A Flat Four-Beam Compact Phased Array Antenna

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***Abstract*—This paper presents a flat four-beam compact phased array antenna. The low-cost and compact phased array antenna is designed using a circular array of four circular microstrip antennas made of low-cost material and four 1-bit phase shifters. The main beam of the antenna can be switched in four directions with the gain of about 4 dBi in each main-beam direction. More than 90° half-power beamwidth and over 10 dB F/B ratio are obtained. In addition, the diversity performance is considered and the diversity performance of this antenna can be provided with the envelope correlation about 0.6.**

***Index Terms*—Flat antenna, phase shifters, phased array, switched-beam array antenna.**

I. Introduction

SMART antenna is supposed in addition to increasing capacity. It can be classified into three categories: diversity antenna, switch beam antenna, and adaptive antenna [1]. Among the three types, switch beam antenna switches the main beam toward the desired direction. It was found that a four-beam antenna provides the acceptable performance with the most compact configuration. Kuga and Arai [2] introduced a flat-four beam switched array antenna that provided a directive gain of 2.7 dBd. The antenna was found to be suitable as a remote terminal antenna for indoor wireless local area network (WLAN) systems. Beam switching is carried out by switching input terminals of the hybrid couplers through terminal one to terminal four. Since each aperture is 1.55λ in length, hence the drawback of this antenna is its large dimension. The other candidate of the switch beam antenna is a single-port adaptive antenna using switched parasitic elements developed by Scott *et al.* [3]. The antenna employs the concept of multiple Yagi-Uda arrays sharing the active element. The parasitic elements are switched to appear as director, reflector, or "invisible" to switch beam of the antenna. Since a monopole antenna is proposed as a prototype, this antenna is not low profile. Karmakar and Bialkowski [4] developed a dividing/phasing network for a compact switched-beam array antenna for land-vehicle mobile satellite communication. The device is formed by a switched radial divider/combiner and 1-bit phase shifters. Using 8-element array is too complicated system for a WLAN system.

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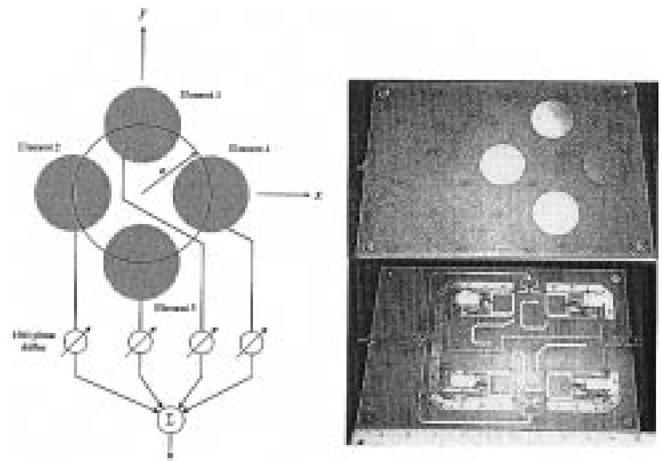


(a) (b)

Fig. 1. A flat four-beam compact phased array antenna. (a) Antenna configuration and (b) photograph of the prototype.

To mitigate the drawback of the aforementioned antenna, this paper presents a flat four-beam compact phased array antenna. The circular array consists of four circular microstrip antennas. Each element is connected to the power combiner through a 1-bit phase shifter. The prototype antenna is fabricated using low-cost material and tested at the frequency of 1.8 GHz. The acceptable characteristics show that this antenna can be applied in a wireless communications system.

II. Design

A flat four-beam compact phased array antenna was designed based on a circular array principle. Since four beams and low production costs are desired, four elements of circular microstrip antenna for realizing an omnidirectional pattern are selected. The circular microstrip antenna for the TM_{010}^{z} mode was designed to provide omnidirectional pattern in azimuth plane [5]. The beam switching can be achieved by utilizing 1-bit phase shifters offering the cheapest solution. These four array elements are combined at the power combiner. Fig. 1(a) and (b) show an antenna configuration and a prototype of a flat four-beam compact phased array antenna, respectively. The required phase shift for the array elements can be obtained using principles presented in [5]. In the design, a horizontal beamwidth is specified to be 90° to cover the service area and the front to back ratio is to be $\geq$ 10 dB. The array radius "a" is the parameter that controls the radiation pattern.

