Evaluation and Examination of Aperture Oriented Antennas

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Abstract

The exhaustive evaluation and analysis of aperture oriented antennas for different dimensions at two different frequencies (1800 MHz and 2.4 GHz) is presented in this paper. Design and comparison of the antennas for their performance is done through MATLAB. It is inferred that the circular aperture antenna has 95% higher directivity than rectangular aperture antenna. In addition, for the circular aperture antenna HPBW is 0.2849 degrees and for rectangular aperture HPBW is 1.0143 degrees. Also, circular patch antenna has less side lobe power than that of rectangular aperture antenna.
Keywords: *aperture antenna, electromagnetic radiation, directivity, beam width.*

I. Introduction

An antenna that has a part of its structure as physical aperture through which electromagnetic wave flow is known as an aperture antenna and it is most widely used in microwave frequencies. Aperture antennas are used in the applications requiring high directivity. Aperture antennas have two common shapes, one is rectangular and another circular [1][2]. Aperture antenna with rectangular and circular shapes is selected to evaluate the radiation pattern, directivity and beam width in this paper. The uniform distribution is considered to demonstrate the electromagnetic field distribution [3][4]. This paper is proposed to analyze the performance of the rectangular and circular aperture antenna with respect to directivity and beam width for different dimensions and for two different frequencies (2.4 GHz and 1800 MHz).

The aperture based rectangular antenna is the most wanted microwave based antenna as it follows rectangular co-ordination module. The module efficiently express the field and performs easier integration [5].

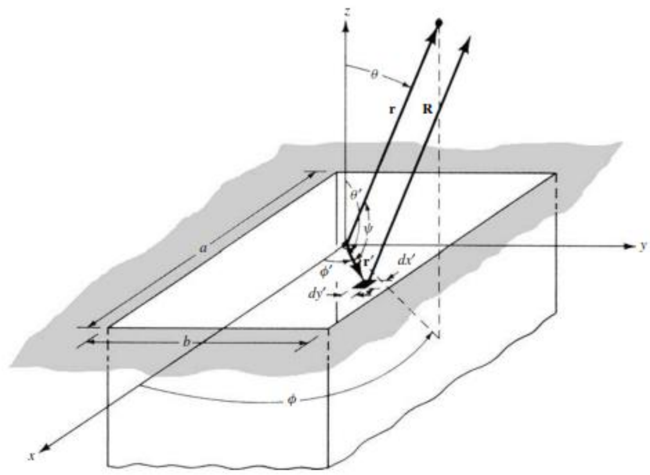

Fig 1: Aperture based Rectangular antenna on ground plane

Let us assume the rectangular aperture is placed in the xy plane of the infinite ground plane.
The differential path takes the form of

$$r' \cos\psi = r'.\hat{a_r} = \left(\widehat{a_x}\ .x' + \widehat{a_y}\ .y'\right).\left(\widehat{a_x}\ .\sin\theta\cos\emptyset + \widehat{a_y}\ .\sin\theta\sin\emptyset + \hat{a_z}.\cos\theta\right)$$
$$= x'\sin\theta\cos\emptyset + y'\sin\theta\ \sin\emptyset \quad (1)$$

Far-zone field radiation by aperture antenna is given as

$$E_r = 0$$
$$E_\theta = j\frac{abkE_0\ e^{-jkr}}{2\pi r}\left[\sin\emptyset\ \left(\frac{\sin X}{X}\right)\left(\frac{\sin Y}{Y}\right)\right] \quad (2)$$
$$E_\emptyset = j\frac{abkE_0\ e^{-jkr}}{2\pi r}\left[\cos\theta\ \cos\emptyset\ \left(\frac{\sin X}{X}\right)\left(\frac{\sin Y}{Y}\right)\right] \quad (3)$$
$$H_r = 0$$
$$H_\theta = -\frac{E_\emptyset}{\eta}$$
$$H_\emptyset = \frac{E_\theta}{\eta}$$

