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Reconfigurable Enhanced Gain Beam Steerable Antenna for S-Band Radar Communication

Lipsa Singh, Debaprasad Barad and Subhrakanta Behera
School Of Electronics Engineering, KiiT University, Bhubaneswar-751024, India.
lipsas5@gmail.com, deba7482@gmail.com, & skbeherafet@kiit.ac.in

Abstract:* *A novel compact, low cost printed antenna with beam steering and gain enhancement capability is presented in this paper. The antenna is structured with a substrate for designing the radiator patch and a partially covered superstrate with appropriate air gap for steering the beam and improves the directivity, instead of relying on additional parasitic elements and phase shifters that increases the complexity of the design. The antenna is excited from the probe feeding point. Partially covering of radiator patch by a high refractive superstrate causes phase deviation in electromagnetic radiation. The antenna beam is able to cover up both E-plane and H-plane. This design is based on a new technique which may not have been implemented earlier. The antenna design and simulation is carried out using IE3D electromagnetic EM simulator and study of various parameters of the designed antenna is well explained in this paper. The gain is enhanced up to $3\ dBi$ at the center frequency $2\ GHz$ experimentally it is found that a beam deflection of 43 degrees is achieved with a beam tilting ranging from $0°\ to\ 43°$.

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

I. INTRODUCTION

MICROSTRIP patch antennas are printed type of antennas which consists of dielectric substrates, the structure of printed antenna varies from single layer to multi layer. The layers may be a combination of dielectric substrates or composite of air gaps. Microstrip antennas are highly advantageous as compared to other bulky antennas, as they are low profiled, less volume, light weighted ,easily fabricated, cheap and can be made conformal[1]-[3]. These compact printed antennas are widely used in military applications, microwave radar and satellite communication and a vast application in wireless communication [4]. Beam steering in antenna theory is used to steer the main lobe of the antenna for directional transmission and reception, which have an impactful application in radar and satellite communication [5]-[6]. Beam steering technique reduces interference, saves power, increases the gain and directivity of the microstrip antenna. Beam steering through phase arrays is performed by phase shifting of the RF signals of the array antennas so that all the phase shifted signals become coherent for a particular direction of interest. The major drawback of beam steering using phased antenna arrays is that phased array design is very large and complex as it employs many subsystems such as antenna arrays, phase shifters and beam forming unit for performing beam steering in a microstrip antenna [7]-[9]. The gain and directivity of an antenna increases as the permittivity and permeability of the superstrates increases.

In this paper the main beam of the antenna is experimentally found to deflect at higher angles as the refractive index of the superstrate is increased. It presents a novel mechanism to control and manipulate gain and beam direction of microstrip antenna, mainly the radiated beam is deflected in E-plane and H- plane along with the position of the superstrate in $xy\ plane$[10]-[13]. It was found that the main beam of the antenna is deflected in the direction of the part of the patch that is covered partially and also depends upon the refractive index of the superstrate. The 3-dB beam-width for partially covered antenna with superstrate is reduced to 33 degrees, which indicates higher directivity in the direction of highest radiation. The gain was found to increase by 3.14 dB after using high refractive index superstrates. [14]- [19]

In present generation wireless communications network antenna plays vital role in signal transmission and reception. Unlike other methods of gain enhancement methods like switching beam techniques, retro directive antennas and integrated lens antennas as per the literature, the technique that has been implemented here is simpler as the complexity of the design if highly reduced. The proposed antenna in our design is a multi layer structure, which enables higher gain and directivity as compared to other literature.

The suggest antenna is designed to resonate at 2 GHz center frequency. The 2 GHz band is mostly used in S-band radar communication. In this center frequency the gain is enhanced as well as enhancement of antenna directivity is achieved using high refractive superstrate. Control of beam in E-plane and H-plane is also achieved in the suggested reconfigurable microstrip antenna.

