THE EFFECT OF THE FEEDS (SBFA AND LBFA) ON PARAMETERS OF PARABOLIC REFLECTOR ANTENNA

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ABSTRACT

This study is concerned with the investigation of two types of feeds that are to be used for excitation the surface of parabolic reflector antenna operating in Q-band .
First type is short backfire antenna and the other is long backfire antenna , both of them have the same back reflector (conical). Good agreement has been achieved for the parameters of radiation pattern with measured results for other research workers .

تأثير المغذيات (الهوائي العكسي القصير والهوائي العكسي الطويل) على معاملات هوائي القطع المكافئ العاكس

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الخلاصة

"تناولت الدراسة نوعين من المغذيات تم استخدامها لإثارة سطح هوائي القطع المكافئ .النوع الاول هو الهوائي العكسي القصير والآخر كان الهوائي العكسي الطويل .كل من هذين الهوائيين يمتلك عاكس خلفي مخروطي الشكل . تم أستحصال نتائج نظرية كانت لحد كبير متوافقة مع ما مقاس عمليا من قبل باحثين آخرين."

1. INTRODUCTION

Reflector antennas have been used for about sixty years in radio astronomy, microwave communication and remote sensing .
The use of radio wave in the wavelength range between 1-10 centimeters has resulted in many innovations in directional antenna design . In particular, it has become a common practice to focus microwave energy into a desired directional beam by the use of a metallic reflecting surface excited by radiation from a small ,relatively nondirectional source where maximum directivity of the antenna is desired , the reflector shape is usually parabolic with a primary source located at the focus and directed

in to the reflector area. The reflector may be a section of a surface formed by rotating a parabola about its axis (circular paraboloid),a parabolic cylinder, or a parabolic cylinder bounded by parallel conducting planes [1]. The word paraboloid will be used only where subject matter refers specifically to the circular paraboloid ,which is the surface generated by rotating a parabolic curve about its axis.

Large professional antenna often use multiple reflector feeds, like the cassegrain [2] (hyperbolic sub-reflector) and gregorianian (elliptical sub-reflector) configurations. Even better is shaped-reflector system [3] , where both reflector shape are calculated for best efficiency and neither reflector is parabolic .

A parabolic dish antenna can provide very high gain at microwave frequencies, but only with very sharp beam widths. To achieve optimum gain, careful to detail is required: checking the parabolic surface accuracy with a template , matching the feed to the (F/D) ratio of the dish , and , most importantly, accurately locating the phase center of the feed at the focus [4].

This paper describes an investigation the effect of two types of feeds,on the radiation characteristics of parabolic reflector antenna , located at its focus. The first type is short backfire antenna and second type is long backfire antenna.

The aperture distribution of the parabolic reflector are computed in two steps .First, the current induced on the surface of the reflector by radiation from the feed is determined Next, the electric fields in the aperture ,arising from these currents ,are computed .the assumptions made in the derivation are:

(a) the reflector is in the far-zone of the feed, so that only fields varying as the reciprocal of the distance from the feed to the reflector are significant.

(b) The feed pattern is the same with the reflector in place as when it is absent.

(c) Energy traveling in the region between the reflector aperture and the feed follows the straight line paths predicated by geometric optics, while the polarization of the aperture field is determined by the plane-wave boundary conditions at the reflector surface, namely , that the total tangential electric field in the incident and reflected waves must be zero.

2. ANTENNA FEEDS

The performance of any antenna depends on types of feed which used as exciter of antenna surface , also the mean reason for this difference in performance is due to the variation of antenna radiation parameters of antenna by using many way in excited [5 , 6 , 7].

In this investigation ,we used two types of feeds to obtain the radiation pattern of parabolic reflector antenna as follow :

(a) SHORT BACKFIRE ANTENNA (SBFA)

It is consists of a rectangular waveguide (WG_{22}) with TE_{10} .exciting an antenna centered between a pair of reflectors . sub-reflector of (0.488 λ) diameter and main-reflector (conical back reflector) of (1.42 λ) a diameter, with slant angle ($\alpha=15^o$), the two reflectors are separated by spacing (0.488 λ) [8],as shown in figure (1a)

(b) LONG BACKFIRE ANTENNA (LBFA)

It is consists of a main reflector , sub- reflector and a cylindrical dielectric rod, fed through an open ended circular waveguide with dominant mode (HE_{11}),the reflectors diameters are (0.8) and (5.2) wavelengths, respectively.The surface wave structure (dielectric rod) is made of perspex ($\varepsilon_r=2.6$) with optimum dimentions (4λ) length, (0.4λ) diameter [9 , 10 , 11] ,as shown in figure (1b).

To get the same relation of electric field component , set up on observation point ($p(r,\theta,\phi)$ in far field region) we used main reflector for both feeds as a conic in shape but only different in source of excitation with respect of short and long backfire antenna .

