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Low-Cost Planar MM-Wave Phased Array Antenna for Use in Mobile Satellite (MSAT) Platforms

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***Abstract*— In this paper, a compact 8×8 phased array antenna for mobile satellite (MSAT) devices is designed and investigated. 64-elements of 22 GHz patch antennas with coaxial-probe feeds have been used for the proposed planar design. The antenna is designed on a low-cost *FR4* substrate with thickness, dielectric constant, and loss tangent of 0.8 mm, 4.3, and 0.025, respectively. The antenna exhibits good performance in terms of impedance-matching, gain and efficiency characteristics, even though it is designed using high loss substrate with compact dimension (W_{sub}×L_{sub}=55×55 mm^2). The antenna has more than 23 dB realized gain and -0.8 dB radiation efficiency when its beam is tilted to 0^o elevation. The center frequency of the designed array can be controlled by adjusting the values of the antenna parameters. Compared with the previous designs, the proposed planar phased array has the advantages of simple configuration, low-cost, low-profile, and easy fabrication. Simulations have been done to validate the feasibility of the proposed phased array antenna for MSAT applications.**

***Keywords*—Low-cost design, MSAT, patch antenna.**

I. Introduction

DUE to significant growth of demand for information, and comfort on the move, researchers/engineers have been putting remarkable efforts in the investigation on the satellite TV reception for cellular devices. The reception part of the MSAT platforms consists of the antenna, the RF front-end, low noise block (LNB), phase shifters and equalization circuits [1]. Various kinds of antennas and platforms have been introduced in [2-4]. In 1989, the first design for MSAT was introduced which required a low-cost and compact antenna with 40º beam-width coverage [5]. Our work presented here primarily focuses on the design of low-profile, low-cost planar phased array antennas for MSAT reception.

One of the major challenges in MSAT systems is the design of low-profile mm-Wave antennas with sufficient gain and wide bandwidths. Moving the design of antennas to higher frequency bands will bring new challenges [6]. The purpose of this study is to derive a compact design of planar array antenna which could be integrated easily with other circuits in the MSAT systems.

The designed antenna is working in the frequency range of 21-23 GHz. It consists of 64-elements of patch radiators with coaxial-probe feeds. The spacing between the patch antenna elements is 6.8 mm (λ/2 of 22 GHz). In addition, using the 22 GHz patch antenna elements, the input-impedance and radiation properties of 2×2, 4×4, and 8×8 planar arrays are investigated. The results show good performance in terms of different antenna parameters.

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II. The Proposed Antenna Design

The antenna is designed on a cheap FR4 substrate with thickness (h), dielectric constant (ε_r), and loss tangent (δ) of 0.8 mm, 4.3, and 0.025, respectively. Figure 1 illustrates the geometry of the antenna. As seen, 64-elements of patch antennas with coaxial-probe feeds have been used for the proposed planar array antenna. The parameter values of the final antenna and its elements (Fig. 2) are listed in Table 1.

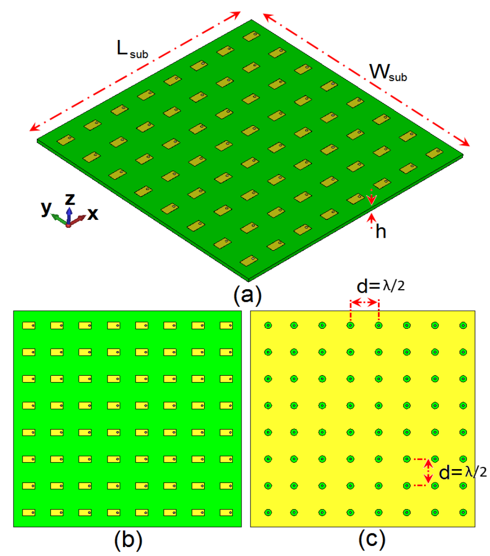

Fig. 1. Proposed antenna configuration, (a) side view, (b) top layer, and (c) bottom layer (GND).

