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Electronically Reconfigurable High-Gain Steerable Antenna for Mobile Satellite Communication

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***Abstract:** An electronically reconfigurable parasitic printed antenna is proposed for beam steering in Mobile Satellite Communication. Parasitic antenna array with an RF switch successfully steer the beam in elevation plane as well as in azimuth plane. Control of the beam steering angle is achieved with the effect of parasitic array and RF switch. Two RF switches enable three modes of operation, in which the beam is able to steer in three directions with angle* $\mathbf{34^\circ, 0^\circ}, and - \mathbf{34^\circ}$ *. The antenna resonates at 3.5 GHz with the high gain response. The geometry of the proposed antenna is implemented on an FR4 substrate with* $\mathbf{73 \times 20 \times 1.56\ mm^2}$ *of physical dimension. The observational study was carried out using IE3D EM Simulator.*

Keywords: Printed antenna, Beam Steering, multilayer Structure, gain Enhancement, Superstrate, Beam tilting.

I. INTRODUCTION

MOBILE satellite communications require compact high gain antenna for tracking the incoming signals from different sources and from different mobile terminals. Since communication system upgraded with the modern technology, the fixed satellite terminal should have to be replaced with mobile satellite terminal. The antenna radiates electromagnetic of different profile with movement of the terminal, the radiated pattern should be stably adopted by the communication system. The installation mobile terminal with compact size require small antenna, which reduces the size of the communication terminal with great factor. High frequency microwave communication with compact size is only possible by using Microstrip patch Antennas (MPAs). The patch antennas are generally used for its Low profile, light weight, ease of fabrication and economically low cost design [1] - [3].

The directivity of the electromagnetic waves radiated from the antenna can be manipulated by using beam steering techniques, as required. Beam steering operation can be realized by using various method suggested in the literature survey [4]-[6]. The intended direction of the main beam is to steer towards a desired direction with a tilting angle of θ_t. Beam steering with stable $|S_{11}|$ parameter is a very difficult task [7]. The reconfigurable beam steering is realized using phased array antenna, phase shifter, using parasitic element and many other techniques [8]-[11]. Beam steering using parasitic structure is somewhat easy, as this structure reduces the complexity and design cost. The MPA with parasitic structure is easy to fabricate and antenna analysis is quite easier than other methods proposed earlier [12]. However the main target is to achieve beam steering and improve the coverage angle $(0^\circ - 360^\circ)$ with a compact size of $< 100\ mm^2$. Besides that the radiation efficiency and the gain of the steerable antenna needs improvement [13].

Recent work on beam steering using parasitic exhibits, multi-layer structure with complex and expensive hardware configuration, in which beam tilting is very poor $(-2^\circ\ to + 2^\circ)$ [14]. Some other work related to parasitic structure was carried out in which the MPAs uses very complex structure, expensive hardware structures like an RF PIN diode and switches, and greater dimension with the finite ground plane, which are practically unsuitable for the application in compact mobile communication. It has been observed that the MPAs has an unstable reflection coefficient ($|S_{11}|$), poor gain, and minimum steering angle θ_t [15]-[17].

In this proposed work, a simple square patch is designed to resonate at $3.5\ GHz$. The proposed antenna is structured with parasitic array to realize the beam steering operation. The proposed structure having an enhanced gain around $6\ dBi$. Beam steering is achieved using parasitic arrays with switched via, this enables the MPA to operate in three different modes (RR, DR, RD). The modes are configured by shorting the via's or removing the via connections. The proposed MPA enjoys compactness with physical dimensions of $< (75 \times 21) mm^2$ and single layer implementation. The proposed antenna uses a single port for easy analysis. The MPA presented here is having novel application in a mobile satellite communication, which enhance the coverage angle.

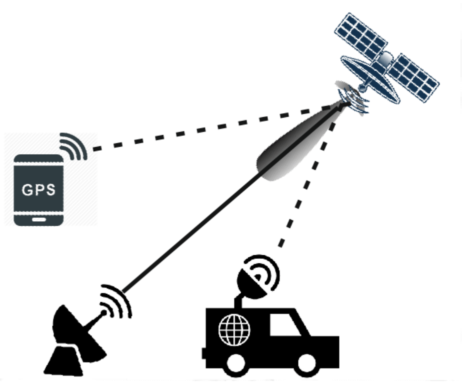

Fig. 1 Requirement of Multi-directional wave propagation.
NOTE: Direction of Wave propagation is marked in solid line and the dotted line shows the additional wave propagation required.

