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Research Article

A Design of Wide Band and Wide Beam Cavity-Backed Slot Antenna Array with Slant Polarization

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Design of antenna array under the limitation of restricted size is a challenging problem. Cavity-backed slot antenna is widely used because of its advantages of small size, wide band, and wide beam. In this paper, a design of wide band and wide beam cavity-backed slot antenna array with the slant polarization is proposed. To obtain wide band and wide beam with limited size, the inverted microstrip-fed cavity-backed slot antenna (IMF-CBSA) is adopted as the element of 1×4 antenna array. The slant polarized antennas and their feeding networks are adopted because of their simple structures. The performance of the proposed antenna array is verified by the simulations and experiments. The measured VSWR < 2 bandwidth is 55% at the center frequency 21.8 GHz, and the gain is larger than 12.2 dB. Experimental results demonstrate that the proposed design achieves wide band and beam with the size of 68 mm × 56 mm × 14.5 mm.

1. Introduction

Slot antennas have advantages of low-profile, light weight, and ease of integration [1, 2]. The cavity-backed slot antenna (CBSA), where the slot is backed with rectangular cavity, achieves unidirectional radiation [3–5]. The CBSA can be fed by probe [5], metal waveguide, substrate integrated waveguide (SIW) [6], and microstrip [7, 8]. With the use of printed circuit board, the structure of the SIW and microstrip is simpler than the probe and metal waveguide. The size of microstrip is smaller than the SIW. Therefore, the microstrip-fed CBSA (MF-CBSA) has simple structure and small size.

The bandwidth of the MF-CBSA element depends on the parameters of the slot. By the slot design, the slot antennas can have wider band than patch antennas. In general, the wide-slot MF-CBSA has larger bandwidth than the narrow-slot MF-CBSA [9, 10]. For example, the bandwidth of the MF-CBSA in [10] achieves up to 35%. The inverted microstrip-fed CBSA (IMF-CBSA) has better performance on the gain and bandwidth than the MF-CBSA [11]. For example, the bandwidth of the IMF-CBSA in [11] is 43% which is larger than that of the MF-CBSA in [10].

Though the IMF-CBSA element has wide beam, the beam widths of the IMF-CBSA arrays in [11, 12] are not enough large because they are plane arrays. To obtain the wide beam array, the element should have wide beam and the array should be a linear array. The purpose of this study is to design an antenna array with the wide band, wide beam, high gain, and slant polarization.

Though the IMF-CBSA arrays in [11, 12] obtain wide band and high gain, the polarization is horizontal polarization and circular polarization, respectively. The slant polarized and circular polarized antennas can receive both vertical and horizontally polarized waves. The slant polarized antennas and their feeding networks are simpler than those circular polarized antennas [13]. The slant polarization can be obtained by two methods: the simultaneously excited horizontal and vertical polarized element or rotating horizontal or vertical polarized element [14–17]. The antenna and feeding network designed by the second method are simpler than those of the first method.

In this paper, a design of wide band and wide beam cavity-backed slot antenna array with the slant polarization is proposed. To obtain wide band and wide beam with limited

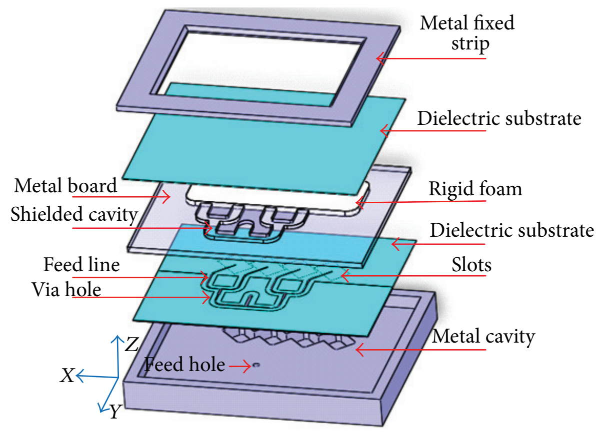

FIGURE 1: 3D structure model of IMF-CBSA array.

size, the inverted microstrip-fed cavity-backed slot antenna (IMF-CBSA) is adopted as the element of 1×4 antenna array. The 45° slant polarization is achieved by slanting the IMF-CBSA. The good performance of the proposed antenna array is verified by the simulations and experiments. The measured VSWR < 2 bandwidth is 55% at the center frequency 21.8 GHz, and the gain is larger than 12.2 dB.