Table 1: Dimesion values of the proposed antenna

Parameter	W_{sub}	L_{sub}	h_{sub}	W_P	L_P	W_C
Value (mm)	55	55	0.8	3	1.7	0.6
Parameter	W_d	L_d	d=λ/2	r	r_1	h
Value (mm)	2.4	2.4	6.8	1.72	0.5	0.8

III. Single Element Patch Antenna

The schematic of the single element patch antenna fed by coaxial probe is shown in Fig. 2. Basically, the microstrip patch antenna is a conductor in a variety of shapes printed on the top layer of substrate with a full ground. Its operation frequency is inversely proportional to the radiator length [7].

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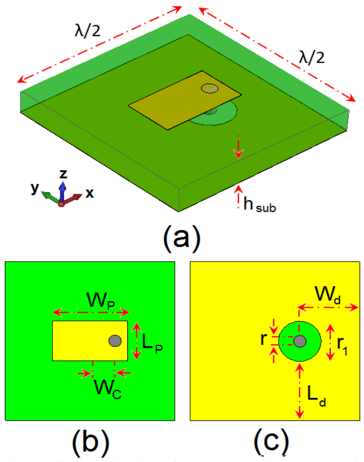

Fig. 2. Configuration of the single element 22 GHz patch antenna, (a) side view, (b) top layer (resonator), (c) bottom layer (ground plane).

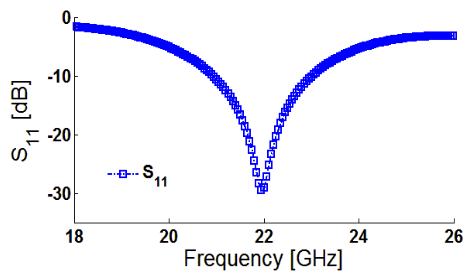

Fig. 3. Simulated S_{11} characteristic of the patch antenna.

Figure 3 illustrates the simulated S_{11} characteristic of the patch antenna. As illustrated, the antenna operates in the frequency range of 21 to 23 GHz (2 GHz bandwidth). The operation band of this design can be controlled by adjusting the values of the antenna parameters such as radiator length and feeding point. The simulated S_{11} curves with different values of W_P and W_C are plotted in Fig. 4. As illustrated in Fig. 4(a), when the length of the rectangular patch decreases from 4 to 2 mm, the center of the antenna resonance decreases from 27 to 17 GHz.

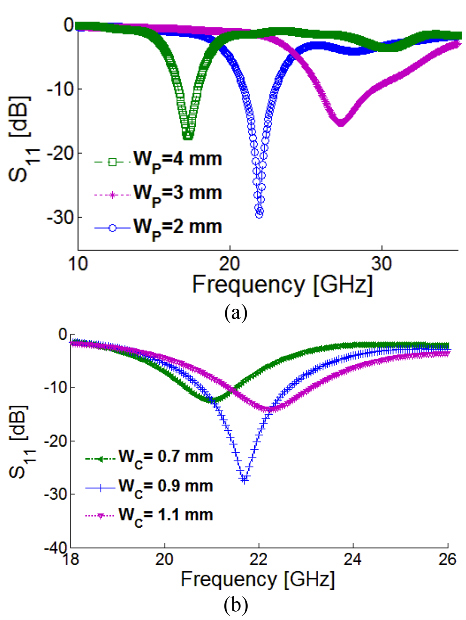

Fig. 4. Simulated S_{11} curves for different values of (a) W_P, and (b) W_C.

Another important parameter of the proposed design is the feeding point. Its main effect occurs on the impedance matching and also operation frequency characteristics of the antenna. Figure 4 (b) illustrates the simulated S_{11} characteristics with various lengths of W_C. As the distance between feeding point and center of antenna increases from 0.7 to 1.1 mm, the operation frequency of antenna is varied from 20.8 to 22.2 GHz. From this result, we can conclude that the antenna operation frequency is controllable by changing the antenna parameters. As seen in Fig. 4 (b), for W_C = 0.9 mm, the antenna has a good impedance matching at the desired frequency (22 GHz).

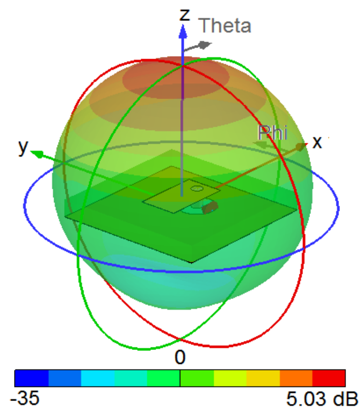

Fig. 5. Simulated 3D radiation pattern of the patch antenna at 22 GHz.

