Journal of Basrah Researches ((Sciences)) Volume 37.Number 5.A ((2011))

Available online at: www.basra-science journal.org

ISSN -1817 -2695

Calculation of Directivity for rectangular aperture antenna

Hayfaa R.A.Kareem, Waleed H.Al-Musawee and Ali A.S.Obaid
Department of physics, college of Education, University of Basra, Iraq.
E-mail: aasobaid @ Yahoo.com
Received 6-3-2011, Accepted 13-10-2011

Abstract

Mathematical expression in a closed form for the directivity calculation of a rectangular aperture antenna is derived in order to evaluate how efficient a simple formula presented by other research workers is utilized to calculate the directivity of aperture antennas.

1. Introduction

An antenna that has as part of its structure a physical aperture which is rectangular in shape,through which electromagnetic wave flow,is known as a rectangular aperture antenna.
Obvious examples of such antennas are pyramidal horn,rectangular slot in a metallic source structure, and an open-ended rectangular waveguide.

Aperture antennas are often selected for use in applications requiring high directivity. It is,therefore, important to be able to evaluate the directivity of the antenna as accurately as possible. In this paper, techniques are presented for evaluating directivity based on radiation pattern information and on aperture field information.In addition, simple estimated formula based on the knowledge of the half-power beam width in both principal electric and magnetic planes is presented that provides an approximate value for the directivity.

2. Radiation from aperture antenna

A general rectangular aperture is shown in Fig. (1).For an aperture electric field polarized along the y-axis, the final far-zone (radiated)electric field components based on both aperture electric and magnetic fields are given by:[1]

$$E_\theta = jk\frac{e^{-jkr}}{4\pi r}\left(1+\frac{z_o}{z_w}\cos\theta\right)F_x \sin\varphi \qquad (1\text{-a})$$

$$E_\varphi = jk\frac{e^{-jkr}}{4\pi r}\left(\cos\theta+\frac{z_o}{z_w}\right)F_x \cos\varphi \qquad (1\text{-b})$$

where: k is the propagation phase constant of the free space, z_o is the characteristic impedance
of the free space, z_w is the wave impedance of the propagating mode , and F_x is a function relates to the electric aperture field through the relation:

$$F_x=\int_{Sa} E_{ay}(x,y)\,e^{jk(ux+vy)}\,dx\,dy \qquad (2)$$

with u= sinθcosφ and v= sinθsinφ
The integral in eq.(2) is taken over the physical aperture surface S_a located in the xy-plane. Considering the most general case

of rectangular aperture distribution for which the aperture electric filed has a cosinusoidal distribution in x-and y-directions, i.e.

$E_{ay} = E_o \cos(k_x x) \cos(k_y y)$ (3)

Where k_x and k_y are the transverse phase constants in the x- and y- directions; respectively, the eq.(2) reduces to:

$$F_x = E_o \int_{-a/2}^{a/2} \cos(k_x x)\, e^{jkux}\, dx \int_{-b/2}^{b/2} \cos(k_y y)\, e^{jkvy}\, dy \quad (4)$$

The integration of eq. (4) with respect to x and y can be carried out in close form, and thus after some considerable work, it yields [2]

$$F_x = E_o \left[2\, \frac{ku \cos(k_x a/2) \sin(kua/2) - k_x \sin(k_x a/2) \cos(kua/2)}{(ku)^2 - k_x^2}\right] \times \left[2 \frac{kv \cos(k_y b/2) \sin(kvb/2) - k_y \sin(k_y b/2) \cos(kvb/2)}{(kv)^2 - k_y^2}\right] \quad (5)$$

substitution of eq. (5) into eqs. (1) gives:

$$E_\theta = jk \frac{e^{-jkr}}{\pi r} E_o \left(1 + \frac{z_o}{z_w} \cos\theta\right) \sin\varphi \left[\frac{ku \cos\left(\frac{k_x a}{2}\right) \sin\left(\frac{kua}{2}\right) - k_x \sin\left(\frac{k_x a}{2}\right) \cos\left(\frac{kua}{2}\right)}{(ku)^2 - k_x^2}\right] \times \left[\frac{kv \cos\left(\frac{k_y b}{2}\right) \sin\left(\frac{kvb}{2}\right) - k_y \sin\left(\frac{k_y b}{2}\right) \cos\left(\frac{kvb}{2}\right)}{(kv)^2 - k_y^2}\right] \quad (6\text{-a})$$

$$E_\varphi = jk \frac{e^{-jkr}}{\pi r} E_o \left(\cos\theta + \frac{z_o}{z_w}\right) \cos\varphi \left[\frac{ku \cos\left(\frac{k_x a}{2}\right) \sin\left(\frac{kua}{2}\right) - k_x \sin\left(\frac{k_x a}{2}\right) \cos\left(\frac{kua}{2}\right)}{(ku)^2 - k_x^2}\right] \times \left[\frac{kv \cos\left(\frac{k_y b}{2}\right) \sin\left(\frac{kvb}{2}\right) - k_y \sin\left(\frac{k_y b}{2}\right) \cos\left(\frac{kvb}{2}\right)}{(kv)^2 - k_y^2}\right] \quad (6\text{-b})$$