2. Structure of Slant Polarized IMF-CBSA Array

2.1. Structure of IMF-CBSA Array with Feeding Network. The structure design of the IMF-CBSA array with the feeding network is illustrated in Figure 1. The metal strips are added to fix the structure. The feeding network is designed and added. The exciting port of the array is a coaxial probe. Through a converting structure from the coaxial probe to the shielded microstrip line, the electromagnetic wave is transmitted to the shielded microstrip line. A 1-4 power divided network based on the shielded microstrip line is designed to feed four antenna elements with the equal amplitude and phase. The whole size of the array structure is 68 mm × 56 mm × 14.5 mm.

Figure 2 shows a block diagram of the feeding network configurations. As shown in Figure 3, the coaxial probe and the 1-4 power divider based on the shielded microstrip line are regarded as Region I. Region II is the converter from the shielded microstrip line to the microstrip line.

2.2. Slant Polarized IMF-CBSA Element Design. The configuration of the slant polarized IMF-CBSA element is shown in Figure 4. From the top to the bottom, there are four layers including a dielectric substrate covered on the top layer, a rigid foam layer, a dielectric substrate with a feeding line on the upper surface and a slot on the lower surface, and a back cavity on the bottom layer. The dielectric substrate is Rogers 5880 with the relative permittivity $\varepsilon_r = 2.2$ and the thickness 0.254 mm. The coordinate system is also shown in Figure 4. As shown in Figure 1, the antenna is rotated to have 45° slant polarization. The detailed geometrical parameters of the slant polarized IMF-CBSA element are listed in Table 1. These parameters are determined through the optimization process of simulations.

TABLE 1: Geometrical parameters of the slant polarized IMF-CBSA element.

Symbol	Value (mm)	Description
l_s	8.4	Slot length
w_s	5.6	Slot width
l_c	9.0	Cavity length
w_c	6.2	Cavity width
h_c	3.4	Cavity depth
t	0.254	Dielectric substrate thickness
h_p	1.5	Rigid foam thickness
s	4.8	Distance from the feeding line to the cavity short edge
l_m	2.95	Feed line extension from the cavity long edge
w_m	0.3	Width of the microstrip line

The slant polarized IMF-CBSA is simulated to verify the performances. The voltage standing wave ratio (VSWR) of the antenna is shown in Figure 5(a), where the bandwidth of VSWR < 2 at the center frequency 23.45 GHz is about 61%. The radiation pattern at 22 GHz is shown in Figure 5(b). The maximum gain is 5.6 dB. At the XOZ-plane (i.e., $\varphi = 0^{\circ}$ plane) and YOZ-plane (i.e., $\varphi = 90^{\circ}$ plane), the 3 dB beam width is 91° and 97°, respectively. The maximum radiation direction is not perfectly perpendicular to the plane of the antenna (XOY-plane). This is because the feeding line is unsymmetrical along the long side and wide side direction of the slot. By adjusting the location of the feeding line, well radiation pattern direction is achieved.

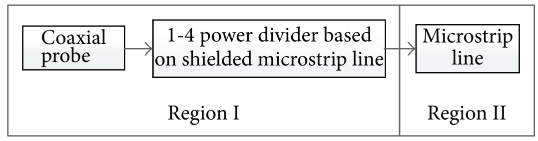

Figure 2: Block diagram of the feeding network configurations.