The induced current method [12] is used to computed the electric field radiation in far field for both feeders , there for

$$\overline{E} = -j\beta Z_{\circ} A \qquad (1)$$

where (β) is the wave number corresponding to the free space wavelength and ($Z_{\circ}$) represents the characteristic impedance of free space (A)و is the magnetic vector potential which is associated with the electric surface current density (J_m) and given by:

$$\overline{A} = \frac{e^{-j\beta r}}{4\pi r} \int_S J_m \, e^{j\beta \hat{r}\cdot r'} \, da \qquad (2)$$

the section area (da) is given by

$$da = \csc^2(\alpha)\rho_m d\rho_m d\phi_m \qquad (3)$$

where (α) is the slant angle of the main reflector.

Now substitute equations (2) and(3) in (1)

$$\overline{E} = -j\beta Z_{\circ} \int_S J_m e^{j\beta \hat{r}\cdot r'} \csc^2(\alpha)\rho_m d\rho_m d\phi_m \qquad (4)$$

rewriting above equation in polar coordinate yield

$$E_\theta = -j\beta Z_\circ (A_x \cos\theta \cos\phi + A_y \cos\theta \sin\phi - A_z \sin\theta) \quad (5)$$

$$E_\phi = -j\beta Z_\circ (- \mathrm{A}_x \sin\phi + A_y \cos\phi) \quad (6)$$

(3) THE RELATION BETWEEN GEOMETRICAL AND WIDTH OF FEED RADIATION OF PARABOLIC REFLECTOR

All parabolic dishes have the same parabolic curvature, but some are shallow dishes, while others are much deeper and more like a bowl. They are just different parts of parabola which extends to infinity. A convenient way to describe how much of the parabola is used the (F/D) ratio , the ratio of the focal length (F) to the diameter (D) of the dish. All dishes with same (F/D) ratio require the same feed geometry , in proportion to the diameter of the dish.

The geometric of parabolic has relation with angle of feeder determine the ratio (F/D) , which is mean the angle of radiation feed should be covered the surface of reflect and with out losses in radiation from reflector edges [13].

As shown in figure (2), we begin with the formula for a vertically orientated parabola with its vertex on the origin

$$y^2 = 4FZ \quad (7)$$

the coordinate of point (Q') which is locate at edge of reflector surface is given by

$$Q'(y,z) = Q'(D/2, \mathrm{d})$$

where (d) is the deep of parabola from reflector aperture plane.
Again from figure (2)

$$\tan\theta_f = \frac{y}{2F} \quad (8)$$

by using the following relation

$$\tan\theta_f = 2\tan(\theta_f/2)/1 - \tan^2(\theta_f/2) \quad (9)$$

also

$$\tan\theta_f = 4\mathrm{F}\ \mathrm{y}/4\mathrm{F}^2 - \mathrm{y} \quad (10)$$

when y = D/2
finally the equation which gives the relation between the angle of radiation fed and ratio (F/D) is

$$\cot\theta_m = 2(\frac{F}{D}) - \frac{1}{8(\frac{F}{D})} \quad (11)$$

4. THEORETICAL ANALYSIS

The aperture field method (AFM) has been used to derive the radiation field equations for parabolic reflector antenna of focal length (F) and diameter (D) operating in Q-band , fed by (BFA) located at its focal point .

We consider the system of coordinate for parabolic reflector (x_a , y_a) and the Cartesian reference system (x_a , y_a , z_a) as shown in figure (3)

Suppose that (in Cartesian coordinates) the directional coordinate (x_f , y_f , z_f) (arrived from feeder BFA) of the reflected radiation beam points towards the parabolic surface as result of the back-reflector of (BFA) which is set up in far field region with respect to the parabolic surface .

In order to calculate radiation fields components in far field region we begin to determine the magnetic vector potential ($\overline{A}_f$) which is associated with the electric surface current density $\overline{J}_m(\rho_m , \phi_m)$, by

$$\overline{A}_f = \frac{e^{-j\beta r_f}}{2\pi r_f} \int_S \overline{J}_m(\rho_m , \phi_m)\, e^{j\beta \hat{r}\cdot r'}\, da \qquad (12)$$

the second step in analysis is calculated the radiation electric field by using well-known formula

$$\overline{E} = -\, j\beta\, Z_\circ\, \overline{A}_f \qquad (13)$$

and the magnetic field

$$\overline{H} = \frac{1}{Z_\circ}(\hat{r} \times \overline{E}) \qquad (14)$$

where $Z_\circ = \sqrt{\frac{\mu_\circ}{\varepsilon_\circ}}$ represents the characteristic impedance of the free-space and $\beta = \omega\sqrt{\mu_\circ \varepsilon_\circ}$ represent the wave number corresponding to the free-space wavelength .

therefore the radiation components field came from feeder in terms of polar coordinate are:

$$E_{\theta_f} = -j\beta\, Z_\circ A_f \cos\theta_f \sin\phi_f \qquad (15\ a)$$

$$E_{\phi_f} = -j\beta\, Z_\circ A_f \cos\phi_f \qquad (15\ b)$$

The total radiation field components set up at the surface of the parabolic reflector are given by

$$E_i = \hat{\theta}\, E_{\theta_f} + \hat{\phi}\, E_{\phi_f} \qquad (16)$$

since the radiation fields set up on the parabolic surface, when parabolic diameter larger than wavelength $(r \rangle\rangle \lambda)$, we can applied the geometric optics (G.O) on the plane surface [14].