The 2-Dimension plot is sufficient to represent the radiation fields. Below equations describe the E-plane and H-plane

$$E_r = E_\emptyset = 0$$
$$E_\theta = j\frac{abkE_0\ e^{-jkr}}{2\pi r}\left[\frac{\sin\left(\frac{kb}{2}\sin\theta\right)}{\frac{kb}{2}\sin\theta}\right]$$

$$E_r = E_\theta = 0$$
$$E_\emptyset = j\frac{abkE_0\ e^{-jkr}}{2\pi r}\left\{\cos\theta\ \left[\frac{\sin\left(\frac{ka}{2}\sin\theta\right)}{\frac{ka}{2}\sin\theta}\right]\right\}$$

(4)

If the aperture antenna dimensions is greater than the wavelength, then the multiple side lobes appears in the radiation pattern. The number of side lobes increases as the dimension increases [6].

II. Analysis of rectangular and circular aperture antennas

In aperture based circular antennas, cylindrical coordinates is followed for the solution of the fields.
The differential paths and differential areas can be written as

$$r' \cos\psi = x'\ \sin\theta\ \cos\emptyset + y'\ \sin\theta\ \sin\emptyset = \rho'\ \sin\theta\ \cos(\emptyset - \emptyset')$$
$$ds' = dx'\,dy' = \rho'\,d\rho'\,d\emptyset' \quad (5)$$

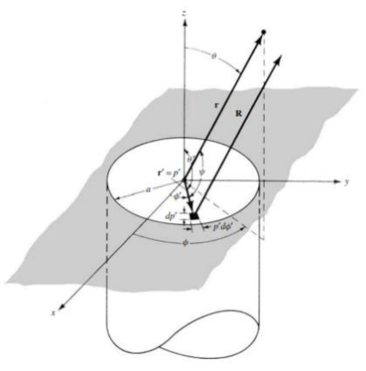

Fig 2: Circular aperture antenna on infinite ground plane.

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Circular aperture mounted on an infinite ground based plane, and the field is over the opening is assumed to be constant [9][10] and is

$$E_a = \hat{a}_y E_0 \qquad\qquad \rho' \leq a$$

Where E_0 is a constant.

$$M_s = \begin{cases} -2\,\hat{n} \times E_a = +\hat{a}_x 2\,E_0\,, & \rho' \leq a \\ 0, & elsewhere \end{cases}$$

$$J_s = 0 \qquad\qquad everywhere$$

Electric field components in E and H plane can be simplified as

E-Plane (Ø = π/2)

$$E_r = E_\emptyset = 0$$

$$E_\theta = j\frac{ka^2 E_0\, e^{-jkr}}{r}\left[\frac{\mathrm{J}_1(ka\ \sin\theta)}{ka\ \sin\theta}\right] \tag{6}$$

H-Plane (Ø = 0)

$$E_r = E_\theta = 0$$

$$E_\emptyset = j\frac{ka^2 E_0\, e^{-jkr}}{r}\left\{\cos\theta\left[\frac{\mathrm{J}_1(ka\ \sin\theta)}{ka\ \sin\theta}\right]\right\} \tag{7}$$

The directivity for the aperture antenna can be found by computing the radiated power (P_{rad}) and the maximum radiation intensity (U_{max}) .As the aperture is on infinite based ground of plane, radiated power is high. The average PDF is calculated for the fields at physical bounds of the aperture [7][8].

III. ANALYSIS AND SIMULATION RESULTS

The maximum radiation intensity occurs at ɵ=00. The beam width is termed as the angle of separation between two points on max. Pattern HPBW is defined as the degree of radiation intensity maximum occurring at one-half beam value. Another important terminology is First Null Beam width (FNBW) which is the angular separation occurring between the first nulls of the pattern.

