Wide Angle Scanning Reconfigurable Beam Steering Antenna

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***Abstract*—A wide-angle scanning reconfigurable beamsteering parasitic patch array antenna is introduced in this paper. For beam-steering antennas using microstrip, the beam scanning range is very limited where the typically achieved scanning is in the range of -30° to +30°. Increasing the parasitic elements does not provide significant improvement in terms of the beam scanning where only additional 3° to 5° is achieved. In this work, with additional parasitic elements, the scanning from broadside is improved by with a novel approach where the ground plane reduction is applied. With the optimized switching locations at the parasitic elements, five measured directive beam patterns of -50°, -30°, 0°, +30°, +50° can be obtained with the respective switching condition. An average gain of ~8 dBi can be obtained at all five measured directions. For all sets of beam patterns, a common measured S_{11} bandwidth from 5.696 GHz to 5.895 GHz can be achieved.**

***Keywords*—beam steering, wide-angle, parasitic patch array.**

I. INTRODUCTION

Reconfigurable beam steering with patch antenna has gained significant interest due to its compact, simple and low cost design [1, 2]. However, beam steering with patch antenna hampered by the problem of achieving adequate steering angle from the broadside where the typically achieved scanning is in the range of -30° to +30° from the broadside. Various techniques have been developed to perform beam-steering with patch antennas [2-4]. In most recent work [5], although the antenna is able to steer the beam towards multiple directions, none of the beam is able to tilt more than 30° towards the broadside. In this work, further investigation is carried out in designing beam-steering antenna with linear switched parasitic array in order to overcome the issue of attaining tilt angle more than 30° in parasitic patch array antenna with simple structure and conformal profile.

This paper presents a wide-angle scanning beam-steerable parasitic patch array antenna with a capability of attaining improved beam tilt angle. The design adopts the conventional Yagi-Uda parasitic patch array technique [6, 7], which change the radiation pattern due to existence of mutual coupling between driven element and parasitic element. Although previously proposed Yagi-Uda patch array [6] able to steer the beam for more than 40° elevation angle, it only achieves such improved steer angle at one of the elevation, either at +θ or -θ direction. In this work, the enhanced beam tilt angle is achieved with the introduction of ground plane reduction technique at the parasitic patch array antenna. Additional beam directions, apart from the maximum tilt beam are achieved by applying some imbalanced switching conditions on the parasitic elements. In current design, to proof of concept, the representation of a shorting pin is considered as the artificial switch at the switching locations. The presence and absence of the shorting pin is considered as the ON state and OFF state respectively. The fabricated antenna able to reconfigure the radiation pattern into five different directions of -50°, -30°, 0°, +30° and +50° while maintaining constant reflection coefficient bandwidth around center frequency of 5.8 GHz. Compared with the existing works [2, 8-9] , this antenna has its advantage by its simple design and conformal profile.