According to the boundary conditions: the tangential component of reflected electric field (E_r^t) equal to the tangential component of incident electric field set up on the surface

$$\hat{n} \times E_r = \hat{n} \times E_i \tag{17 a}$$

and the vertical component of reflected electric field is equal to the vertical component of incident electric field set up on the reflector surface

$$\hat{n} \cdot E_r = \hat{n} \cdot E_i \tag{17 b}$$

by using the law of vectors on both side of equation (17a) we get

$$\hat{n} \times (\hat{n} \times E_r) = (\hat{n} \cdot E_r)\hat{n} - E_r$$

and the other side

$$\hat{n} \times (\hat{n} \times E_i) = (\hat{n} \cdot E_i)\hat{n} - E_i$$

therefore $(\hat{n} \cdot E_r)\hat{n} - E_r = -(\hat{n} \cdot E_i)\hat{n} + E_i$

from equation (17b)

$$E_r = 2(\hat{n} \cdot E_i)\hat{n} - E_i \tag{18}$$

the normal unit vector $(\hat{n})$ at any point on the surface of parabolic reflector in terms of Cartesian coordinates is given by [15]

$$\hat{n} = -\hat{x}_f \sin(\theta_f / 2)\cos\phi_f - \hat{y}_f \sin(\theta_f / 2)\sin\phi_f - \hat{z}_f \cos(\theta_f / 2) \tag{19}$$

substitute the last equation in equation (18) and by using the trigonometric transformation rules yield

$$\hat{n} \cdot E_i = [-\sin(\theta_f / 2)\cos\theta_f + \cos(\theta_f / 2)\sin\theta_f]E_{\theta_f}$$

from above procedure

$$2(\hat{n} \cdot E_i)\hat{n} = 2\sin(\theta_f / 2)E_{\theta_f}[-\hat{x}_f \sin(\theta_f / 2)\cos\phi_f - \hat{y}_f \sin(\theta_f / 2)\sin\phi_f - \hat{z}_f \cos(\theta_f / 2) \tag{20}$$

from equation (18) and (20) we get

$$E_r = \hat{x}_f[E_{\theta_f}\cos\phi_f - E_{\phi_f}\sin\phi_f] + \hat{y}_f[-E_{\theta_f}\sin\phi_f - E_{\phi_f}\cos\phi_f] \tag{21}$$

The first assumption was made by putting the feeder of parabolic dish antenna at the focus ,so that energy would radiated uniformly in both directions in magnitude and phase. Therefore the energy that is not radiated toward the reflector will be wasted ,and we want a feed antenna radiates only toward the reflector, and has a phase pattern that appears to radiate from a single point.

Inspection of equation (20) shows that the electric field vector, reflected from the surface of parabolic reflector has constant amplitude and phase shift. This phase shift may be treated at aperture plane by inter the factor (e^{-jPQ}) .

Where (Q,P) are two points located on the reflector surface and aperture plane respectively, and these two points are in the same direction (Z_f) and parallel to antenna axis .

So that the tangential electric field vector at aperture surface plane in point Q is

$$E_t = e^{-jPQ}[\hat{x}_f(-E_{\theta_f}\cos\phi_f + E_{\phi_f}\sin\phi_f) + \hat{y}_f(-E_{\theta_f}\sin\phi_f - E_{\phi_f}\cos\phi_f) \qquad (22)$$

The magnetic surface current density (M_s) which is in contact with tangential field distribution for coordinate aperture plane (ρ,ϕ') of parabolic is given by [16]

$$M_s = -\hat{n}\times E_t\,(\rho,\phi') \qquad (23)$$

This leads to write the relation (21) in terms of another coordinate system ,centered in circular aperture

$$z_a = -z_f \;\;,\; x_a = -x_f \;\;,\; y_a = y_f \;\;,\; \phi' = (\pi - \phi_f) \qquad (24)$$

where ϕ' the angle between (x_a) axis and the projection O_{ap} on the (x_a , y_a) plane.