These field components are rather complicated functions of θ and φ, but they are simplified in the principal magnetic H-plane and electric E-plane. In the H-plane (xz - plane)$\varphi = 0$, $u = \sin$, $v = 0$, and hence,eqs.(6) reduce to :

$$E_\theta = 0 \quad (7\text{-a})$$

$$E_\varphi = jk \frac{e^{-jkr}}{\pi r} E_o \left(\cos\theta + \frac{z_o}{z_w}\right) \times \frac{b}{2} \times \frac{\sin(k_y b/2)}{(k_y b/2)} \times \left[\frac{k \sin\theta \cos\left(\frac{k_x a}{2}\right) \sin\left(\frac{ka}{2}\sin\theta\right) - k_x \sin\left(\frac{k_x a}{2}\right) \cos\left(\frac{ka}{2}\sin\theta\right)}{(k \sin\theta)^2 - (k_x)^2}\right] \quad (7\text{-b})$$

In the E-plane (yz-plane) $\varphi=90°$, $u=0$, $v=\sin\theta$, and therefore, eqs.(6) become :

$$E_\theta = jk \frac{e^{-jkr}}{\pi r} E_o \left(1 + \frac{z_o}{z_w} \cos\theta\right) \times \frac{a}{2} \times \frac{\sin(k_x a/2)}{(k_x a/2)} \times \left[\frac{k \sin\theta \cos\left(\frac{k_y b}{2}\right) \sin\left(\frac{kb}{2}\sin\theta\right) - k_y \sin\left(\frac{k_y b}{2}\right) \cos\left(\frac{kb}{2}\sin\theta\right)}{(k \sin\theta)^2 - (k_y)^2}\right] \quad (8\text{-a})$$

$$E_\varphi = 0 \quad (8\text{-b})$$

The normalized form of these principal plane patterns is:

$$E_{\varphi N} = E_\varphi(\theta)/E_\varphi(\theta = 0°) \qquad \varphi = 0°$$

$$= \frac{\left(\cos\theta + \frac{z_o}{z_w}\right)}{\left(1 + \frac{z_o}{z_w}\right)} \frac{\left[k \sin\theta \cos\left(\frac{k_x a}{2}\right) \sin\left(\frac{ka}{2}\sin\theta\right) - k_x \sin\left(\frac{k_x a}{2}\right) \cos\left(\frac{ka}{2}\sin\theta\right)\right]}{\left[(k \sin\theta)^2 - k_x^2\right]\left[\frac{\sin(k_x a/2)}{(k_x a/2)}\right] \times a/2} \quad (9\text{-a})$$

$$E_{\theta N} = E_\theta(\theta)/E_\theta(\theta = 0°) \qquad \varphi = 90°$$

$$= \frac{(1+\frac{z_o}{z_w}\cos\theta)}{(1+\frac{z_o}{z_w})} \frac{[k\sin\theta \cos\left(\frac{k_y b}{2}\right)\sin\left(\frac{kb}{2}\sin\theta\right) - k_y \sin\left(\frac{k_y b}{2}\right)\cos\left(\frac{kb}{2}\sin\theta\right)]}{[(k\sin\theta)^2 - k_y{}^2]\left[\frac{\sin(k_y b/2)}{(k_y b/2)}\right] \times b/2} \tag{9-b}$$

3. Directivity of an antenna

One very important description of an antenna is how much it concentrates electromagnetic energy in one direction in preference to radiation in other directions. This characteristic of an antenna is called its directivity and is defined as the ratio of the maximum radiation intensity of an antenna to its average radiation intensity,i.e.

$$D = \frac{U_{\max}}{U_{ave.}} = \frac{U_{\max}}{P_r/\Omega_A} = \Omega_A \frac{U_{\max}}{P_r} = \Omega_A \frac{U_{\max}}{\int_S U(\theta,\varphi)d\Omega} \tag{10}$$

where P_r represents the total radiated power and Ω_A represents the solid angle subtended to the radiation space. For an omnidirectional antenna such as an aperture antenna located in free space where the radiated power is distributed over all space,Ω_A=4π square radians. Substituting this result for Ω_A into eq. (10) gives:

$$D = 4\pi \frac{U_{max}}{\int_S U(\theta,\varphi)d\Omega} \tag{11}$$

The total radiated power P_r is evaluated by integration the radiation intensity (power flow per unit solid angle)over all radiation space. The radiation intensity(θ,φ) is related to the far-zone (radiated)electric field components, through a direct relationship [3]

$$U(\theta,\varphi) = \frac{r^2}{2Z_o}\left(|E_\theta|^2 + |E_\varphi|^2\right) \tag{12}$$

