiates as shown in Figure 5(a). When SW_3 is ON and SW_1 is in the OFF state and port 1 is considered, the antenna radiates as depicted in Figure 6(a). Surface current distribution plot for other configurations are not shown in this paper for brevity. The prototype of the antenna is shown in Figure 8.

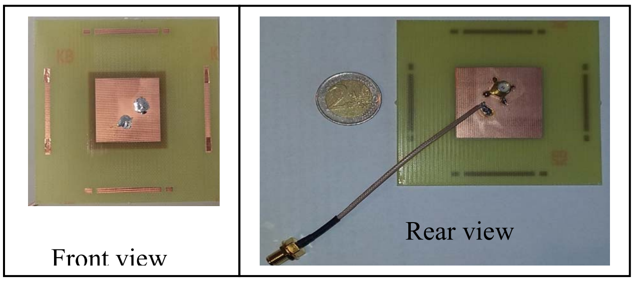


Figure 8. Photograph of the fabricated antenna

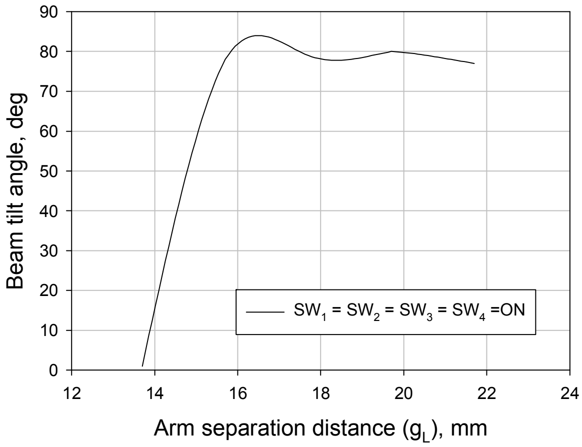


Figure 9. Variation of arm separation distance (g_L) with beam tilt angle

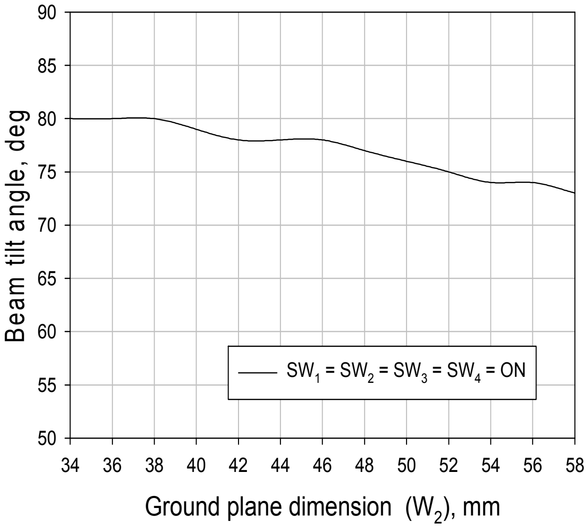


Figure 10. Variation of beam tilt with ground plane dimension (W_2)

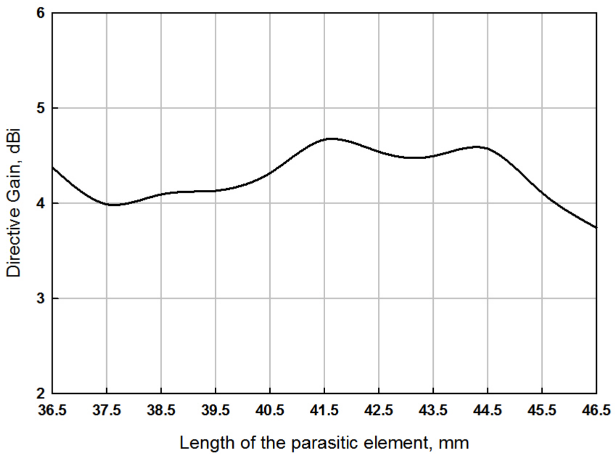


Figure 11. Variation of directive gain with increase in the length of the parasitic element

Figure 9 shows the variation of arm separation distance with beam tilt angle. It is observed that as the parasitic arm separation distance from the main radiating element is decreased the beam tilt achieved reduces. When the separation distance is less than 14 mm the beam is directed towards the boresight direction. The effect on the variation of ground plane dimension with beam tilt angle is shown in Figure 10. It is observed that as the ground plane dimension increases the beam tilt achieved decreases. Figure 11 shows the variation of the directive gain of the proposed antenna with increase in the length of the parasitic element when SW_1 is ON while SW_2, SW_3 and SW_4 are OFF and both ports are excited with a phase difference of 90^0.

4. Conclusion

A multi-directional switched beam antenna at 2.45 GHz is developed that can direct the beam towards boresight 0^0 or ± 80^0 in both E and H planes. The antenna resonance remains within 2:1 VSWR bandwidth irrespective of the direction of the switched beam. The directive gain of the proposed antenna at the tilt angles are higher than a dipole antenna and hence make it as suitable candidate for WSN application. Moreover, the two ports on the antenna give the option to choose the desired polarisation. The radiation efficiency of the antenna can be increased using a low loss dielectric constant material as the substrate. Further work on the integration of PIN diodes as switches along with the bias network is in progress.

6. Acknowledgements

The authors acknowledge the financial assistance from Enterprise Ireland and UGC (University Grants Commission), Government of India under Faculty Research Program, Email: sujithrpkd@gmail.com

7. References

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