Equation (22) become

$$E_t(\rho,\phi') = \hat{x}_a E_{ax} + \hat{y}_a E_{ay}$$

$$E_{ax} = (-j\beta Z_\circ)\frac{e^{-j\beta(r_f+PQ)}}{2\pi r_f}[-A_f\cos\theta_f\sin\phi_f\cos\phi' - A_f\cos\phi_f\sin\phi'] \qquad (25a)$$

$$E_{ay} = (-j\beta Z_\circ)\frac{e^{-j\beta(r_f+PQ)}}{2\pi r_f}[-A_f\cos\theta_f\sin\phi_f\sin\phi' - A_f\cos\phi_f\cos\phi'] \qquad (25b)$$

To determine the radiation field components for the parabolic reflector antenna at far-field point $P(r,\theta,\phi)$ the electric vector potential at this point in terms of magnetic surface current density M_s can be written as follow :

$$\overline{F} = \int_{sa} M_S(\rho,\phi')\frac{e^{-j\beta R}}{4\pi R}\,da \qquad (26)$$

since the point set at far-field region for the parabolic $r \rangle\rangle \frac{2D^2}{\lambda}$,i.e.,

$$\frac{1}{R}\approx\frac{1}{r} \quad , \quad \text{where} \;\; R = r - \hat{r}\cdot r'$$

By using the transformation relations

$$r' = \hat{\rho}\rho$$

$$\hat{r} = \hat{\rho}\sin\theta\cos(\phi-\phi') + \hat{\phi}\sin\theta\sin(\phi-\phi') + \hat{Z}\cos\theta$$

$$da = \rho d\rho d\phi'$$

where da is the cross section area , r' is the local vector and $\hat{r}$ is a unit vector,

by using this approximations, one can get

$$\overline{F} = -\frac{e^{-j\beta r}}{4\pi r}\hat{n}\times\int_{sa}\overline{E}_a(\rho,\phi')e^{-j\beta\rho\sin\theta\cos(\phi-\phi')}\rho d\rho d\phi' \qquad (27)$$

where $\hat{n} = +Z_a$

$$F = \hat{x}F_x + \hat{y}F_y$$

$$F_x = \frac{e^{-j\beta r}}{4\pi r}P_x \quad , \quad F_y = \frac{e^{-j\beta r}}{4\pi r}P_y$$

$$P_x = \int_0^{2\pi}\int_0^{r_a} E_{ax}e^{-j\beta\rho\sin\theta\cos(\phi-\phi')}$$

$$P_y = \int_0^{2\pi}\int_0^{r_a} E_{ay}e^{-j\beta\rho\sin\theta\cos(\phi-\phi')}$$

where r_a is the radius of parabolic reflector .finally, the electric radiation field in terms of the electric vector potential F yield [16]

$$E = -j\omega\varepsilon_\circ Z_\circ F\times\hat{r}$$

$$E = \hat{\theta}E_\theta + \hat{\phi}E_\phi$$

$$E_\theta = -j\beta[-F_x\sin\phi + F_y\cos\phi] \qquad (28a)$$

$$E_\theta = -j\beta[F_x\cos\theta + F_y\sin\phi] \qquad (28b)$$

5. RESULTS AND DISCUTION

The radiation patterns of parabolic reflector antenna (F/D=1.48) , excited by SBFA and LBFA in principle E&H-plane , has been calculated by using numerical solution of radiation field components of equation (28) in far field region which are getting from using AFM in theoretical analysis .These patterns are shown in figure (4) and (5) with same ratio of (F/D).

Also the results of parameters of radiation pattern shown in table (1) in the same of ratio of surface reflector that excited by two feeds.

The radiation pattern which are getting in this theoretical study are compared with the corresponding experimental results of [8] in principle E&H-plane for each two feeds are shown in figure (6) and (7) and table (2) , as well two studies are gives a best agreement (good agreement) between these patterns in main lobes and nearest side lobes.

The excitation angle of surface reflect (which covered the diameter of reflect completely) is choose to satisfy the same ratio F/D = 1.48 for both of feeders . so that excitation angle of the first type of feeds (SBFA) has been choose at -3dB for radiation beam while the second feeder (LBFA) have excitation angle has been taken at -6dB in order to keep on the (F/D=1.48) with out change.

6. CONCLUSION

The radiation field of parabolic reflector antenna is investigated and formulated in closed form by using AFM, Also, the effect of the feeds on parameters of parabolic reflector antenna are stimulated for two different feeds. Different excitation angle for the two feeds has been calculated which gives the same ratio F/D which is the condition in order to obtain the same radiation pattern for parabolic reflector antenna.