Thus the total HPBW of the rectangular aperture antenna is given by

$$\Theta_h = 2\,\theta_h = 2\ \sin^{-1}\left(\frac{0.443\lambda}{b}\right)\ rad = 114.6\ \sin^{-1}\left(\frac{0.443\lambda}{b}\right)\ degrees$$

When b>>0.443 λ then

$$\Theta_h \cong \left(0.886\ \frac{\lambda}{b}\right) rad = 50.8\left(\frac{\lambda}{b}\right) degrees \tag{8}$$

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The rectangular aperture antenna parameters at the frequency of 1800MHz are given in Table 1.

TABLE 1: rectangular aperture antenna parameters at the frequency of 1800MHz

A (cm)	**B(cm)**	**Area (cm2)**	**Directivity**	**HPBW E plane (degree)**	**FNBW E plane (degree)**
2.286	1.016	2.322	1.05E+03	8.3005	18.799
2.323	1.345	3.124	1.41E+03	6.2701	14.2007
3.333	1.032	3.439	1.56E+03	8.1718	18.5078
3.000	1.613	4.839	2.19E+03	5.2284	11.8413
4.130	2.286	9.441	4.27E+03	3.6891	8.3552
4.286	2.323	9.956	4.50E+03	3.6304	8.2221
5.229	3.456	18.071	8.18E+03	2.4402	5.5266
5.489	3.986	21.879	9.90E+03	2.1157	4.7918
6.453	3.689	23.805	1.08E+04	2.2861	5.1776
6.236	4.101	25.623	1.16E+04	2.0564	4.6574

The rectangular aperture antenna parameters at the frequency of 1800MHz are given in Table 2.

TABLE 2: rectangular aperture antenna parameters at the frequency of 2.4GHz

A (cm)	**B(cm)**	**Area (cm2)**	**Directivity**	**HPBW E plane (degree)**	**FNBW E plane (degree)**
2.286	1.016	2.322	1.05E+03	6.2254	14.0994
2.323	1.345	3.124	1.41E+03	4.7026	10.6506
3.333	1.032	3.439	1.56E+03	6.1289	13.8808
3.000	1.613	4.839	2.19E+03	3.9213	8.8810
4.130	2.286	9.441	4.27E+03	2.7668	6.2664
4.286	2.323	9.956	4.50E+03	2.7228	6.1666
5.229	3.456	18.071	8.18E+03	1.8302	4.1450
5.489	3.986	21.879	9.90E+03	1.5868	3.5938
6.453	3.689	23.805	1.08E+04	1.7146	3.8832
6.236	4.101	25.623	1.16E+04	1.5423	1.0143

The circular aperture antenna parameters at the frequency of 1800MHz are given in Table 3.

TABLE 3: Circular aperture antenna parameters at the frequency of 1800MHz

a(cm)	**Area (cm2)**	**Directivity**	**HPBW E plane (degree)**	**FNBW E plane (degree)**
1.161	2.322	1.92E+03	4.1918	10.0345
1.562	3.124	3.47E+03	3.1157	7.4584
1.719	3.439	4.20E+03	2.8311	6.7772
2.419	4.839	8.32E+03	2.0119	4.8160
4.720	9.441	3.17E+04	1.0311	2.4682

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4.978	9.956	3.52E+04	0.9776	2.3403
9.035	18.071	1.16E+05	0.5386	1.2894
10.939	21.879	1.70E+05	0.4449	1.0650
11.902	23.805	2.01E+05	0.4089	0.9788
12.811	25.623	2.33E+05	0.3799	0.9094

The circular aperture antenna parameters at the frequency of 2.4GHz are given in Table 4.

