Design of High Gain Microstrip Array Antenna and Beam Steering for X Band RADAR Application

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***Abstract*— In this paper high gain microstrip array antennas have been designed and analyzed for X band RADAR application. The array elements are excited by using inset feeding technique. Interestingly, all the array antennas are tuned exactly at centre operating frequency of 10 GHz. Rogers RT/duroid 5880™ having relative permittivity of 2.2 has been used as substrate for all the array antennas. The results show that the studied antenna array attained an operating band ranging from 9.77 GHz – 10.15 GHz with a bandwidth 380 MHz. It also revealed that the proposed 2×4 element array achieved a peak gain of 15.5 dB, a directivity of 15.82 dBi and a return loss of –30.27 dB. A beam steering of (θ, φ) = (16º, 0) with half power beam width (HPBW) of 16.88º is achieved using switched line phase shifter for 1×4 elements array antenna. Beam steering antenna shows return loss of -33.28 dB, very good VSWR of 1.04 and high bandwidth of 880 MHz. The ANSYS high frequency structural simulator (HFSS) has been used to perform all the simulations works.**

***Contribution*— A 2×4 elements microstrip array antenna and a 1×4 elements beam steering array antenna have been proposed for X band RADAR application.**

Index Terms*— *High gain array; Phase shifter; Beam steering; X band; Microstrip patch antenna; HFSS.

I. INTRODUCTION

RADAR stands for radio detection and ranging which is remote object detection and tracking system. Microstrip patch array antennas are widely used in RADAR because of its high gain, low profile, lightweight, easy to integrate and cost-effective and precise control of radiation pattern [1-3]. Direction of radiation of an antenna can be changed either mechanically i.e. moving the antenna or electronically with the help of switched line phase shifter [4]. If any antenna has such special feature then the antenna can be said to be as beam steering antenna. Due to having additional feature of changing the direction of radiation of main lobe, beam steering array antennas are frequently used in many modern communication systems especially in RADAR and Satellite [5]. Electronically reconfigurable beam steering antenna is good one for reducing the volume and weight of the antenna rather than mechanical approach. In [1], a 4×24 elements patch array antenna has been simulated and proposed for marine RADAR application which operates at 9.4 GHz having bandwidth of 200 MHz. In [6], a 1×4 microstrip phased array antenna has been designed on Rogers RT/Duroid 6006™ by using switch line phase shifter for 5 GHz Wi-Fi application. They used corporate feed network connected to phase shifters with array elements. An X band phased array antenna is presented in [7] which has been fabricated on F4B substrate (110×110 mm^2). The antenna possesses return loss of -10 dB and gain of 20 dB and its operating range covers X-band (9.6 GHz - 11.1 GHz). A 32×8 high gain microstrip array is designed using CST for X band at 9.37 GHz which possesses high gain of 28 dB while side lobe level of -25 dB and low HPBW (5º in E-plane and 10º in H-plane) [8].

In this paper, main effort is given to design, characterize and propose a high gain microstrip patch array antenna for X band (8 GHz–12 GHz) RADAR application at 10 GHz centre operating frequency. Then the concentration is shifted to design and proposed beam steering antenna using switched line phase shifter. This research article has been organized as follows: section II describes single element microstrip patch antenna, 1×2 elements array, 1×4 elements array and 2×4 elements array and 1×4 elements beam steering array antennas in five subsections (A, B, C D and E), respectively. A synopsis of estimated all performance parameters has been presented in table I at the end of subsection E. Finally some conclusion remarks, limitations and future plans have been mentioned in section III.

II. ARRAY DESIGN AND ANALYSIS

The design configurations of single element patch, 1×2, 1×4 and 2×4 elements array antennas as well as the 1×4 elements beam steering antenna have been presented and analysed one by one in this section. All the antennas have been operated within X band.

A. *Single Element Microstrip Patch Antenna*

Before designing array, inset feed single element microstrip patch antenna has been designed at centre operating frequency of 10 GHz as shown in Fig. 1. The volume of Rogers RT/duroid 5880™ substrate is of 23×29.9×0.89 mm^3 and size of patch is of 11.9×9.7 mm^2. The 50 Ω feed line is of 9.14×2.74 mm^2. The dimension of inset gap is of 1.23×2.95 mm^2. The antenna shows return loss of –14.33 dB with bandwidth of 200 MHz as shown in Fig. 2. Keeping phi = 0, variation of gain and directivity over theta from -180º to +180º have been depicted in Fig. 3.

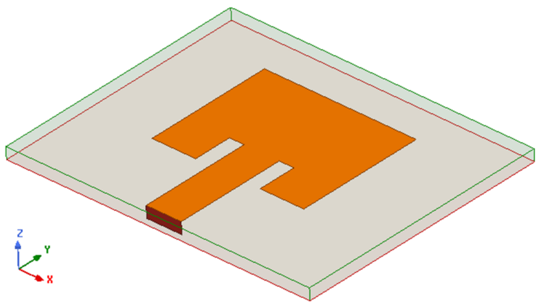


Fig. 1. Single element microstrip patch antenna (MPA).