II. ANTENNA DESIGN AND DISCUSSION

A. *Antenna design*

The suggested antenna structure is designed on a FR substrate with dielectric constant (εr) of 4.3, substrate thickness (h) of 0.762, and loss tangent ($\tan\delta$) of 0.0018. Preliminary the antenna is designed using single substrate. In this substrate main radiator of the antenna patch is placed. The radiator patch is having width of Wp and length of Lp. The physical dimensional values of the antenna patch length and width is calculated from the given equation [equ.1-3]. In which ε_{eff} is the effective dielectric constant and h is substrate thickness. The designed MSA is fed by probe feeding technique, where the $50\,\Omega$ co-

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axial probe is connected through SMA connector. The probe feed point is placed at the center of the square patch (radiator patch). With this the conventional MSA is designed and shown in figure 1(a).

The physical dimensions of the suggested antenna are determined from

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

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

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

As mentioned the designed conventional antenna structure is modified for realizing beam steering / tilting the beam angle from one predefined angle to another. The main beam of the designed antenna is tilted with some angle by using high refractive superstrate. The High refractive superstrate is placed on the extreme top layer of the radiator patch with height (ga). This superstrate is having physical dimension of $(L_s \times W_s \times h_s)\, mm^3$ and dielectric constant of (єr) of 4. The position of the superstrate is varied in $x - y\ plane$ in order to control the beam angle of the main radiating lobe. The superstrate is periodically shifted along the E-plane $(x - y\ plane)$, which covers only half of the radiator patch. Figure 1 (b) illustrates the structure of the suggested antenna design for beam steering. Along with this the probe feeding gives additional phase shifting to the electromagnetic waves emitted from the radiator patch. As the feeding location is shifted $45°$ towards the lower negative quadrant. The increased beam angle can be achieved by increasing the refractive index(r_i).

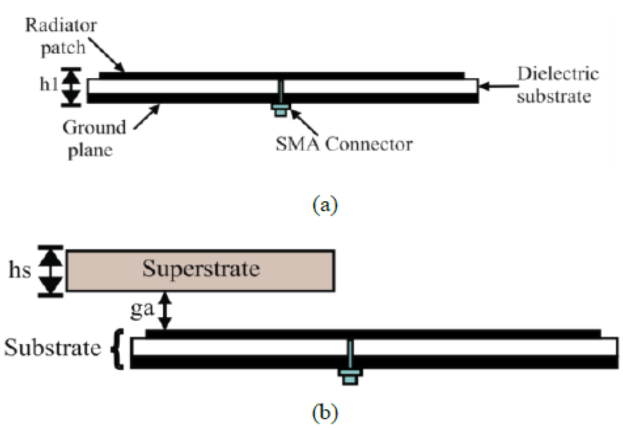


Fig. 1. Cross sectional view of the suggested antenna.

(a) Conventional Microstrip Antenna structure.
(b) Suggested MSA structure for Beam tilting.

TABLE 1

PHYSICAL DIMENSIONS OF THE SUGGESTED ANTENNA	
Parameters	**Value**
Dielectric constant (Єr)	4.3
Substrate height	0.762mm
Lp	38mm
Wp	38mm
Dielectric constant of Superstrate(Єrs)	4
Superstrate height	4mm
Ls	72mm
Ws	72mm
Air gap (g_a)	6mm

Particular dimensions of the proposed antenna.

The transmission line model of the suggested antenna structure with high refractive superstrate (figure 1 (b)) is exposed in figure 2. Each layer is having its own reactance value. The reactance value of each layer replaces the corresponding layers in the transmission line equivalent model as shown in figure 2.

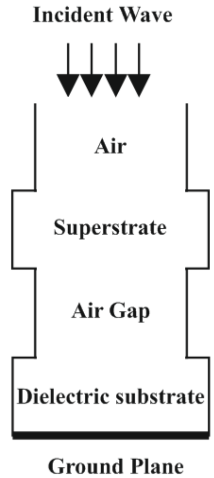
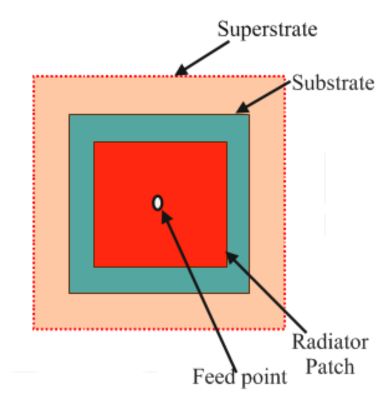


Fig. 2. Equivalent Transmission line model of the suggested antenna structure (figure 1a).