Table I shows the antenna characteristics as a function of array radius. When "a" is small, half-power beamwidth is wide, resulting in low directivity and high correlation between individual beam patterns. On the other hand, when "a" is large, a relatively narrow beamwidth in addition to high minor lobes is ob-

TABLE I
ANTENNA CHARACTERISTICS AS A FUNCTION OF ARRAY RADIUS

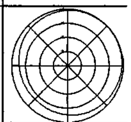
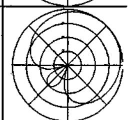
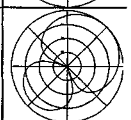
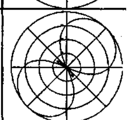
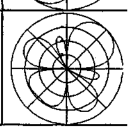
a/λ	Antenna characteristics				
	HPBW	F/B ratio (dB)	Directivity (dBi)	Envelope correlation ρ_e	Beam shape
0.250	186°	7.05	5.63	0.87	
0.375	116°	20.45	7.65	0.44	
0.500	86°	4.36	8.13	0.26	
0.750	54°	0.16	8.09	0.02	
1.000	42°	11.48	7.88	0.47	

TABLE II
VALUES OF PHASE SHIFT FOR THE FOUR BEAM DIRECTIONS

Beam direction ϕ_o \ Phase	Element 1	Element 2	Element 3	Element 4
0°	0°	92°	0°	-92°
90°	-92°	0°	92°	0°
180°	0°	-92°	0°	92°
270°	92°	0°	-92°	0°
45°	-40°	40°	40°	-40°
135°	-40°	-40°	40°	40°
225°	40°	-40°	-40°	40°
315°	40°	40°	-40°	-40°

tained. The optimum "a" of 0.375λ provides the desirable characteristics. Half-power beamwidth, front-to-back (F/B) ratio, directivity and envelope correlation are 116°, 20.45 dB, 7.65 dBi, and 0.44, respectively.

Let us consider the phase shift value for a four element circular array with "a" of 0.375λ. Table II lists the values of the phase shift for the four beam directions. It is found that if the beam directions are to be same as directions of elements, two-bit phase shifters, i.e., 0°, 92°, and $-92°$, must be used. However, if we specify the beam directions to be between elements where ϕ is 45°, 135°, 225°, and 315°, 1-bit phase shifters of ±40° can be applied with the same antenna characteristics. Consequently, a very compact flat four-beam array antenna can be realized.

III. ANTENNA CHARACTERISTICS

A prototype antenna has been designed for operation at the frequency of 1.8 GHz. It is made of an FR-4 substrate ($\varepsilon_r = 4.6$). Each circular microstrip element has radius of 2.35 cm. Array radius is 6.25 cm. Branch line hybrid coupler reflection type phase shifter was designed using two HSMP-3810 PIN diodes. The forward and reverse impedance of this diode are $4.3 - j24.7\ \Omega$ and $68.9 + j245.4\ \Omega$, respectively. The phase shift values of $80° \pm 7°$ of four 1-bit phase shifters over the frequency range from 1.76 GHz to 1.84 GHz were measured using an HP8720C. The four to one Wilkinson power combiner has its insertion loss of 0.4 dB. The bandwidth of VSWR ≤ 2 is 15%. VSWR of the antenna for each switched-beam direction that ϕ equals 45°, 135°, 225°, and 315° is 1.0059, 1.2599, 1.1469, and 1.0715, respectively, at the operating frequency of 1.8 GHz. The gain patterns of the antenna were measured at the frequency of 1.8 GHz in an in-house anechoic chamber utilizing an HP8720C network analyzer. The maximum gain of 4.6, 4.4, 3.6, and 4.3 dBi are observed in respective switched-beam directions as shown in Fig. 2. Also, the radiation pattern in elevation plane was measured and illustrated in Fig. 3. The antenna has linear polarization along the z-axis. The maximum gain is rather less than the expected one because of losses in phase shifter and power combiner. However, the average gain is about 4 dBi with variation of less than 1 dB. Main beam in each direction possesses over 90° half-power beamwidth, thus making this antenna to be able to cover overall azimuthal directions. F/B ratio of more than 10 dB is also achieved.