Substitution for E_θ and E_φ from eqs.(6) into eq. (12) yields:

$$U(\theta,\varphi) = \frac{k^2}{2\pi^2 Z_o}[(1+\frac{Z_o}{Z_w}\cos\theta)^2\sin^2\varphi + (\cos\theta + \frac{Z_o}{Z_w})^2\cos^2\varphi] \times$$
$$[\frac{ku\cos(k_x a/2)\sin(kua/2) - k_x\sin(k_x a/2)\cos(kua/2)}{(ku)^2 - k_x{}^2}]^2 \times$$
$$[\frac{kv\cos(k_y b/2)\sin(kvb/2) - k_y\sin(k_y b/2)\cos(kvb/2)}{(kv)^2 - k_y{}^2}]^2 \tag{13}$$

Inspections of this equation shows that radiation intensity U(θ,φ) reaches its maximum value in the broadside direction (θ = 0°) and hence, eq.(13) reduces to :

$$U_{max} = \frac{k^2}{2\pi^2 Z_o}(1+\frac{Z_o}{Z_w})^2(\frac{a}{2})^2(\frac{b}{2})^2[\frac{\sin(k_x a/2)}{k_x a/2}]^2[\frac{\sin(k_y b/2)}{k_y b/2}]^2 \tag{14}$$

where we have introduced the pattern variables u=sin0cosφ=0 and v=sin0sinφ = 0. Substitution of eq.(14) for U_{max} and eq.(13)for U(θ,φ)into eq. (11)yields

$$D = 4\pi(\frac{a}{2})^2(\frac{b}{2})^2(1+\frac{z_o}{z_w})^2[\frac{\sin(k_x a/2)}{(k_x a/2)}]^2[\frac{\sin(k_y b/2)}{(k_y b/2)}]^2 \div$$
$$\int_o^{2\pi}\int_o^{\pi}[(1+\frac{Z_o}{Z_w}\cos\theta)^2\sin^2\varphi + (\cos\theta + \frac{Z_o}{Z_w})^2\cos^2\varphi] \times$$
$$[\frac{ku\cos(k_x a/2)\sin(kua/2) - k_x\sin(k_x a/2)\cos(kua/2)}{(ku)^2 - k_x{}^2}]^2 \times$$

$$\left[\frac{kv\cos(k_y b/2)\sin(kvb/2) - k_y\sin(k_y b/2)\cos(kvb/2)}{(kv)^2 - k_y^2}\right]^2 \sin\theta\, d\theta\, d\varphi \qquad (15)$$

Exact evaluation of directivity using eq.(15) requires both a knowledge of the pattern over all space of radiation ($0\le\theta\le\pi$) and $0\le\varphi\le2\pi$) as well as the integration of the pattern.The integral in eq.(15) is usually performed by numerical integration.

4. Formal formula for calculating the directivity of an antenna

The pattern integration required for accurate evaluation of directivity can be avoided by a new approach presented by Stutzman [4]. This approach is based on determining the radiated power from the aperture in the aperture plane where it is easier to integrate.Stutzman relationship for calculating the directivity of an aperture antenna is entirely required the knowledge of the aperture fields .It states that:

$$D = \frac{4\pi}{\lambda^2}\frac{\left|\int_{sa} E_a\, da\right|^2}{\int_{sa}\left|E_a\right|^2 da} \qquad (16)$$

This simple formula assumes the following: 1. The pattern peak is directed broad side to the aperture plane. 2.The aperture is largely relative to the operating wavelength.3.The aperture fields nearly forming a plane wave. To examine the validity of Stutzman's formula given by eq.(16) let us consider the following special cases.

4.1Directivity of uniform rectangular aperture

If the aperture is excited in an idealized fashion such that the aperture fields are uniform in phase and amplitude across its physical structure it is referred to as a uniform rectangular aperture.Such distribution is practically achieved by loading the side-walls of rectangular waveguide with dielectric slabs under proper selection of dielectric constant and dielectric thickness [5].Suppose the aperture electric field is y-polarized, then the uniform rectangular aperture electric field is:

$$\mathbf{E}_a = \hat{y}\, E_o \qquad for\ |x| \le \frac{a}{2} \quad \text{and} \quad |y| \le \frac{b}{2} \qquad (17)$$

In this case, as it seen from eq.(3), the transverse phase constants k_x and k_y are both equal to zero and $z_w=z_o$. Then the directivity of uniform rectangular aperture from eq.(15) becomes:

$$D_{TEM} = \frac{16\pi}{\int_0^{2\pi}\int_0^{\pi}(1+\cos\theta)^2\left[\frac{\sin(kua/2)}{(kua/2)}\right]^2\left[\frac{\sin(kvb/2)}{(kvb/2)}\right]^2 \sin\theta\, d\theta\, d\varphi} \qquad (18)$$

From eq. (16) the directivity of uniform amplitude reduces to:

$$D_{TEM} = \frac{4\pi}{\lambda^2}\, a\times b = 4\pi\frac{A_p}{\lambda^2} \qquad (19)$$

Where A_p is the physical aperture area.Eq.(19) is a general result and implies that the directivity of uniform amplitude aperture is the highest obtainable from uniform phase aperture.

