Two-Dimensional Pattern Scanning by Linear Phased Array with Pattern Reconfigurable Elements

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***Abstract*–**In this paper, a linear phased array with pattern reconfigurable elements is studied to perform a two-dimensional pattern scanning. Compared with the traditional linear array, the new linear array can scan the patterns in two-dimensional directions , i.e. θ-direction and φ-direction. The results indicate that the main beam of the proposed array can continuously scan from θ=30^{o} to θ=150^{o} in the *E*-plane by adjusting the feed phases of reconfigurable elements and from φ=-50^{o} to φ=50^{o} in the H-plane by switching the elements operating states.

***Index Terms*–**array antenna, reconfigurable, pattern synthesis, scanning, microstrip antenna.

I. INTRODUCTION

Phased array is studied extensively because it can provide a high gain and scan its patterns [1]. The elements in phased array may be arranged in a line or a plane. The linear phased array is used widely due to its simple configuration, and it can scan its radiation pattern in one-dimension. To perform a beam scanning in two-dimension, traditionally, a planar phased array is necessary, thus the complexity and cost of the array will be increased significantly. Recently, the reconfigurable antenna, which can reconfigure its patterns and frequencies using PIN or MEMS switches, has been presented and studied extensively [2-3]. Because an additional degree of freedom is added, the reconfigurable antenna has a tremendous potential to improve the performance of the phased array. Some efforts have been made to apply the reconfigurable antenna into phased array design [4]. In this paper, a linear phased array with pattern reconfigurable elements is proposed to realize two dimensional scanning through adjusting reconfigurable element feed phases in one dimension and shifting the elements operating states in the other dimension.

II. RECONFIGURABLE ANTENNA ELEMENT

The geometry of the antenna is shown in Fig. 1. The antenna consists of three parallel strips printed on a grounded dielectric substrate with a relative dielectric constant of ε_r=2.2 and a thickness of *H*=6.35mm. All of the strips have a width of *W*=2.0mm. The center strip length is L_m=29mm, and is fed with a coaxial probe. This feed probe is moved *g*=11.8mm away from the end of the center strip to improve the impedance match. The two parasitic strips have the same length of L_r=33mm. The space between the adjacent strips is *S*=20mm. A gap with a width of d_m=1.2mm is located close to each end of the parasitic strips and 2.0mm (d_1) away from the strip end. Four switches, i.e., *k*1, *k*2, *k*3 and *k*4, are installed in four gaps, respectively. The parasitic strips can be elongated or shortened by closing or opening the switches. The ground

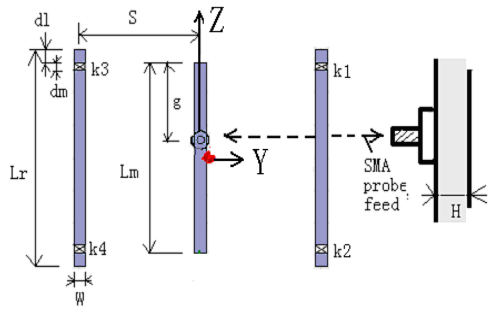


Fig. 1. Geometry of the pattern reconfigurable antenna element.

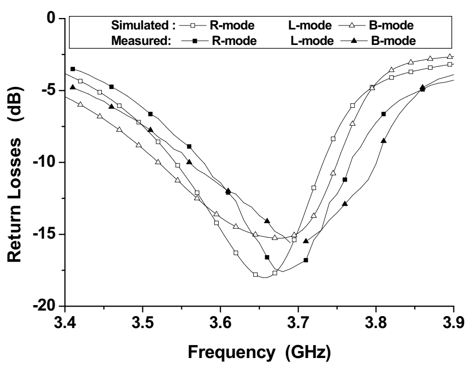
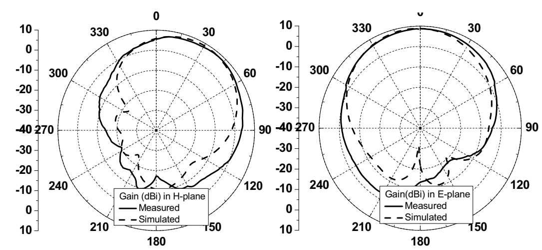


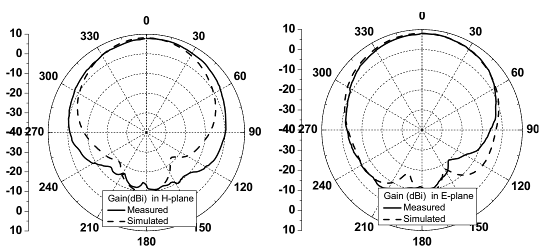
Fig. 2. Simulated and measured return losses for the three modes.

plate has an area of 90mm×140mm.

