Reconfigurable Antenna with Parasitic Layer Containing 8-element Dipole Array

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Abstract— **A pattern reconfigurable antenna with two layers offering successive beam tuning in two planes is proposed. A driven patch antenna is designed on the lower layer that is fed with two coaxial probes asynchronously, whereas the upper layer contains an 8-element dipole array. The electromagnetic wave is coupled from the driven patch to the eight parasitic dipoles, which then control the direction of radiation based on the status of the varactor tuning elements. To that end, eight varactors are placed in slots at the center of the parasitic dipoles to achieve the required pattern reconfigurability from the antenna. By selecting the excitation feeder and adjusting the varactor's capacitances, the radiation beam can be scanned from -30° to 30° in planes phi = 90° and phi = 0°. Furthermore, the antenna maintains more than 7 dBi gain in all the operating modes.**

Keywords—reconfigurable antenna; dipole array

I. Introduction

Recently, reconfigurable antennas have obtained high attention because of their great role in new generation wireless communication systems. Normally, the reconfigurable antenna is defined as a radiator that can change its frequency or radiation characteristics via particular methods. Typical changeable characteristics include operating frequency, impedance bandwidths, polarizations and radiation patterns [1]. Among those, antennas with beam steering are particular interesting since they can steer the main beam toward the desired direction to avoid noise sources, enhance signal detection and reduce the required power for transmitting signal towards the intended direction [2-5].

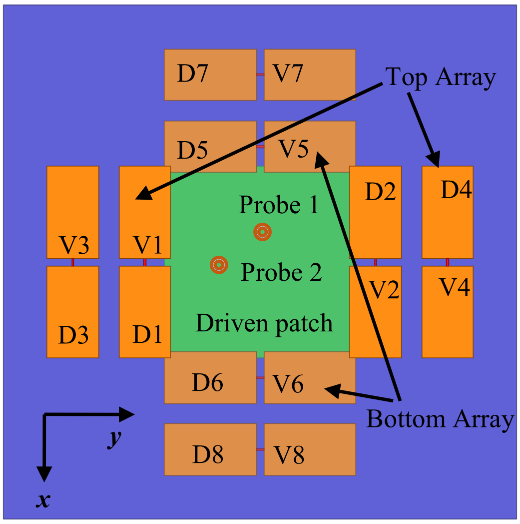
A phased array can achieve accurate beam steering in a wide range. However, it is unsuitable for many applications due to its complexity, size, weight and high cost. In contrast, many simpler antenna designs have been proposed that can reconfigure their radiation patterns in multiple directions [2, 4, 6, 7]. The four parasitic coupled multilayer patch antenna in [2], slot-patch-ring multilayer antenna in [4], and tapered slot antenna in [7] can switch the main beam in four directions. However, since pin diodes are used to realize the reconfigurability in those designs, beam switching is allowed in certain direction. On the other hand, using tunable switches like varactor didoes, antenna's radiation with suitable structures can be tuned to different directions. In [8], the reconfigurable antenna is capable to execute continuous beam tuning utilizing variable reactive loading but the tuning is only achieved in one dimension.

In this paper, a novel pattern reconfigurable antenna with two layers offering successive beam tuning in two planes is presented. A microstrip patch antenna is placed on the lower layer as a driven radiator and it is fed by two coaxial probes that work asynchronously. Eight microstrip dipoles are designed on both sides of the upper layer as parasitic elements to reradiate the electromagnetic energy coupled from the driven element. A varactor is mounted to the slot at the center of each dipole in order to change the surface current distribution and consequently reconfigure the radiation pattern. Through changing the capacitance value of varactors, the main radiation beam can be scanned within the range from -30° to 30° in both phi planes, phi = 90° and phi = 0°. The antenna operates at 2.5 GHz and the reflection coefficient is reasonably stable in all configurations.

