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Polarization Switching in Fan-Beam Reflector-Backed Array Antenna

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Abstract—A systematic technique for switching between horizontal and vertical polarizations is introduced. A fan-beam antenna array for base station applications employing a grounded reflector is implemented, and the proposed approach is implemented and validated on it. The antenna array is realized using planar monopole elementary elements against a non-parasitic reflector, which yields a desirable fan-beam pattern. The corresponding 3 dB H-plane beamwidth can be easily adjusted by changing the reflector height. Two versions of the antenna arrays are used to demonstrate suppression of unwanted asymmetrical modes in the current distribution yielding improved cross-polar isolation. The measured H-plane 3-dB beamwidth is approximately 127 degrees at 900 MHz and 124 degrees at 955 MHz. The corresponding side lobe level is almost -11.7 dB and -8.7 dB at 900 MHz, while the back lobe level of -9.3 dB and -11 dB at 955 MHz from measurements. The gain is within the acceptable level in both cases and compared with simulations that possess good agreement. By taking into account the antenna design and manufacturing aspects, such antennas will pave the way to be employed in OFDM reconfigurable antenna applications and Identification Friend or Foe (IFF).

1. INTRODUCTION

Several papers have reported an extended main reflector and a sub-radiator for back lobe suppression, along with the concept of a non-parasitic reflector. A fan-beam antenna is a directional antenna such that it has a beamwidth in one dimension much wider than that in other directions. For example, an antenna with a 3-dB of 120° in the azimuthal plane but only a few degrees in elevation would be considered a fan beam array antenna [1, 2]. Historically, fan beams have been used in radar applications for height finding. More recently, this type of antenna has been adopted for mobile cellular radio because of its ability to have directivity in a particular plane. In this regard, a fan beam array antenna was introduced in [3] for WiMAX application that was designed by the combination of radiating elements, coplanar waveguide (CPW) line, a grounded CPW, and the grounded reflector. This antenna integrated with a bandpass filter can operate at the WiMAX frequency band along with a 50° to 125° wide frequency scanning range. For an indoor cellular application, it is also demonstrated how a fan-beam array antenna could direct the main beam of an antenna from a high wall towards the floor and users. In this regard, a tilted beam array antenna having 360° beam coverage was proposed in [4] for an unmanned aerial vehicle (UAV) radar applications.

It is well known that high gain dish antennas are most suitable for radar applications, whereas dipole array antennas are appropriate for cellular applications. However, they are similar in their strict requirements for low front-to-back lobe ratios, tight beamwidth, and relatively high gains. For radar applications, we need a predominantly narrow band while achieving wider bandwidth in short-range cellular communication. This concludes with the usefulness of methods in antenna design that

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allow better control over the current distribution on radiating elements to support improved impedance bandwidths and directivity [5].

Several papers have reported using antenna arrays with extended main reflectors and sub-radiators [6–11]. The concept of a non-parasitic reflector was also introduced in the literature along with the design of a fan-beam array antenna. In this regard, a reflector antenna array is developed in [12] to create multi-spots coverage. The number of antennas is halved using only two multibeam reflect arrays that can make a complete multisport coverage like conventional four reflector array antennas. The proposed concept is explored based on simulations and validated via experimental measurements.

Similarly, in [13], they designed an antenna array for 5G applications by combining a parasitic patch, a transmission line, semicircle ground structure, T-shaped slots, a parasitic strip, a CPW, and heart-shaped slices. Also, in [14], they presented a low-sidelobe fan-beam array antenna utilizing a non-parasitic grounded reflector. They have employed a six-element conventional monopole using Dolph-Tschebyscheff distribution along with a broadband feed network. This design operates within the frequency band of 1.7 to 2.2 GHz with an advantageous vertical polarization having a sidelobe level (SLL) of almost −26 dB. In [15], the authors introduced a linear array with horizontal polarization in the dual-band frequency ranges 0.8–1.05 GHz and 1.71–2.2 GHz using U-shape non-parasitic reflector concept. While investigating these papers, it is discovered that the control of H-plane 3 dB beamwidths might be obtained by manipulating the ground plane.

The first attempt to utilize the bandwidth extended technique of fractals was proposed in [16] and [17]. Also, the concept of a grounded reflector is investigated in detail in the context of input impedance matching across a relatively wide bandwidth. Similarly, in [18], they proposed a concept of bandwidth enhancement and antenna miniaturization using newly developed structures termed as reactive impedance surface (RIS). Various planar antenna structures like patch and dipole are placed on the corresponding RIS and match their related physical characteristics with the identical antennas over perfect magnetic conductor (PMC) and perfect electric conductor (PEC) [19, 20].