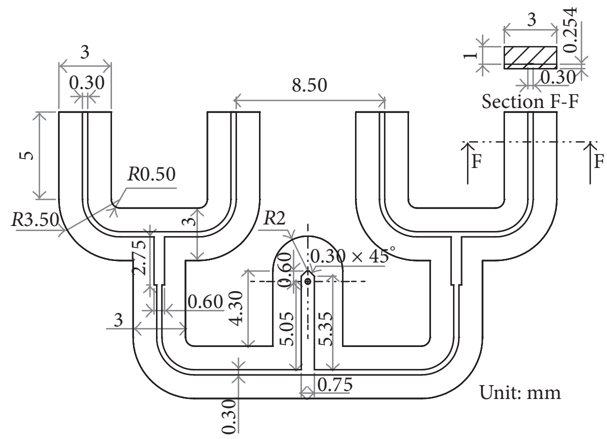

Figure 3: Structures of Region I in the feeding network.

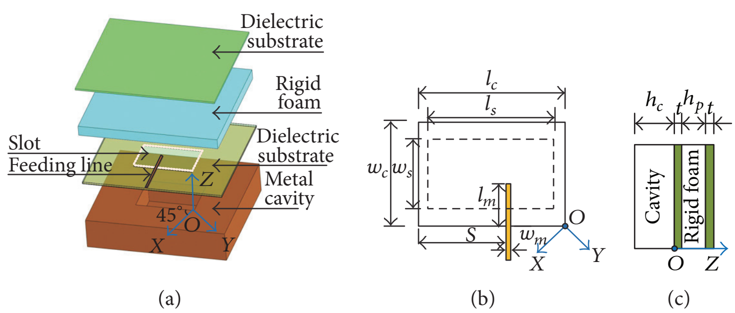

Figure 4: Configuration of the slant polarized IMF-CBSA element. (a) 3D model; (b) top view; (c) side view.

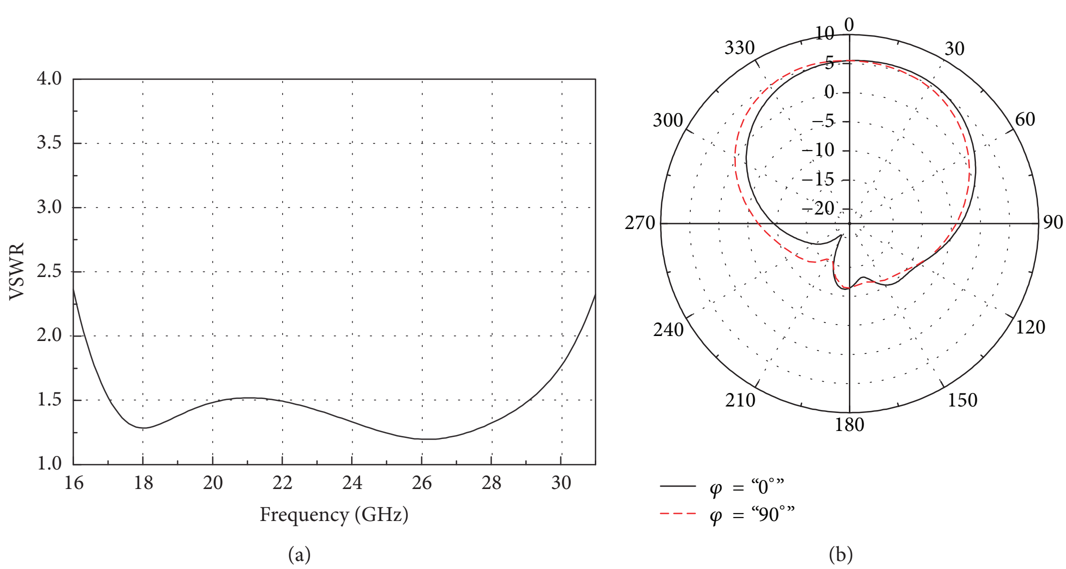

Figure 5: (a) VSWR of slant polarized IMF-CBSA element obtained in the simulation; (b) radiation pattern of slant polarized IMF-CBSA element obtained in the simulation.