II. ANTENNA DESIGN

A. Antenna Structure

Fig.1 depicts the physical structure of the wide-angle

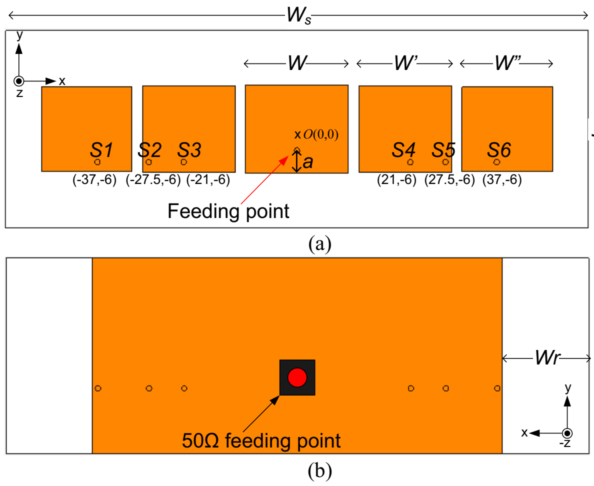

Fig. 1 Geometry of the antenna. (a) Front (b) Back

scanning reconfigurable beam-steering antenna. The antenna adopts five parallel patches printed on a partially grounded Taconic dielectric substrate. The thickness of the substrate is1.6 mm and it has dielectric constant (ε_r) of 2.2. The center rectangular patch is the driven element of this antenna. It has a width of W = 19 mm and length of L = 16.1 mm. It is fed through a subminiature (SMA) probe from the back of the antenna. The feed location a is 4.2 mm and it is optimized to achieve 50 ohm input impedance for operating frequency of 5.8 GHz. The size of the antenna is given by substrate width, W_s = 36 mm and substrate length, L_s = 108 mm. The parasitic elements are smaller with respect to the driven element where the width and length are denoted as W', L', W'' and L''. The physical dimension of the parasitic elements is as follows: W' = 0.9 x W mm, L' = 0.98 x L mm, W'' = 0.88 x W mm and L'' = 0.96 x L mm. The gaps between all elements are kept as 2 mm to allow the mutual coupling exist between the elements.

In Fig. 2(b), the Wr denotes the ground plane reduction size and it is 16 mm. The parasitic elements are deployed with six shorting pins that act as the artificial switches (*S1*, *S2*, *S3*, *S4*, *S5* and *S6*) which are connected to the ground plane at the back of the antenna. The location of the switches is crucial in determining the optimum tilt angle. Consider that O is the origin (0,0) of the antenna, as depicted in Fig. 1(a). Referred to the origin, the coordinate locations of the switches are depicted in Fig. 1(a).

B. Radiation Mechanism

When the driven element is fed by a RF wave, a mutual coupling phenomenon exists between the exited element and the other isolated parasitic elements due to the electromagnetic interaction between them [6,7]. In parasitic array antenna, the mutual coupling effect is used to steer the beam in a desired direction with a simple rule of thumb that the any one of the parasitic elements should be shorted to the ground.

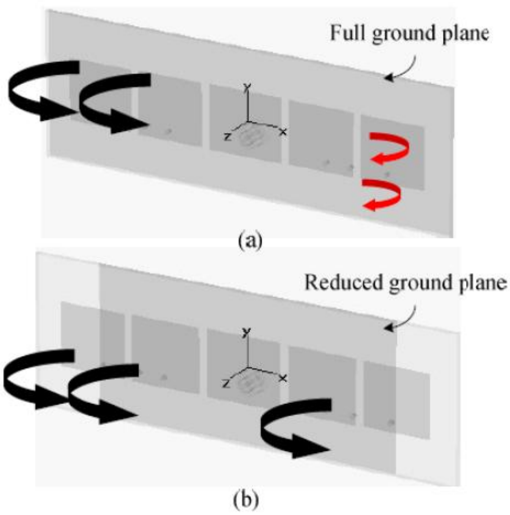

Fig. 2 Beam steering phenomenon. (a) With full ground plane (b) With partial ground plane

The shorting locations play important role in identifying a steering angle. By shorting the parasitic to the ground plane, the parasitic element acts as a reflector thus it will push the beam in an opposite direction where another un-shorted parasitic element works as a director. Investigation conducted shows that the conventional patch array antenna unable to perform enhanced beam-steering more than 35° angles due to the strong reflection effect by the finite ground plane. This phenomenon is illustrated in Fig. 2(a).

Consider that the two parasitic elements on the left are shorted to the ground and the remaining elements act as directors. Although the parasitic reflectors and the parasitic directors tend to steer the beam towards the direction of black arrows, a strong reflection from the full ground plane (red arrows) hampers the collaborative effort by the parasitic elements. Once the ground plane is reduced, the strong reflection from the full ground plane is could be reduced, therefore the steering can be enhanced. The ground plane reduction helps to improve the beam steering where a maximum beam tilt of a 50° can be obtained. Following that, this maximum steering is reduced to 35° by switching ON *S6*. Overall, by manipulating the strength of the ground plane reflection with the switches, five beam patterns with the respective steering angles are obtained and presented in Table 1.

TABLE I. DETAILS OF SWITCH CONFIGURATION AND STEERED ANGLE

Radiation Pattern	Configuration						Angles
	S1	*S2*	*S3*	*S4*	*S5*	*S6*	θ
P1	ON	ON	ON	OFF	OFF	OFF	-50°
P2	ON	ON	ON	OFF	OFF	ON	-35°
P3	OFF	OFF	ON	ON	OFF	OFF	0°
P4	ON	OFF	OFF	ON	ON	ON	+35°
P5	OFF	OFF	OFF	ON	ON	ON	+50°

III. RESULTS

The antenna is fabricated and the measured results are compared with the simulated results. In simulations and measurement, 1.6 mm height and 0.5 mm radius of copper pins are used as the artificial switches to control the switching mechanism of the antenna. These switches are modelled and located at the switching locations as shown in Fig. 1(a). The simulations are carried out with CST electromagnetic modelling software.