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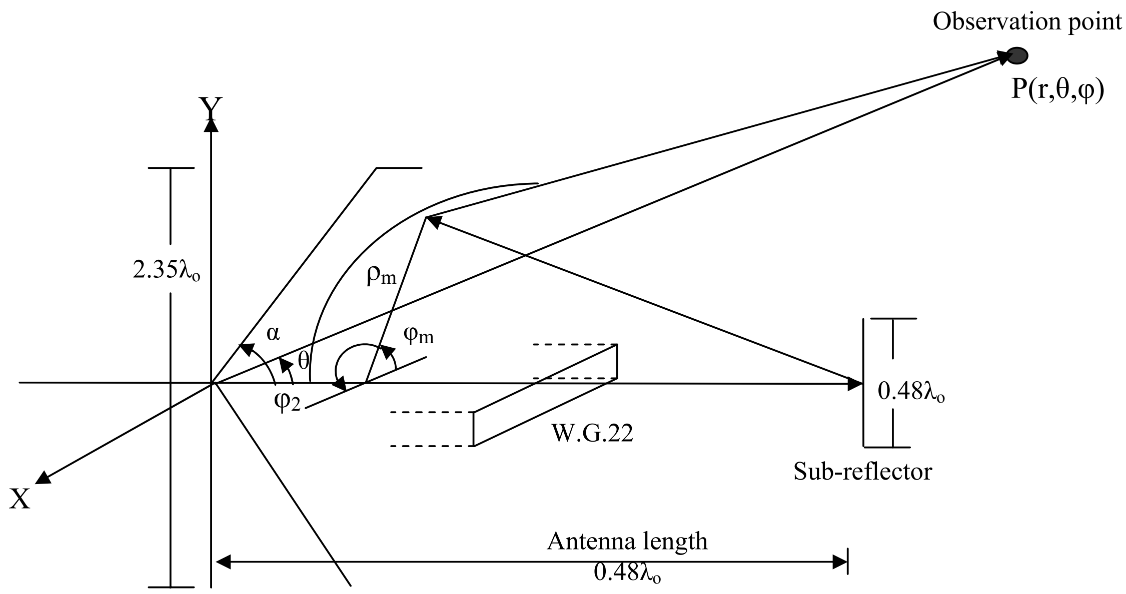


Fig (1a) rectangular wave guide excited by short backfire antenna feed with conical rim