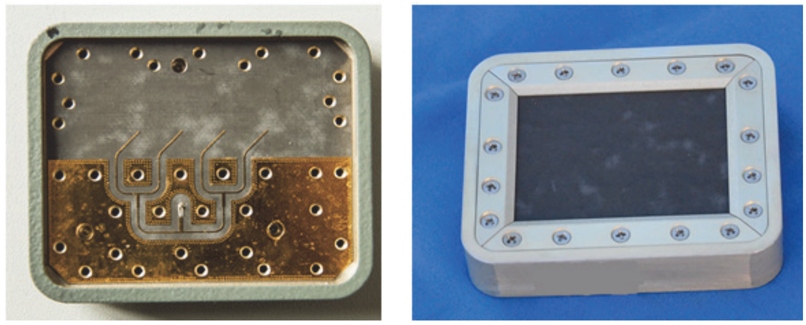
(a) (b)

Figure 6: Photograph of the fabricated IMF-CBSA array. (a) The unassembled product; (b) the final product.

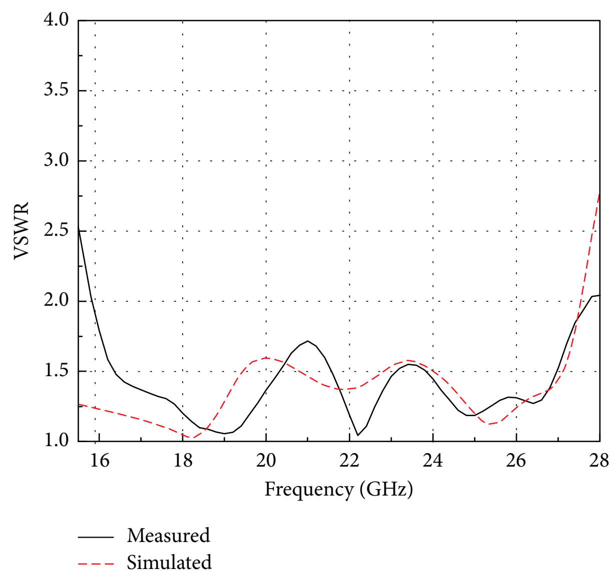

Figure 7: Simulated and measured VSWR of IMF-CBSA array.

3. Experimental Results and Discussions

The photograph of fabricated IMF-CBSA array is shown in Figure 6. Both the simulated and measured VSWR for the IMF-CBSA array are presented in Figure 7. For VSWR < 2, the measured frequency ranges from 15.8 GHz to 27.8 GHz. Thus, the bandwidth of IMF-CBSA array is about 12 GHz, and the relative bandwidth is 55% at the center frequency 21.8 GHz. From Figure 7, we can observe that the simulated and measured performance achieves good coherence. However there is a little difference at 15.5 GHz and 28 GHz. This is because the simulation model does not have fixed screws and the via holes of shield microstrip line on the PCB adopt metal wall to reduce calculated amount.

Figure 8 shows the simulated and measured radiation patterns in XZ-plane and YZ-plane at 18 GHz, 22 GHz, and 26 GHz. From Figure 8, we can observe that the measured radiation patterns show good coherence with the simulated radiation pattern. The measured values of the beam width and the gain are listed in Table 2. At YZ-plane, the radiation pattern has wide beam which is larger than 59.1°. The maximum gain is more than 12.2 dB within the whole band. The radiation and aperture efficiencies are 86.8% and 91.8% at 22 GHz, respectively.

Table 2: Measured beam width and gain of IMF-CBSA array.