A. Radiation Pattern

The normalised radiation pattern results are presented in Fig. 3, 4 and 5. Regardless of the switching configuration, ~8 dBi of realised peak gain can be achieved in all steered directions. Note that, the steering is only carried out in H-plane and no tilting is exhibited on E-plane. The radiation pattern shown by P1 is the default direction of a single element patch antenna. When the parasitic elements are introduced beside the original driven patch, the beam pattern will be altered due to the effect by mutual coupling. However, the configuration by P3 which only switches ON the S3 and S4 is able to steer the beam at 0° direction. It can be seen from Fig. 4 that the steering angle is reduced slightly from 35° to 30°.

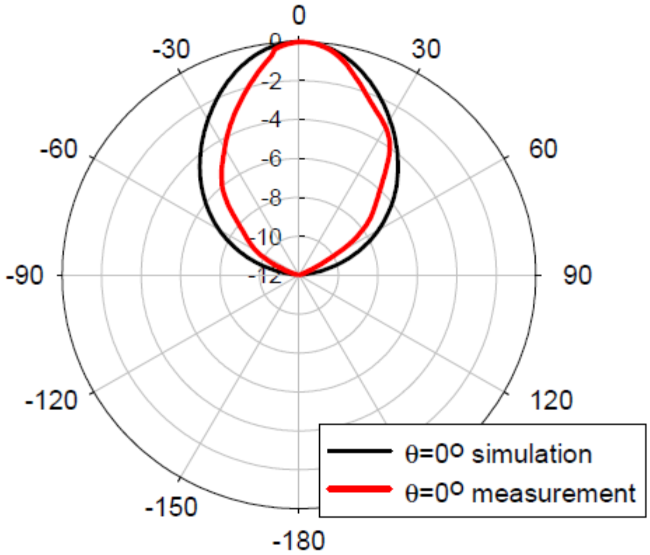

Fig. 3 Simulated and measured normalized radiation patterns for P3

The main objective of this work is to attain the maximum tilt angle at elevation angles of +θ and –θ directions. In such a scenario, it can be observed from Fig. 5 that the antenna able to steer the beam pattern at +50° and – 50° at H-plane. This can be obtained with the use of switches at parasitic elements which change the nature of parasitic element of as directors and reflectors. The ground plane reduction further improved the tilt angle.

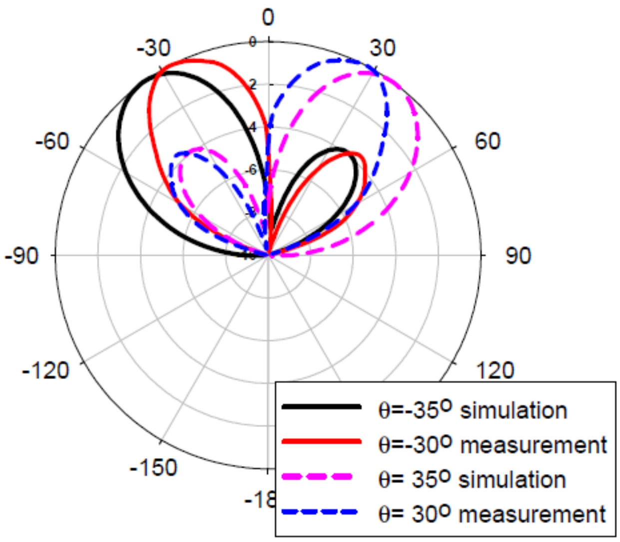

Fig. 4 Simulated and measured normalized radiation patterns for P2 and P4

The authors would like to thank Research University Grant UTM (Vote 05H34 and 00M23)).

S1 and S6 are especially introduced to improve the reflection by the reflector parasitic elements to improve the tilt angle. With the use of simulation, it has been further identified that the imbalance switching condition help the antenna to steer the beam another two directions, +35° and -35°. However, in measurement it can be observed that the steering angle dropped about 5°.

