THEORETICAL STUDY OF THE RADIATION FIELDS OF SHORT BACKFIRE ANTENNA EXCITED BY A LINEAR ARRAY OF A RECTANGULAR WAVEGUIDE

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Abstract :

The mathematical expressions of the far-field radiation pattern are derived from a short backfire array fed by a rectangular smooth walls w/g . New type of sub-reflector in conjunction with a half-wave length rim around the edge of main-reflector used to impose the electrical characteristics of this type of antenna. The calculated patterns agree reasonably well with the results of other research workers.

Introduction :

Employing the backfire principle, conceived by Ehrenspeck [1], which has been the subject of extensive experimental studies [2-3]. The technique provides means for increasing significantly the directivity of an endfire antenna without increasing its physical length.

Ehrenspeck [4] has also developed a short backfire antenna (SBFA) in which the backfire principle was applied to a single dipole (exciter) rather than to an endfire array.

A SBFAs has the structure consists of two parallel circular metal plates of unequal diameters. The front small plate (sub-reflector) acts as a mirror to reflect the wave incident from the exciter backward to the large plate (main-reflector) which in turn reflects the wave back again to an observation point located in the front of the antenna. These were placed perpendicularly and co-axially to the central axis of the antenna and were spaced by a half wavelength.

Several antennas can be arranged in space and interconnected to produce directional radiation pattern. Such a configuration of multiple radiating elements is referring to as an array antenna, or simply, an array, which represents a good technique to improve the radiation properties of antenna.

SBFAs [5-8] are highly efficient radiators of simple and compact construction. Owing to their favorable pattern characteristics, they lend themselves to the arraying technique of high-gain antennas for satellite communications, tracking, and telemetry.

Linear array antennas often comprise many identical radiating elements are, positioned at regular intervals along the aperture. Ignoring the effect of mutual interaction between elements, an assessment of the antenna radiation pattern can be easily made, using the pattern multiplication theorem. An array individual element pattern is assumed to represent the radiation from each and every element in the array, when acting alone. The total antenna radiation pattern results simply from the product of 'element pattern' and 'array factor'. In the other side the using of uniformly excited arrays of identical elements leads to reduce the side lobes level [9].

This paper presents a theoretical analysis to SBFA with linear fed array, a rectangular smooth walls waveguide used as a feeder to excite the antenna with a microwave energy, was positioned midway between and parallel to the plates.

Mathematical Description :

The basic idea of array theory is the principle of suppression of the field [10]. The analysis begins by considering a linear array of N- rectangular waveguides elements of dimensions (a) and (b) in x and y-direction, respectively. As shown in figure (1) the linear arrays were fed at the mid element centered on the origin, and operated in the dominant TE_{10}-mode which has a cosine distribution in the broad dimension and a uniform distribution in the narrow dimension. The tangential fields in the aperture of the feeder are:

$$\overline{E}_a = \hat{y}\ E_\circ \cos(\frac{\pi}{a}x) \tag{1-a}$$

$$\overline{H}_a = -\hat{x}\ \frac{E_\circ}{Z_g} \cos(\frac{\pi}{a}x) \tag{1-b}$$

Where $Z_g = \frac{w\mu}{\beta}$ is the wave guide impedance for TE-waves .

The radiation field of one element at an observation point $P_1(r_1, \theta_1, \phi_1)$ may be calculated by a well-known technique [11] based on the equivalent electric and magnetic surface current densities, where only transverse θ and ϕ components are retained, as:

$$E_{1\theta} = A \ \sin\phi_1 (\ 1 + \frac{\beta_{10}}{\beta} \cos\theta_1 \ ) \cdot D \tag{2-a}$$

$$E_{1\phi} = A \ \cos\phi_1 (\ \cos\theta_1 + \frac{\beta_{10}}{\beta} \ ) \cdot D \tag{2-b}$$

Where:

$$A = \frac{w\mu\pi B_1}{ak_c^2} \ \frac{e^{-j\beta r_1}}{2\lambda r_1} 2\pi ab \tag{3}$$

$$D = \frac{\cos(\frac{\beta a u_1}{2}) \sin(\frac{\beta b v_1}{2})}{[\ \pi^2 - (\beta a u_1)^2 \ ] \ (\frac{\beta b v_1}{2})} \tag{4}$$