Frequency (GHz)	Beam width (°)		Gain (dB)	
	$\varphi = 0°$	$\varphi = 90°$	$\varphi = 0°$	$\varphi = 90°$
18	24.3	59.1	12.20	9.98
22	21.3	84.3	13.46	9.67
26	18.3	84.3	13.11	10.37

To analyze the performance of feeding network, the feeding network simulation is conducted and the corresponding VSWR performance is shown in Figure 9. For Region I shown in Figure 2, the frequency of VSWR < 2 ranges from 15.5 GHz to 28.5 GHz. For Region II shown in Figure 2, the VSWR value is below 1.07 in this whole band. From the results in Figure 9, we conclude that feeding network achieves good performance.

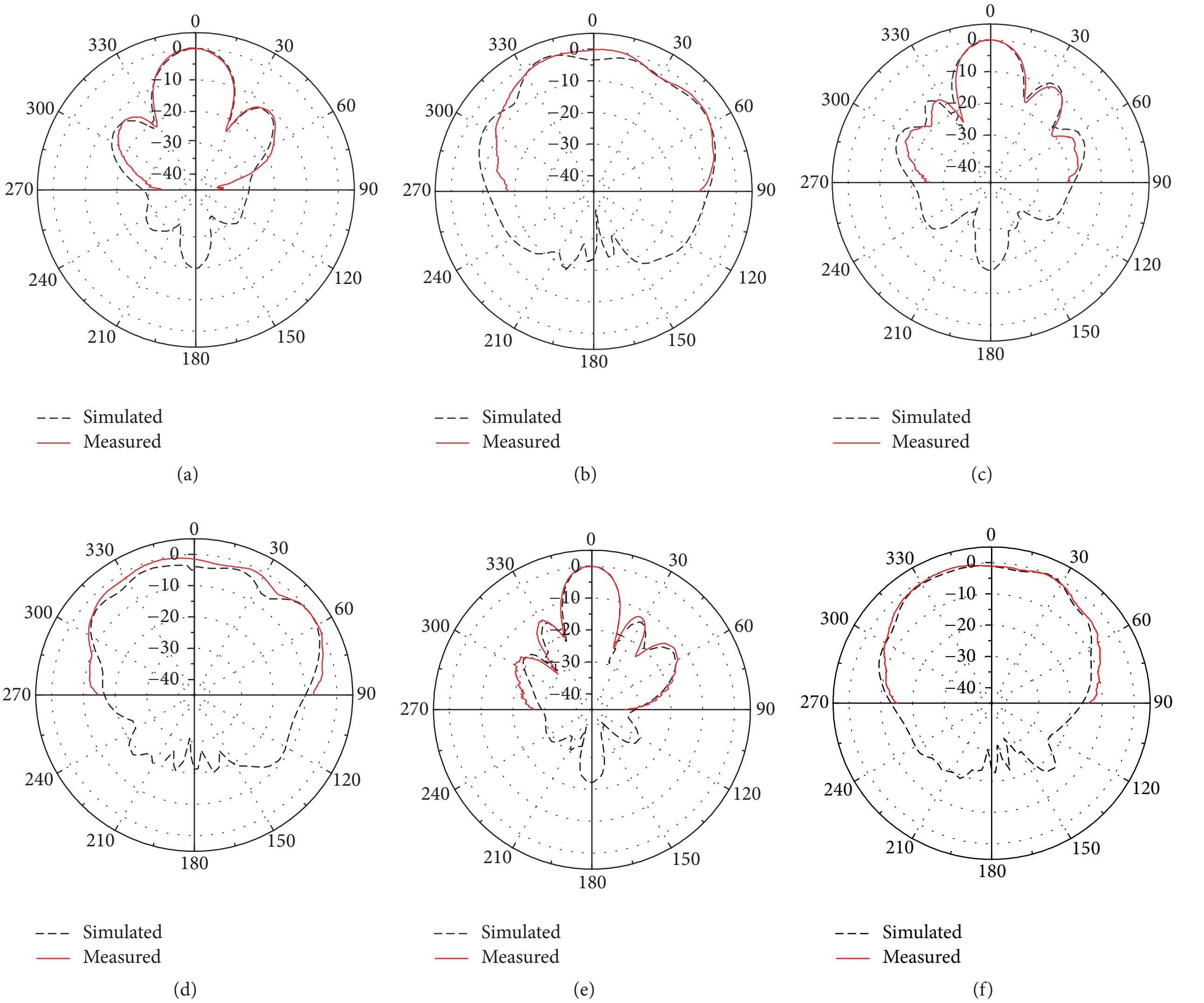

Figure 8: Simulated and measured radiation patterns of IMF-CBSA array in XZ-plane ($\varphi = 0^\circ$) and YZ-plane ($\varphi = 90^\circ$): (a) 18 GHz in XZ-plane; (b) 18 GHz in YZ-plane; (c) 22 GHz in XZ-plane; (d) 22 GHz in YZ-plane; (e) 26 GHz in XZ-plane; (f) 26 GHz in YZ-plane.

The simulated radiation pattern of the antenna array without the feeding network is also discussed. The configuration of the 1 × 4 IMF-CBSA array without feeding network is shown in Figure 10. In order to obtain the 45° slant polarization, each antenna element has a 45° rotation around the z-axis. To avoid producing grating lobe and reduce the mutual coupling, the distance d_e between antenna elements is chosen to be 8.5 mm after the optimization process of simulation.