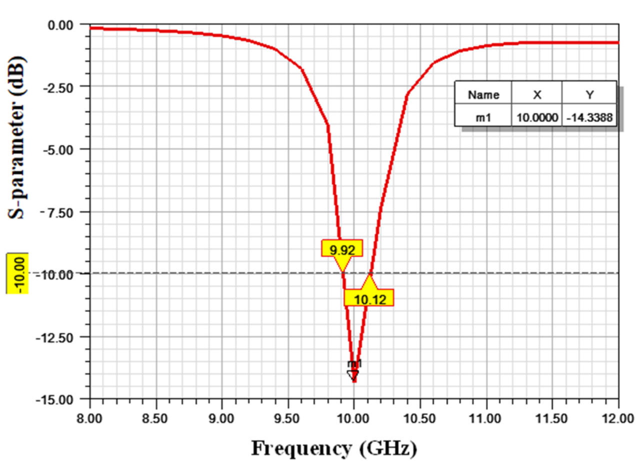
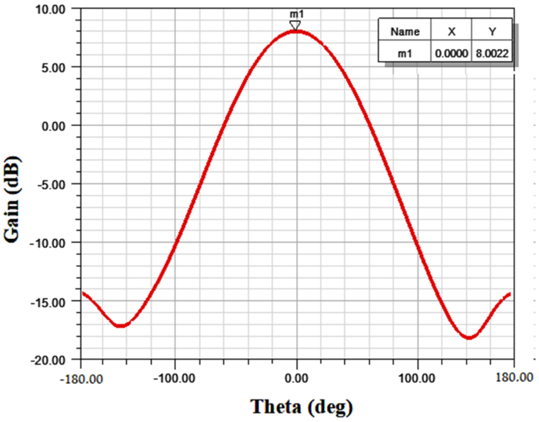
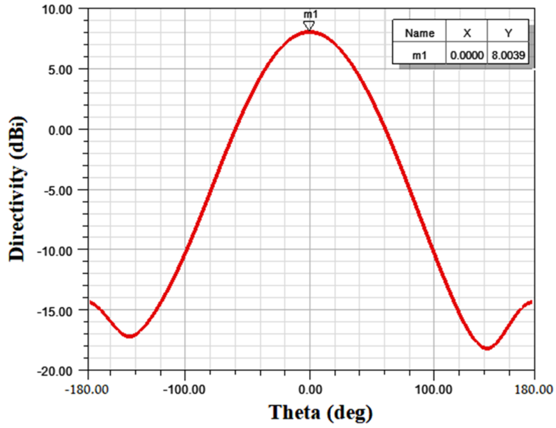


Fig. 2. $|S_{11}|$ of single element MPA.



(a) Gain Vs theta



(b) Directivity Vs theta

Fig. 3. (a) Gain and (b) Directivity of single element MPA.

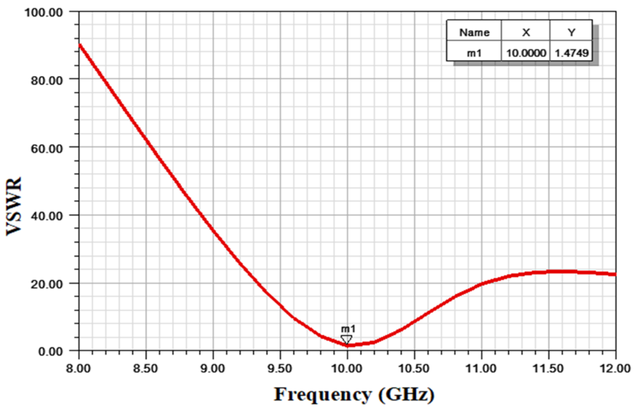


Fig. 4. VSWR of single element MPA.

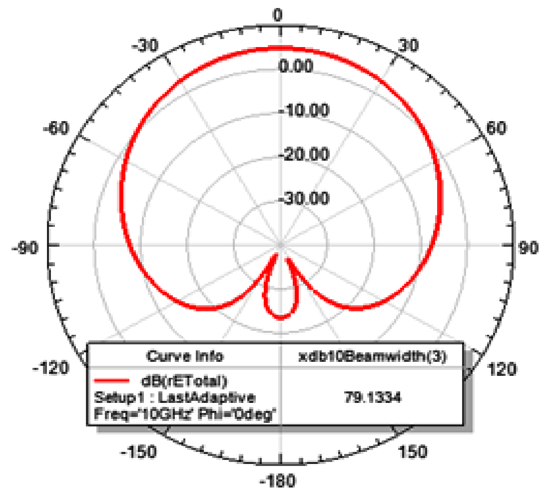


Fig. 5. Radiation pattern of single element MPA in polar form.

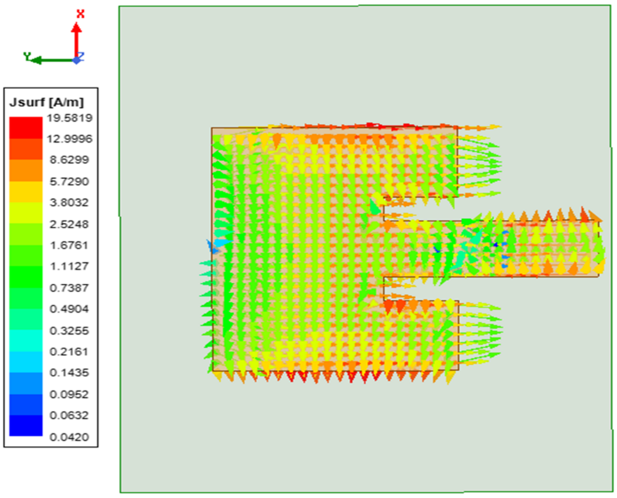


Fig. 6. Surface current distribution of single element MPA.

Maximum gain of 8.0022 dB and directivity of 8.0039 dBi have been obtained at centre operating frequency of 10 GHz. As per Fig. 4, VSWR of the antenna is of 1.47. The surface current distribution and polar form of radiation pattern of the antenna have been shown in Fig. 5 and 6. From the Fig. 5, it is seen that the beam width of the single element microstrip antenna is of 79.13º at 3 dB point, so the HPBW is of 79.13º.