4.2Directivity of an open-ended rectangular waveguide

One of the smallest aperture antennas is the open-ended rectangular waveguide. When it is operated is the dominant TE_{10} mode frequency band, the aperture electric field is cosine-tapered in the x-direction and is uniformed in the y-direction i.e.

$$\mathbf{E_a} = \hat{y}E_o\cos\left(\frac{\pi}{a}x\right) \qquad for\ |x| \le \frac{a}{2} \quad and \quad y \le \frac{b}{2} \qquad (20)$$

It is noted from eq.(3) that $k_x = \pi/a$ and $k_y=0$. Substituting these values into eq.(15) gives the exact directivity expression for TE_{10} mode.

$$D_{TE_{10}} = 4\pi\left(1+\frac{z_o}{z_w}\right)^2 \div \int_o^{2\pi}\int_o^{\pi}\left[\left(1+\frac{z_o}{z_w}\cos\theta\right)^2\sin^2\varphi + \left(\cos\theta+\frac{z_o}{z_w}\right)^2\cos^2\varphi\right] \times \left[\frac{\cos(kua/2)}{1-(kua/\pi)^2}\right]^2\left[\frac{\sin(kvb/2)}{(kvb/2)}\right]^2 \sin\theta\, d\theta\, d\varphi \,]$$

(21)

where $z_w = z_{TE_{10}} = \frac{k z_o}{\sqrt{k^2-k_x^2}} = \frac{k z_o}{\sqrt{k^2-(\pi/a)^2}}$ *and hence* $\frac{z_o}{z_w} = \frac{\sqrt{k^2-(\pi/a)^2}}{k}$

From eq. (16) the directivity of TE_{10} mode is simplified to:

$$D_{TE_{10}} = \frac{32}{\pi}\frac{a}{\lambda}\frac{b}{\lambda} = \frac{4\pi}{\lambda^2}\left(\frac{8}{\pi^2}\right)ab = \frac{4\pi}{\lambda^2}(0.81)A_p \qquad (22)$$

It is seen that this directivity is reduced by a factor of 0.81(the aperture taper efficiency ε_{ap}) from that of the same aperture when uniformly illuminated. This formula provides only a rough approximation for a small aperture [6,7].

5. Estimated directivity formula

It is very useful to have an approximate directivity expression that depends only on the half - power beam widths of the principal plane patterns. This is expected to yield good results since we know that the directivity varies inversely with the beam solid angle ($D = 4\pi/\Omega_A$) and the beam solid angle is primarily controlled by the main radiation lobe. Thus, we expect to find that directivity inversely proportional to the half -power beam width of the principle E-and H-plan pattern, i.e. $D \alpha (HP_E HP_H)^{-1}$,where the product of the principal plane beam widths approximates the beam solid angle.

For uniform rectangular aperture, it is found that [4].

$$D_{u_{rect}} = \frac{32383}{HP_{E^o} HP_{H^o}} \qquad (23)$$

where HP_E and HP_H are the principal plan beam widths in degrees.

For a rectangular aperture with a cosine amplitude taper in the H-plane and uniform phase, as found in the open -ended waveguide operating in the dominant TE_{10} mode,[4]

$$D_{TE_{10}} = \frac{41253}{HP_{E^o} HP_{H^o}} \qquad (24)$$

Other simple approximated formulas have been proposed,but that are mostly for special cases.[8, 9]

6. Computed results and discussion

For a given frequency of operation of 10 GH_z , for example, equations (9) have been solved to determine the electric field components E_θ and E_φ radiated from a rectangular waveguide propagating, either the TEM wave for which $k_x = 0$ and $k_y = 0$,or the TE_{10} mode for which $k_x = \pi/a$ and $k_y=0$, in both principal H-plane ($\varphi = 0°$ plane) and E-plane ($\varphi = 90°$ plane).

The polar plot of the radiation pattern, for all radiation space ($0 \le \theta \le \pi$and $0 \le \varphi \le 2\pi$) are shown in Figs. (2) and (3) respectively. From these figures, it is clear that the half –power beam widths for the TEM wave are equal to $HP_H = 88°$ and $HP_E = 156°$ from which it is found that the directivity of uniform rectangular aperture, using the estimated formula (23), equals to 2.306=3.355 dB.For the TE_{10} mode $HP_H = 113°$, $HP_E = 170°$, and hence, using eq. (24) gives,D_{TE10} = 2.147=3.318 dB.