Where (B_1 : constant)

$$k_c = \frac{\pi}{a}$$

$$\beta_{10}^2 = \beta^2 - k_c^2$$
$$u_1 = \sin\theta_1 \cos\phi_1$$
$$v_1 = \sin\theta_1 \sin\phi_1$$

and

$$\theta_1 = \tan^{-1}(\sqrt{x_s^2 + y_s^2} \ / z_1)$$
$$\phi_s = \tan^{-1} (y_s / x_s)$$
$$\phi_1 = \pi - \phi_s$$

The radiation field of linear array of N-elements in x-direction spaced between elements is:

$$E_{1\theta} = f_x(\psi) \cdot A \sin\phi_1 \ (1 + \frac{\beta_{10}}{\beta} \cos\theta_1 \ ) \cdot D \tag{5 –a}$$

$$E_{1\phi} = f_x(\psi) \cdot A \cos\phi_1 \ (\cos\theta_1 + \frac{\beta_{10}}{\beta} \ ) \cdot D \tag{5 –b}$$

where $f_x(\psi) = \dfrac{\sin N(\frac{\psi}{2})}{N \sin\frac{\psi}{2}}$ is the array factor of a linear array with an uniform current excitation and $\psi = \beta d_x \sin\theta_1 \cos\phi_1 - \alpha_x$, N-number of elements, β is the wave number corresponding to the free space wave length and α_x is a progressive phase.

The boundary conditions on the surface of the sub-reflector require that the tangential components of the electric field to be zero, where the tangential components of the magnetic field are doubled. Then the tangential field on the surface of the sub-reflector is given by:

$$H_{ts} = \hat{x}\, H_{xs} + \hat{y}\, H_{ys} \tag{6}$$

$$H_{xs} = -\frac{2}{z_\circ}\left(E_{1\theta} \sin\phi_1 + E_{1\phi} \cos\theta_1 \cos\phi_1 \right) \tag{7 -a}$$

$$H_{ys} = \frac{2}{z_\circ}\left(E_{1\theta} \cos\phi_1 + E_{1\phi} \cos\theta_1 \sin\phi_1 \right) \tag{7 -b}$$

The radiation fields set up at an observation point $P_2(\, r_2, \theta_2\, , \phi_2\,)$ du to the surface current density are then given by:

$$E_{2\theta} = jw\mu \frac{e^{-j\beta r_2}}{2\pi r_2} \cos\theta_2 \left(Q_{xs} \sin\phi_2 - Q_{ys} \cos\phi_2 \right) \tag{8 -a}$$

$$E_{2\phi} = jw\mu \frac{e^{-j\beta r_2}}{2\pi r_2} \left(Q_{xs} \cos\phi_2 + Q_{ys} \sin\phi_2 \right) \tag{8 -b}$$

The functions Q_{xs} and Q_{ys} are defined by:

$$Q_{xs} = \iint H_{xs} \exp[\, j\beta\, (\, x_s\, u_2 + y_s\, v_2\,)\,]\, dy_s\, dx_s \tag{9 -a}$$

$$Q_{ys} = \iint H_{ys} \exp[\, j\beta\, (\, x_s\, u_2 + y_s\, v_2\,)\,]\, dy_s\, dx_s \tag{9 -b}$$

Where the integration is now over the cross-section area of the sub-reflector which is lies in the xy-plane, and:

$$u_2 = \sin\theta_2 \cos\phi_2$$
$$v_2 = \sin\theta_2 \sin\phi_2$$
$$\theta_2 = \tan^{-1}\left(\sqrt{x_m^2 + y_m^2} \,/\, z_2 \right)$$
$$\phi_m = \tan^{-1}\left(y_m / x_m \right)$$
$$\phi_2 = \pi - \phi_m$$

Again, the boundary conditions imposed by perfect conductor of the main-reflector lead to:

$$H_{xm} = -2j\beta\, \frac{e^{-j\beta r_2}}{4\pi r_2} \cos\theta_2\;\, Q_{xs} \tag{10 -a}$$

$$H_{ym} = -2j\beta\, \frac{e^{-j\beta r_2}}{4\pi r_2} \cos\theta_2\;\, Q_{ys} \tag{10 -b}$$