When $k1$ and $k2$ are open, $k3$ and $k4$ are closed, the effective length of the left parasitic strip is longer than the right one, and the pattern in *xoy*-plane turns right (i.e., positive plane). In this case the antenna operation is called *R*-mode. According to the symmetry, when $k1$ and $k2$ are closed, $k3$ and $k4$ are open, the called *L*-mode can be constructed and its pattern in *xoy*-plane turns left (i.e., negative plane).When all switches are open, the antenna pattern is broadside, the same as the conventional antenna, shortly named *B*-mode. The antenna is simulated using commercial software Ansoft HFSS9.0. As in [5-7], the ideal switch model is used in measuring the characteristics because it can provide an acceptable error. The simulated and measured return losses are shown in Fig. 2. The result indicates that the antenna can operate well around 3.67GHz in the three modes. The simulated and measured radiation patterns in the *E*-plane (*xoz*-plane) and *H*-plane (*xoy*-plane) at 3.67GHz are shown in Fig. 3. Based on Fig. 3, it can draw the conclusion that the main beam of the antenna can be scanned in *H*-plane by switching the antenna states among *L*-, *R*-, and *B*-modes. The main beam direction and the corresponding half power beam coverage in *H*-plane are (*R*-mode, φ=30°, 2°~60°), (*L*-mode, φ=-30°, -2° ~-60°) and (*B*-mode, φ=0°, -30°~30°), respectively. The gains are 8.80, 8.80 and 8.03dBi, and the half power beam coverage in *E*-plane are (53°~117°), (53°~117°) and (48°~138°), respectively, for *L*-, *R*- and *B*-modes.



(a)



(b)

Fig. 3. Simulated and measured radiation patterns at 3.67 GHz; (a) *R*-mode and (b) *B*-mode.

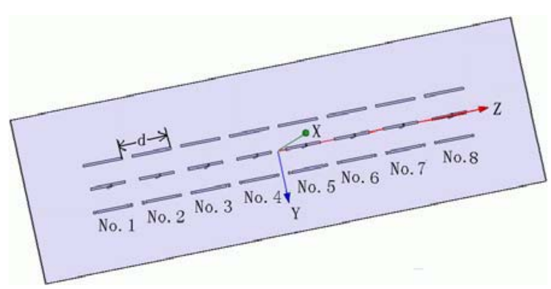
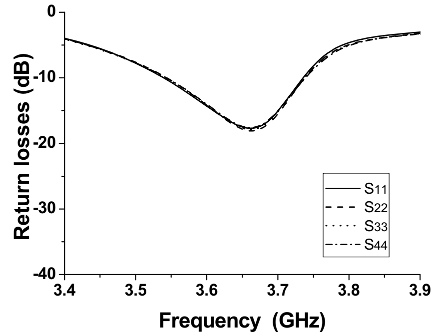


Fig. 4. Configuration of the linear phased array.

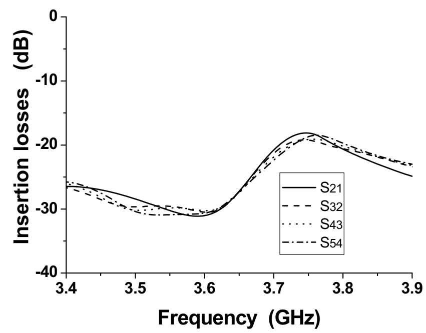
III. LINEAR PHASED ARRAY WITH RECONFIGURABLE ANTENNA ELEMENTS

Figure 4 shows the configuration of the proposed linear phased array. Eight elements, named *No.1*-*No.8*, are arranged along *z*-axis with an element spacing of $d=\lambda_0/2$, where λ_0 is the wavelength in free space at the operation frequency. All of the elements in the phased array operate with the same mode. The return losses of each port and the mutual couplings between elements are studied. When the array operates with *R*-mode, the simulated return losses of each port and the mutual couplings between two adjacent elements are shown in Fig. 5. In this figure, it can be observed that a return loss of -18dB is achieved for each port and a mutual coupling of less than -26dB is obtained between the adjacent elements at the operation frequency of 3.67GHz. The additional studies also demonstrate that the mutual coupling between other elements is lower due to a larger spacing. When the phased array operates with *B*-mode, the low return losses and the weak mutual couplings between antenna elements can be obtained, too.

