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A Wideband Open-Slot Antenna with High Front-to-End Ratio

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Abstract

A new design of open-slot antenna with a high front-to-back (F/B) gain ratio is proposed in this work. In order to enhance unidirectional radiation characteristics of the open-slot antenna, a two-element array and a pair of symmetrical notched slits are utilized. The two-element array achieves a power combination and increases the front-endfire radiation gain. The pair of symmetrical slits acts as a power reflector, which suppresses the backward radiating power. In addition, three arrays of eight-element metal strips are added and used as a power director so that the forward power and the F/B ratio of the open-slot antenna can enhance. From the measured results, the proposed antenna demonstrates a F/B ratio of 22.3 dB and possesses superior unidirectional radiation performance.

Keywords : open-slot antenna, antenna array, front-to-back ratio, unidirectional radiation.

1. Introduction

With the rapid development of wireless communication systems, the antennas with the low cost and the compact size are in demand for various applications, such as the wireless local area network (WLAN). The monopole slot antenna has received much attention due to its easy impedance matching, compact size, low profile and light weight, and good radiation efficiency. A moderate impedance bandwidth and omni-directional radiation have been provided for the monopole slot antenna by a quarter-wavelength open slot cut in the finite ground plane, and the devices being fed by a microstrip transmission line [1-4]. In [5], a unidirectional monopole slot antenna with a front-to-back ratio of 18.29 dB at 2.4 GHz has been demonstrated. The techniques of using a stub-protruded feeding line, inserting two symmetrical stubs into the radiating slot, adding an upper finger, changing ground geometry and etching two asymmetrically vertical slits, can effectively enhance the impedance bandwidth and the front/back ratio in the operated frequency band.

This paper proposes another topology to enhance the F/B ratio of the monopole slot antenna by utilizing a two-element array structure. The impedance-bandwidth increases because of a low quality factor. A transmission-line phase shifter of 180 degree is embedded in a T-junction power divider in order to derive a sum radiation pattern, a power-combining pattern. Like to the technique in [5], a pair of an open uniform slit, like a power reflector, is etched in the upper and lower edge of the ground plane such that the backward radiation can be suppressed. Furthermore, three arrays of eight-element metal strips, which act as a power director, are placed in the front of the antenna for the purpose of high radiation directivity. The mechanisms of the proposed techniques are analyzed by presenting comparisons of the surface current distribution in the ground plane.

2. Antenna Design

The geometrical configuration and coordinate system of the proposed microstrip-fed unidirectional monopole slot antenna array are illustrated in Fig. 1. It comprises conventional monopole slot antennas, a slotted ground plane and three arrays of 8-element metal strips. The antenna are printed on a circuit board material such as FR-4 substrate (ε_r = 4.4, tan δ = 0.02, h = 1.6 mm), and fed by a high-impedance feeding line of width 0.7 mm. The design parameters of the proposed antenna are listed in Table I. Two monopole slots are cut at the right edge of the finite ground plane of a microstrip structure. Its length, S_L = 20 mm is approximately a quarter guided wavelength at 2.4 GHz. A T-junction power divider is used to provide equal power for injecting into the antenna elements. In addition, Two antenna elements are separated by one half of the free-space wavelength in order to yield a desired directivity. The open slit is similar to that of the power reflector and changes the traveling direction of the surface currents flowing along the upper and lower edges of the ground plane from the *y*-axis to the *x*-axis. The above techniques can decrease the back radiation resulting from the backward surface wave. In order to achieve good radiation in the end-fire direction, three arrays of three-element metal strips, are placed in front of the radiating notch antenna.

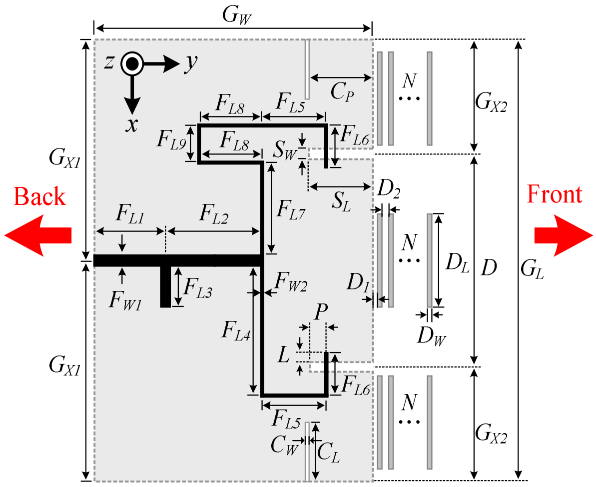


TABLE I : Parameters of the Antenna

Parameters	(mm)	Parameters	(mm)
G_L	150	F_{L8}	17.65
G_W	100	F_{L9}	5.7
S_L	20	F_{W1}	3
S_W	3	F_{W2}	0.7
G_{X1}	75	L	2.75
G_{X2}	43.75	P	5
D	62.5	C_L	20
F_{L1}	41.2	C_W	1
F_{L2}	23.8	C_P	20
F_{L3}	7.6	D_1	1
F_{L4}	38.15	D_2	1.5
F_{L5}	20	D_L	32
F_{L6}	12.65	D_W	1
F_{L7}	32.45	N	8

Figure 1 : Geometrical configuration and coordinate system

3. Results and Discussion

A comparison of the simulated radiation patterns of the single-slot antenna and the two-element slot antenna array at 2.4 GHz is shown in Fig. 2. Due to the array topology, the radiation pattern of the *xy*-plane of the slot antenna array shows a good directivity. The F/B ratio in the +*y*-axis is effectively enhanced from 3.12 dB to 11.67 dB.