The radiation electric field set up at an observation point $P_3(r_3, \theta_3, \phi_3)$ in the far-field region due to the electric surface current density, which is associated with H_{tm} on the main-reflector, is:

$$E_{3\theta} = -jw\mu \frac{e^{-j\beta r_3}}{4\pi r_3} \cos\theta_3 \, (Q_{xm} \sin\phi_3 - Q_{ym} \cos\phi_3) \tag{11 -a}$$

$$E_{3\phi} = -jw\mu \frac{e^{-j\beta r_3}}{4\pi r_3} \, (Q_{xm} \cos\phi_3 + Q_{ym} \sin\phi_3) \tag{11 -b}$$

Where

$$Q_{xm} = \iint H_{xm} \exp[\, j\beta(x_m u_3 + y_m v_3)\,]\, dy_m \, dx_m \tag{12 -a}$$

$$Q_{ym} = \iint H_{ym} \exp[\, j\beta(x_m u_3 + y_m v_3)\,]\, dy_m \, dx_m \tag{12 -b}$$

Where

$u_3 = \sin\theta_3 \cos\phi_3$

$v_3 = \sin\theta_3 \sin\phi_3$

and the integration above is taken over the cross-section area of the main-reflector.

Results and Discussion :

The radiation fields pattern of this type of antenna, in the principle E and H-plane are obtained from equations (11) by numerically evaluating the appropriate integrals. These patterns are compared in figures (2,3) and (4) respectively with the corresponding experimental results of [12-13].

A good agreement between the theoretical and experimental patterns is noted for the main lobe, and nearly identical half power beam-widths are obtained in H-plane for different number of elements. Some deviation in the side lobe level may be attributed to the experimental errors and the negligible radiation diffracted from the edge of the sub-reflector and without the effect of the near – zone field measurement in the calculated pattern.

The H-plane and E-plane normalized pattern functions for the SBFAs excited by the uniform linear array of rectangular wave guide with TE_{10}-mode, are plotted in figure (5) and figure (6) as a function of the number of elements. It is seen from figure (5) that the radiation pattern is improved by increasing the number of array element in H-plane while the parameters of the radiation filed for the linear array in the E-plane are the same as for the single element, since the elements arranged around yz-plane as shown in figure (6) .

Figure (7) shows that the patterns of SBFAs for seven elements are relatively insensitive to the variation of the distance between elements.

Table (1) shows the comparison between the results of radiation field parameters of the SBFAs under test and the results of the same parameters of a SBFAs fed by a coaxial w/g [14].

A good agreement between these results is noted to reveal the difference in the feed type and the mode excited in each antenna.

Conclusions :

It is concluded that the radiation fields of $SBFA_s$ fed by rectangular w/g may be mathematically formatted in closed form by using aperture method. An improvement in radiation characteristics of this type of antenna has been obtained when a linear array of these rectangulars w/g is introduced. This analytical technique provides a greater insight to the basic of the short backfire antenna.

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Table(1): Comparison between theoretical results of the radiation parameters of SBFA fed by a rectangular waveguide.

No. of elements N_x	H-plane				Co-polar				Max. Cross-polar (dB)	Postion of cross-polar (deg.)	Directivity (dB)
	-3 dB B.W. (deg.)	-10 dB B.W. (deg.)	S.L.L (dB)	Post. Of SLL (deg.)	-3 dB B.W. (deg.)	-10 dB B.W. (deg.)	S.L.L (dB)	Post. of SLL (deg.)			
3*	20.6	38.0	-25.9	40.0	23.0	40.2	-26.5	40.0	-40.0	50.0	22.10
3**	22.1	39.4	-27.4	61.5	24.0	42.3	-26.7	43.0	-38.9	19.0	21.05
5*	13.3	24.0	-22.0	27.0	18.0	34.4	-25.9	50.0	-42.5	65.0	24.72
5**	16.7	29.3	-32.0	28.0	20.1	35.6	-29.3	52.0	-40.5	59.5	23.26
7*	10.9	20.0	-20.0	21.5	15.0	28.6	-21.3	27.0	-45.1	75.0	25.81
7**	13.0	22.5	-22.0	22.5	16.6	29.2	-33.5	28.0	-43.3	90.0	24.72

(*) Theoretical results in this study
(**) Theoretical results reproduced from Godaymi [14]

Caption figures:

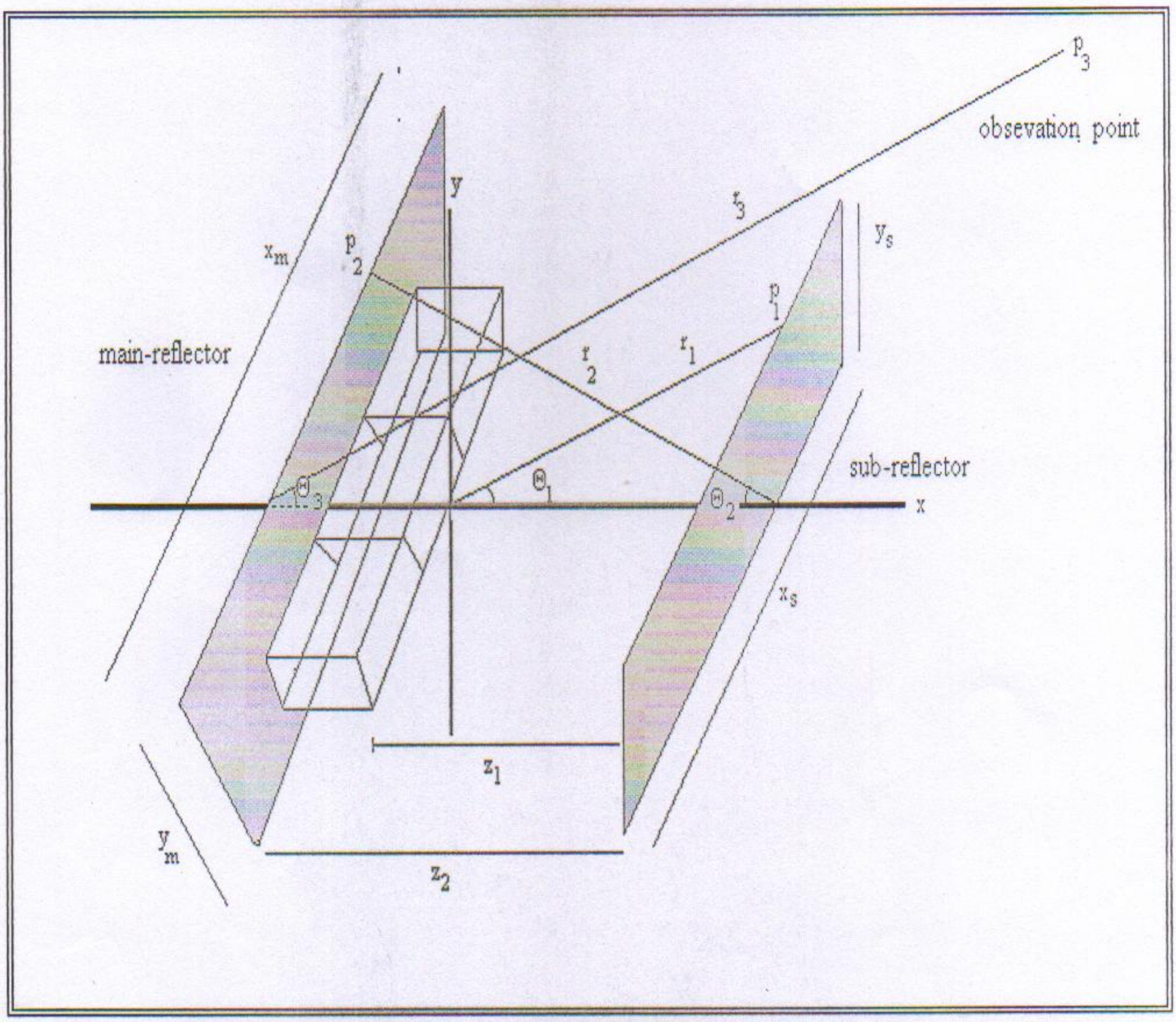

Fig. (1) : Coordinate system of SBFAs fed by a rectangular w/g.