The radiation characteristics of the uniform phased array are analyzed. When the phased array operates in *R*-mode, the array can scan its patterns in *E*-plane (i.e., $\varphi=30^{\mathrm{o}}$) by changing the progressive phase $\Delta\psi$. The local coordinate system $x'y'z'$ displayed in Fig. 6 is used to observe the patterns of the phased array. The *E*-plane scan characteristic vasi $\Delta\psi$ are shown in Fig. 7(a) and the patterns in *H*-plane are shown in Fig.7(b). While the array is scanning, the x' axis and z' axis are turning in the plane $\varphi=30^{\mathrm{o}}$ (i.e., *E*-plane) of the *xyz* coordinate system with the x' axis pointing to the maximum radiation at all time. The y' axis is perpendicular to the $x'o'z'$ plane, is pointing the positive direction of the y axis and is changeless. The $x'o'y'$ plane is the *H*-plane of the array, so the *H*-plane of the array is being changed while the array is scanning.



(a)



(b)

Fig. 5. Simulated return losses of each port and mutual coupling between adjacent elements in R-mode: (a) return loss and (b) mutual coupling.

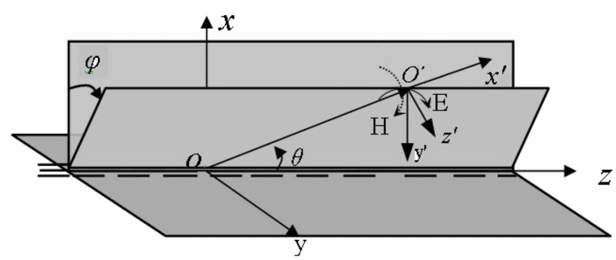
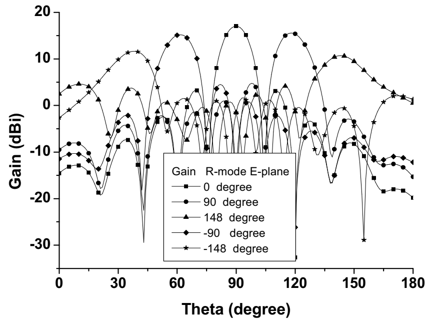
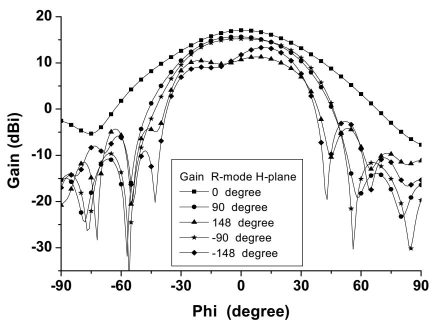


Fig. 6. Three-dimensional coordinate systems for array with R-mode.

Based on the symmetry, when the linear phased array operates in *L*-mode the radiation characteristics can be obtained. When the array operates with *B*-mode, it can scan its patterns in *E*-plane (i.e., $\varphi=0^{\mathrm{o}}$) and the results are shown in Fig. 8. While scanning, the local coordinate system $x'y'z'$ is constructed as the one in *R*-mode and the scan characteristic in *H*-plane are obtained. The detailed data of *R*- and *B*-mode are listed in Table 1. From Table 1, we can

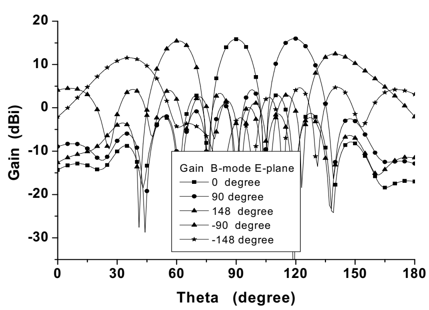


(a)

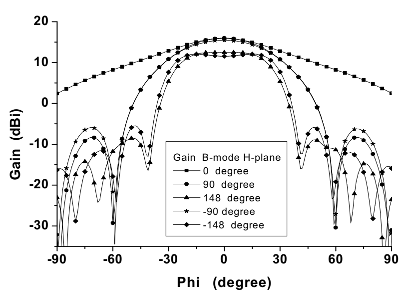


(b)

Fig. 7. Radiation pattern of linear phased array in R-mode with various progressive phases: (a) *E*-plane: φ=30° and (b) *H*-plane.