The simulated 3D radiation pattern of the single element patch antenna at 22 GHz is illustrated in Fig. 5. It can be seen that the antenna has a good radiation behavior with low back-lobe and 5.03 dB realized gain at 22 GHz. Simulated maximum gain, radiation and total efficiencies of the single element patch antenna over operation frequency are illustrated in Fig. 6. As seen, the antenna radiation and total efficiencies are around -1 dB. In addition, the antenna has more than 5 dBi maximum gain.

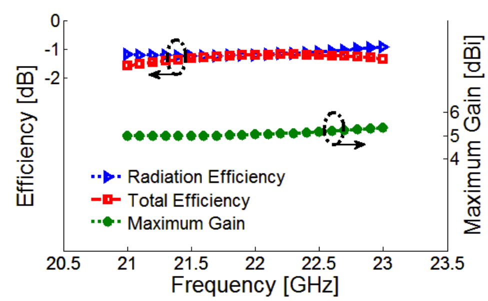

Fig. 6. Simulated maximum gain, radiation and total efficiencies of the antenna over its operation band.

IV. The Proposed Phased Array Antenna

Figure 7 shows the configuration of a 1×8 linear array with eight elements of 22 GHz patch antenna elements. The distance between antenna elements (d) is chosen as λ/2 (6.8 mm). The simulated S-parameters of the linear array are illustrated in Fig. 8. As illustrated, the linear antenna array operates at the frequency range of 21-23 GHz with -20 dB S_{nn}. In addition it has less than -20 dB mutual-coupling between the elements which makes it sufficient for beam steering.

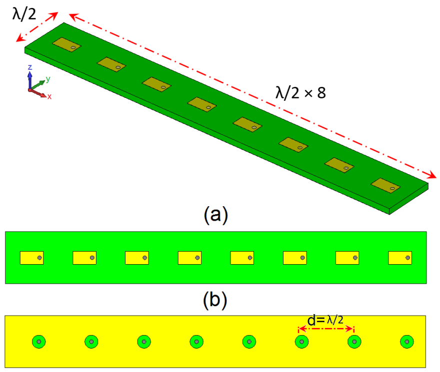

Fig. 7. Geometry of the linear phased array patch antenna, (a) side view, (b) top layer, and (b) bottom layer (GND).

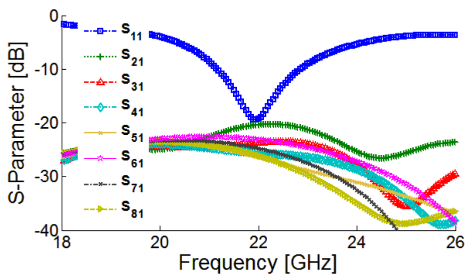

Fig. 8. Simulated S-parameters for the linear array.

The beam-steering property of the array radiation patterns with directivity values in the scanning range of 0-70 degree are shown in Fig. 9. As seen, the array has a good beam steering property with more than 14 dBi directivty when its beam is tilted to 0° elevation. Realized gain values of the array at the scanning angles of 0°, 20°, 40°, 60°, and 70° are illustrated in Fig. 10. As seen, the array has more than 10 dB realized gain at the scanning ranges of 0 to +60 degree.

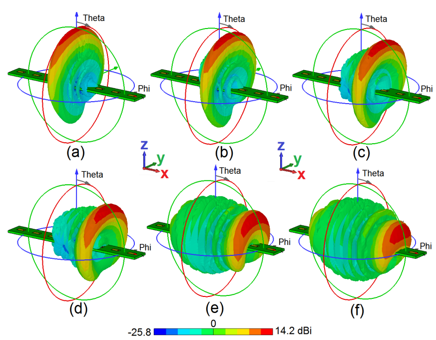

Fig. 9. 3D Radiation patterns of the antenna array at different scanning angles, (a) 0º, (b) 15º, (c) 30º, (d) 45º, (e) 60º, (f) 70º.

