Multi-directional Switched Beam Antenna at 2.45 GHz for WSN Application

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Abstract

The design and development of a multi-directional switched beam antenna at 2.45 GHz for wireless sensor network application 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 of the antenna when excited with a 90^0 phase difference leads to a circular polarisation in the beam directed towards the boresight. It is also noteworthy noting that the resonance frequency of the antenna remains within the desired ISM frequency band 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 the portion of total radiated power directed at the receive node is effectively used, whereas 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 provides improvements over omnidirectional antennas in terms of the energy consumption, sensitivity of the receiver, and propagation range in WSN environments. Directional antennas that can change patterns according to the location of the target sensors provides 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 antenna based on the Yagi-Uda principle has 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 parasitic array is 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 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 Fig.1 (a). 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 stripes are used to realise the switches. The copper stripes 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. The beam tilt is achieved for different switching conditions ($SW_1 + SW_1 =$

SW_1, SW_2 + SW_2 = SW_2, SW_3 + SW_3 = SW_3, SW_4 + SW_4 = SW_4) with the two ports excited in-phase as well as with a 90^0 phase difference. The antenna is simulated and optimised using CST microwave studio.

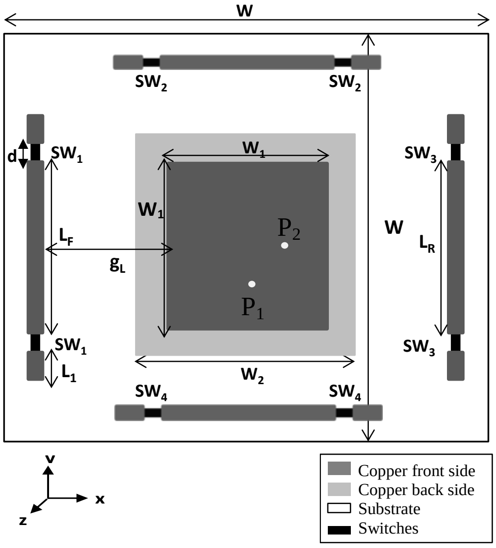


Fig. 1. Geometry of the proposed antenna

3 Results and discussions

The simulated reflection coefficient of the antenna for different switching conditions port excitation is shown in Fig. 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 Fig.3. It is observed that an isolation of more than 30 dB is obtained between the port 1 and port 2.

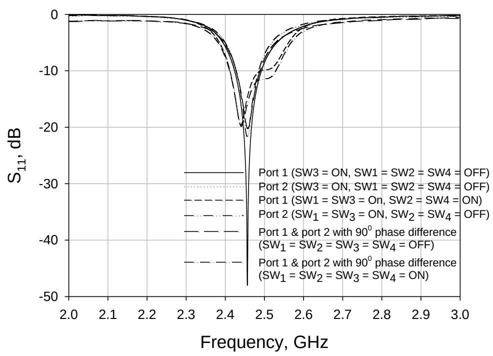


Fig.2. Simulated reflection coefficient of the antenna for different switching conditions

When 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 OFF state and also as a bore-sight radiator when all the switches are in the ON state. Fig.4. shows the radiation pattern for different switching conditions. 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 %.

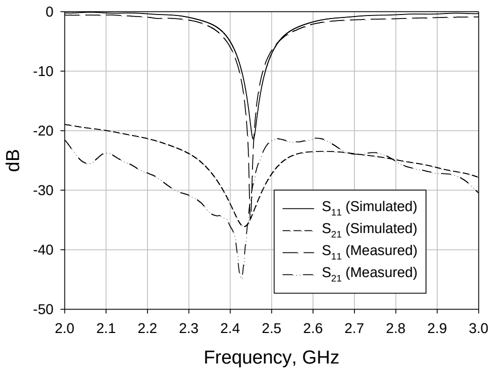
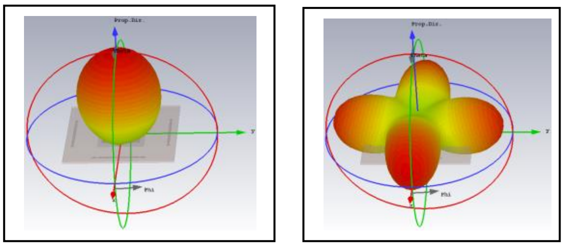
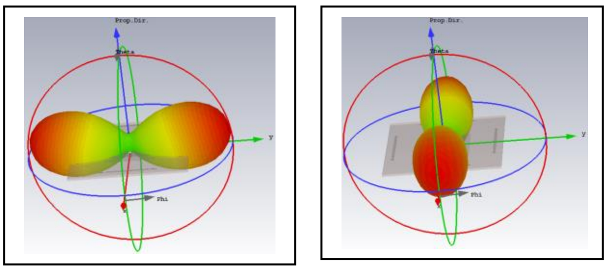


Fig.3. Simulated and measured reflection coefficient $|S_{11}|$ and port isolation $|S_{21}|$



(a) (b)

Fig.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)

Fig.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

Fig.5 (a) shows the radiation pattern of the antenna when port 1 is excited and switches SW_1 and SW_3 are in ON state and switches SW_2 and SW_3 are in the OFF state. Fig. 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%.

