Gain incremental binomial array antenna with ground embedded ring-sector slots

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Abstract

A single-feed circularly polarized (CP) microstrip binomial antenna array with asymmetric ring-sector two-pair slots embedded on the ground plane for gain increment is presented in this paper. The binomial feed network is simply achieved using the annealing technique. Input port is placed at the one side of array elements. This unequal power divider is composed of quarter and three quarter wave transformer. From the binomial structure and ground embedded slots, despite FR4-substrate with low radiation efficiency, high antenna gain can be obtained because the ground embedded slot can increase the radiation efficiency by decreasing the quality factor of a microstrip antenna and asymmetric ring-sector two-pair slots on the ground plane can easily increase an antenna gain. The antenna gain and CP performance can be adjusted by the ring-sector slot size. Details of the binomial feed network and antenna design are described. The performance of the proposed antenna has been analyzed.

1. INTRODUCTION

It is well known that microstrip patch antennas are widely used in military and modern communication systems because of low profile, light weight, and easy manufacturability. However, conventional single patch antennas have major weakness of low gain and directivity. Several gain enhanced microstip antennas have been reported with parasitic patch [1], photonic bandgap (PBG) structures [2] and a slotted ground plane [3]. Generally, for achieving high gain and directivity in microstrip antennas, linear or planar antenna arrays are widely used. Among these antenna arrays, binomial array with low side-lobe level is very suitable in many modern communication systems exposed to many complex noise signals by multi-path fading. But, the design of feed network for binomial array is complicated and need the large area in the antenna system. In this paper, binomial array with a simple and compact binomial feed network using simulated annealing technique is used. Simulated annealing technique is applied to many array applications, such as the synthesis of arrays in order to reduce the peaks of side lobes by acting on the elements' positions and weight coefficients [4]. Also, for appropriate phase-shifting and power splitting, it is used in planar arrays [5]. To increase antenna gain, asymmetric ring-sector two-pair slots embedded on the ground plane are used at the location below the radiating patch. Annular ring-sector ground embedded slots is also operated as perturbation segment to produce circularly polarized (CP) characteristic. In the microstrip patch antenna, many works using various types of perturbation segment for CP operation have been performed [6, 7]. Among others, CP microstrip patch antenna using annular slot is widely used in many application [8].

In this paper, a binomial array antenna with a feed network used simulated annealing technique and with asymmetric ground embedded ring-sector slots is presented.

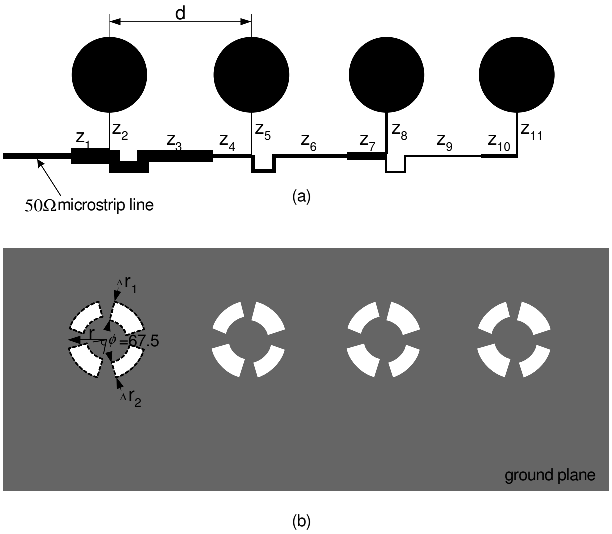


Fig. 1: Geometry of the proposed binomial array. (a) Top view. (b) Bottom view of binomial array

2. DESIGN PROCESS

A. *Binomial feed network design*

Fig. 1 shows the binomial array with ground embedded slots and the binomial feed network terminated with the load impedance of R_L = 112.4 Ω. In Fig. 2 the symbols of impedances of quarter and three quarters wave transformer length are shown. R_L is the same impedance as the input