For electrically small ($A_p/\lambda^2 < 1$) and large ($Ap / \lambda^2 > 1$) rectangular aperture area, exact and approximated solutions are obtained for the directivity of uniform amplitude distribution using eq. (18) and eq.(19) respectively.These result, are listed in table (1) and plotted versus (Ap/ λ^2) in Fig. (4).Exact and approximate solutions have also been found for the directivity of a rectangular waveguide propagating the dominant TE_{10} mode using eq.(21) and eq.(22) respectively. Such results, are listed in table (2) andplottedinFig.(5).For both cases it is clear that the exact and approximated values of the directivity are in a good agreement for electrically large aperture and getting less and less for electrically small aperture .This is an expected result since the validity of Stutzman's formula (16) requires that the aperture is largely relative to a wavelength.

Finally, it is to be mentioned that no approximations have been introduced in the exact expression (15) for determining the directivity other than the usually and justified far-field approximation where the radial component E_r of the radiation field has been ignored.In Stutzman's formula (16)the radiated power is determine at the aperture plane where it is easier to integrate. In this case the E_r plays a considerable role in near field of the antenna and cannot be neglected. This may interpret the cause of small discrepancy between the exact and approximate value of directivity even the aperture area is largely relative to the wavelength.

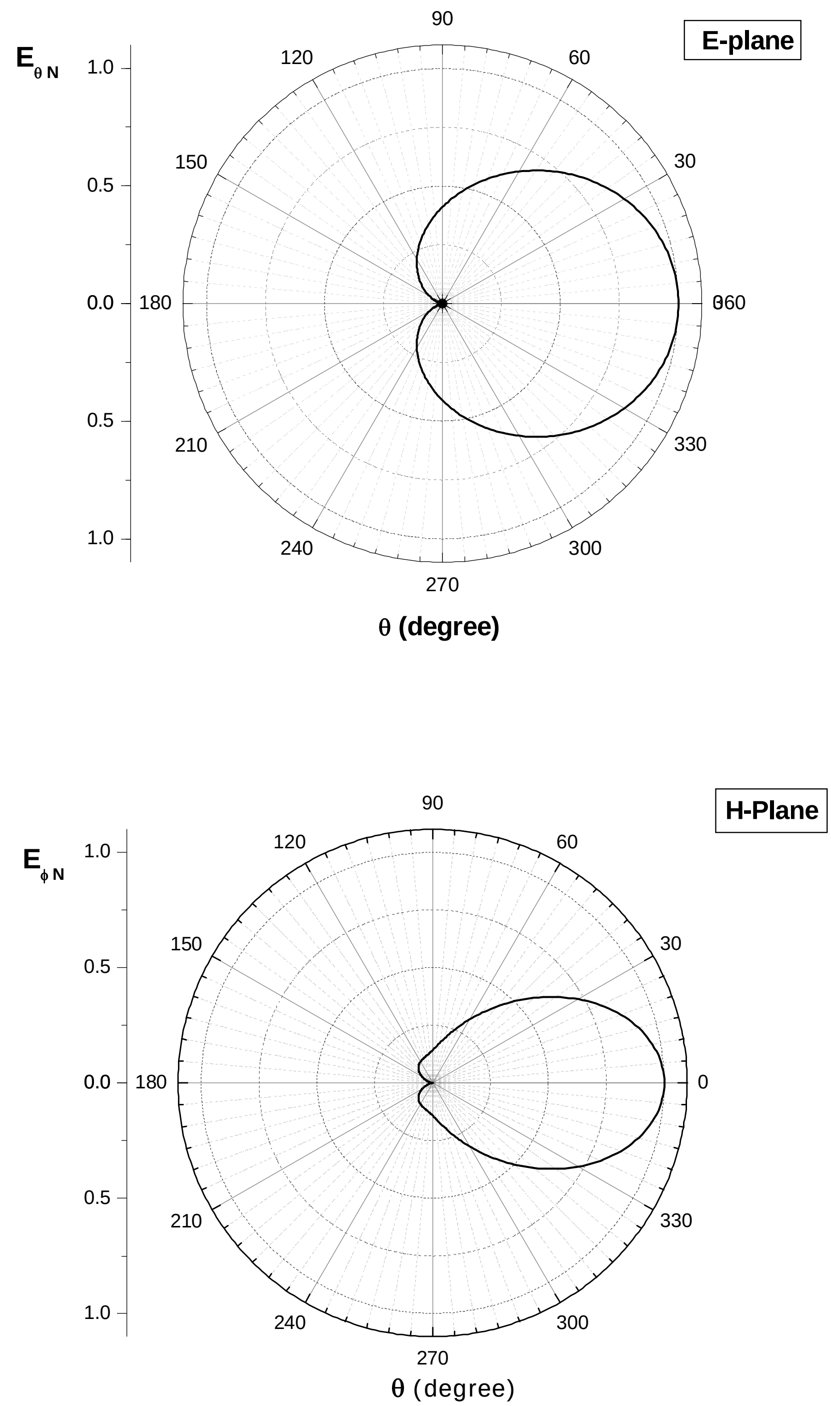

Fig.2 Radiation patterns of an open-ended rectangular waveguide in free space propagating the TEM wave.