The simulated performance of the antenna array without the feeding network is shown in Figure 11 and Table 3. In the $\varphi = 90^\circ$ plane within the whole band, the gain of the array achieves at least 10.6 dB, and the 3 dB beam width of the array achieves at least 84.6°. The S-parameters of the IMF-CBSA array without feeding network are shown in Figure 12. The S-parameters of each port are less than −20 dB; thus the mutual coupling between the elements is acceptable.

Table 3: Beam width and gain of the IMF-CBSA array without feeding network obtained in the simulation.

Frequency (GHz)	Beam width (°)		Gain (dB)	
	$\varphi = 0^\circ$	$\varphi = 90^\circ$	$\varphi = 0^\circ$	$\varphi = 90^\circ$
18	24.9	111.2	10.62	10.61
20	22.9	109.7	10.90	10.96
22	21.4	102.0	11.64	11.79
24	19.5	94.1	12.52	12.55
26	18.0	84.6	13.12	13.31

4. Conclusion

A wide band and wide beam CBSA array with the slant polarization is proposed and investigated in this paper. The IMF-CBSA is chosen as the element of array to obtain the

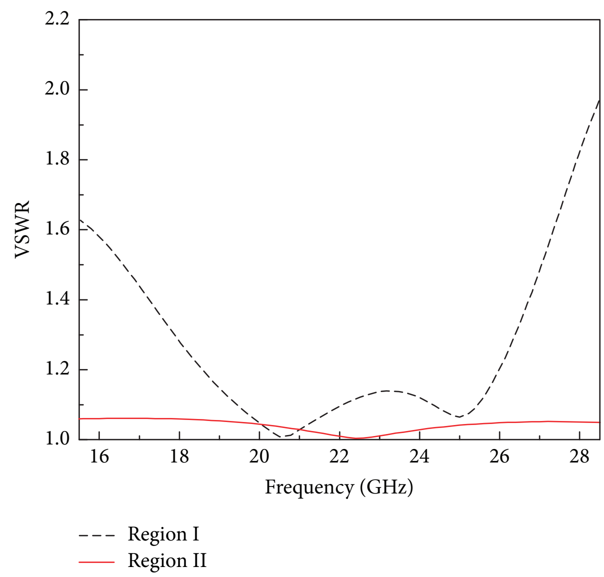

FIGURE 9: VSWR of feeding network in the simulation.