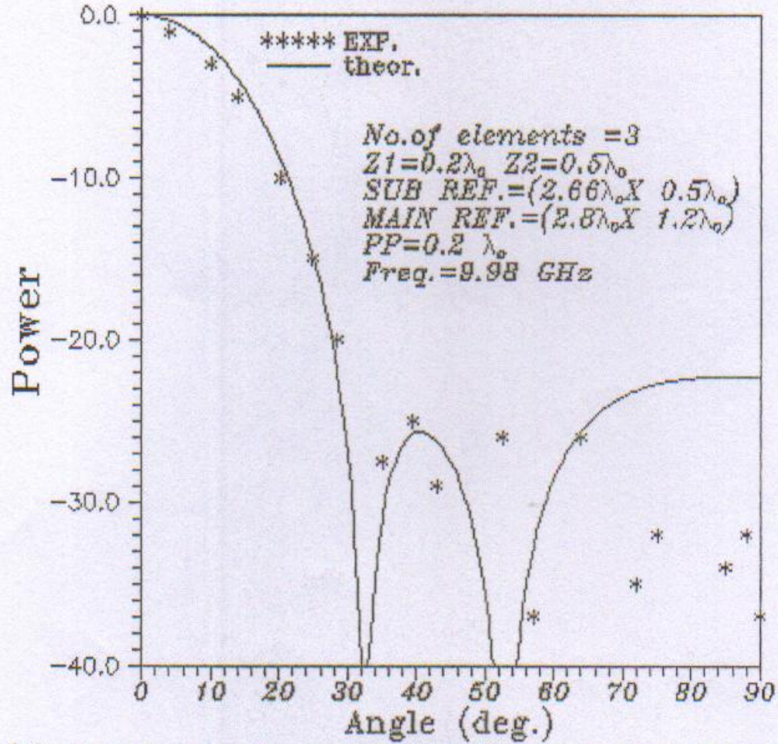

Fig.(2): Radiation pattern of SBFA fed by three rectangular waveguide.

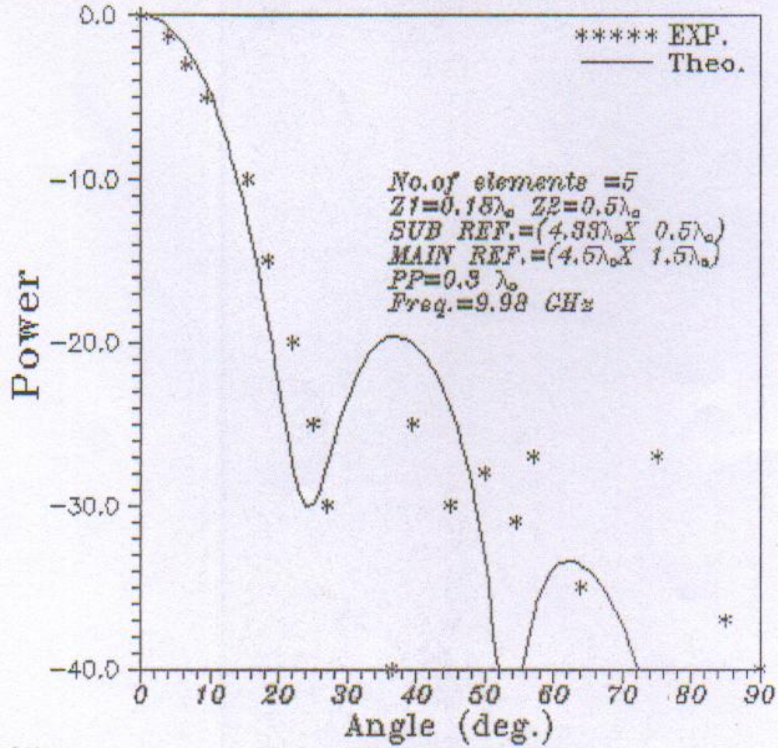

Fig.(3): Radiation pattern of SBFA fed by five rectangular waveguide.