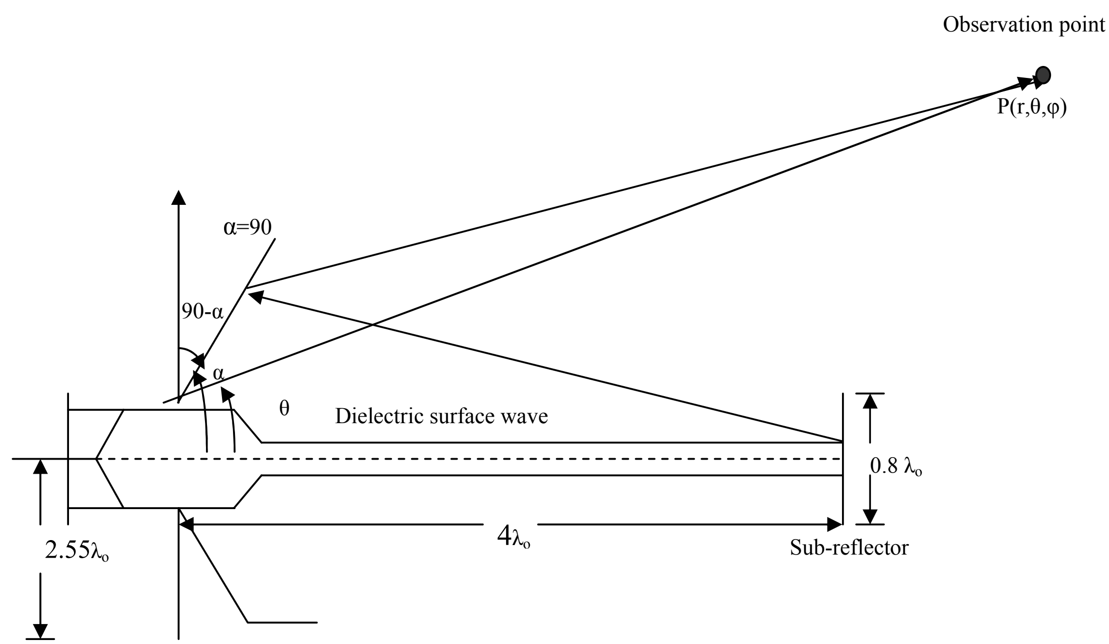
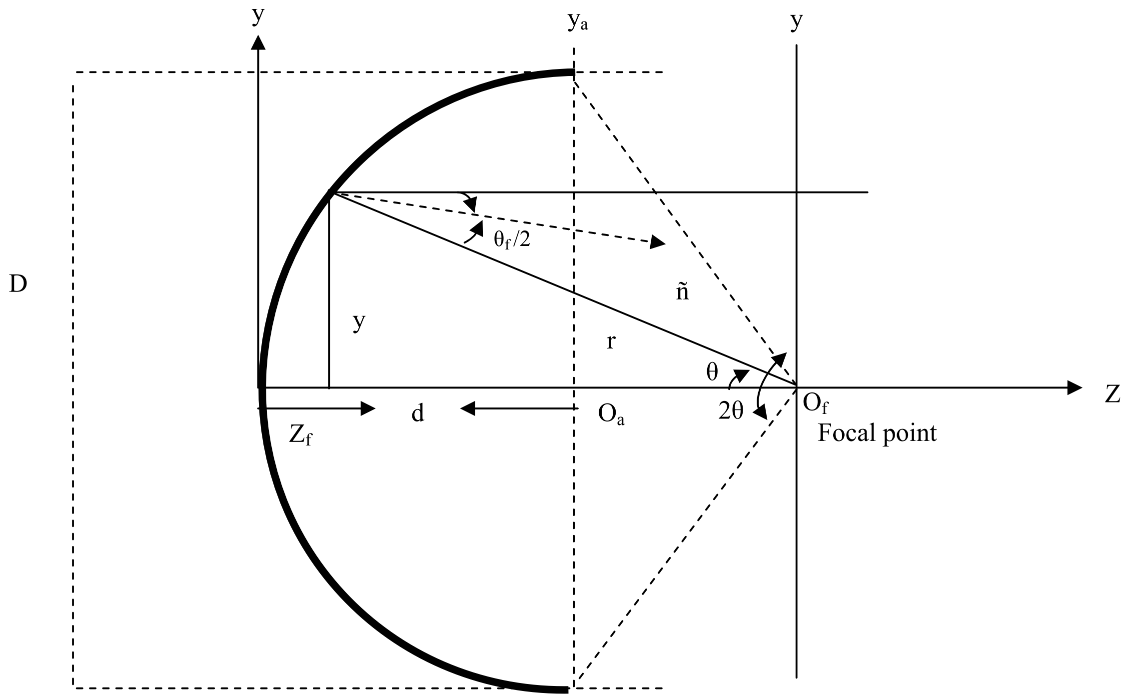
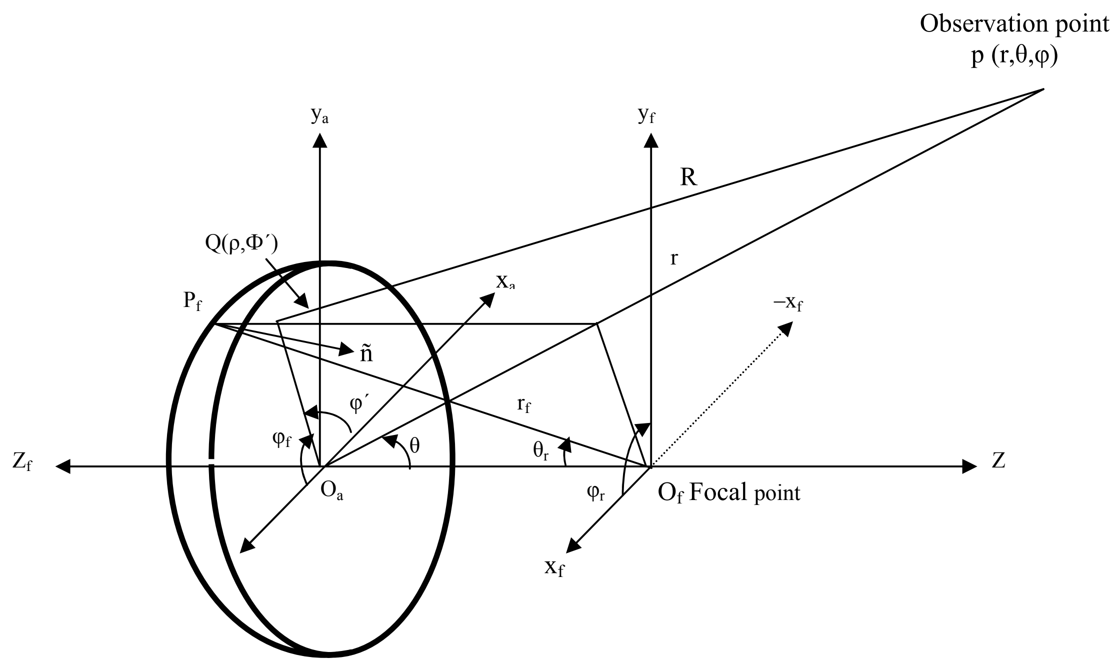


Fig (1b) Long backfire antenna with large conical reflector, dielectric rod wave guide



