Performance of Bidirectional and Unidirectional Elliptical Ring Antennas Fed by Circular Disc Monopole

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Abstract

This paper presents the characteristics of bidirectional and unidirectional elliptical ring antenna fed by circular disc monopole. The antenna design for dual band radiation is studied to meet the requirement of low-cost and simple configuration together with of being bidirectional pattern or unidirectional pattern. The characteristics of the proposed antennas were investigated by using Computer Simulation Technology (CST®). The mode effect of the elliptical waveguide and the feeder are firstly introduced to determine the lower edge bandwidth of the proposed antenna. From the simulation, the proposed antennas can achieve bidirectional pattern and unidirectional pattern over the bandwidth of the Personal Communication System band (PCS: 1.85 – 1.99 GHz) and the Industrial Science Medical band (ISM: 2.40 – 2.48 GHz). The bidirectional radiation pattern is desirable for many applications in long and narrow path service cell and the unidirectional radiation pattern is applicable for very long cell communication or point to point communication.

1. INTRODUCTION

Nowadays, many modern wireless communication systems operate in two or more frequency bands. The advances in software-defined and reconfigurable radio network can be changed the mode of system operation, including the frequency bands used [1]. Therefore, the antenna design requires antenna operation in more frequency bands such as dual-band of fundamentally narrowband antennas [2] to overcome the complex implementation of multiple antennas, each tuned to operate over a specific frequency band. The multi-purpose hardware devices can combine the cellular systems and wireless LANs systems together by employing only single antenna which several bandwidth enhancement techniques are used.

The antenna radiation must be considered to guarantee the good signal link. The removal of radio wave blind zones such as tunnels and underground areas is an important issue for mobile communications [3]. A bidirectional antenna is preferable to employ than an omnidirectional antenna due to a bidirectional pattern in azimuth plane is capable of expanding the cell length. An array configuration consisting of monopole or microstrip antennas can also be used to produce a bidirectional pattern, but it is difficult to miniaturize the dimensions due to the complicated feed network and power loss. Many bidirectional antennas have the drawbacks of complicated structure and inefficient wide bandwidth to operate in dual band [4]-[5]. The unidirectional antenna is desirable for long path cells or point-to-point communications due to its high directivity. Therefore, the antenna must be designed based on each system requirement.

The new antennas are proposed in this paper by using the elliptical ring [6] or the shorted-end elliptical ring fed by circular disc monopole [7] for bidirectional beam or unidirectional beam. The concept of the impedance matching in the previous works does not support these new antenna structures. Therefore, it is necessary to research the mechanism of the electromagnetic field in details. This work is originally studied the degree of the influence from the circular disc monopole and the elliptical ring that surrounds this circular disc monopole for dual band operation (PCS and ISM bands).

In this paper, the antenna design is described in detail, and the antenna is investigated in terms of return loss/impedance bandwidth and radiation pattern. Computer Simulation Technology [8] is used as a design and simulation tool.

2. ANTENNA GEOMETRY

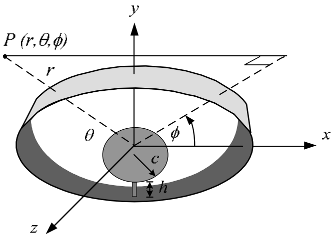
This section presents two antenna structures that are classified by their patterns. The first one provides bidirectional pattern by using an elliptical ring to surround a circular disc monopole. It is well-known that the feeding technique of the circular disc monopole can enhance the bandwidth of the antenna. Therefore, it is the key of being the dual-band antenna. The elliptical ring is used to prevent the leakage beams direct to the both sides of the circular disc monopole. The second one provides unidirectional pattern by using the reflector that is attached to the back aperture of the elliptical ring to obtain higher directivity. The parameters of both antenna configurations are summarized in Table 1.