Fig 1 illustrates the concept of modern satellite communication system. In which number of satellites operated need to connect with the satellite for exchanging their information. The antenna of satellite propagates a high power EM wave along a specified direction marked in solid lines. In order to cover up all devices the satellite needs multidirectional wave propagation [18]-[21].

II. ANTENNA DESIGN AND DISCUSSION

The proposed Microstrip antenna (MPA) is designed and analyzed using IE3D electromagnetic simulation software. The below section reflects the Step by step design procedure of the proposed MPA.

A. *Antenna design*

The proposed MPA is designed to resonate at $3.5\,GH.$. The structure of the proposed antenna structure was implemented using FR4 substrate. The substrate is having a dielectric constant of $\varepsilon_r = 4.4$, substrate thickness of $h = 1.56\,mm$, and the loss tangent of the substrate is $\tan\delta = 0.002$. The proposed MPA is structured in single dielectric substrate, in which the antenna geometry is designed on the top of the substrate and the bottom side of the substrate is the ground plane. The cross section view of the proposed MPA is shown in fig. 2. The behavior of the designed MPA is analyzed using a single port placed at the down center of the middle patch and the shorted via's marked in orange color.

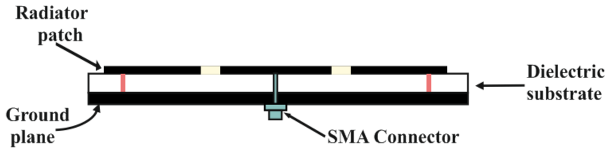

Fig. 2 Cross sectional view of the proposed antenna.

The geometry of the proposed microstrip antenna (MPA) implanted at the top of the substrate surface includes three different patches, out of which one is considered as driver patch and other two are considered as parasitic array. The driver patch is placed at the center of the antenna geometry with physical dimensions of $25 \times 20\,mm^2$ and the parasitic patches are self-similar to each other with physical dimension of $22.5 \times 20\,mm^2$. The parasitic patches are placed alongside with the driven patch in $x - Plane$. The combine structure of the proposed MPA with driven and parasitic elements having physical dimension of $74 \times 20\,mm^2$. The antenna radiator patch along with the parasitic patch structured the top view and shown in figure 3.

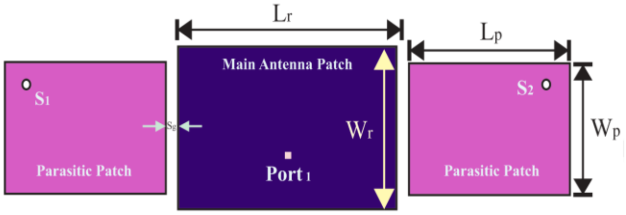

Fig. 3. Top view of the proposed antenna.

The physical dimensions of the suggested antenna are determined from;

$$W_p = \frac{1}{2} \times \frac{c}{\mathcal{F}_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{-1/2} \qquad \dots (1)$$

$$L_p = \frac{1}{2} \times \left(\frac{1}{\mathcal{F}_r\sqrt{\varepsilon_{eff}}\ \sqrt{\mu_0\varepsilon_0}}\right) - 2\Delta l \qquad \dots (2)$$

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\left(1 + 12\,\frac{h}{w}\right)^{-1/2} \qquad \dots (3)$$

The physical dimensions of the designed steerable antenna are calculated using the specified formula [equation 1-3] and the actual values are displayed in table 1. The physical dimension of the proposed antenna is optimized to achieve better impedance matching and tuning of the resonant frequency. The antenna is excited using the probe feed coax cable connected to the radiator patch.