B. 1 × 2 Elements Array Antenna

A 1×2 elements microstrip array antenna has been designed by using two single elements microstrip patch which has been described in detail in the previous subsection. The array antenna has been made on same substrate having volume of 37×23×0.89 mm^3. A spacing of 0.7λ is used between two successive elements of the array antenna to reduce mutual coupling effects. The spacing between two patches is of 22.588 mm. The inset gap and distance are adjusted to 1.16 mm and 2.08 mm. The width of 50 Ω line feed and 100 Ω line feed are 2.74 mm and 0.8 mm, respectively. The 3D structure of antenna is shown in Fig.7. The $|S_{11}|$ parameter of the array antenna is drawn with respect to X band frequency range (8 GHz-12 GHz) as in Fig.8. The array significantly improves its return loss to -30.19 dB at the same centre frequency of 10 GHz. The antenna operates wide range of frequency band of 530 MHz ranging from 9.76 GHz to 10.29 GHz. The gain and directivity of the 1×2 elements array antenna have also increased to 8.92 dB and 8.96 dBi (Fig. 9) at 10 GHz. Fig. 10

shows the voltage standing wave ratio (VSWR) of the antenna which is of 1.06 at centre operating frequency. The polar plot of radiation pattern of the antenna presents HPBW of 41.27º as in Fig.11. Surface current distribution of the 1×2 elements array antenna has been presented in Fig. 12.

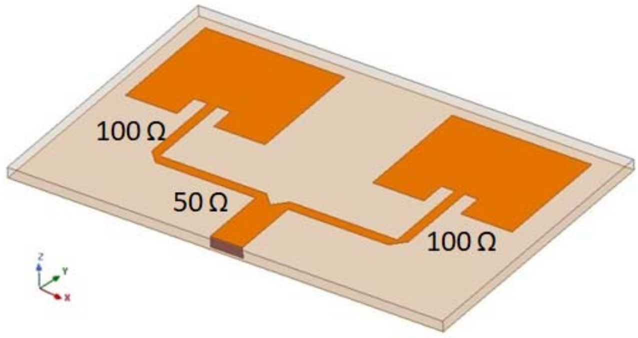


Fig. 7. 1×2 elements array antenna.

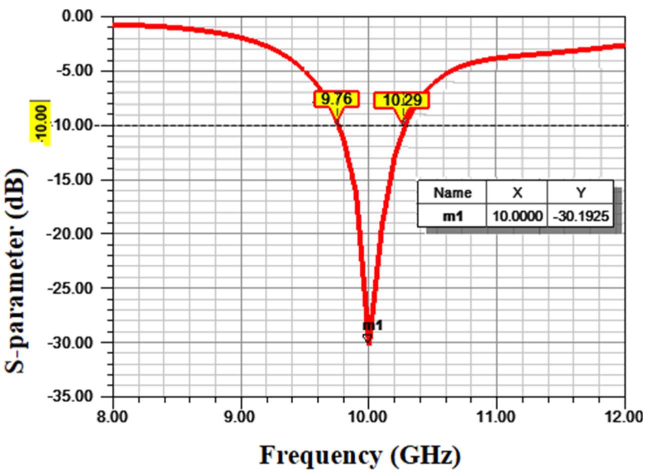
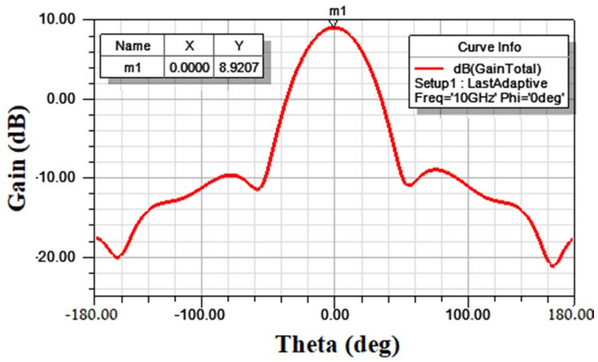
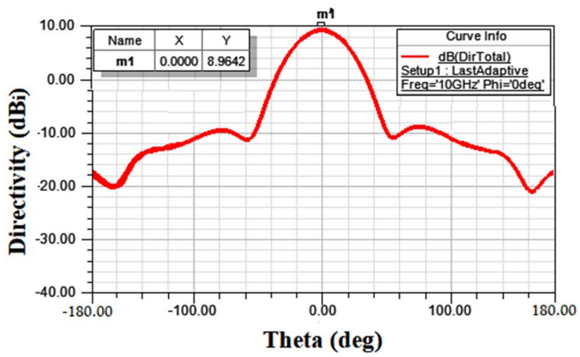


Fig. 8. $|S_{11}|$ of 1×2 elements array antenna.



(a) Gain Vs theta



(b) Directivity Vs theta

Fig. 9. (a) Gain and (b) Directivity of 1×2 elements array antenna.