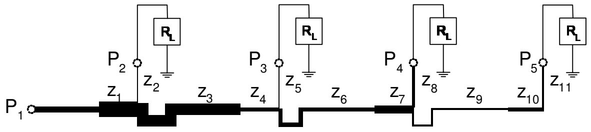


Fig. 2: Binomial feed network

impedance of radiating element with ground embedded slots. Input impedance is 50 Ω. The total ground size is 280 × 110 mm^2. This feed network is fabricated on FR4-substrate with thickness of 1 mm. For finding the solution within the limitation of fabrication, the maximum line impedance is set to be 120 Ω. Using simulated annealing algorithm, the appropriated values are listed in Table 1. The center frequency is 2.54 GHz in this case. Because of a bend type transmission line, little difference is found between simulated annealing and real values. To obtain in-phase at all ports except input port and the distance of binomial array elements with less than $\lambda_g / 2$, three quarter wave transformer is used, such as Z_3, Z_6 and Z_9. Ratio of divided power is 1 : 3 : 3 : 1 at P_2, P_3, P_4 and P_5, respectively. This means that different value of magnitude of s-parameter is about 4.77 dB. Fig. 3 shows

TABLE 1: IMPEDANCE AND LENTH OF TRANSFORMERS

	Simulated Annealing		Real value	
	[Ω]	[mm]	[Ω]	[mm]
Z_1	27.5	15.3	27.5	15.3
Z_2	116.5	17.1	113.1	16.3
Z_3	30	46.9	30	49.3
Z_4	52	16.2	52	15.6
Z_5	117	17.2	101	17.6
Z_6	58	49.1	58	51.8
Z_7	37	15.8	39	14.8
Z_8	74	16.7	65	18
Z_9	78.5	50.2	78.5	50.2
Z_{10}	46.5	16.1	53	15.9
Z_{11}	76	16.7	76	17.5

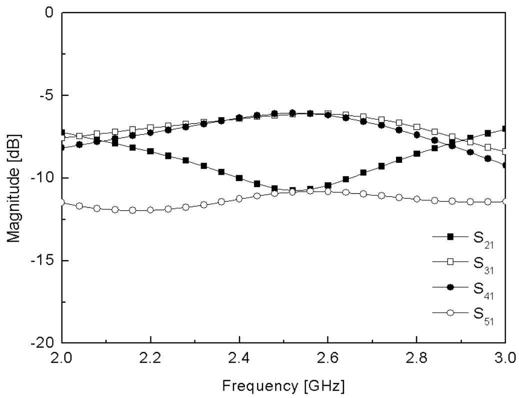


Fig. 3: Magnitude of s-parameter at each port

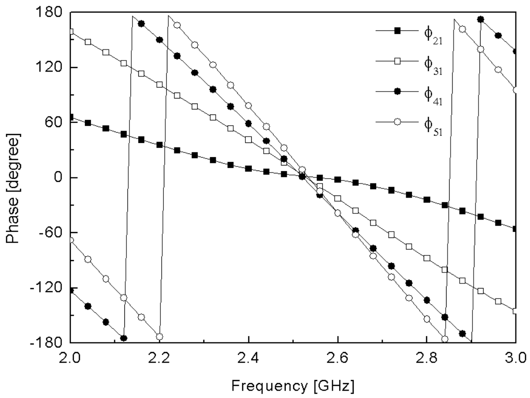


Fig. 4: Phase at each port

the magnitude of s-parameters, which are about 4.72 dB. Fig. 4 is the plot of phases of each port. At the center frequency 2.54 GHz, all ports are in-phase. For in-phase at all ports and maintenance of distance of binomial elements, three quarter wave length transformer is modified to a bend type transmission line. Distance of each port is d = 59 mm, which is $\lambda_g / 2$ at the center frequency of 2.54 GHz.