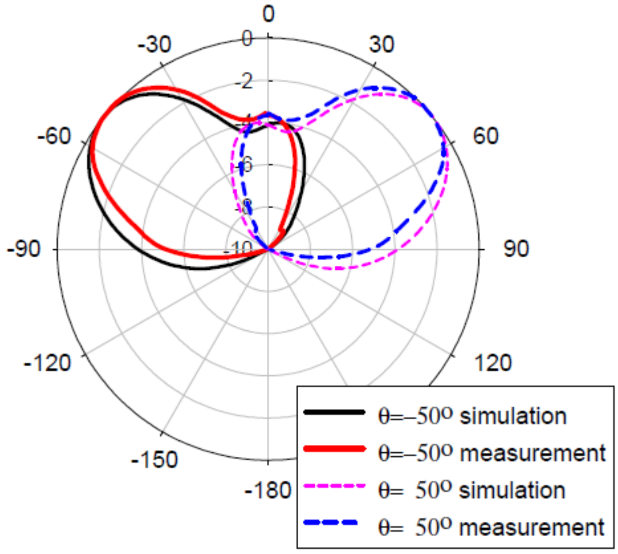

Fig. 5 Simulated and measured normalized radiation patterns for P1 and P5

B. *Reflection Coefficient*

Fig. 6 and 7 show the simulated and measured reflection coefficient of the antenna. It can be expected that the result of P1 and P5 configurations is similar due to the symmetrical location of the switches only at opposite orientation. Similar result also can be observed for the configuration P2 and P4. It can be noticed that the measurement and simulation agrees well where both results able to achieve S_{11} < -10 dB for operating frequencies around 5.8 GHz. Regardless of the switching condition, the reflection coefficient of the antenna is not much altered. Overall, these different modes share a common bandwidth from 5.696 GHz to 5.895 GHz.

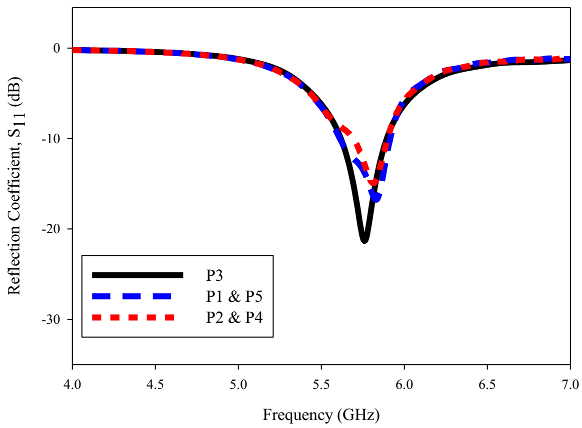

Fig. 6 Simulated reflection coefficient

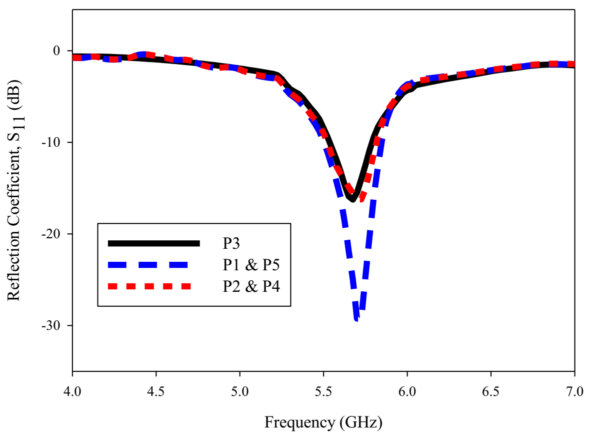

Fig. 7 Measured reflection coefficient

IV. Conclusion

A wide-angle scanning reconfigurable beam steering antenna is successfully developed with a ground plane reduction approach. Featured with additional parasitic elements; the ground plane reduction technique; and optimized switching locations, the proposed antenna able to attain the best tilt angle while maintaining acceptable reflection coefficient at the operating frequency of 5.8 GHz. The fabricated antenna able to steer the beam to five directions at - 50°, -30°, 0°, +30° and +50° with an average peak gain of 8 dBi. Regardless the different switching conditions, a common measured S_{11} bandwidth from 5.696 GHz to 5.895 GHz can be achieved. With a compact dimension of 36 mm x 108 mm the proposed antenna can be easily installed at portable wireless devices. Further investigations have to be carried out in identifying the suitable switches to control the reconfiguration of the antenna and the installation challenges to deploy the DC biasing circuit.

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