In this paper, the concept of a non-parasitic grounded reflector is established for switching between horizontal and vertical polarizations. An array made up of planar monopole elements fed against a grounded reflector is investigated and analyzed. A grounded reflector can be considered a conventional ground of standing planar monopole antenna rather than a parasitic reflector of the type used in the Yagi-Uda array. The expected null in the z-direction is hidden by the contribution of the anti-symmetrical mode of the ground plane or the overall radiated power of a non-parasitic reflector [18]. It must be noted that this behavior can be changed, and the grounded reflector can be used as a conventional reflector for reducing the back lobe of the array antenna. Therefore, the ground of planar monopole array elements must be inactive with an anti-symmetrical mode that is made by a non-parasitic grounded reflector at the operating frequency.

2. PROPOSED ANTENNA ARRAYS DESIGN

The corresponding schematic diagrams for the two antennas proposed in this paper are shown in Fig. 1. For the construction of both antenna arrays, an FR4 epoxy substrate with a thickness of

Table 1. Dimensions of the proposed antenna arrays (All units are in mm).

Parameter	Value	Parameter	Value
w_1	69	R_1	34.75
l_1	12	w_2	0.7
l_{g2}	29.5	l_{g1}	114.5
l_{s2}	510	l_{s1}	420
s_1	54	l_2	14.65
w_3	3	w_{g1}	75
w_s	120	–	–

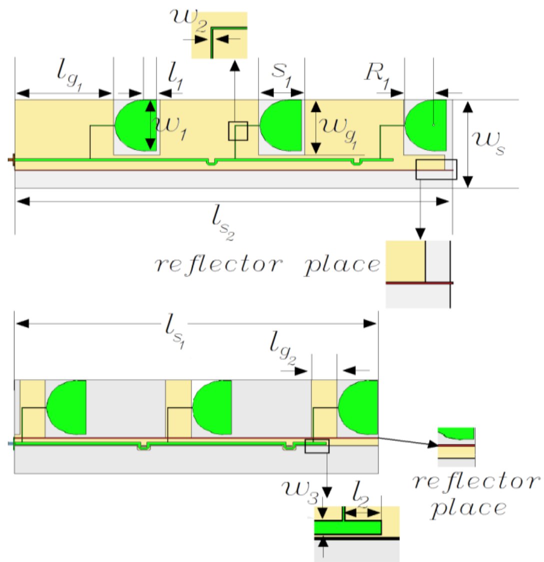

Figure 1. Array schematics (not to scale): Top (Array 1): is the conventional array; Bottom (Array 2): enhanced array.

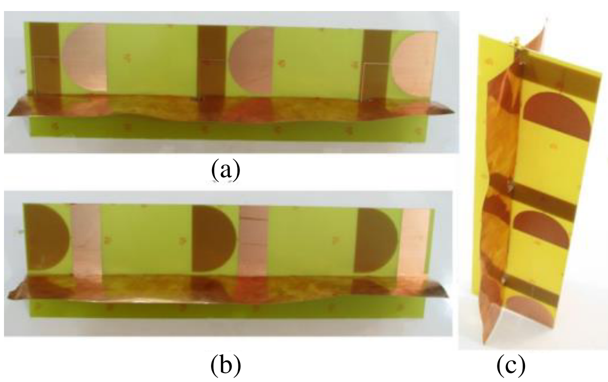

Figure 2. Fabricated proposed modified array antenna: (a) top view, (b) bottom view, (c) perspective view.

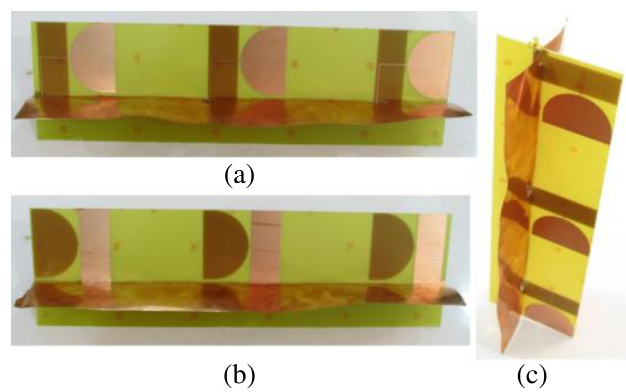

Figure 3. Fabricated basic array antenna: (a) top view, (b) bottom view, (c) perspective view.