(a)

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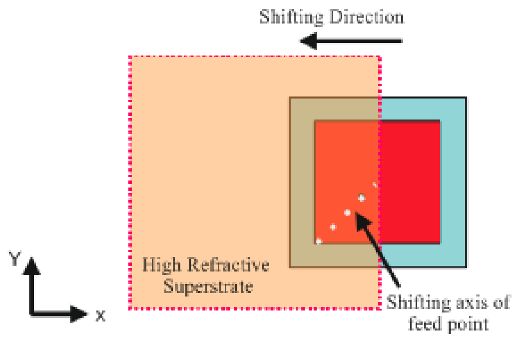

(b)

Fig. 3. Top view of the suggested steerable antenna.

(a) Top view with superstrate.
(b) Shifting of superstrate and Feed location.

B. *Beam tilting*

Figure 3(a) illustrates the top view of the suggested printed antenna. The layout of the main antenna radiator patch is marked in red color on the substrate. Initially the feeding point is decided to place at the center of the square patch $(x = 0, y = 0)$, which is demonstrated in figure 3 (a). As mentioned above the suggested design uses a high refractive index superstrate for achieving beam steering, figure 3 (b) illustrates the top view of the suggested printed Antenna for beam steering application. The beam angle of the radiated electromagnetic wave is tilted in both E-plane and H-plane. The electromagnetic wave radiated mainly along with the z direction from the radiator patch. This electromagnetic wave forms a main beam with increased power as well as gain. This beam can be tilted to some angle $(+ve\ angle\ or\ -ve\ angle)$ as per requirement and some case to enhance the directivity of the transmitting or receiving antenna. This beam titling is proportional to the shifting of the superstrate. With partially covering the radiating patch by a high refractive index superstrate having $\varepsilon_r = 4$ with a height of $g_a = 6\ mm$, we observe a small deviation in the beam angle. Further shifting the superstrate toward the left side along with x-axis give more deviation angle. At a particular position of superstrate the suggested printed antenna is having maximum tilting in beam angle, this happens when the superstrate covers $1/3^{th}$ portions of the radiating patch. In this way the suggested antenna realizes beam tilting of $43°$. Addition to this the feeding phase angle is changed in the suggested design to have additional beam tilting, better impedance matching and improved gain response. As pointed in figure 3 (b) the feeding point is shifted diagonally towards the lower negative quadrant, which causes an additional phase shift of $45°$. In a broad view, relocation of feeding point enhances the angle of beam tilting up to 43°. Combining the phase shifting and superstrate shifting operation gives better beam tilting / beam steering. The radiated electric field of the main beam at angle θ_s .

III. Results and Analysis

The suggested printed antenna is designed and simulated using Method of Moment based IE3D software. This is featured with Integrated Electromagnetic simulation package for arbitrary 3D volumetric passive devices, having graphical user interface. The simulated return loss characteristic plot is shown in figure 4. This figure demonstrates that the suggested antenna is having a very deep return loss at 2GHz with -10dB reference level. At 2 GHz the suggested steerable antenna is having better impedance matching.

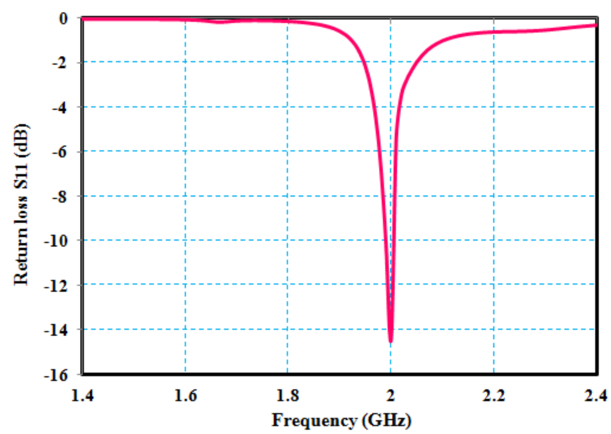

Fig. 4. Return loss characteristic $|S_{11}|$ of the suggested steerable Antenna.

