Investigation on the effect of the gap and size of the parasitic structure in multi-direction steerable antenna for WSN

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Abstract. In this paper, a multi-direction steerable radiation pattern antenna is designed and investigated, which operates at 2.45 GHz frequency. The radiation pattern reconfigurable is achieved by locating the driven elements at the centre of the antenna that surround by four parasitic elements. The artificial switches, are currently inserted at the specific position on the parasitic element. The beam steering to be directed into four direction angles; right, left, upwards and downwards, by controlling the state of the switches, ON/OFF. In this research, an investigation on the effect of gap and the size of the parasitic on the steering angles has been carried out. With minimum numbers of switches deployed, the proposed antenna is a potential candidate to serve as a transmitting element in WSN applications.

Keywords: beam steering, gap, parasitic patch, WSN.

1. Introduction

Beam steering antenna are one of the antenna that have attracted significantly attention due to increasing demands with the high data coverage, security and energy efficiency. The existing beam steering can be categorized in many group but one of them are the antenna with the parasitic technique. The configuration of the beam steering are normally very complicated [1]. The conventional antenna may face restriction to meet the requirements and adapt to new conditions due to inflexible characteristics which is high profile, large size, relatively high cost, limited bandwidth, low efficiency and also limited steering angle [2].

Antenna are one of the critical key and components in WSN. WSN are one of the recently creating new applications that can be used in many filed such as sensing, tracking and monitoring. The most desirable featured for WSN is high sensing fidelity, low cost, and flexibility, but the WSN should satisfy the performance objective such as the maximum battery lifetime, sensing coverage and operations period. To achieve this the best candidate can be optimized are the antenna, as there are many type that have certain disadvantage and advantages to WSN. Thus, the antenna that will used in WSN are carefully studied in terms of function and design complexity.

Recently research also show novel approaches of for beam steering technology by using PIN switches [3], [4] and parasitic elements [2]. One solution to overcome this issue is by using the radiation pattern reconfigurable antennas. The RPR antenna are usually driven by one or more radiating elements and parasitic elements that function as directive or reflective unit forming that are directed by a certain angle or directions, this can be done by controlling the ON/OFF switches. However, the existing antenna with the parasitic elements are reported had a low gain [5-7].
An RPR antenna design with minimum number of switches with comparable beam directions needs to be developed. The use of RPR antenna with excessive number of elements degrades the beam steering performance of the antenna, which could be accomplished by using fewer number of the parasitic elements [8]. Usually the maximum tilt angle that could be obtained with 3-element RPR antenna is 25° [9] and the antenna design in [9] used Taconic substrate which has low loss tangent. The tilt angle is expected to reduce with the use of high loss substrate such as FR-4. Therefore, in this paper, the effect of gap and the size of the parasitic with deflected ground structure (DGS) towards the tilt angles is investigated. DGS technique has been applied in [10] and has proven its ability to enhance the performance of the antenna. The aim of the research is to improve the maximum tilt angle of DGS with the reducing and increasing the gap and the size of the parasitic are introduced to RPR antenna as compared to RPR antenna with full ground plane. High degree of beam tilting can improve the sensing coverage in WSN. Similar design approach has been proposed in [5], [11], [12], however the tilt angle steering value is not more than 30°. The aim of this work is to attain at least 30° tilt angle at xz plane even if the antenna is fabricated using FR4. Simulation results are compared and analysed, and important parameter results for optimization is presented.

2. Antenna design and reconfigurations

Figure 1 shows the initial structure of the proposed multi-element RPR antenna that consists of one driven element at the centre, and four parasitic elements located surrounding the driven element. The antenna is designed with the dimension of 150 mm x 100 mm, height of 1.6 mm and the permittivity of $\varepsilon_r=4.3$ by using FR-4 as the substrate. The shape for driven and parasitic element design are rectangular patch shape as it is simple to design, easy to be optimize and easy integration with switches. The patch of the driven element ($L_p \times W_p$) and the all the parasitic elements are placed on the top of the substrate. At the other side of the substrate, the DGS with a dimension of $(W_s \times L_s)/2$ is introduced. The patch and the ground are made by copper with a thickness of $H_t = 0.035$ mm. The dimension of the driven and the parasitic elements are almost identical as the mutual coupling is strong when the size of the driven elements are close to the size of the parasitic elements. Hence, it can be used as the director [12] The switches are placed between the parasitic elements and the ground plane which is currently represented by the shorting pin as the proof of the concept. The shorting pins are positioned at the specific location of the parasitic patch and the direction pattern of the beam steering is changed to the left, right, up or down depending on the switching configurations as tabulated in Table 1. When the material of the shorting pin is set as copper indicates the switch is ON, while when its change to vacuum its represented OFF state. When the switch is ON, the parasitic is grounded via shorting pin, thus it acts as a reflector to reflect the energy of the radiation pattern towards the driven element. Figure 2 shows the ground plane with DGS and optimized ground plane structure, which the parameter $W_s$ is varied to obtain maximum tilt angle as compared to the RPR with full ground plane. The dimensions of the optimized design are as follows (unit in millimeters): $W_p=37.58$, $L_p=27.4$, $W_s=38$, $L_s=2$, $W_i=150$, $L_i=100$, and $W_{DGS} = 37.5$.

| Configuration | Tilt direction | Switch 1 | Switch 2 | Switch 3 | Switch 4 |
|---------------|---------------|----------|----------|----------|----------|
| I             | Left          | ON       | OFF      | OFF      | OFF      |
| II            | Right         | OFF      | ON       | OFF      | OFF      |
| III           | Upwards       | OFF      | OFF      | ON       | OFF      |
| IV            | Downdwards    | OFF      | OFF      | OFF      | ON       |
Figure 1: Geometry of the initial design of the multi-element RPR antenna (a) front view (b) back view

Figure 2: The back view (a) with DGS and (b) with optimized DGS
3. Results and discussion

The preliminary works has been done by using ideal diodes for proof of the concept. The antenna was originally designed as microstrip patch antenna with full ground and feed at the middle of the driven patch. Parameter sweep has been conducted by increasing or reducing the gap and the size of the parasitic to investigate how the beam steering of the antenna are effected. Figure 3 shows the simulated reflection coefficient result of the proposed antenna with the increasing and reducing the gap between the parasitic and the driven elements.