1.6 mm, a relative dielectric constant of 4.3, and a loss tangent of 0.02 is used. The reflector for these arrays was made of a copper sheet in the x-y plane perpendicular to the elements. Fig. 1 shows the dimensional diagram for corresponding array 1 and array 2 with a detailed description in Table 1. The fabricated prototypes for the basic antenna array along with top, bottom, and perspective views are shown in Figs. 2(a), (b), and (c), respectively, while the fabricated prototypes for the proposed modified antenna array along with the top, bottom, and perspective views are shown in Figs. 3(a), (b), and (c), respectively.

3. RESULTS AND DISCUSSION

The magnitude of S_{11} (dB) for the basic and proposed antennas taken from simulation and measurements is shown in Fig. 4. It depicts that the measured bandwidth is from 885 to 955 MHz for antenna array 1 and from 780 to 985 MHz for proposed antenna array 2. Array 2 has a much better input impedance bandwidth than array 1. It is also clear from Fig. 4 that simulation and measurements are in good agreement in both array 1 and array 2 cases.

Table 2. Leading key electrical characteristics of the radiation patterns for the modified array antennas.

Frequency	3 dB Beamwidth		Tilt angle at E-plane		Side-lobe Level (SLL)		Back-lob level (BLL) at E-plane	
	HFSS	Measurement	HFSS	Measurement	HFSS	Measurement	HFSS	Measurement
900 MHz	32.5° × 124.0°	33.6° × 127.2°	0.0°	3.6°	−10.1 dB	−11.7 dB	−10.7 dB	−9.3 dB
955 MHz	30.5° × 120.0°	27.6° × 124.2°	−5.0°	−1.2°	−8.7 dB	−9.2 dB	−11.0 dB	−9.3 dB

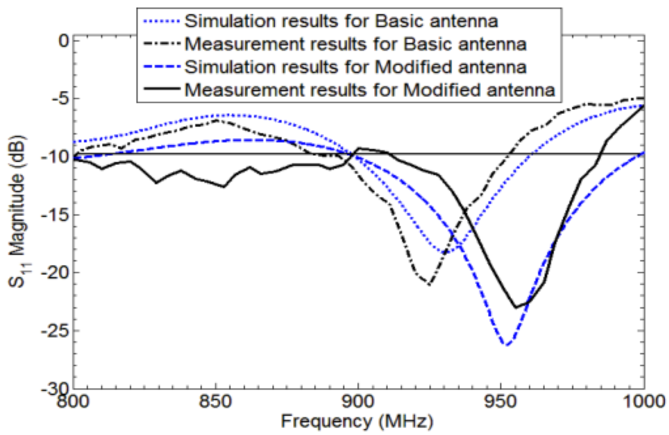

Figure 4. The magnitude of S_{11} (dB) for the basic and proposed antennas both from simulation and measurements.

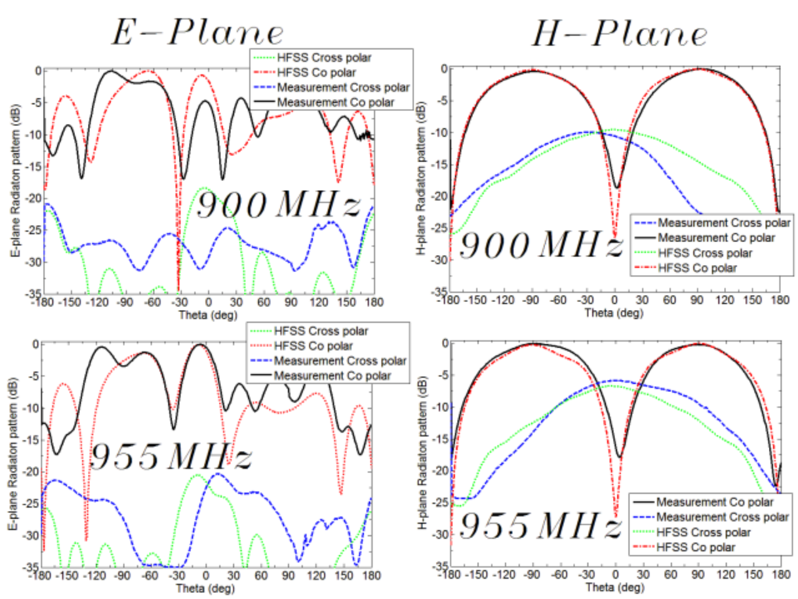

Figure 5. Radiation patterns for antenna array 1: H-plane co-polar pattern has a null at $\theta = 0$ degree. The left plots represent the E-plane characteristics, and the right plots are the H-plane.