II. Antenna Model and Operating Principle

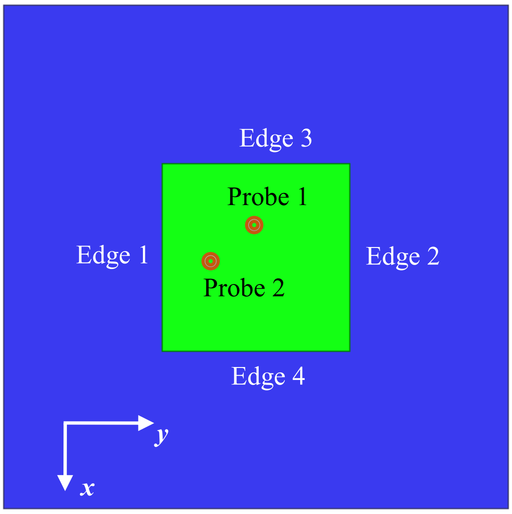
The proposed antenna model shown in Fig. 1 consists of two 100 × 100 mm^2 square substrates with relative permittivity 2.2, but of different thicknesses. The thickness of the lower and upper substrates are $h1$ = 3.175 mm and $h2$ = 0.787 mm, respectively. The gap between the substrates is hd = 5 mm. A 37.3 × 37.3 mm^2 square patch is designed on the top of the lower grounded substrate. The patch is fed with two coaxial probes asynchronously; probe 1 and 2 are placed at x- and y-axes with an offset 6.5 mm away from the center of patch. Eight parasitic dipole elements are arranged in four pairs, placed on the upper substrate and on the four side of the driven patch. Dipoles D1, D2, D3, D4 are placed along y-axis on the top side of upper substrate and dipoles D5, D6, D7, D8 along x-axis are on the reverse side. The dimensions of all dipoles are 37.3 × 10 mm^2. Each dipole has a 1.5 mm slot, where a varactor diode is placed and total eight varactors (V1-V8) are used. To achieve beam reconfigurability, varactors with a range 0.5-10 pF is selected and tuned.

When the patch is excited with any of the two feeders, EM is coupled from the patch to the parasitic dipoles. If the parasitics and driven patch are on the same layer, only a slight EM coupling will be coupled to the parasitic dipoles as the driven patch mainly radiates in the broadside direction. In this design, the parasitic layer containing the 8-element dipole array is located at 5 mm height over the driven patch. Thus, the parasitic dipoles can absorb more energy from broadside radiation and reradiate it in a certain direction. The radiation pattern of the entire model is the combination of patterns caused by the driven patch and parasitic dipoles.

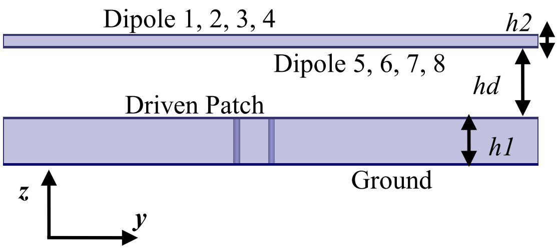


D: Dipole V: Varactor

(a)



(b)



(c)

Fig. 1. Antenna model: (a) top view of first layer (b) top view of second layer and (c) side view of entire model.

As shown in Fig. 1(b), edge 1 and 2 are the radiating edges when the patch is excited through Probe 1. As a result, the parasitic dipoles placed along *x*-axis (D5, D6, D7, D8) absorb little energy and have limited effect to the overall radiation pattern. In such case, in order to change radiation pattern, varactors along *y*-axis (V1, V2, V3, V4) are supposed to be tuned. Thus, beam steering can be done in the phi = 90˚ plane. Through EM software simulations, it is noticed that when a small capacitance value is assigned, the magnitude of the surface current on the dipoles becomes small and the dipole contributes very little to the overall radiation pattern. On the other hand, a large varactor capacitance can result in strong surface current distribution. When probe 1 is excited, large capacitance for varactors V1 and V3 (D1, D3) and small value for varactors V2 and V4 (D2, D4), the active radiators (including driven patch, dipole 1 and dipole 3) together tilt the main beam toward -y direction. Further increase in the capacitance values cause larger tilt angle. For the reverse case, the main beam is tilted toward +y direction. In the same way the radiation can be steered along the x-axis, in the phi = 0˚ plane, by exciting Probe 2 and tuning the varactors (V5, V6, V7, V8).

III. Results

The pattern reconfigurability performances of the proposed antenna are simulated using HFSS for different combinations of the varator's capacitance value. For the ease of control, the 8 varactors are divided into 4 groups: (V1, V3), (V2, V4), (V5, V7), (V6, V8). Varactors are tuned to have the same capacitances to obtain smooth beam steering in both of the phi planes. Table 1 listed six beam steering configurations including the boresight direction. The antenna can tune from -30° to 30° in both phi planes (phi = 90° and phi = 0°).