A. Bidirectional Elliptical Ring Antenna Fed by Circular Disc Monopole

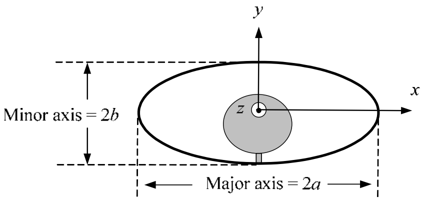
The structure of the antenna consists of two parts; the elliptical ring and the feeder, as shown in Figs. 1(a) – 1(c). The inner edge of the elliptical ring is defined in terms of the semi-major axis *a* and semi-minor axis *b*. The thickness and the length of the elliptical ring are defined by *t* and *d,* respectively. *w* is the thickness of the circular disc monopole. The feeding gap *h* is set up of 1 mm. The feed point is located at the center of the ring length.

B. Unidirectional Elliptical Ring Antenna Fed by Circular Disc Monopole

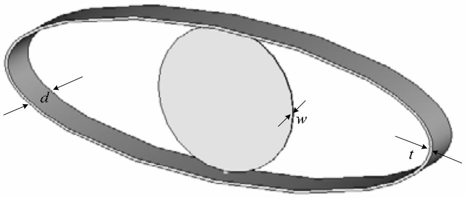
In addition to the geometry of the bidirectional antenna, the back aperture is also used to modify bidirectional pattern to be unidirectional pattern, as shown in Fig. 1(d). The thickness of the back aperture is fixed at 1 mm. The spacing from feed point to the back aperture is defined by *D*.



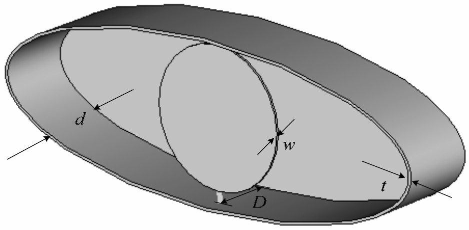
(a) Perspective View



(b) Cross-sectional View



(c) Bidirectional Elliptical Ring Antenna Fed by Circular Disc Monopole



(d) Unidirectional Elliptical Ring Antenna Fed by Circular Disc Monopole

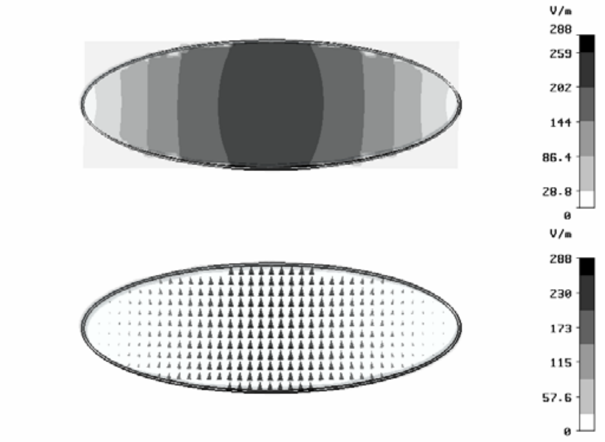
Fig. 1: Antenna Configuration

TABLE 1: ANTENNA PARAMETERS

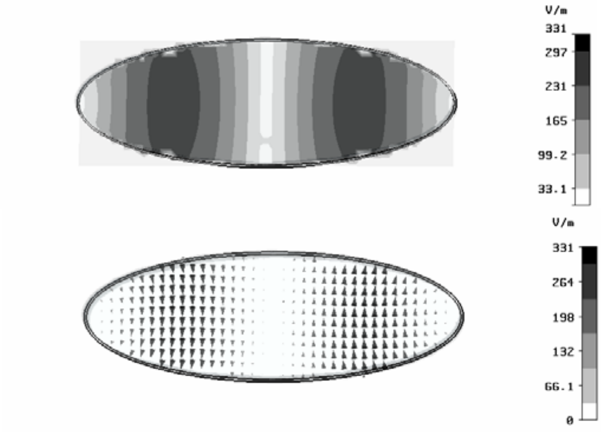
Dimensions	Parameters
Semi-major axis	*a*
Semi-minor axis	*b*
Radius of CDM	*c*
Ring length	*d*
Ring thickness	*t*
CDM thickness	*w*
Feeding gap	*h*
Spacing from feed point to back aperture	*D*
Thickness of back aperture	1 mm