![Figure 3: Simulated reflection coefficient, $S_{11}$ for the proposed antenna.](image)

The tilt angles of the radiation pattern seem to be changed when the gap and the size of the parasitic are changed. First, the gap between parasitic and driven elements are changed and the results simulations show the changes in the angle tilting and the gain of the antenna. The process has been repeated for the remaining five gap measurement and shown in the figure 4 below.

![Figure 4: Radiation pattern for different gaps.](image)
Figure 4 The polar plot for five different size of the gap (a) configuration left (b) configuration right (c) configuration upwards (d) configuration downwards.

Table 2: summarized of the result that effected by the size of the gap

| Config. | Gap=1mm | Gap=2mm | Gap=3mm | Gap=4mm | Gap=5mm |
|---------|---------|---------|---------|---------|---------|
|         | Degree  | Gain    | Degree  | Gain    | Degree  | Gain    |
|         | angle   | (dB)    | angle   | (dB)    | angle   | (dB)    |
|         | tilt    |         | tilt    |         | tilt    |         |
| I       | 6°      | 0.067   | 30°     | 2.74    | 33°     | 2.61    |
|         |         |         |         |         |         |         |
| II      | 7°      | 0.199   | 30°     | 2.74    | 33°     | 2.58    |
|         |         |         |         |         |         |         |
| III     | 8°      | -0.661  | 20°     | 1.81    | 13°     | 3       |
|         |         |         |         |         |         |         |
| IV      | 3°      | -0.941  | 24°     | 1.94    | 19°     | 2.88    |

From the simulated result when the gap are increased or decreased. The most suitable gap to be used are at 3mm which can be seen that, when the gap are 3mm the angle can be tilted more than 30 degree and the gain also high compared to the other result.

Besides that the others factor that also influence the angle tilting and the gain are the size of the parasitic which has been investigated and the result are show in figure 5 which show the reflection coefficient while figure 6 show the direction of the steering.
Figure 5 : Simulated reflection coefficient, $S_{11}$ for the proposed antenna when the size of the length, $a$ are varies.

![Figure 5](image)

Figure 6 : The polar plot for eight different size of the length, $a$.

![Figure 6](image)

Table 3 : summarized of the result that effected by the length of the parasitic

| Length, $a$ | 0.84mm | 0.86mm | 0.88mm | 0.90mm | 0.92mm | 0.94mm | 0.96mm | 0.98mm |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Degree tilt | 32°    | 32°    | 33°    | 33°    | 34°    | 34°    | 34°    | 34°    |
| Gain(dB)    | 2.68   | 2.61   | 2.59   | 2.58   | 2.57   | 2.6    | 2.5    | 2.61   |

The simulated result for the parasitic by changing the length show that the higher the value of the length the better the angle tilting of the antenna as shown in the table 3. The size of the width of the
parasitic also been investigated and studied. So that the angle and the gain can be improves better. Figure 7 show the reflection coefficient when the size width are varies, while figure 8 show the result of the steering.

**Figure 7**: Simulated reflection coefficient, $S_{11}$ for the proposed antenna when the size of the width, $b$ are varies.

**Figure 8**: The polar plot for eight different size of the width, $b$.

**Table 4**: summarized of the result that effected by the width of the parasitic

| Width, $b$ (mm) | 0.984 | 0.986 | 0.988 | 0.990 | 0.992 | 0.994 | 0.996 | 0.998 |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Degree angle tilt | $22^\circ$ | $23^\circ$ | $25^\circ$ | $29^\circ$ | $30^\circ$ | $31^\circ$ | $32^\circ$ | $33^\circ$ |
| Gain(dB)         | 2.96  | 2.69  | 2.68  | 2.6   | 2.62  | 2.59  | 2.58  | 2.58  |
The simulated result shown in the table 4 shows that when the width of the parasitic increase the angle tilting also increase but the gain are decrease. So from the study of the gap and the size of the parasitic, both of the parameters play a huge role in the angle tilting and also the gain of the antenna. To achieved the better tilting angle and gain the best size of the parasitic and gap are chosen based on the investigation that been done. Which is the gap=3mm and the parasitic elements are (a= 0.90mm b=0.998mm). From this value of gap and parasitic the steering achieved are for configuration I and II are 33° while for configuration III are 13°, and for configuration IV are 19°.

4. Conclusion
This paper proposed a design of multi element RPR beam steering antenna with optimized ground plane by using DGS technique. To achieve the steering capability, the parasitic array technique is applied on the proposed design, by placing almost identical parasitic patches next to the driven patch. Which has been studied and proves. The beam steering antenna is realized by grounded the shorting pin of the parasitic. The direction of the beam pattern is capable to be changed in four directions. The tilt angle is more than 30 degree when the DGS technique is integrated to the structure.

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