TABLE I. Six Beam Steering Configurations

Config.	**1**	**2**	**3**	**4**	**5**	**6**
Varactors	**Probe 1**			**Probe 2**		
V1 (pF)	10	10	0.5	0.6	0.6	0.6
V2 (pF)	0.5	10	10	0.6	0.6	0.6
V3 (pF)	10	10	0.5	0.6	0.6	0.6
V4 (pF)	0.5	10	10	0.6	0.6	0.6
V5 (pF)	0.5	0.5	0.5	10	10	0.5
V6 (pF)	0.5	0.5	0.5	0.5	10	10
V7 (pF)	0.5	0.5	0.5	10	10	0.5
V8 (pF)	0.5	0.5	0.5	0.5	10	10
Phi	90°	90°	90°	0°	0°	0°
Theta	-30°	0°	+30°	-30°	0°	+30°

Fig. 2 shows the S11 parameter for configurations 1, 2 and 3, when Probe 1 excited. The antenna resonates at 2.55 GHz with a -10 dB impedance bandwidth of 2.53-2.57 GHz. Because of the symmetry, configurations 1, 3 have the same S11 for all frequency and it is the same for configurations 4 and 6 as well. S11 parameter is stable in all these four configurations and has the same bandwidth. The configuration 2 gives a resonance at 2.67 GHz due to the same capacitance considered for all four varactors, V1-V4. However, it can be tuned to 2.55 GHz and the performances remain unchanged. The configuration 5 exactly follows the configuration 1.

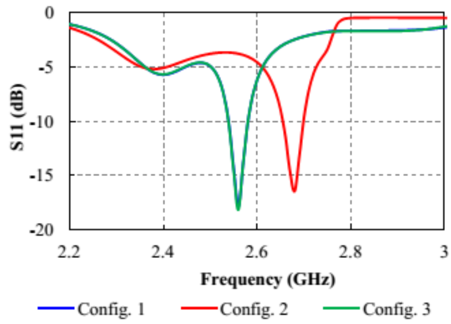


Fig. 2. S11 parameter for configurations 1, 2 and 3.

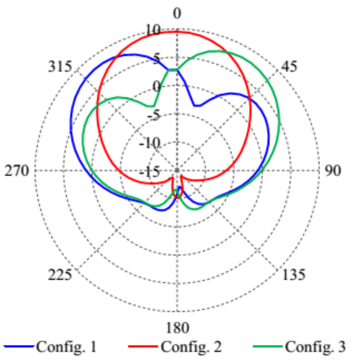


Fig. 3. 2D radiation patterns for configuration 1, 2 and 3 in plane phi = 90°.

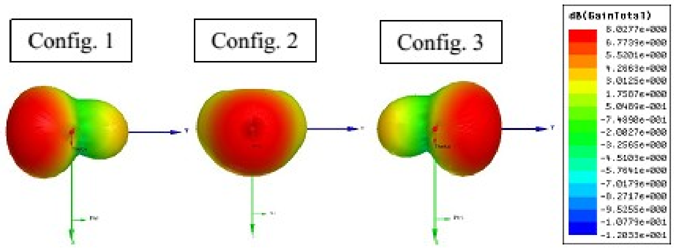


Fig. 4. 3D radiation patterns for configurations 1, 2 and 3.

Fig. 3 depicts the 2D radiation patterns for the configurations 1, 2 and 3. The main beam direction can be within -30° to 30° including the boresight direction. As given in the Table 1, when V1 = V3 = 10 pF and the rest varactors are tuned to 0.5 pF, the beam tilts 30° in the – *y*-axis, in phi = 90° plane. When V2 = V4 = 10 pF and the rest varactors are tuned to 0.5 pF, the beam tilts 30° in the + *y*-axis in the same phi plane. However, when the values are chosen as for the configurations 2 or 5, the antenna radiate in the boresight direction.

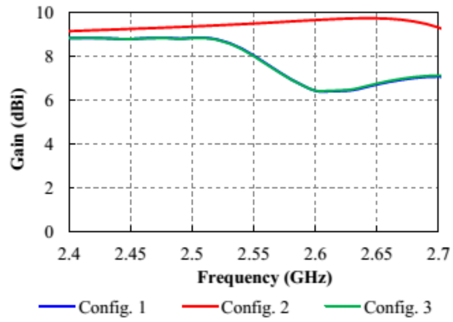


Fig. 5. Peak antenna gain for –y, +y and boresight configurations.

The peak gains of configuration 1, 2, and 3 are shown in Fig. 5. At the resonances, the peak gain is more than 8 dBi for all investigated the configurations. This is a reasonable value of gain for so many terrestrial wireless systems.

IV. Conclusion

A novel design of reconfigurable antenna, which includes a driven patch at one layer and right parasitic dipoles at another top layer, has been presented. The tunability of the beam direction is achieved by adjusting the capacitance of the eight varactors placed in central slots within the dipoles. Six configurations are realized with different combinations of the varactors capacitances. Two coaxial probes, which select the plane of beam steering, are used asynchronously to excite the driven patch. The entire tuning range is from -30° to 30° in the both phi planes, phi = 90° and phi = 0°. The steerable beams have more than 8 dBi gain in all the investigated scenarios. More configurations from the same antenna can be realized by changing the varactors capacitances.

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