a=2.286cm ,b=1.016cm ,freq.=10 GHz

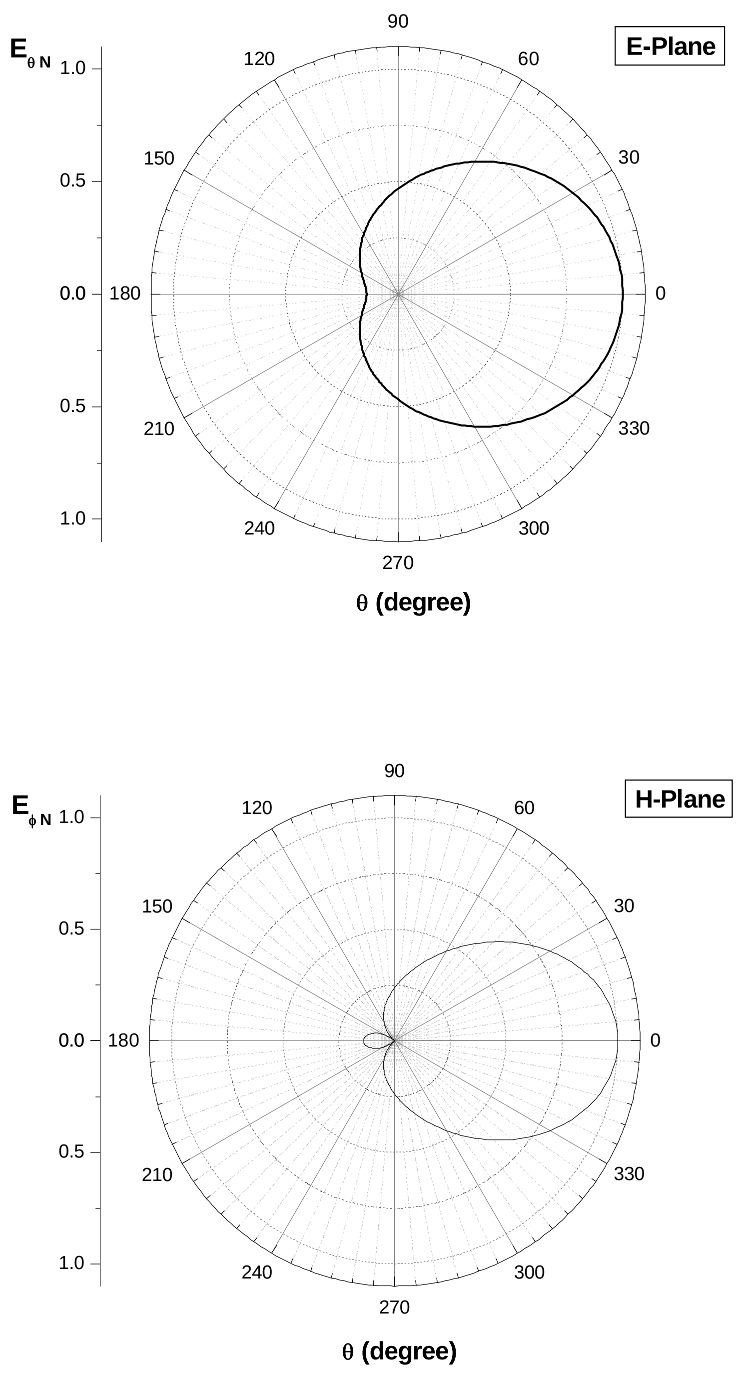

Fig.3 Radiation patterns of an open-ended rectangular waveguide in free space propagating the TE_{10} wave.

a=2.286cm ,b=1.016cm ,freq.=10GHz

Table (1)Directivity calculation for rectangular aperture antenna propagating TEM mode.

a=2.286 cm , b=1.016cm , A_p=a×b=2.323cm ^{2}

Freq.(GHz)	cm)λ(	$λ^2 A_p$ /	D_{TEM} (dB.) Exact. formula	D_{TEM}(dB.) Stutzman's formula.
7	4.286	0.126	6.157	1.998
8	3.75	0.165	6.550	3.168
9	3.333	0.209	6.975	4.195
10	3.000	0.258	7.425	5.109
11	2.727	0.312	7.891	5.935
12	2.500	0.372	8.365	6.700
13	2.308	0.436	8.836	7.389
14	2.143	0.506	9.300	8.035
15	2.000	0.581	9.748	8.636
20	1.500	1.032	11.753	11.131
25	1.200	1.613	13.599	13.070
30	1.000	2.323	15.242	14.654
35	0.857	3.161	16.500	15.992
40	0.750	4.130	17.574	17.153
45	0.666	5.229	18.484	18.178
50	0.600	6.453	19.339	19.091