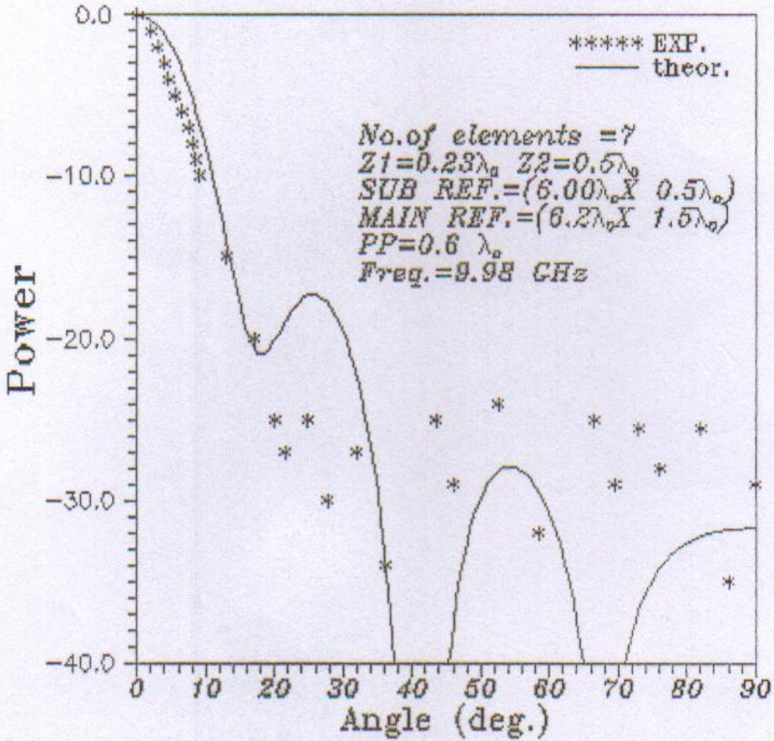

Fig.(4): Radiation pattern of SBFA fed by seven rectangular waveguide.

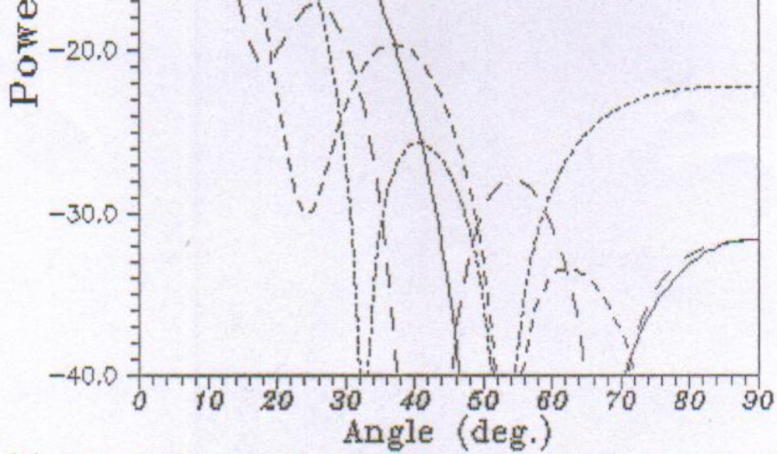

Fig.(5): Radiation pattern of SBFA fed by N rectangular waveguide.

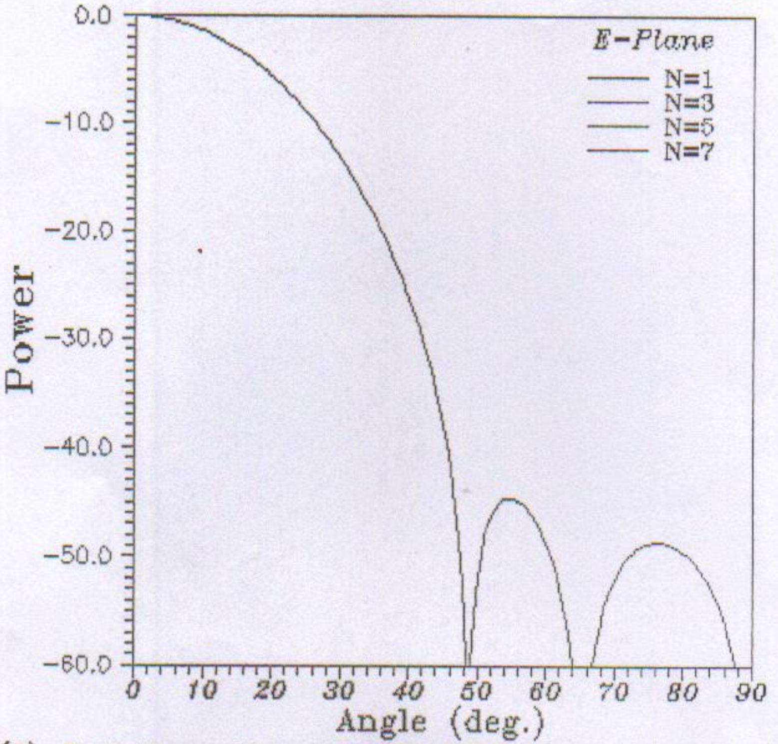

Fig.(6): Radiation pattern of EBFA fed by N rectangular waveguide.