3. UNDERLYING MODES

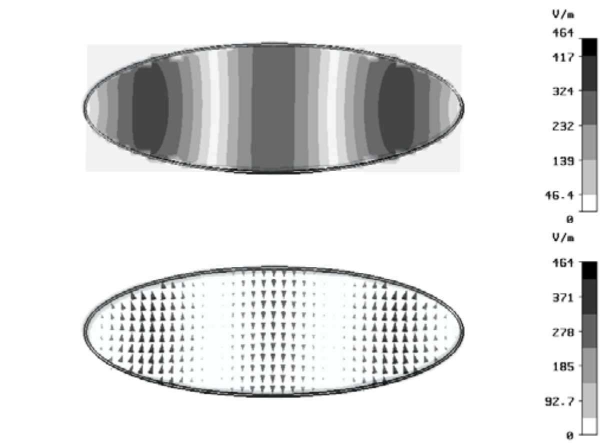
The electromagnetic fields inside the elliptical ring can be considered based on the waveguide principal. The background of the mode inside the elliptical waveguide is studied by the simulation to understand the bandwidth characteristics of the proposed antenna. The first three modes of the elliptical waveguide, TE_{C11}, TE_{C21} and TE_{C31} modes are presented in Fig. 2. In the simulation, the cross-sectional dimensions of the waveguide must be identical to the cross sectional dimensions of the elliptical ring. The magnitudes of the electric fields inside the waveguide are shown in the gray scale format and the arrows shows the direction of the vector of electric fields. The excitation with a circular disc monopole can generate multimode. Each mode has different behaviors. The cutoff frequency and the lower edge bandwidth of each mode were tabulated in Table 2 and Table 3. The waveguide length in the simulation is set up at 20 mm. For the dominant mode (TE_{C11} mode), the difference between cutoff frequency and the lower edge bandwidth is high. The lower edge bandwidth data of the waveguide was analyzed to determine the influence of the mode that affect to the lower edge bandwidth of the designed antenna.



(a) Electric Field of TE_{c11} Mode



(b) Electric Field of TE_{C21} Mode



(c) Electric Field of TE_{C31} Mode

Fig. 2: Modes inside an Elliptical Ring

TABLE 2: MODES IN WAVEGUIDE FOR CONSIDERING BIDIRECTIONAL ANTENNA
(The cross sectional dimensions of the waveguide are identical to bidirectional antenna. *a*, *b* and the waveguide length is set up at 7.5 cm, 2.5 cm and 2 cm, respectively)

Mode	Frequency (GHz)	
	Cutoff frequency	Lower edge bandwidth
TE_{c11}	1.13	2.02
TE_{c21}	2.09	2.15
TE_{c31}	3.03	3.09

TABLE 3: MODES IN WAVEGUIDE FOR CONSIDERING UNIDIRECTIONAL ANTENNA
(The cross sectional dimensions of the waveguide are identical to unidirectional antenna *a*, *b* and the waveguide length is set up at 9 cm, 3 cm and 20 mm, respectively.)

Mode	Frequency (GHz)	
	Cutoff frequency	Lower edge bandwidth
TE_{c11}	0.99	1.79
TE_{c21}	1.83	1.92
TE_{c31}	2.65	2.70

4. LOWER EDGE OF BANDWIDTH

Initially, both antennas were simulated and their dimensions were set up as listed in Table 4. To obtain dual-band antenna covering PCS and ISM bands, the parametric study is necessary for the antenna design. The investigation of the antennas is put emphasis on the bandwidth characteristic when *c*, *h* and *D* are varied.