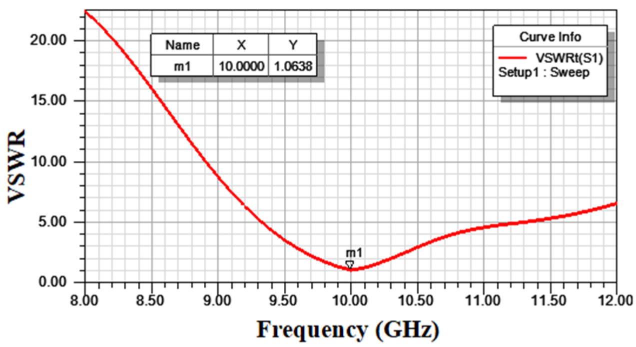


Fig. 10. VSWR of 1×2 elements array antenna

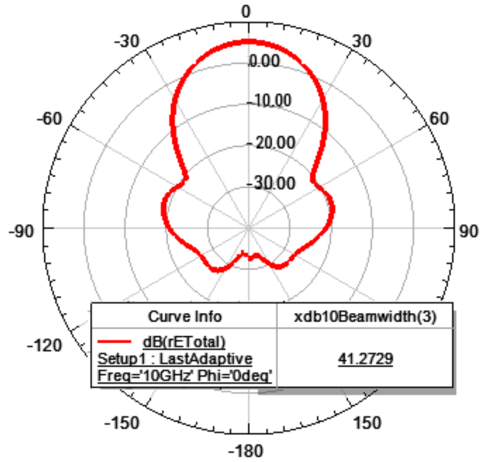


Fig. 11. Radiation pattern of 1×2 elements array antenna in polar form.

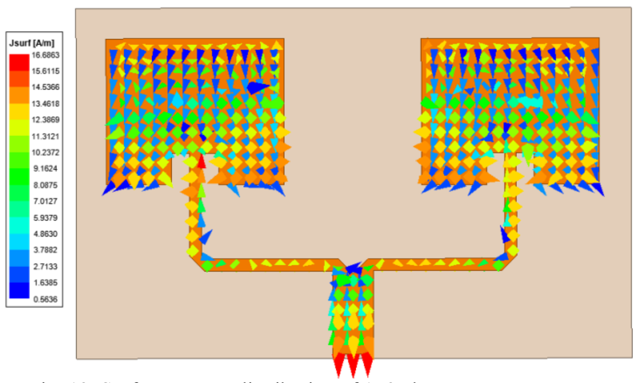


Fig. 12. Surface current distribution of 1×2 elements array antenna.

C. 1 × 4 elements array antenna

This subsection represents design structure shown in Fig.13 and the simulation results of 1×4 elements microstrip array antenna which has also been simulated by using ANSYS HFSS. The length and width of substrate of the newly designed array are 37 mm and 84.86 mm, respectively. The dimension of the patches and spacing between two patches are kept same as the previously designed 1×2 array antenna. Therefore, only inset distance and feed line width have been readjusted to get better impedance matching. The inset distance for this design is of 2.9 mm. The corporate feed method is used to excite the each array elements. In this design, the patch elements are connected using quarter wavelength microstrip line and T- junction power divider. The width of 50 Ω, 70.7 Ω and 100 Ω feed lines are 2.74 mm, 1.57 mm and 0.8 mm, respectively.

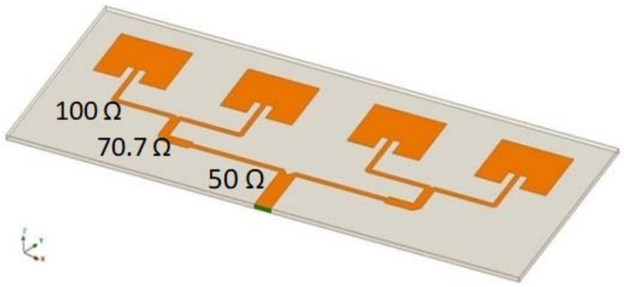


Fig. 13. 1×4 elements array antenna.

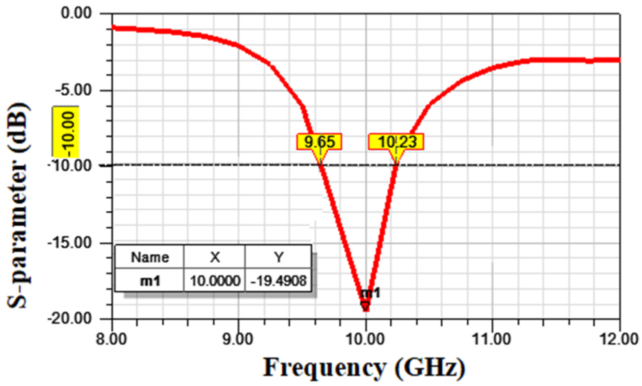
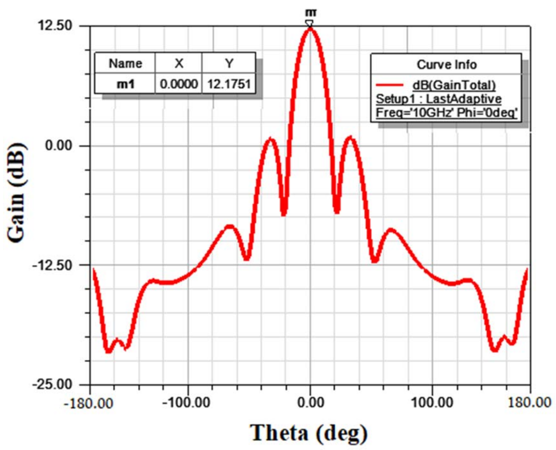
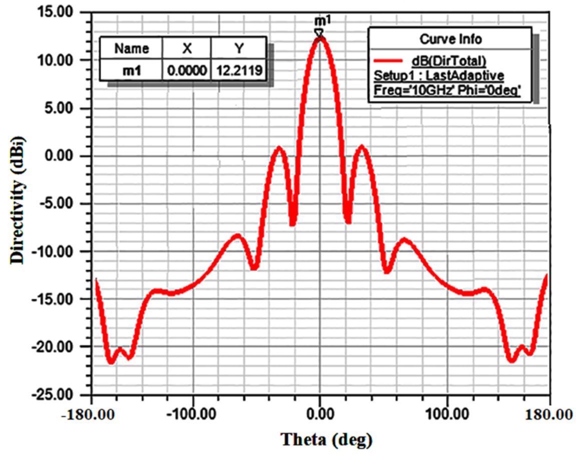


Fig. 14. $|S_{11}|$ of 1×4 elements array antenna.