The distributions of the simulated surface current density and vector current component on the ground plane for the antenna array with and without the slits at 2.4 GHz are shown in Fig. 3. When the slits are embedded, the current densities at the longitudinal edges of the ground plane are reduced, and then the back lobe is suppressed. Table II lists the simulated results of the gain and F/B ratio for several types of the open-slot antenna, including the single slot, the 2-element array and the arrays with the two slits of different positions. As observed in the results, when the better slit's position (C_p) is 0.25 λ, the back radiation in the -*y*-direction is effectively suppressed approximately by 2.71 dB, compared with the array without the slits.

Table III shows the variation in the simulated gain and F/B ratio of the slit array without and with the metal strips in the front of the radiating open slot. Because of the increase of the radiating power in the end-fire direction, which results from the electromagnetic coupling between the ground plane and the metal strips, the front gain at the +*y*-axis enhances and the back radiation is apparently decreased with the increase in the number (N) of the strip elements. Fig. 4 is the variation of the current density on the source and the strip elements. It is shown that the current density significantly decays and becomes stable when the element number (N) is 5. As conclusion, it is predicted that the F/B ratio will slightly affected if N is larger than 8. Fig. 5 shows the measured reflection coefficients (S_{11}) of the four cases of the open-slot antenna, which are the conventional single-slot antenna, the 2-element slot array, the array with the slits, and the slit array with the strip director (proposed). In our experiment, the impedance matching condition of the open-slot antenna is slightly affected by embedding the two slits and placing the strip arrays. The measured radiation patterns in the three cut planes of four antenna topologies are shown in Fig.6. In accordance to the results, for the proposed antenna, the main beam in the end-fire direction becomes sharper and the 3-dB beamwidths in the *xy*- and *yz*-planes reduce.

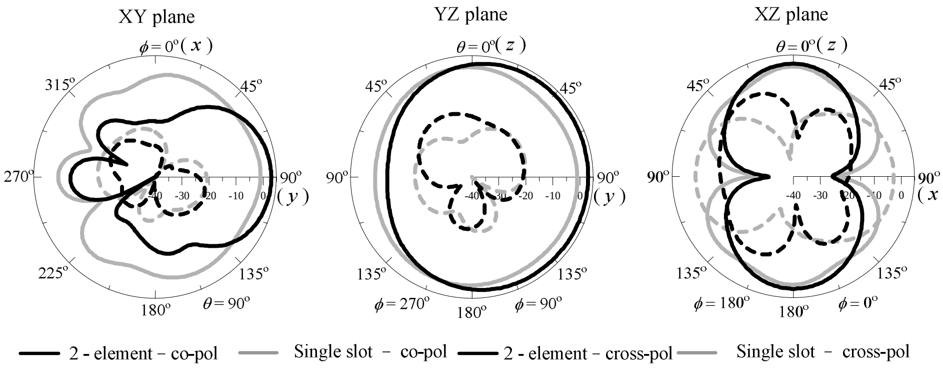
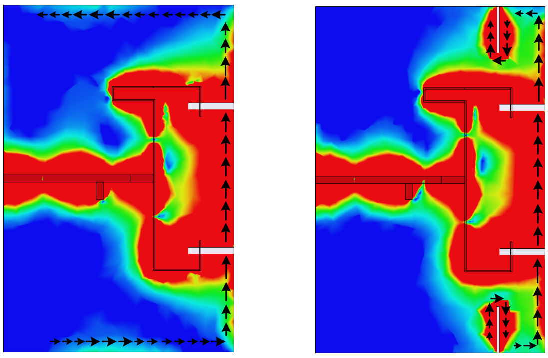


Figure 2 : Comparison of the simulated radiation patterns of the single slot and the two element slot antenna at 2.4GHz



(a) (b)

Figure 3 : Distributions of the simulated surface current density of the array with and without the slits at 2.4 GHz: (a) without slits (b) with slits.