Fig(2) The relation between parabolic geometry and feed angle



Fig(3) The coordinates system of parabolic reflector Antenna

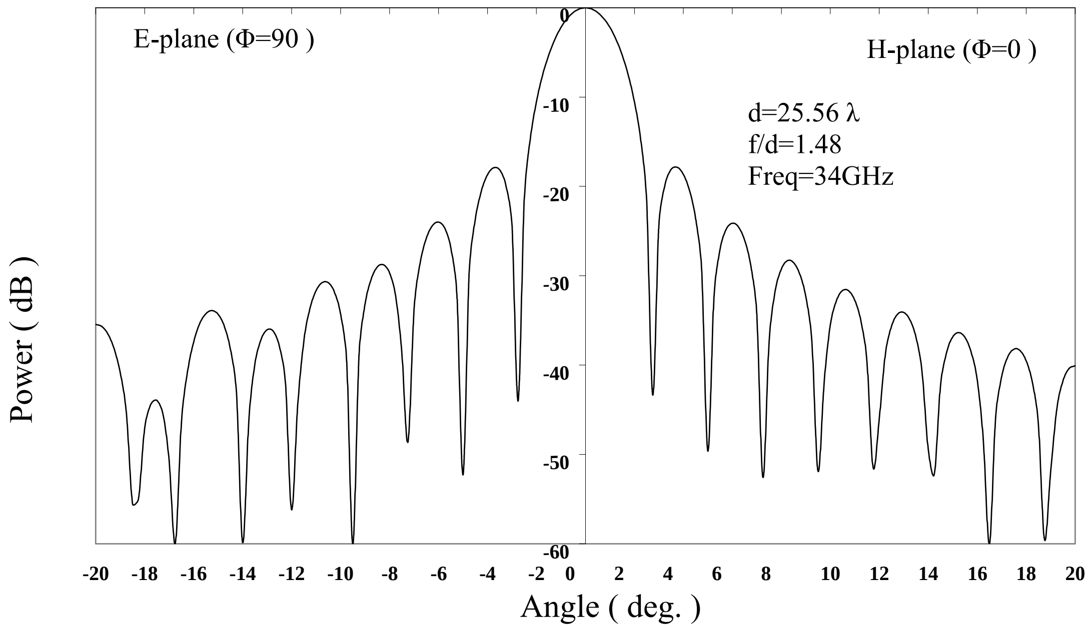


Fig (4):- Radiation pattern of parabolic reflector antenna fed by SBFA.

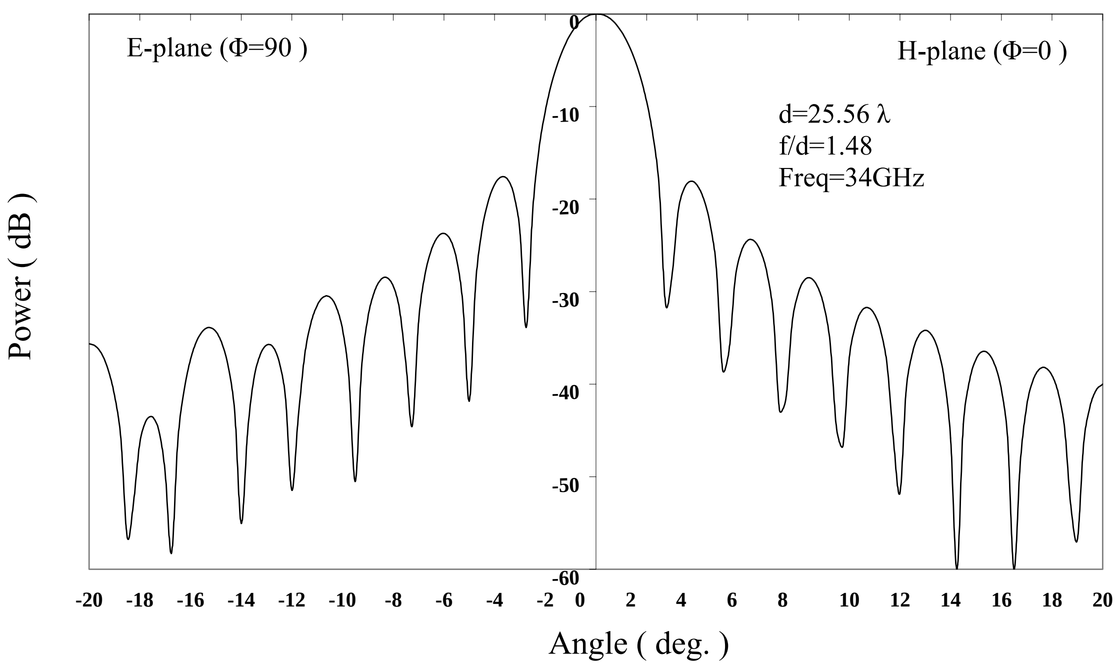


Fig (5):- Radiation pattern of parabolic reflector antenna fed by LBFA.