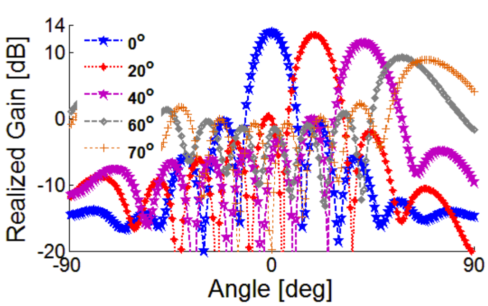

Fig. 10. Simulated realized gain characterisitics of the antenna at different scanning angles.

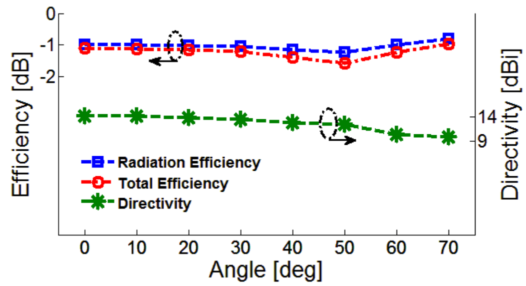

Fig. 11. Directivity, radiation efficiency and total efficiency characteristics of the simulated linaer array antenna at the sanning angles from 0 to +70 degree.

The adiation and total efficiencies and directivity of the simulated array for the scanning range of 0 to 70 degree are illustrated in Fig. 11. As seen, the antenna radiation and total efficiencies are almost constant for the scanning range of 10° to 70° with more than -1.2 dB values. Furthermore, when the scanning angle of beam-steering characteristic is ≤+60, the array has more than 10 dBi directivity. In order to achieve a beam scanning in two-dimension (2D) a planar phased array is needed. However the complexity and cost of the antenna will increase.

As illustrated in Fig. 1, 64 elements of the rectangular patch antennas have been used to design the final structure on the FR-4 substrate. One of the important system blocks to achieve a functional array antenna is the feed network. There are various feed network designs that could be used for this purpose (such as the corporate feed network shown in Fig. 12). The feed network of proposed phased array can be implemented using low loss phase shifters (such as HMC933LP4E) for beam steering issue.

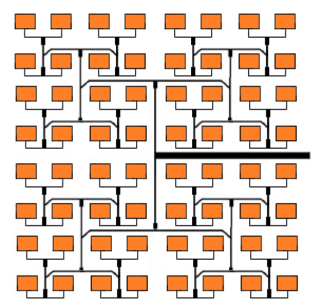

Fig. 12. Schematic of the corporate feed network for the planar phased arrays.

It should be noted the usage of the feed network could has influence on the antenna parameters in terms of directivity, mutual coupling, gain and etc. Additionally, the mutual coupling in combination with the feed network caused notable changes in the excitation currents. So, the losses of the antenna performance in the vicinity of feeding network and active elements should be considered for next researches, but not included in this paper.

Current distribution for the proposed planar phased array antenna at 22 GHz is shown at Fig. 13. As illustrated, the current flows are mostly distrubited around of the patch elements. Figure 14 shows the radiation beams of the proposed 8×8 phased array antenna with directivity values at different scanning angles. It can be seen that the antenna has a good beam steering characteristic with high-level directivity characteristic at the different scanning angles.

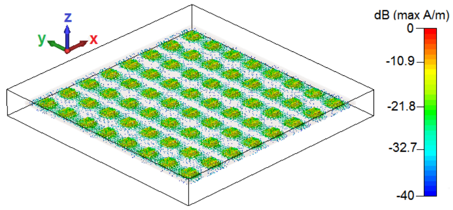

Fig. 13. Simulated current distribuion of the proposed planar array at 22 GHz.

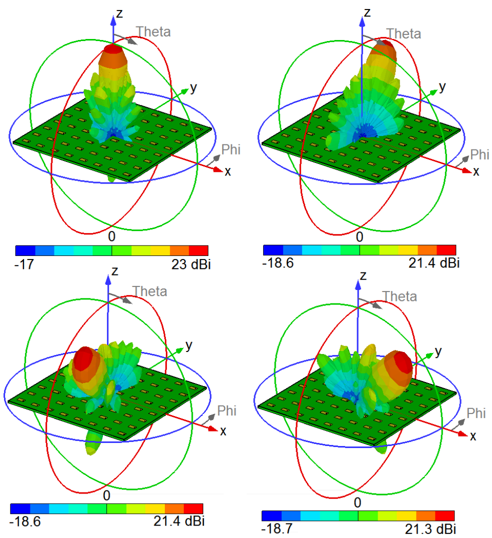

Fig. 14. 3D Radiation beams of the array at different scanning angles.