TABLE II : Two-element array and the arrays with the slits of different positions

Parameters \ Case			Single slot	2 - element	With slits (slits position C_p)				
					0.125	0.388	0.250	0.313	0.375
xy-plane	Gain (dB)	+ y	-0.97	3.01	4.04	4.14	4.37	3.25	3.17
		- y	-4.09	-8.66	-11.31	-10.68	-11.37	-11.23	-10.29
	F/B ratio		3.12	11.67	15.35	14.82	15.74	14.48	13.46
xz-plane	Gain (dB)	+ z	0.67	1.72	1.52	1.56	1.78	1.46	1.70
		- z	0.08	1.57	1.19	1.27	1.46	1.42	1.55

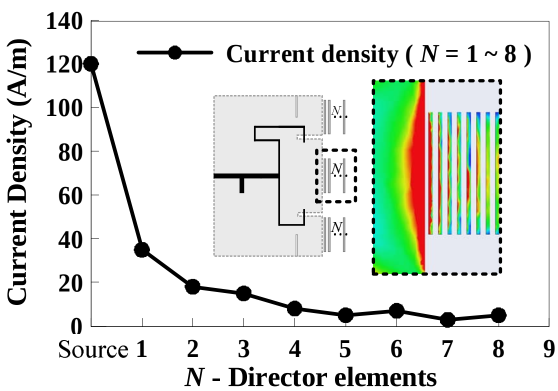


Figure 4 : Variation of the current density on the source and the strip elements.

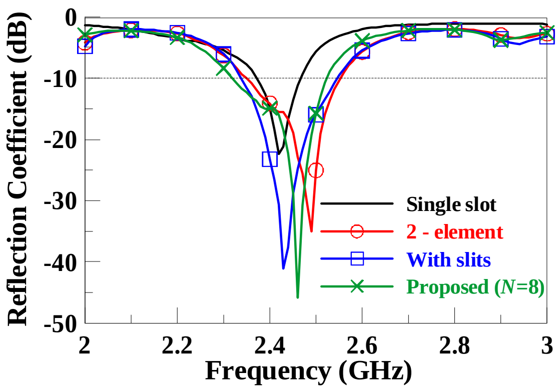


Figure 5 : Measured reflection coefficients (S_{11}) of four antennas topologies.

TABLE III : Gain performance of the array without and with the metal strips of different elements.

Parameters \ Case			No strip	With strips (*N* = 1 ~ 8)							
				N = 1	*N* = 2	*N* = 3	*N* = 4	*N* = 5	*N* = 6	*N* = 7	*N* = 8
xy-plane	Gain (dB)	+ y	4.37	4.74	4.87	5.06	5.27	5.68	5.78	6.06	6.12
		- y	-11.37	-10.07	-10.31	-10.78	-11.17	-13.84	-14.35	-17.19	-24.68
		F/B ratio	15.74	14.81	15.18	15.84	16.44	19.52	20.13	23.25	30.08
xz-plane	Gain (dB)	+ z	1.78	0.43	-0.09	-0.76	-1.49	-2.42	-3.54	-4.93	-5.69
		- z	1.46	0.57	0.16	-0.42	-1.17	-1.91	-2.99	-4.35	-4.97

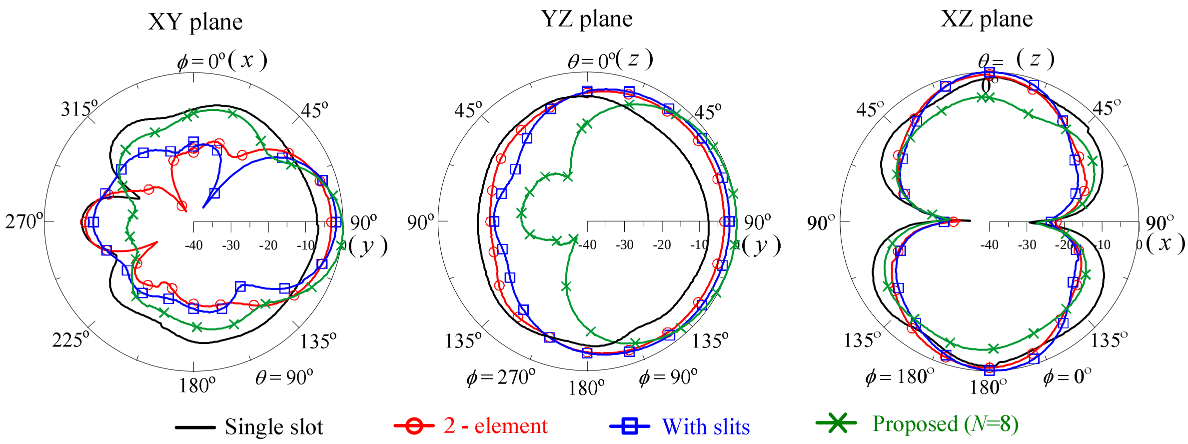


Figure 6 : Measured radiation patterns in the three cut planes of four antennas topologies.

4. Conclusion

In this paper, we demonstrate a design procedure of a unidirectional open-slot antenna structure and the antenna has a good end-fire radiation capability. The array topology with out-of-phase feeding ports can enhance the impedance bandwidth and the front-to-back ratio. The technique of embedding slits in the ground plane achieves an improvement of suppression of the back radiation. By adding a power director in the front of the antenna, the power radiating in the end-fire direction becomes strong. Therefore, the front-to-back ratio of the antenna also increases. The proposed antenna structure may be utilized as a candidate of the unidirectional radiation system.

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