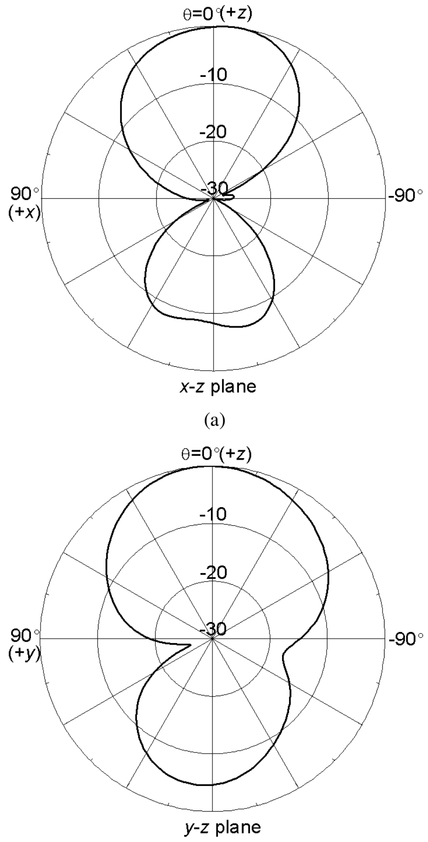
B. Radiating patch design

Asymmetric annular two-pair slots embedded on the ground plane are shown in Fig. 1 (b). These slots at the location below the radiating patch are perturbed the current distribution and resulted in CP radiation and increase antenna gain due to the radiation efficiency increment as the quality factor decrement. The radius of the radiating patch is 17 mm and radii of asymmetric ring-sector slots embedded on the ground plane are Δr_1 and Δr_2 are 8.5 and 7.0 mm, respectively. The angle of the ring-sector is 67.5°. The CP performance can be easily adjusted by the proper slot length ratio of the asymmetric ring-sector slots. In the single element, the slot length ratio of the embedded slots is close to about 1.2 (Δ_1 / Δ_2), the best CP operation can be obtained. Axial ratio is 0.68 dB at 2.54 GHz centred and the gain enhancement about 2.8 dBi higher as the reference antenna which is a single radiating element with perturbation segment on the radiating patch. The measured peak gains of the single proposed and reference antennas are 5.0 dBi and 2.2 dBi, respectively. The simulated radiation efficiency of proposed single element is found to be 59.7 %, which is much greater than that of the single reference antenna (about 29.8 %). This single element is used in 4-elements binomial array.

3. SIMULATED AND EXPERIMENTAL RESULTS

The radiation patterns of proposed binomial array simulated at 2.54 GHz are plotted in Fig. 5. The xz- plane pattern on the x-axis placed array elements indicated that this binomial array is radiated properly. At 2.54 GHz, the measured peak gain of the binomial array is 11.3 dBi and the axial ratio is 1.5 dB.

Fig. 6 shows the simulated and measured return loss of the proposed binomial array antenna. The measured return loss is shift to high frequency range about 60 MHz. In the single element, because of decreasing the quality factor by embedded slots on the ground plane, impedance bandwidth is wider than the reference single element. Similarly that of the binomial array is also wider than the reference antenna with 4-elements.



(b)

Fig. 5: Radiation pattern of proposed binomial array

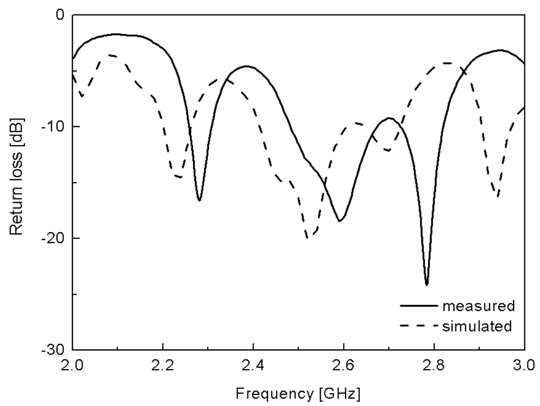


Fig. 6: Return loss of proposed binomial array

4. CONCLUSIONS

For antenna gain enhancement a binomial array using simulated annealing technique and asymmetric ring-sector two-pair slots embedded on the ground plane is presented. Radiation efficiency increment by decreasing quality factor is higher than that of a conventional microstrip patch. And a simple and compact binomial feed network is achieved by the simulated annealing method.

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