Table(2)Directivity calculation for rectangular aperture antenna propagating TE_{10} mode.
a=2.286 cm , b=1.016 cm , A_p=a×b=2.323cm^2

Freq.(GHz)	cm.)λ(	$λ^2 A_p$ /	D_{TEM}(dB.) Exact. formula. eq(21)	D_{TEM}(dB.) stutzma'ns formula. Eq.(22)
7	4.286	0.126	5.678	1.082
8	3.75	0.165	5.946	2.253
9	3.333	0.209	6.243	3.280
10	3.000	0.258	6.566	4.195
11	2.727	0.312	6.913	5.019
12	2.500	0.372	7.281	5.784
13	2.308	0.436	7.667	6.473
14	2.143	0.506	8.067	7.120
15	2.000	0.581	8.476	7.720
20	1.500	1.032	10.561	10.215
25	1.200	1.613	12.490	12.155
30	1.000	2.323	14.139	13.739
35	0.857	3.161	15.472	15.076
40	0.750	4.130	16.534	16.238
45	0.666	5.229	17.459	17.262
50	0.600	6.453	18.335	18.176

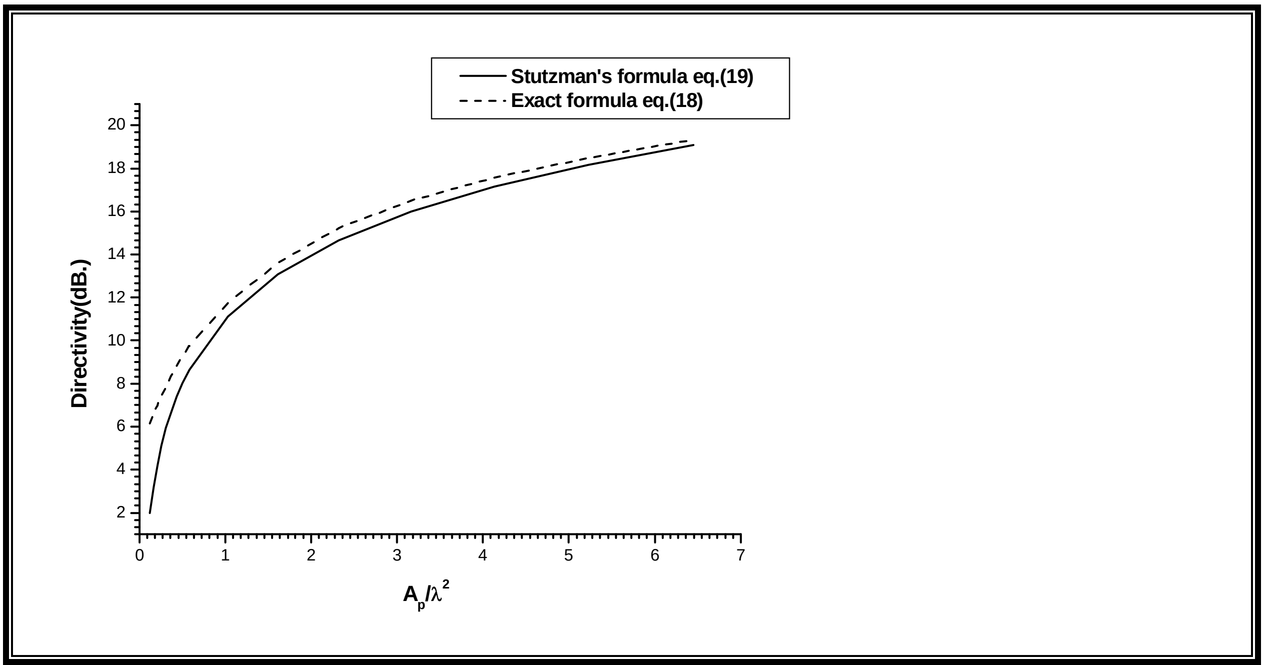

Fig.4 Directivity versus A_p/λ^2 for rectangular waveguide propagating the TEM wave