(a) Gain Vs theta



(b) Directivity Vs theta

Fig. 15. (a) Gain and (b) Directivity of 1×4 elements array antenna.

Fig. 14 shows the S-parameter versus frequency curve. From the figure it is seen that the antenna radiates signal ranging from 9.65 GHz to 10.23 GHz with centre frequency of 10 GHz. The bandwidth of the array antenna is of 580 MHz. The array antenna shows significant enhancement in both gain (12.17 dB) and directivity (12.21 dBi) as depicted in Fig. 15. The VSWR of the antenna is of 1.23 as in Fig. 16. Radiation pattern and current distribution through the surface of the array antenna is presented in Fig. 17 and 18, respectively. The HPBW of the antenna is 18.34º at ($\theta = 0$, $\varphi = 0$) position.

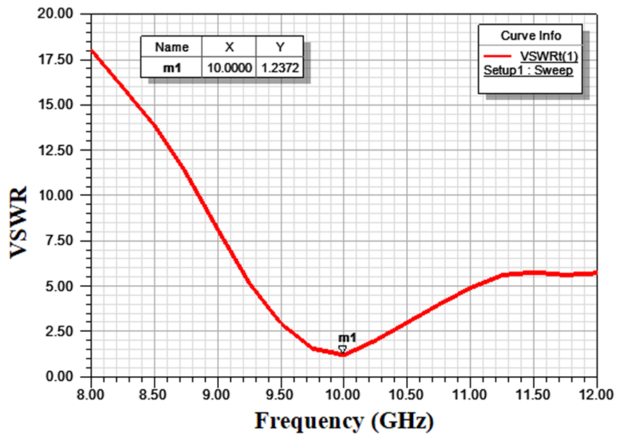


Fig. 16. VSWR of 1×4 elements array antenna.

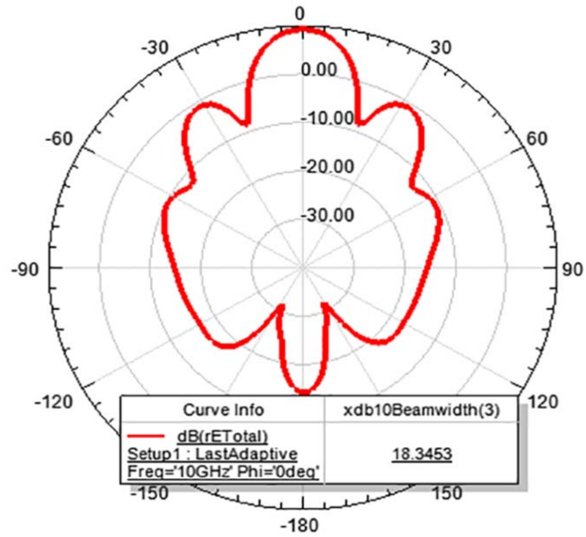


Fig. 17. Radiation pattern of 1×4 elements array antenna in polar form.

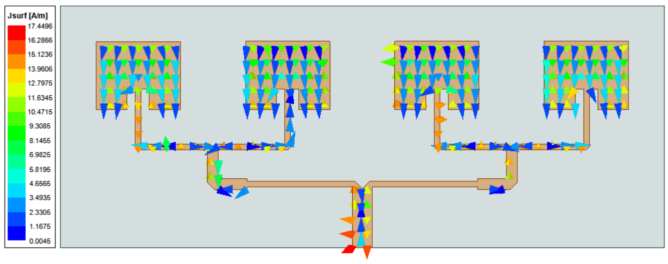


Fig. 18. Surface current distribution of 1×4 elements array antenna.

D. Proposed 2× 4 elements array antenna

To enhance the directivity further, additional four elements have been added and made a 2×4 elements array. Similar to the 1× 4 elements array antenna, all the elements of 2×4 array antenna are excited by using 50 Ω, 70.7 Ω and 100 Ω feed lines as shown in Fig.19. The adjacent rectangular patch elements are separated by 22.588 mm in the direction of both x and y axis. The length and width of Rogers RT/duroid 5880™ substrate (ε_r =2.2) are 46 mm and 84.86 mm, respectively. The thickness of the substrate is of 0.89 mm.

Inset gap of the array antenna is of 1.16 mm which is same as for the aforementioned 1×2 and 1×4 array antennas but inset distance is changed to 2.9 mm for achieving better impedance matching. From Fig. 20, it is noticed that the 2×4 array antenna shows better return loss of -30.27 dB at 10 GHz. It operates over 9.77 GHz – 10.15 GHz frequency range which lies into X band RADAR application. The array shows bandwidth of 380 MHz.

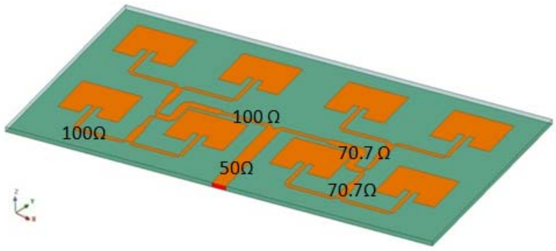


Fig. 19. Proposed 2×4 elements array antenna.