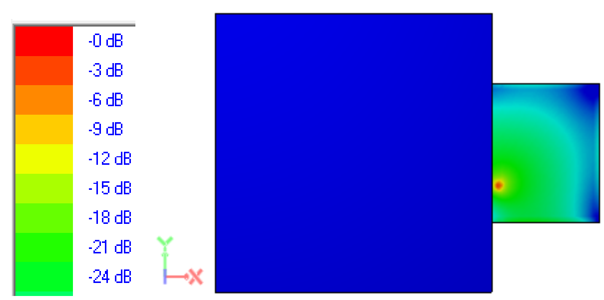

Fig. 5. Surface current distribution of the suggested antenna at 2 GHz.

NOTE: The current distribution of the radiator patch is shown in the lower layer, behind the superstrate marked in continuous blue color.

The current distribution of the suggested antenna is shown in figure 5. In which the current is distributed over the radiator patch, shown in multi-color and superstrate is having null current flow, shown in blue color. The corresponding color pallet is shown in the same figure.

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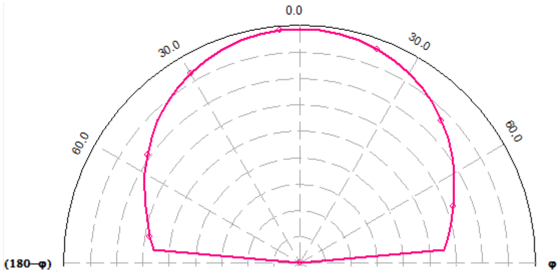
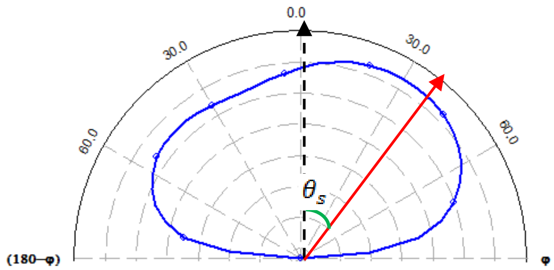
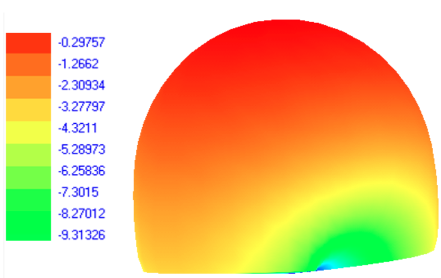


(a)

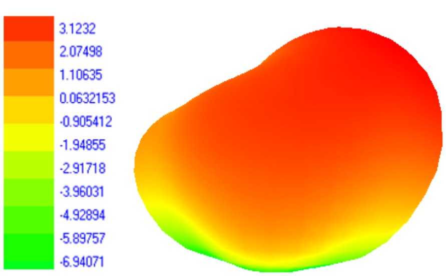


(b)

Fig. 6. Simulated 2D Radiation pattern of the suggested steerable antenna.
(a) 2D Radiation pattern with absence of the superstrate.
(b) 2D Radiation pattern with the presence of the superstrate.



(a)



(b)

Fig. 7. Simulated 3D Radiation pattern of the suggested steerable antenna.
(a) 3D Radiation pattern with absence of the superstrate.
(b) 3D Radiation pattern with the presence of the superstrate.

The 2D radiation pattern of the suggested antenna is shown in figure 6. In which the fig. 6 (a) is the radiation pattern of the initial design where the beam is on vertical z-direction. The fig. 6(b) is the radiation pattern of the suggested beam steerable antenna usable for radar application, where the beam is tilted with angle θ_s. The corresponding 3D radiation pattern is shown in figure 7 (a) and (b). Analyzing the radiation pattern of the suggested antenna, we got the main beam is tilted with $43°$. The voltage standing wave ratio (VSWR) of the suggested antenna is illustrated in figure 6. In which the VSWR at the respective resonance is well below 3 dB at the resonant frequency.