V. Investigation on the Proposed Design with Different Numbers of Antenna Elements

In this section, the investigation on the performance of the proposed 22 GHz planar array with different numbers of the patch antennas has been done. Figure 15 shows the configurations of the arrays with 2×2, 4×4, and 8×8 numbers of antenna elements.

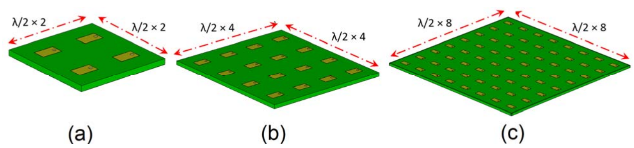

Fig. 15. Configuration of the planar arrays, (a) 2×2, (b) 4×4, and (c) 8×8.

The spacing between the elements of the arrays is λ/2. Figure 16 shows the simulated S-parameters (S_{nn} & S_{nm}) of the arrays. It can be seen that the designed arrays have good and similar performances in the frequency range of 21 to 23 GHz. As illustrated in Fig. 16 (a), -20, -22, and -28 dB reflection coefficients (S_{nn}) are achieved for 2×2, 4×4, and 8×8 planar arrays. Figure 16 (b) shows the highest mutual couplings (S_{nm}) between antenna elements for the proposed arrays.

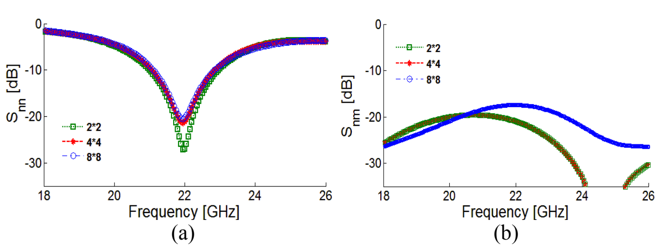

Fig. 16. Simulated S-parameters of the arrays, (a) S_{nn}, and (b) S_{nm}.

3D radiation beams of the planar arrays when their beams are tilted to 0° elevation are shown in Fig. 17. More than 10.5, 16.5, and 23 dBi directivity values with good radiation behaviors and low back lobes have been achieved for all of the planar arrays.

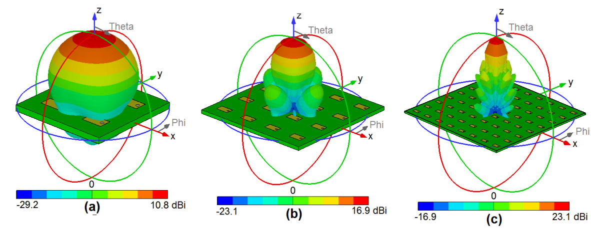

Fig. 17. 3D radiation beams of the planar arrays at 0° scanning angle.

Table 2 summarizes the performances of the designed arrays in terms of realized gain, efficiency, bandwidth, reflection coefficient and mutual coupling. As seen, the arrays exhibit good performance in in different terms of the antenna parameters, even though they have been designed using high loss *FR4* substrates with compact dimensions.

Table 2. Performances of the Planar Arrays at 0^{O}

Array/Param.	*Gain*	*Effic.*	*BW*	*R.C*	*M.C*
1×1	5.3 dB	-1 dB	2 GHz	-30 dB	--
2×2	10 dB	-1.1 dB	1.9 GHz	-28 dB	-20 dB
4×4	16 dB	-0.9 dB	1.9 GHz	-22 dB	-20 dB
8×8	22 dB	-0.8 dB	2 GHz	-20 dB	-17 dB

VI. Conclusion

This study has introduced a compact design of low-cost planar phased array antenna for MSAT applications. 64 elements of 22 GHz patch antennas have been used to form the 8×8 planar array. The array is designed to work in the frequency range of 21 to 23 GHz. The investigated results show good performance in terms of various characteristics of the antenna such as impedance bandwidth, realized gain, efficiency, 3D radiation patterns and beams.

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