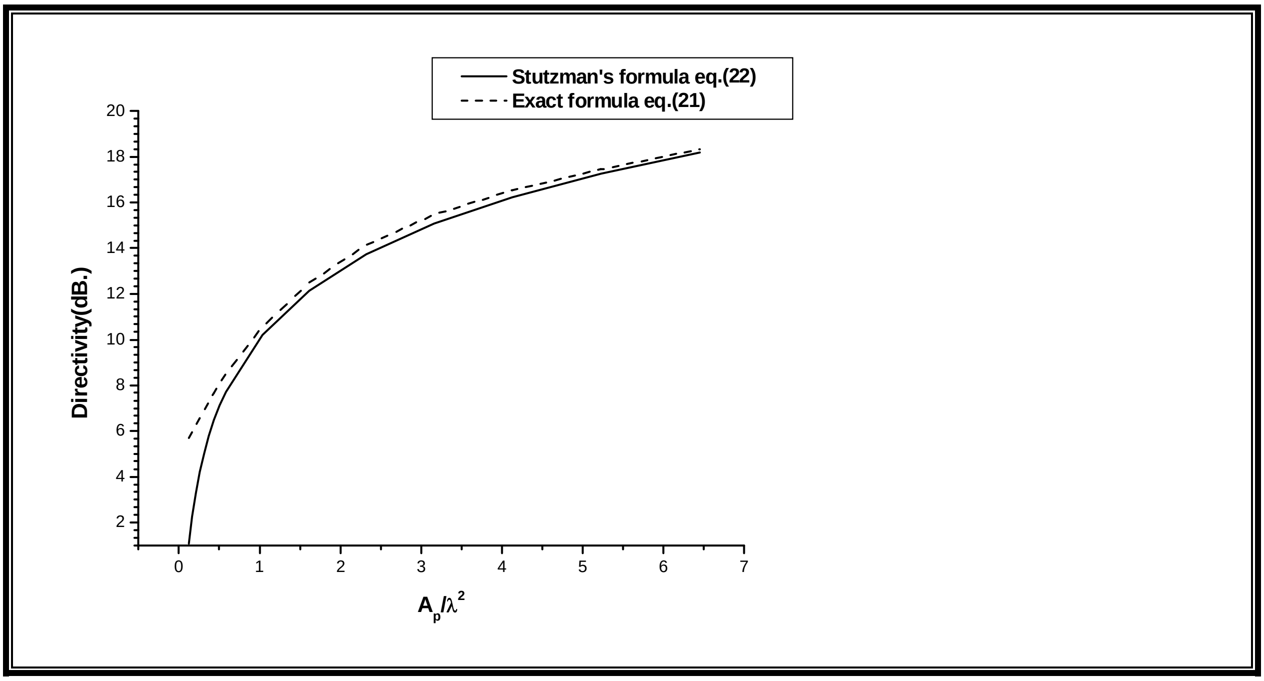

Fig.5 Directivity versus A_p/λ^2 for rectangular waveguide propagating the TE_{10} mode

7. Conclusions

On the basis of the present work, it is found possible to adopt a simple, direct, but powerful relationship presents in the literature [4] to evaluate the directivity of a rectangular aperture antenna provided that the physical aperture area is largely relative to a wavelength. This formula has been applied with success for a pyramidal horn antenna [10].

References

1. kareem, H.R: "propagation and radiation characteristics of corrugated rectangular waveguide", M.SC. thesis, University of Basra,Iraq, (2007).
2. Obaid, A .A .S.: "propagation and radiation characteristics of rectangular corrugated waveguides , "Ph.D. thesis, University of Birmingham , England , (1985)
3. Jordan, E. and Balmain,K. : "Electromagnetic waves and radiating system ", prentice- Hall , Englewood cliffs , ch.4, second edition ,(1968).
4. Stutzman, W.L and Thiele, G.A.:"Antenna theory and design" John Wiley&sons: NY. Second edition,(1998).
5. Obaid , A.A.S. , Maclean , T.S.M. and Razaz , M. :"Electric field cell for microwave frequencies " , International journal of electronics , vol. 55 , pp.857- 860, (1983).
6. Yaghjian, A.D.: "Approximate formulas for the far-field and gain of open-ended rectangularwaveguide ", IEEE Trans. Antenna and propagation , vol. AP – 32, pp. 378-384 , April , (1984).
7. Selvan,K.T. :"simple formulas for gain and far-field of open-ended rectangular waveguides " , IEEE proc. Microwave . Antenna propagation, vol. 145, No.1, February, (1998).
8. Tai, C.T. and Pereira,C.S.:"An approximate formula for calculating the directivity of an antenna", IEEE Trans. Ant & Prop, vol. AP -26, pp.235-236, March (1979).
9. Pozar, D.: "Directivity of omnidirectional antennas", IEEE Ant & prop. Magazine, vol. 35, PP. 50 – 51, Oct. (1993).
10. Obaid .A.A.S.: "Design of a pyramidal horn antenna fed by a rectangular waveguide with impedance walls", Journal ofBasraResearch, vol.27. Part 2, pp. 76-85, (2001).

حساب الاتجاهية لهوائي فتحة مستطيلة الشكل

هيفاء رحيم عبد الكريم و ليد حميد الموسوي و علي عبد الصمد عبيد
قسم الفيزياء / كلية التربية / جامعة البصرة
العراق

الخلاصة :

في هذا البحث تم اشتقاق صيغة رياضية محكمة من دون أي تقريب لحساب اتجاهية هوائي فتحة مستطيلة الشكل لغرض تقييم كفاءة استخدام صيغة رياضية بسيطة نظامية واردة في أدبيات الموضوع عند حساب اتجاهية هوائي فتحة موضع البحث.