TABLE 4: Circular aperture antenna parameters at the frequency of 2.4GHz

a(cm)	**Area (cm2)**	**Directivity**	**HPBW E plane (degree)**	**FNBW E plane (degree)**
1.161	2.322	3.41E+03	3.1438	7.5258
1.562	3.124	6.16E+03	2.3367	5.5938
1.719	3.439	7.47E+03	2.1233	5.0829
2.419	4.839	1.48E+04	1.5089	3.6120
4.72	9.441	5.63E+04	0.7733	1.8512
4.978	9.956	6.26E+04	0.7332	1.7552
9.035	18.071	2.06E+05	0.404	0.9671
10.939	21.879	3.02E+05	0.3337	0.7987
11.902	23.805	3.58E+05	0.3067	0.7341
12.811	25.623	4.15E+05	0.2849	0.6820

On the basis of the present work, directivity and HPBW are evaluated for both rectangular and circular aperture. In perspective of directivity, the circular aperture antenna shows superiority over the rectangular aperture for the same aperture dimensions. As directivity increases, First Null Beam width (FNBW) starts decreasing. In addition, Radiation pattern of aperture antenna shows that number of side lobes increased with increase in directivity.

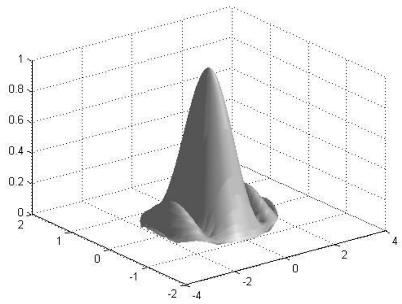

Fig 3: pattern of rectangular aperture antenna with L: 2.286 cm B: 1.016 cm

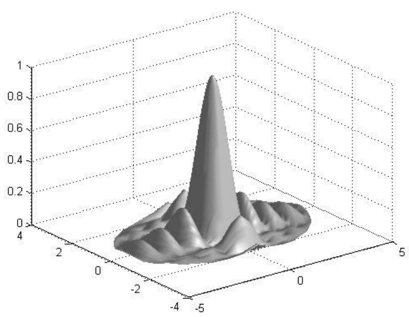

Fig 4: pattern of rectangular aperture antenna with L: 4.286 cm B: 2.323 cm.

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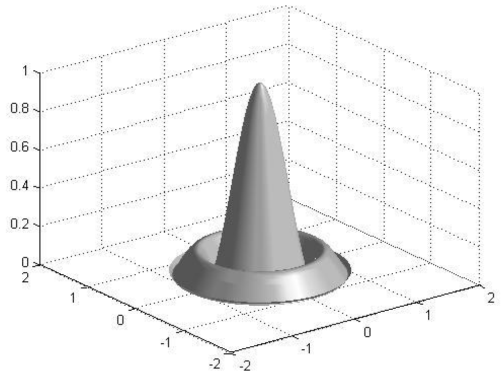

Fig 5: pattern of circular aperture antenna with dimension of Radius: 1.161 cm.

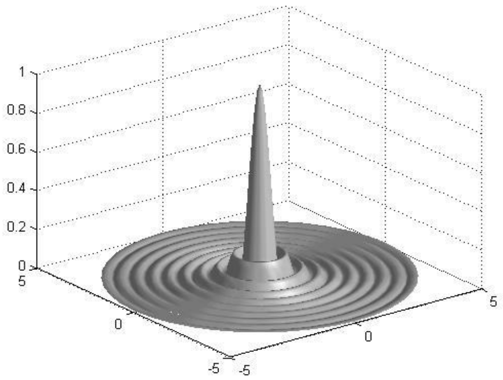

Fig 6: pattern of circular aperture antenna with dimension of Radius: 1.161 cm.

V. Conclusion

Comparison between rectangular and circular aperture antenna has been simulated and results are obtained using MATLAB. In both aperture antennas, directivity increases with dimensions of the aperture. However, half power beam width decreases. Circular aperture antenna has high directivity of 4.1467e+005 at aperture area of 25.623 square.cm. Directivity of the circular aperture antenna has 95% improved directivity when compared to rectangular aperture antenna (Directivity = 2.06E+04 at aperture area of 25.623 square.cm) and hence it can be used in applications of Satellite Communication, Radar Engineering.

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