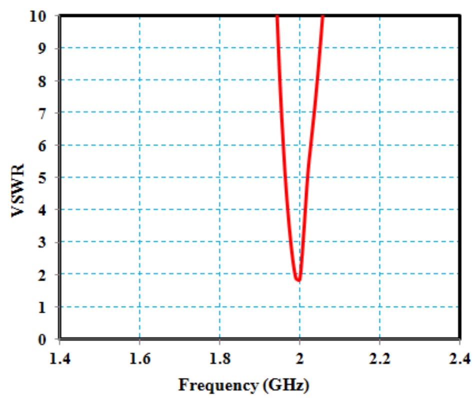


Fig. 8. VSWR plot of the suggested Steerable antenna.

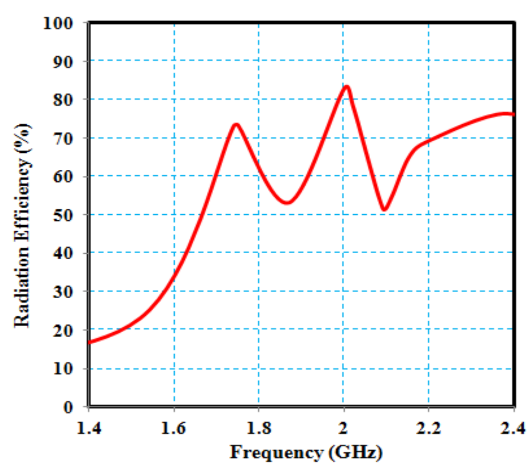


Fig. 9. Radiation Efficiency of the suggested Steerable Antenna.

The radiation efficiency of the antenna is observed and shown in figure 9. The suggested antenna structure exhibits better radiation efficiency of above 80 % at the 2 GHz, which is a notable advantage of the suggested structure. Owning these notable parameters the suggested antenna is well proposed for S-band radar communication. Along with this the suggest antenna is having better gain response at 2GHz, the gain response plot is exposed in figure 10. The gain response of the initial design without superstrate marked in blue dash line and the gain response of the suggested antenna with superstrate is marked in solid red color.

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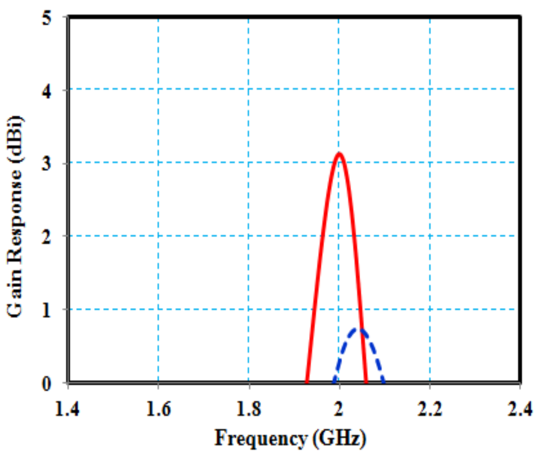

Fig. 10. Gain of the suggested steerable antenna.

NOTE: Solid red color line indicates the gain response of suggested steerable antenna and response of the initial design without superstrate marked in blue dash line.

The gain response of the suggested antenna is enhanced up to 3 dBi, in practical the directivity of the antenna also enhanced. Enhancement of the antenna directivity is novel work towards radar communication. The main theme of this suggested deign is to propagate the electromagnetic wave with desired tilting angle.

IV. CONCLUSION

The discussed steerable printed antenna is suggested for gain enhancement and improved directivity using high refractive superstrate. As demonstrated in the antenna resonates at $2\,GHz$, is mostly applicable for $S-Band$ radar communication and satellite communication. Introduction of superstrate in Z direction helps to steering the main beam up to $43°$ with achieved beam tilting of $0°\ to\ 43°$. In this suggested antenna is having improved directivity with maximum gain of $3\ dBi$. The gain is enhanced from the negative level to positive levels. Reconfiguring the feed location at $45°$ results additional tilting phase angle of the main beam, which was observed and reported in this research work. This novel work with beam steering capabilities and improved directivity is well, and suggested for future radar communication technology.

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