TABLE 4: ANTENNA DIMENSIONS

Dimensions	Antenna Type	
	Bidirectional	Unidirectional
Semi-major axis (*a*)	75.0 mm	90.0 mm
Semi-minor axis (*b*)	25.0 mm	30.0 mm
Radius of CDM (*c*)	25.2 mm	26.5 mm
Ring length (*d*)	12.6 mm	28.8 mm
Ring thickness (*t*)	1.0 mm	1.2 mm
CDM thickness (*w*)	0.4 mm	0.8 mm
Feeding gap (*h*)	1.0 mm	0.6 mm
Spacing from feed point to back aperture (*D*)	*d*/2	
Bottom thickness	-	1.2 mm

A. Simulation Results of the Bidirectional Antenna

Table 5 shows the resonant frequency (f_r) of the circular disc monopole for various radii, 18, 20, 22 and 24 mm, respectively. Since the theoretical equation of the circular disc monopole is given as [7], [9] and [10],

$$f_r = \frac{(30 \times 0.25)}{(2c + h)}, \tag{1}$$

where, *c* and *h* is in unit of mm and f_r is in unit of GHz. The bandwidths of the antennas were also shown. The deviation of the lower edge bandwidth of the antenna can be determined by knowing the resonant frequency of the circular disc monopole and the lower edge bandwidth of the dominant mode in the waveguide. The deviation of the lower edge bandwidth (Δf_D) of the antenna is written as

$$\Delta f_D = \frac{\left(f_{LB} - \dfrac{f_{LM} + f_r}{2}\right)}{\dfrac{f_{LM} + f_r}{2}} \times 100 \text{ (\%)}, \quad (2)$$

where f_{LB} is the lower edge bandwidth of the antenna, f_{LM} is the lower edge bandwidth of the dominant mode, and f_r is the resonant frequency of the circular disc monopole. For the case of bidirectional antenna, f_{LM} is 2.02 GHz as shown in Table 2.

From the simulated results in Table 5, Table 6 and Table 7, the calculated deviations of the lower edge bandwidths are small. So, both influences from the feeding and the waveguide structure play a major role in the antenna bandwidth equally. The plus sign of the deviation means that the influence from the dominant mode is stronger than from the feeding. Conversely, the minus sign of the deviation means the influence of the feeding is more significant than the waveguide structure.

TABLE 5: BANDWIDTH FOR VARIOUS RADII OF CDM

c (mm)	f_r (GHz)	Bandwidth (GHz)	$\frac{\left(f_{LB} - \frac{f_{LM}+f_r}{2}\right)}{\frac{f_{LM}+f_r}{2}} \times 100$ (%)
18	2.027	2.080 – 2.450	2.79
20	1.829	1.927 – 2.444	0.13
22	1.667	1.837 – 2.482	-0.35
24	1.531	1.828 – 5.291	2.95

TABLE 6: BANDWIDTH FOR VARIOUS FEEDING GAP

h (mm)	f_r (GHz)	Bandwidth (GHz)	$\frac{\left(f_{LB} - \frac{f_{LM}+f_r}{2}\right)}{\frac{f_{LM}+f_r}{2}} \times 100$ (%)
0.5	1.546	1.879 – 2.438	5.38
1.0	1.531	1.828 – 5.291	2.95
1.5	1.515	1.647 – 5.193	-6.81
2.0	1.500	1.610 – 2.346	-8.52

TABLE 7: BANDWIDTH FOR VARIOUS SPACING FROM FEED POINT TO BACK APERTURE

D (mm)	f_r (GHz)	Bandwidth (GHz)	$\frac{\left(f_{LB} - \frac{f_{LM}+f_r}{2}\right)}{\frac{f_{LM}+f_r}{2}} \times 100$ (%)
5.3	1.531	1.747 – 2.479	-1.60
6.3	1.531	1.828 – 5.291	2.95
7.4	1.531	1.780 – 2.573	0.25
8.4	1.531	1.799 – 2.622	1.32

B. *Simulation Results of the Unidirectional Antenna*

For the case of bidirectional antenna, f_{LM} is 1.79 GHz (from Table 3). As shown in Table 8, Table 9 and Table 10, the deviation of the lower edge bandwidth is high. Therefore, the influence of being mode in the waveguide plays a major role in the antenna bandwidth. The modal effect will increase when D and c is decreased.