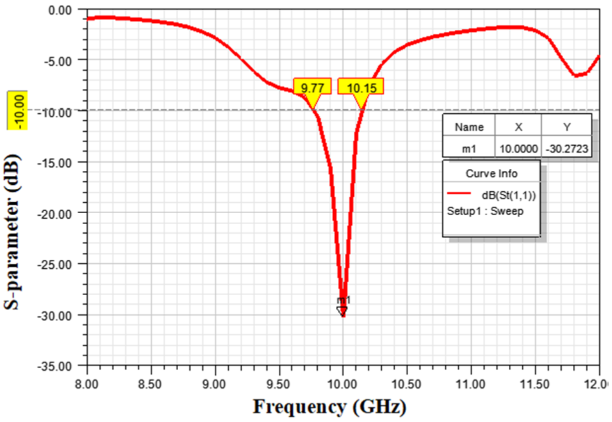
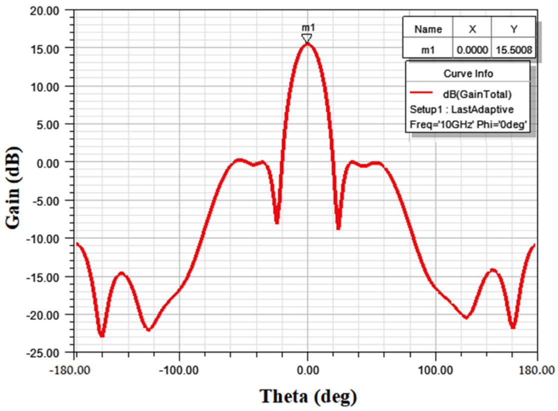
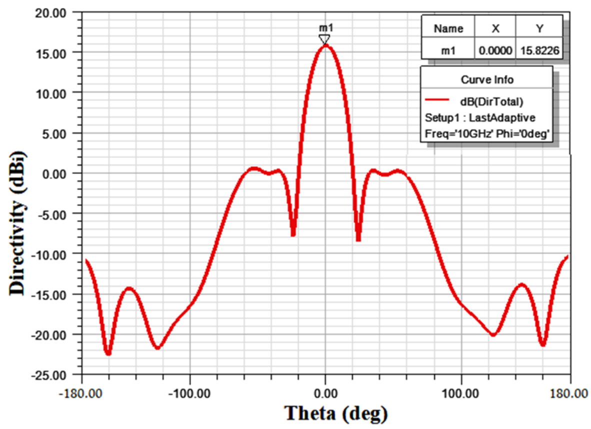


Fig. 20. $|S_{11}|$ of 2×4 elements array antenna.



(a) Gain Vs theta



(b) Directivity Vs theta

Fig. 21. (a) Gain and (b) Directivity of 2×4 elements array antenna.

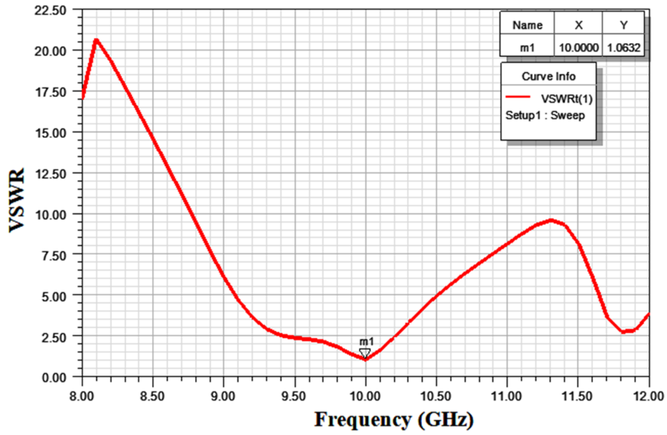


Fig. 22. VSWR of 2×4 elements array antenna.

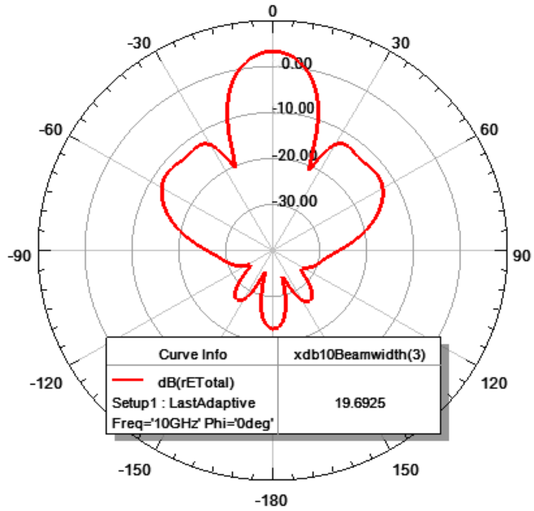


Fig. 23. Radiation pattern of 2×4 elements array antenna in polar form.

The variation of gain and directivity of the proposed 2×4 elements array antenna with respect to theta are presented in Fig. 21. The gain and directivity of the antenna are of 15.5 dB and 15.82 dBi at the centre operating frequency of 10 GHz. It indicates that the proposed antenna possesses high gain and directivity which is essential for RADAR and Satellite applications. The antenna also shows very good VSWR of 1.06 (Fig. 22) which is very close to the unity. From Fig. 23, it can be estimated that the proposed 2×4 array antenna has HPBW of 19.69º. The surface current distribution during the operation of the array antenna is depicted in Fig. 24. This 2×4 array antenna is our finally proposed high gain array antenna for X band RADAR application which performs better performance compared to other previously described array antennas of this paper.