(a)



(b)

Fig. 8. Radiation pattern of the linear phased array in *B*-mode with various progressive phases: (a) *E*-plane: φ=0° and (b) *H*-plane.

observe that unlike the traditional linear array, the proposed linear phased array can realize the two-dimensional pattern scanning (i.e., θ-direction and φ-direction). Based on the studies above, the proposed linear array can continuously scan its main beam from θ=30° to θ=150° in *E*-plane by adjusting the feed phases of reconfigurable elements and from φ=-50° to φ=50° in *H*-plane by shifting the elements operating states.

Table 1. Pattern characteristics in *R*- and *B*-modes with various progressive phases.

$\Delta\psi$	Predicted main beam directions (θ_0, φ_0)	3dB beam coverage in local coordinate system shown by Fig. 5coverage		Gain (dBi)
		E-plane($x'o'z'$-p	H-plane($x'o'y'$-pl	
***R*-mode**				
-148°	(38 °,	θ'=80° ~98°	φ'=-5° ~-25°	12.3
-127°	(47°,	θ'=82° ~98°	φ'=-24° ~27°	13.0
-90°	(62°,	θ'=82° ~96°	φ'=-23° ~26°	15.2
-60°	(71°,	θ'=84° ~96°	φ'=-25° ~26°	16.3
-30°	(81°,	θ'=84° ~95°	φ'=-23° ~26°	16.8
0°	(90°, 30°)	θ'=84°~96°	φ'=-24°~26°	17.0
30°	(99°,	θ'=84° ~96°	φ'=-24° ~25°	16.9
60°	(109°,	θ'=84° ~96°	φ'=-24° ~25°	16.5
90°	(118°,	θ'=84° ~97°	φ'=-24° ~25°	15.6
127°	(131°,	θ'=83° ~99°	φ'=-25° ~25°	13.4
148°	(143°,	θ'=81°	φ'=-5° ~25°	11.3
***B*-mode**				
-148°	(36°,	θ'=78° ~101°	φ'=-28° ~28°	11.5
-127°	(47°,	θ'=78° ~98°	φ'=-24° ~24°	14.5
-90°	(61°,	θ'=77° ~96°	φ'=-24° ~24°	15.4
-60°	(71°,	θ'=84° ~96°	φ'=-27° ~26°	15.6
-30°	(81°,	θ'=84° ~96°	φ'=-28° ~28°	15.7
0°	(90°, 0°)	θ'=84° ~96°	φ'=-29° ~29°	15.9
30°	(100°,	θ'=84° ~95°	φ'=-28° ~28°	16.0
60°	(109°,	θ'=86° ~96°	φ'=-26° ~25°	16.1
90°	(119°,	θ'=86° ~97°	φ'=-23° ~23°	16.0
127°	(133°,	θ'=82° ~101°	φ'=-22° ~22°	14.8
148°	(140°	θ'=82° ~102°	φ'=-24° ~24°	12.5

IV. CONCLUSION

A linear phased array with pattern reconfigurable elements is proposed in this paper. The array elements operate in three switchable states with good performances. The linear phased array can perform the two-dimensional pattern scanning by combining the reconfigurable antenna technology with the traditional linear phased array antenna. The new linear array can scan its main beam from θ=30^o to θ=150^o in *E*-plane by adjusting the feed phases of reconfigurable elements and from φ=-50^o to φ=50^o in H-plane by switching the elements operating states.

ACKNOWLEDGEMENT

This work was in part supported by aviation Science Foundation under grant 20090180007, in part by the new-century talent program of the education department of China under grant NCET070154, in part by national defense research funding under grant 08DZ0229 and 09DZ0204, and in part by research funding of the 25th Institute of China Aerospace Science and Industry Corp.

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