Table 2 shows some important leading key electrical characteristics of the radiation patterns for the modified array antennas in a compact manner. This table clearly reveals that back lobe level is considerably reduced and shows that the proposed configuration is superior from the state of the arts. All antenna parameters are mentioned at both operating frequency bands (900 MHz and 955 MHz) from Ansoft HFSS simulations and measurements.

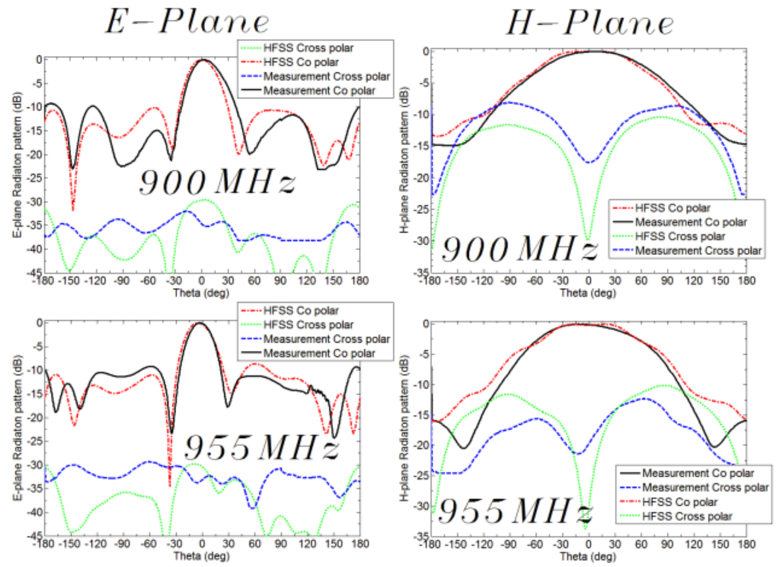

Figure 6. Radiation pattern plots for proposed antenna array 2: H-plane cross-polar pattern has a null at $\theta = 0$ degree. The left plots represent the corresponding E-plane characteristics, and the right plots are the H-plane patterns.

The far-field patterns were measured and simulated for the 900 and 955 MHz operating frequency bands shown in Figs. 5 and 6 for both arrays, respectively. Both figures reveal how polarization is switched from horizontal to vertical by modifying the basic antenna. It is advantageous if users need horizontal or vertical polarization on demand for a specific application and makes it reconfigurable. Also, Table 2 shows pattern characteristics of the modified antenna in simulations as well as measurements. Table 2 reveals the overall radiation characteristics. It is also clear from Table 2 that at a frequency of 900 MHz, the corresponding 3-dB beamwidth is $32.5° \times 124.0°$, and tilt angle at E-plane is 0°, with SLL of -10.1 dB and BLL of -10.7 dB from simulation. The corresponding 3-dB beamwidth is $33.6° \times 127.2°$, and tilt angle at E-plane is 3.6°, with SLL of -11.7 dB and BLL of -9.3 dB from measurements. Similarly, at a frequency of 955 MHz, the corresponding 3-dB beamwidth is $30.5° \times 120.0°$, and tilt angle at E-plane is $-5°$, with SLL of -8.7 dB and BLL of -11 dB from simulation. The corresponding 3-dB beamwidth is $27.6° \times 124.2°$, and tilt angle at E-plane is $-1.2°$, with SLL of -9.2 dB and BLL of -9.3 dB from measurements.

4. CONCLUSION

A systematic technique for switching between horizontal and vertical polarizations is presented and validated on a fan-beam antenna array for base station applications. The concept of a non-parasitic grounded reflector is also developed using a pair of 3-element arrays of planar monopoles. It has been presented how the polarization can be switched in an efficient manner by changing the reflector size in combination with a planar monopole. This whole process ultimately led to a cost-effective reconfigurable array. The conventional planar monopole antenna is used as an array element with an omnidirectional pattern with its 3 dB beamwidth that the grounded reflector height can control. The SLL can be decreased and improved by better feeding network design, and the main lobe can become narrower by employing additional array elements. By taking into account the antenna design-manufacturing aspects, such antennas can be used as a reconfigurable antenna in orthogonal frequency division multiplexing (OFDM) and identification friend or foe (IFF).

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