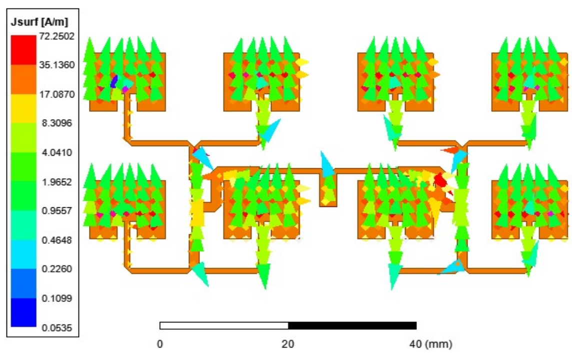


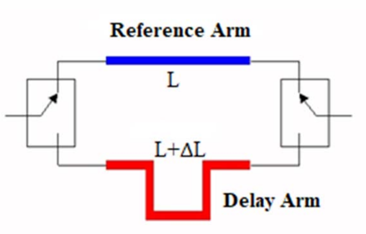
Fig. 24. Surface current of 2×4 elements array antenna.

E. Beam steering antenna

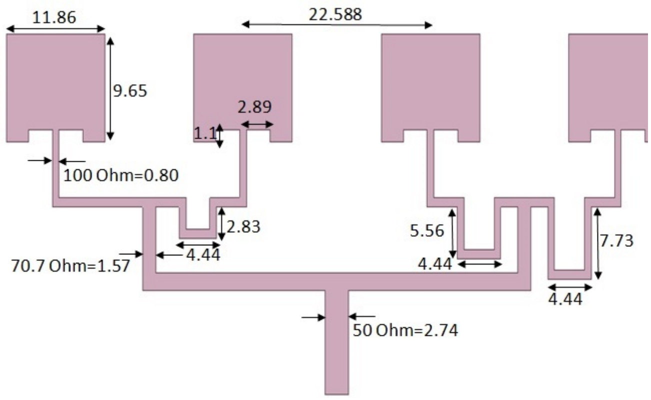
Beam steering means switching the direction of radiation of a directional antenna. Steering of the direction of radiation can be performed by using either mechanically or electronically. Mechanical beam steering can be obtained by rotating the antenna elements physically. On the other hand electronic beam steering can be achieved by using phase shifter. Here, switched line phase shifter has been used in 1×4 elements array antenna which has been discussed in subsection C. The layout with necessary dimension of the proposed 1×4 elements beam steering array antenna is shown in Fig. 25. In Fig. 25 (a), the upper path has transmission line length L and lower path has L+ΔL. The addition length (ΔL) to produce delay can be estimated by using following formula [9]:

$$\Delta L = \frac{\beta c}{2\pi f\sqrt{\varepsilon_{eff}}}$$

where c is the speed of light, β is propagation constant, f is the operating frequency and ε_{eff} is the effective dielectric constant. For the proposed 1 × 4 elements beam steering array antenna, the length of the delay lines for phase shifting are ΔL, 2ΔL and 3ΔL.



(a) Basic switched line phase shifter



(b) Top view of proposed beam steering antenna

Fig. 25. Beam steering 1×4 elements array antenna.

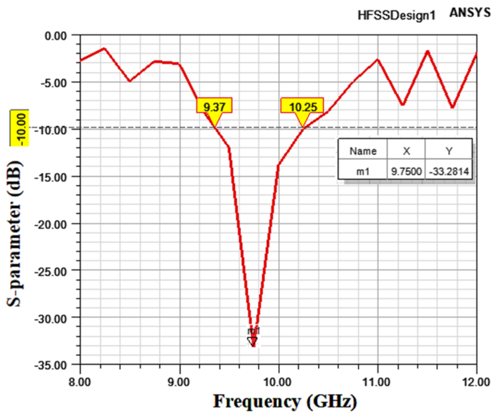
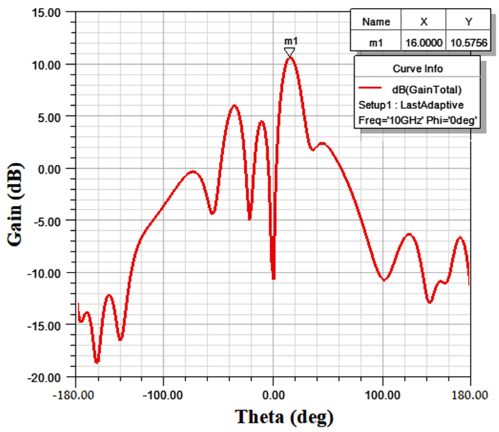
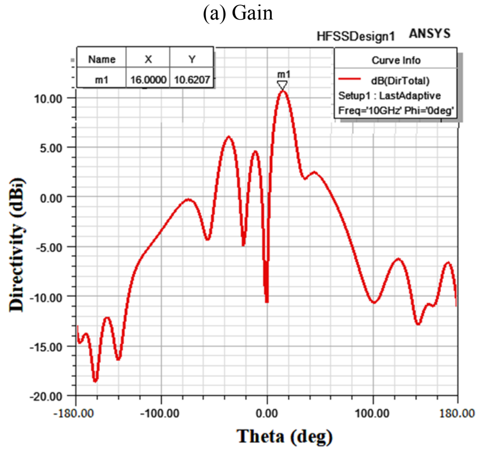


Fig. 26. $|S_{11}|$ of proposed beam steering antenna.