TABLE 8: BANDWIDTH FOR VARIOUS RADII OF CDM

c (mm)	f_r (GHz)	Bandwidth (GHz)	$\frac{\left(f_{LB} - \frac{f_{LM}+f_r}{2}\right)}{\frac{f_{LM}+f_r}{2}} \times 100$ (%)
24.5	1.399	1.978 – 2.847	24.83
25.5	1.349	1.895 – 2.700	21.51
26.5	1.302	1.837 – 2.546	19.59
27.5	1.258	1.786 – 2.323	17.90

TABLE 9: BANDWIDTH FOR VARIOUS FEEDING GAP

h (mm)	f_r (GHz)	Bandwidth (GHz)	$\frac{\left(f_{LB} - \frac{f_{LM}+f_r}{2}\right)}{\frac{f_{LM}+f_r}{2}} \times 100$ (%)
2.6	1.349	1.875 – 2.783	20.19
3.6	1.325	1.824 – 2.655	18.05
4.6	1.302	1.837 – 2.546	19.59
5.6	1.280	1.837 – 2.425	20.45

TABLE 10: BANDWIDTH FOR VARIOUS SPACING FROM FEED POINT TO BACK APERTURE

D (mm)	f_r (GHz)	Bandwidth (GHz)	$\frac{\left(f_{LB} - \frac{f_{LM}+f_r}{2}\right)}{\frac{f_{LM}+f_r}{2}} \times 100$ (%)
18.0	1.302	1.958 – 2.719	27.47
21.6	1.302	1.837 – 2.546	19.59
25.2	1.302	1.741 – 2.629	13.34
28.8	1.302	1.701 – 2.619	10.74

5. SIMULATED RESULTS

The parameters of the antennas in Table 4 were used in the simulation.

A. *Return Loss*

The antennas were designed to obtain the desired bandwidth covering the frequency range between 1.85 GHz to 2.50 GHz. From the simulated results in Fig. 3, the bidirectional antenna can achieve the bandwidth from 1.83 GHz to 5.29 GHz. The bandwidth of the unidirectional antenna is from 1.83 GHz to 2.54 GHz or around 33 %. It is obvious that the bandwidth of the unidirectional antenna is narrower than the bidirectional antenna around 120 % because of its reflector at the back aperture.

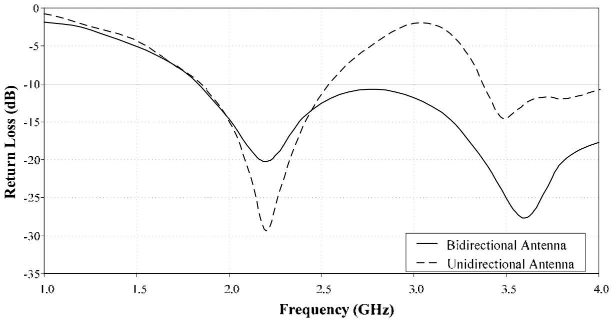
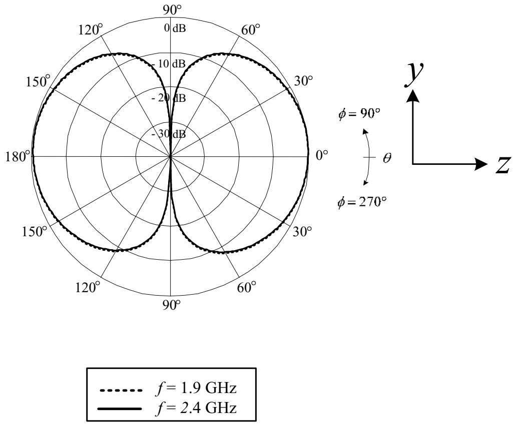


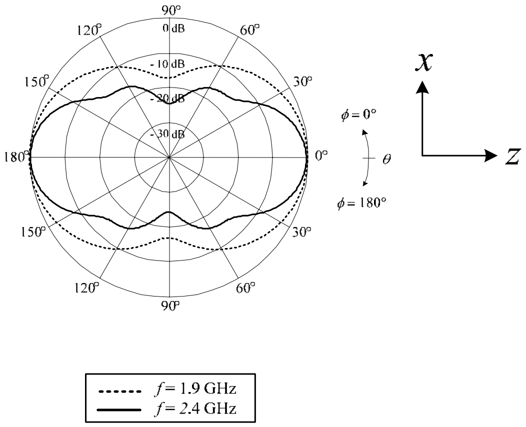
Fig. 3: Return loss vs. Frequency

B. Radiation Patterns

The radiation patterns of the proposed bidirectional antenna and the proposed unidirectional antenna were shown in Figs. 4 - 5, respectively. The HPBW and gain of both antennas are tabulated in Table 11 and Table 12.