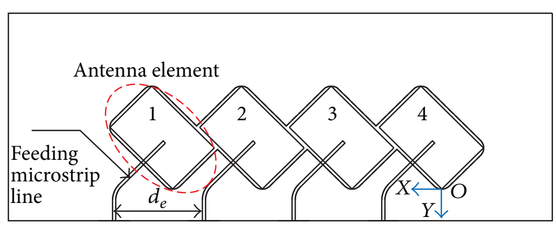

FIGURE 10: Configuration of the 1 × 4 IMF-CBSA array without feeding network.

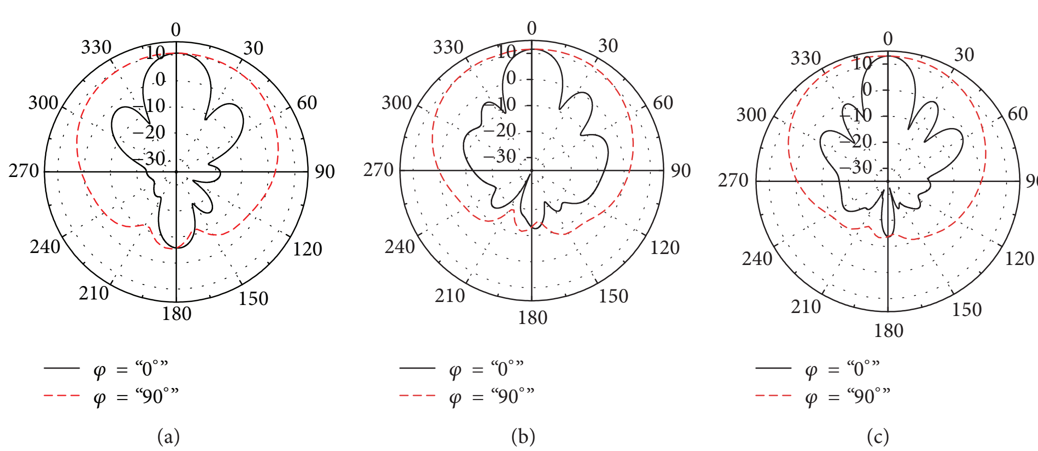

FIGURE 11: Radiation pattern of the IMF-CBSA array without feeding network obtained in the simulation: (a) 18 GHz; (b) 22 GHz; (c) 26 GHz.

wide band and wide beam. The 45° slant polarization is achieved by slanting the IMF-CBSA. The antenna array is simulated, fabricated, and tested. The measured VSWR < 2 bandwidth is 55% (15.8–27.8 GHz) at the center frequency 21.8 GHz. The gain is larger than 12.2 dB. It exhibits wide beam and slant linear polarization with small size of 68 mm × 56 mm × 14.5 mm. The experimental results also demonstrate that the measured radiation patterns are coherent with the simulated radiation patterns.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

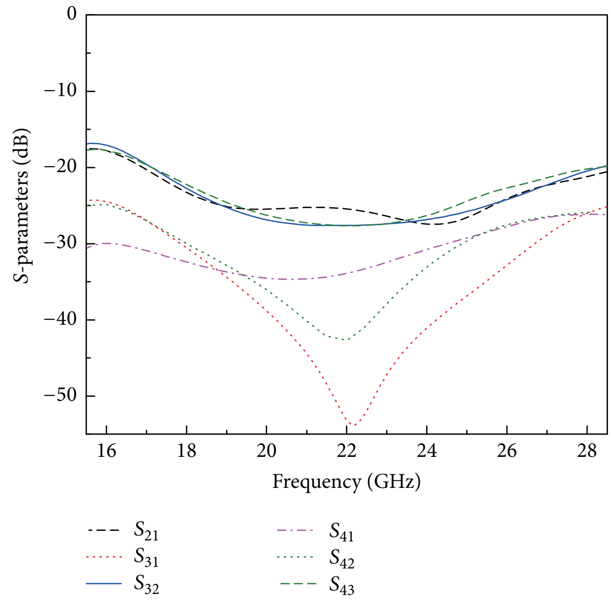

Figure 12: S-parameters of the IMF-CBSA array without feeding network.