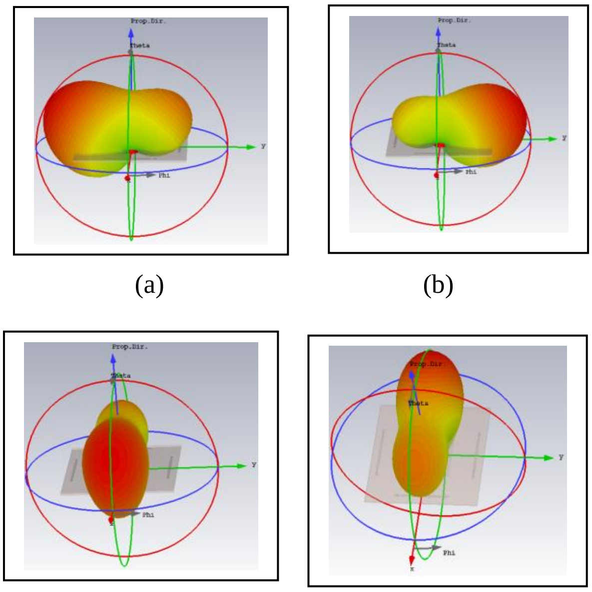


Fig.6. 3D radiation pattern (a) SW_3 = ON, SW_1 = SW_2 = SW_4 = OFF (b) SW_1 = ON, SW_2 = SW_3 = SW_4 = OFF (c) SW_2 = ON, SW_1 = SW_3 = SW_4 = OFF (d) SW_4 = ON, SW_1 = SW_2 = SW_3 = OFF

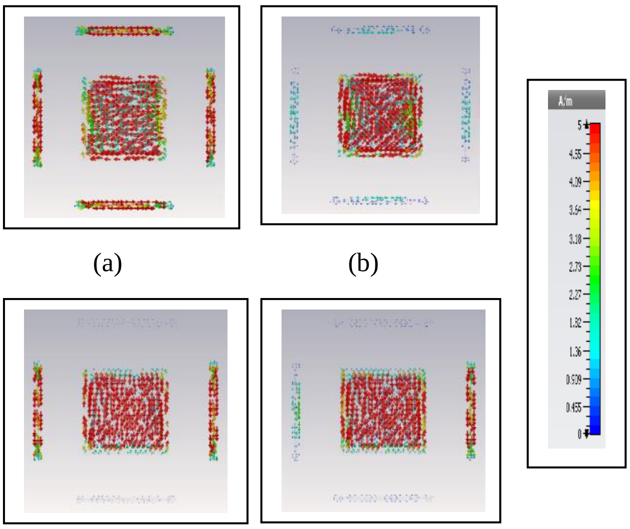


Fig.7. Surface current distribution (a) SW_1 = SW_2 = SW_3 = SW_3 = ON (b) SW_1 = SW_2 = SW_3 = SW_4 = OFF (b) SW_1 = SW_3 = ON, SW_2 = SW_4 = OFF (d) SW_3 = ON, SW_1 = SW_2 = SW_4 = OFF

Fig. 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 Fig.7. It can be seen that from Fig 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 Fig. 4 (b). Similarly, when all the switches are in the OFF state, the max current confines to the centre radiator hence the antenna radiates in the boresight direction as shown in Fig.4 (a). Fig.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 Fig. 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 Fig.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 Fig.8.

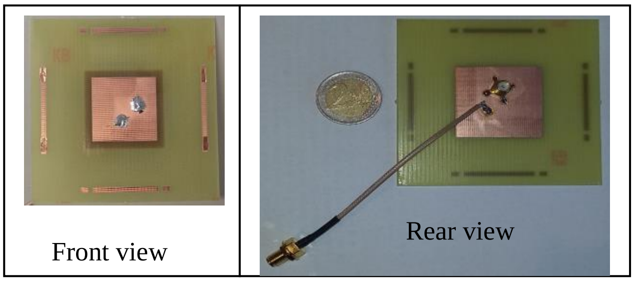


Fig.8. Photograph of the fabricated antenna

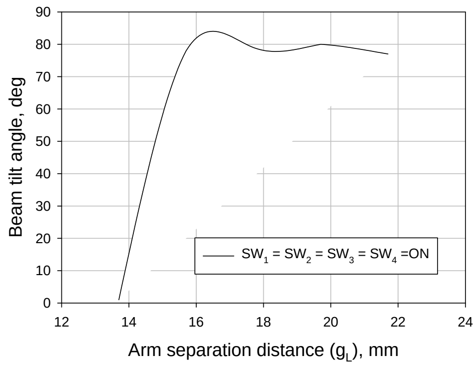


Fig. 9. Variation of arm separation distance (g_L) with beam tilt angle

Fig. 9 shows the variation of arm separation distance with beam title angle. It is observed that as the parasitic arm separation distance from the main radiating element is decreased the beam title 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 Fig. 10. It is observed that as the ground plane dimension increases the beam tit achieved decreases.

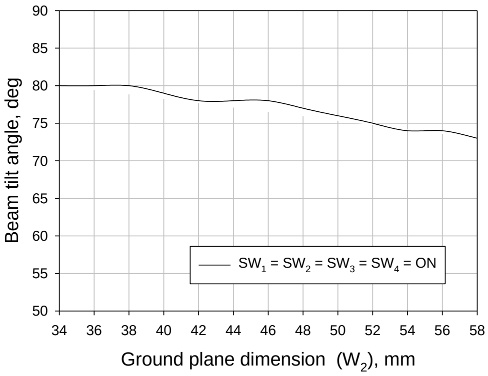


Fig.10. Variation of ground plane (W_2) with beam tilt angle

4 Conclusions

A multi-directional switched beam antenna at 2.45 GHz is development that can direct the beam from boresight direction to all the four side of the antenna in the x-y plane. The antenna resonance remains with the desired ISM frequency band irrespective of the switched beam direction. The directive gain of this antenna in the x-y plane is more than a dipole antenna making it as suitable candidate for WSN application.

Acknowledgements

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