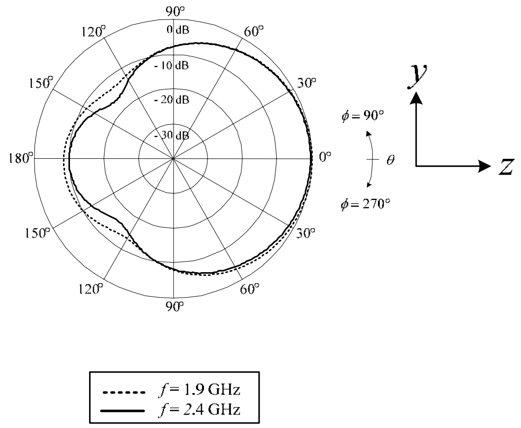


(a) E-plane

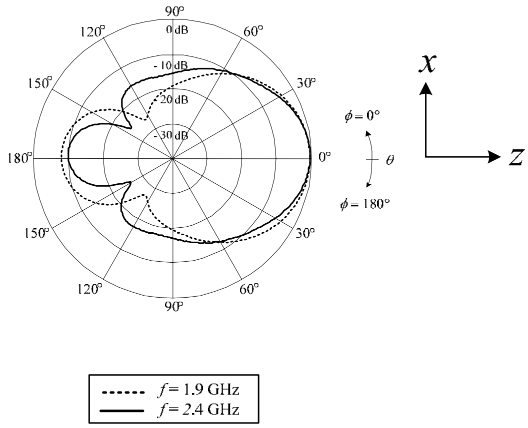


(b) H-plane

Fig. 3: Radiation Patterns of the Bidirectional Elliptical Ring Antenna Fed by Circular Disc Monopole



(a) E-plane



(b) H-plane

Fig. 4: Radiation Patterns of the Unidirectional Elliptical Ring Antenna Fed by Circular Disc Monopole

TABLE 11: RADIATION CHARACTERISTICS AT 1.9 GHZ

Parameter	Antenna Type	
	Bidirectional	Unidirectional
E-plane HPBW (deg)	82	113
H-plane HPBW (deg)	62	56
Maximum Gain (dBi)	5.8	7.6

TABLE 12: RADIATION CHARACTERISTICS AT 2.4 GHZ

Parameter	Antenna Type	
	Bidirectional	Unidirectional
E-plane HPBW (deg)	82	106
H-plane HPBW (deg)	36	46
Maximum Gain (dBi)	7.1	8.4

6. CONCLUSIONS

The study of the characteristics of the bidirectional and unidirectional elliptical ring antennas fed by circular disc monopole were presented in this paper. The lower edge bandwidth of the antenna relates to the elliptical ring structure and the feeder. The lower edge bandwidth of the proposed unidirectional antenna depends on the mode characteristic more than the proposed bidirectional antenna. Both proposed antennas have the bandwidths that cover PCS and ISM bands. From the simulated results, the maximum gain and HPBW in E-plane and H-plane of bidirectional antenna are 5.8 dBi, 82 deg. and 62 deg., respectively, at the frequency of 1.9 GHz. For the same frequency, the maximum gain and HPBW in E-plane and H-plane of the unidirectional antenna are 7.6 dBi, 113 deg. and 56 deg, respectively. The bidirectional and unidirectional antenna is suitable for applying in the base stations that occupy the cell with the narrow and long path. Moreover, the unidirectional antenna is also applicable in the point-to-point communications because its directivity is higher than the bidirectional antenna. The advantages of these antennas are simple configuration and low cost. To achieve the unidirectional pattern, the problem of the size of the reflector can be solved by using the proposed antenna structure.

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