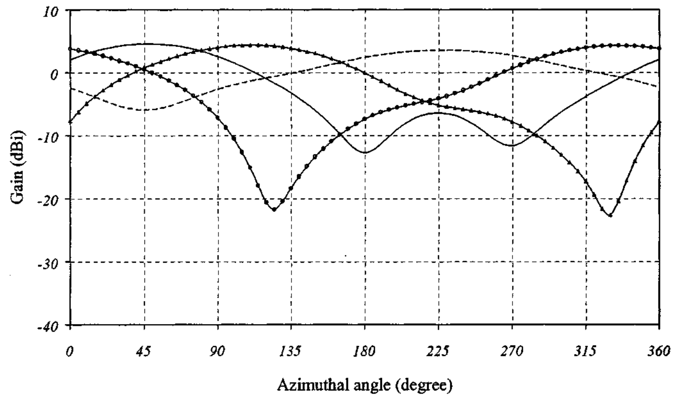


Fig. 2. Measured gain patterns.

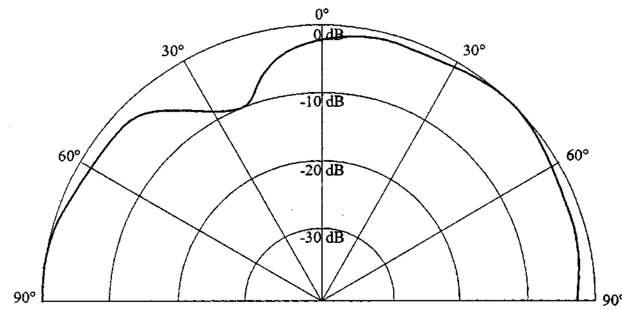


Fig. 3. Radiation pattern in elevation plane.

In addition, in order to consider the diversity performance of this antenna that is useful for enhancing signal reception in mobile communication systems, we found that the diversity performance occurs when the envelope correlation of the antenna is lower than 0.7 [6] and the envelope correlation of the antenna can be approximated from antenna patterns. Accordingly, the envelope correlation of 0.67, 0.56, 0.62, and 0.63 can be found between 45° and 135°, 135° fand 225°, 225° and 315°, 315° and 45° main-beam direction patterns, respectively. Since the envelope correlation of this antenna is less than 0.7, the diversity performance can be obtained.

IV. Conclusion

A flat four-beam compact phased array antenna has been developed to serve as a switched-beam antenna for an access point in WLAN system or a base station in a cellular mobile communications system. This antenna consists of four circular microstrip antennas, four 1-bit phase shifters and a four to one Wilkinson power combiner. Characteristics of the prototype antenna made of a low-cost material show gain of about 4 dBi in each switched direction. All azimuthal directions are covered by four switched-beams with more than 90° half-power beamwidth and higher than 10 dB F/B ratio. In addition, the diversity performance can be obtained with envelope correlation lower than 0.7.

References

[1] C. B. Dietrich Jr., W. L. Stutzman, B. K. Kim, and K. Dietze, "Smart antennas in wireless communications: Base-station diversity and handset beamforming," *IEEE Antennas Propagat. Mag.*, vol. 42, pp. 142–151, Oct. 2000.

[2] N. Kuga and H. Arai, "A flat four-beam switched array antenna," *IEEE Trans. Antennas Propagat.*, vol. 44, pp. 1272–1230, Sept. 1996.

[3] N. L. Scott, M. O. Leonard-Taylor, and R. G. Vaughan, "Diversity gain from a single-port adaptive antenna using switched parasitic elements illustrated with a wire and monopole prototype," *IEEE Trans. Antennas Propagat.*, vol. 47, pp. 1066–1070, June 1999.

[4] N. C. Karmakar and M. E. Bialkowski, "A beam-forming network for a circular switched-beam phased array antenna," *IEEE Microwave Wireless Comp. Lett.*, vol. 11, no. 1, pp. 7–9, Jan. 2001.

[5] C. A. Balanis, *Antenna Theory: Analysis and Design*. New York: Wiley, 1997.

[6] W. C. Jake, *Microwave Mobile Communications*. New York: IEEE Press, 1994.