Acknowledgments

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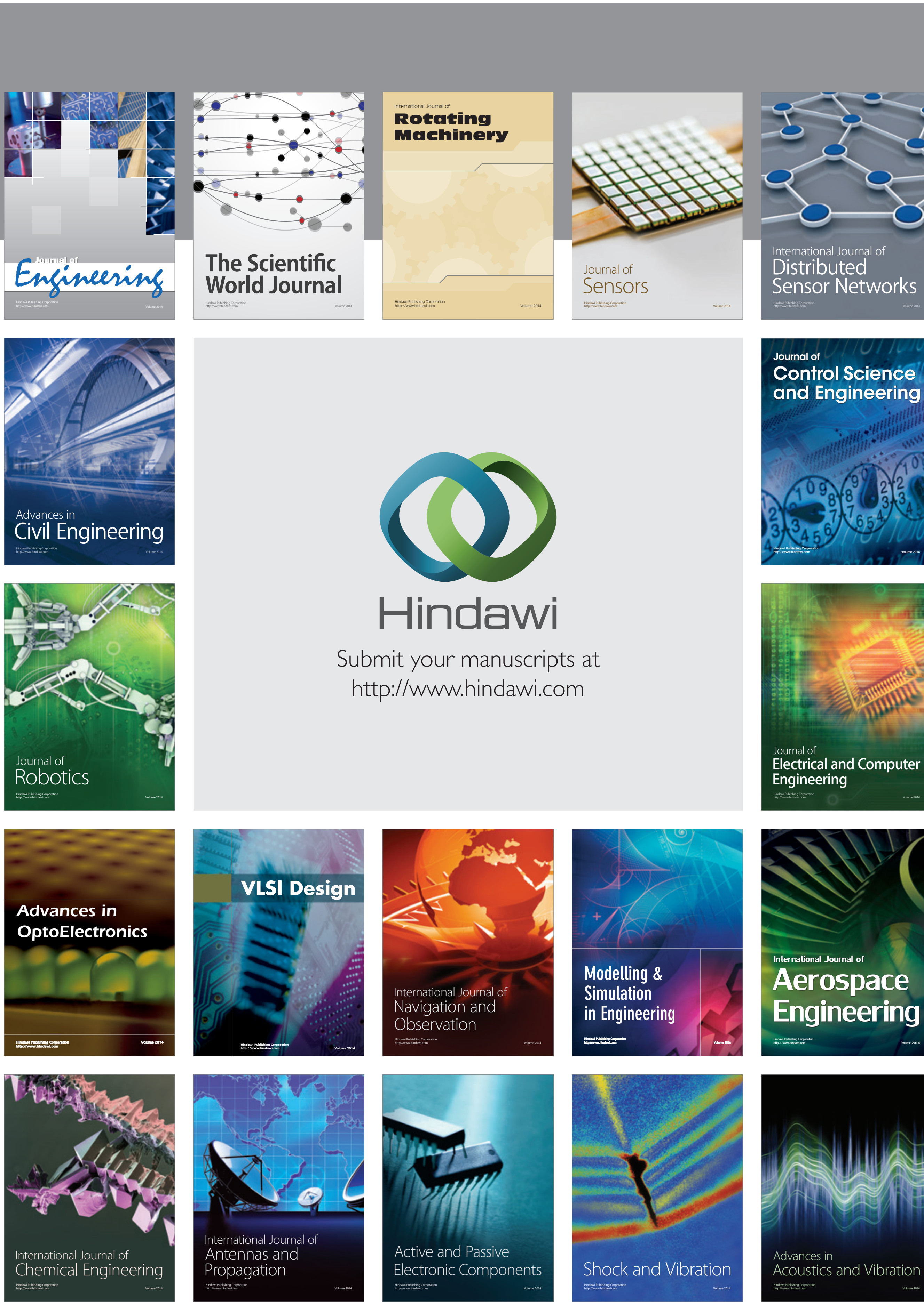
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