After using the delays in the 1×4 elements array antenna, the antenna's main beam is switched from (θ = 0, φ = 0) to (θ = 16º, φ = 0) direction. The proposed beam steering array antenna covers frequency ranging from 9.37 GHz to 10.25 GHz as in Fig. 26. The return loss of the antenna is of -33.28 dB and bandwidth of the antenna is of 880 GHz which covers very wide range of X band frequency. It possesses standard gain (10.57 dB) and directivity (10.62 dBi) at (θ = 16º, φ = 0) as depicted in Fig. 27.



(a) Gain



(b) Directivity

Fig. 27. (a) Gain and (b) Directivity of beam steering antenna.

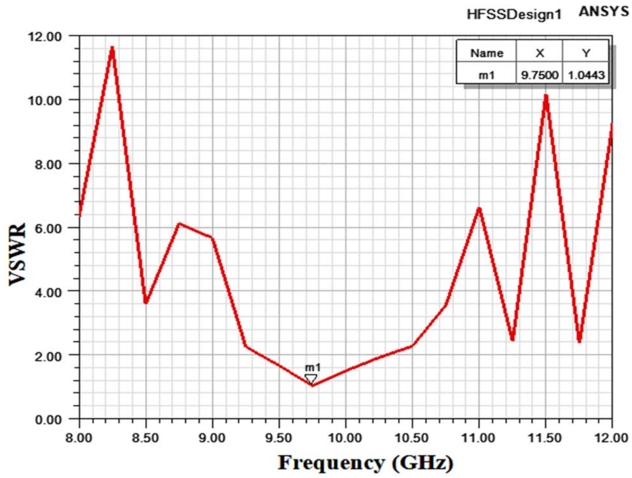


Fig. 28. VSWR of beam steering array antenna.

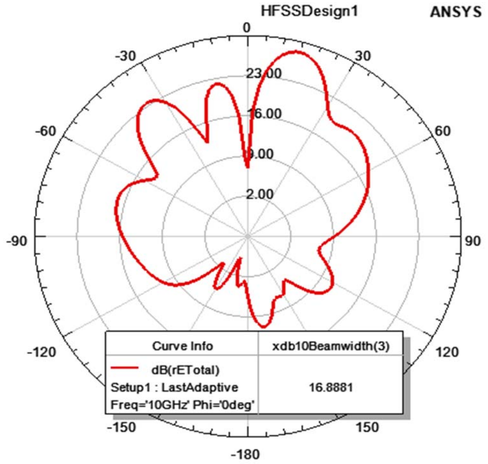


Fig. 29. Radiation pattern of beam steering array antenna in polar form.

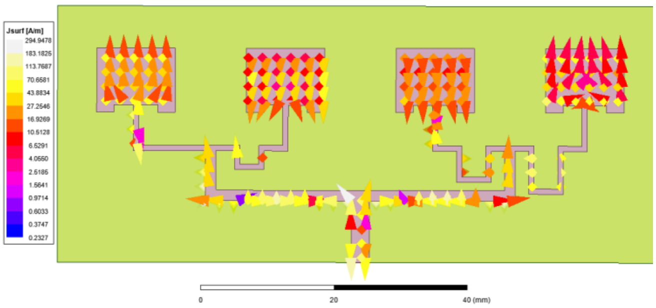


Fig. 30. Surface current distribution of beam steering array antenna.

TABLE I. SYNOPSIS OF ESTIMATE PERFORMANCE PARAMETERS

Parameter	Single element	1×2 elements	1×4 elements	2×4 elements	Beam steering
Return loss (dB)	-14.33	-30.19	-19.49	-30.27	-33.28
Lower cut off frequency (GHz)	9.92	9.76	9.65	9.77	9.37
Higher cut off frequency (GHz)	10.12	10.29	10.23	10.15	10.25
-10 dB Bandwidth (MHz)	200	530	580	380	880
Gain (dB)	8.0022	8.92	12.17	15.5	10.57
Directivity (dBi)	8.0039	8.96	12.21	15.82	10.62
VSWR	1.47	1.06	1.23	1.06	1.04
HPBW (deg)	79.13	41.27	18.34	19.69	16.88

Similarly the proposed beam steering antenna shows very good VSWR of 1.044 at the same beam steering position (θ = 16º, φ = 0) as shown in Fig. 28. The HPBW of 16.88º and current distribution level on the surface of the proposed beam steering antenna for X band RADAR application can be estimated from Fig. 29 and 30. Table I shows the estimated values of all the performance parameters which are estimated by HFSS suit for single element patch, 1×2 elements array, 1×4 elements array, proposed 2×4 elements array and proposed 1×4 elements beam steering array antenna.

III. CONCLUSION

In this paper, a high gain 2×4 elements array antenna and a 1×4 elements beam steering array antenna have been proposed for X band RADAR application. Prior to propose the high gain 2×4 elements array antenna some other antennas like single element microstrip patch antenna, 1×2 elements array, 1×4 elements array antennas have been designed, simulated and discussed in detail. The proposed 2×4 elements array antenna has return loss of –30.27 dB and covers frequency range of 9.77 GHz – 10.15 GHz i.e. it provides bandwidth of 380 MHz. The proposed 2×4 elements array antenna shows high gain of 15.5 dB and directivity of 15.82 dBi. And the proposed beam steering antenna shows 16º shift of direction of main lobe in θ plane with a return loss of -33.28 dB. It also shows very good VSWR of 1.04 and bandwidth of 880 MHz. One limitation of the proposed beam steering antenna is that the antenna possesses comparatively low beam steering angle. In our future work we will concentrate on it and we want to extend its steering capability so that it can scan over a broad range of angle. Both the proposed 2×4 elements array antenna and 1×4 elements beam steering array antenna operate at the X frequency band. Therefore, the proposed both array antennas can be potential candidates to be used in X band RADAR application.

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