TABLE 1

PHYSICAL DIMENSIONS OF THE SUGGESTED ANTENNA

Parameters	**Value**
Dielectric constant (Єr)	4.4
Substrate height	1.56 mm
Length of Radiator Patch (Lr)	25mm
Width of Radiator Patch (Wr)	20mm
Length of parasitic Patch (LP)	22.5mm
Width of parasitic Patch (WP)	19.4mm
Separation Gap gap (g_s)	6mm

Particular dimensions of the proposed antenna.

The proposed antenna uses two individual switches (S_1, S_2)on the parasitic patches presented in layer 1. Switch are the connected via's from the parasitic patch to the ground plane. When via is shorted to ground then the corresponding switch is ON, and it acts as reflector (R) and when the via is open then the corresponding switch is OFF, which act as director (D). The state of these two switches can enable the proposed antenna to operate in different mode. The modes of operation are displayed in table 2.

TABLE 2

Different Modes of Operation

Switch 1	**Switch 2**	**Mode**
ON	ON	RR
OFF	ON	DR
ON	OFF	RD

III. SIMULATED RESULTS AND DESIGN ANALYSIS

The designed structure of the proposed antenna is simulated and optimized using the IE3D EM simulator. The antenna structure is simulated step by step to achieve optimum result. The simulated results are exposed in the below section. The return loss characteristic of the proposed steerable antenna is shown in figure 4. The reflection coefficient $|S_{11}|$ is well below -10 dB, which clears the antenna, is having better impedance matching at the resonating frequency 3.5 GHz.

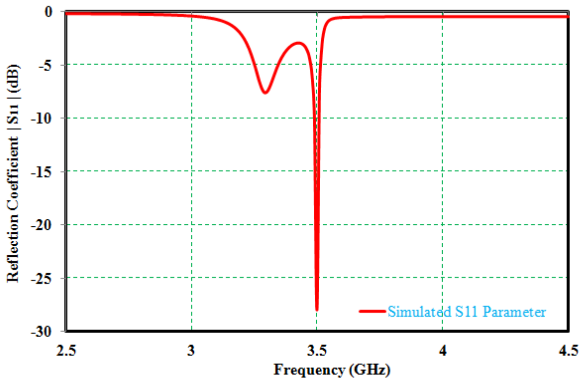

Fig. 4. Return loss characteristic $|S_{11}|$ of the proposed steerable Antenna.

The steering operation of the proposed antenna is observed using three different modes RR Mode, DR mode, and RD mode [Table 2]. In this study the main beam of the antenna is steered in a different direction with an angle θ. In fact the main beam direction is tilted or switched to another direction. The beam is switch in both $E - Plane\ and\ H - Plane$. The switching operation is achieved using the parasitic patch with switching mode. The separation gap between the parasitic element and the physical dimension of the parasitic patch has some physible contribution towards the beam switching. The modes of operation are well described in suitable section below.

A. *Proposed antenna without Switch.*

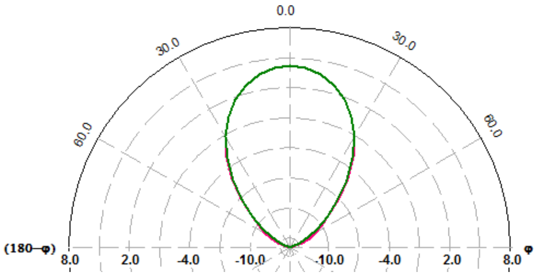

Fig. 5. Radiation pattern of the proposed antenna without switch.

The proposed antenna structure with parasitic element is realized without using of any switch at the parasitic patch. The corresponding radiation pattern shows the antenna propagates the EM wave with 0 ° beam tilt. The corresponding radiation pattern is shown in fig. 5.

B. *RR Mode.*

This mode of operation is realized by switching ON both the switches. In this mode, both the via's are shorted to ground, this enables RR mode [Table 2]. In this mode the main beam along with the $z-$ $plane$ with 0 ° beam shift. The 2D pattern is shown in figure 6

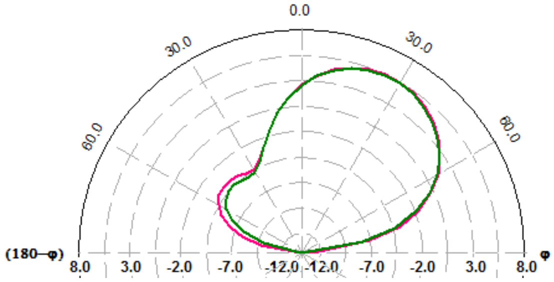

Fig. 6. Radiation pattern of the proposed antenna in RR mode.

C. *DR Mode.*

Realization this mode of operation is possible with the second condition of the table 2. In which S_1 is OFF and S_2 is ON. This enables the beam to deflect the radiating beam with deflection angle of $\theta = 34°$. The radiated EM wave is deflected in both $E - Plane\ and\ H - Plane$. The radiation pattern of this mode is exposed in figure 7.

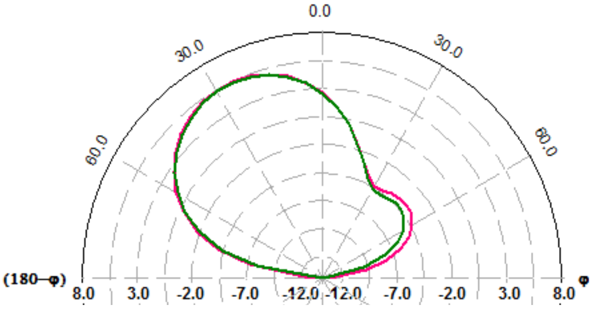

Fig. 7. Radiation pattern of the proposed antenna in DR Mode.

D. *RD Mode.*

The RD mode is realized using the third condition discussed in table 2. In this mode the S_1 is ON and S_2 is OFF, which enables the antenna to deflect the radiation pattern with $\theta = -34°$. The main is deflected in both $E - Plane\ and\ H - Plane$. The corresponding radiation pattern is shown in figure 8.

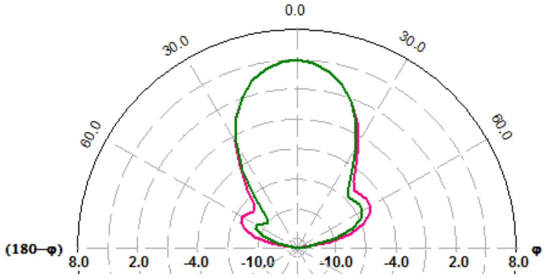

Fig. 8. Radiation pattern of the proposed antenna in RD Mode.

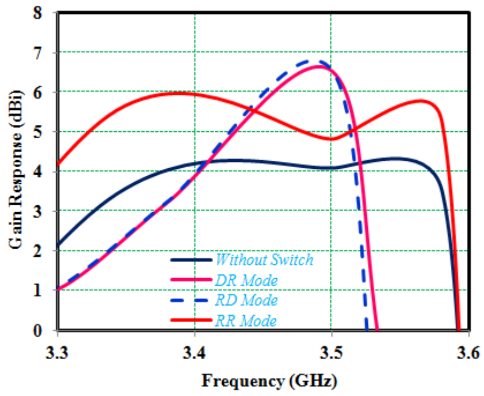

Fig. 9 Gain Response of the Proposed Steerable Antenna.

The gain response of the proposed steerable antenna is exposed in figure 9. From this fig. 9 it has been observed that the gain of the proposed antenna is enhanced by using the shorting via, which act as switches. Better result is observed using DR mode, marked in pink solid line and RD mode, marked in blue dash line.

IV. CONCLUSION

Investigation of novel Beam switching microstrip printed antenna is carried out successfully in this paper. The coupling effect and the parasitic array structure make the realization of beam switching operation to a desired angle $\theta = 34°, 0°, -34°$ .The MSA is designed with single layer with single radiator patch along with two self-similar parasitic patches, and via connected to the ground plane. The simulation study ensures the performance of parasitic patch as a director or a reflector according to the connection via PIN with ground plane. The radiation pattern clarifies the beam-steering operates at three different switching angles. The compact steerable antenna of $75 \times 21\, mm^2$ has an improved gain of 6.7 dBi. Addition to this the proposed designed antenna offers a wider beam width of $51°$. Owning these characteristics the designed antenna is well proposed for mobile satellite communication for multi-directional wave propagation.

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