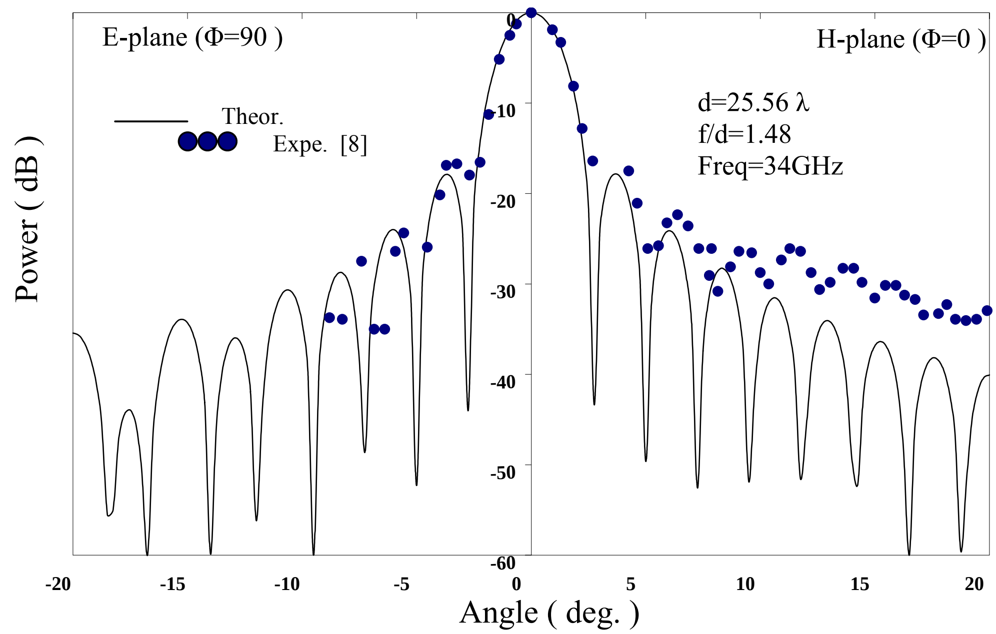


Fig (6):- Comparison between the Radiation pattern of parabolic reflector antenna fed by SBFA.

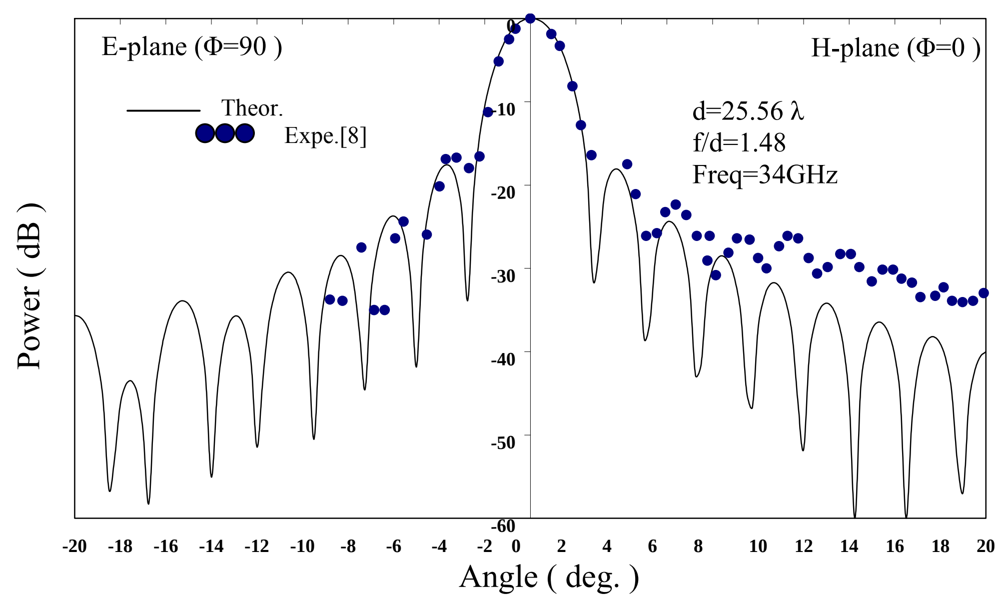


Fig (7):- Comparison between the Radiation pattern of parabolic reflector antenna fed by LBFA.

Table (1) : Radiation field parameters in the principle planes E&H for parabolic reflector antenna fed by backfire antenna (SBFA & LBFA)

Ratio F/D	Frequ.in GHz	Type of feed	H-plane (Φ=0) -3dB B.W (deg)	H-plane (Φ=0) -10dB B.W (deg)	H-plane (Φ=0) F.SLL dB	H-plane (Φ=0) Post.of F.SLL (deg)	E-plane (Φ=90) -3dB B.W (deg)	E-plane (Φ=90) -10dB B.W (deg)	E-plane (Φ=90) F.SLL dB	E-plane (Φ=90) Post.of F.SLL (deg)	Directivity
1.48	34	SBFA	2.29	4	-18.5	4.25	2.29	4	-17.5	4.25	38.09
		LBFA	2.5	4	-18.75	4.25	2.5	4	-17	4.25	38.08

Table (2) : Comparison of Radiation field parameters in the principle planes E&H with . experimental data and same ratio (F/D=1.48).

Type of feed	H-plane (Φ=0) -3dB B.W (deg)	H-plane (Φ=0) -10dB B.W (deg)	H-plane (Φ=0) F.SLL dB	H-plane (Φ=0) Post.of F.SLL (deg)	E-plane (Φ=90) -3dB B.W (deg)	E-plane (Φ=90) -10dB B.W (deg)	E-plane (Φ=90) F.SLL dB	E-plane (Φ=90) Post.of F.SLL (deg)
SBFA	2.29	4	-18.5	4.25	2.29	4	-17.5	4.25
Exp* [8]	2.31	4	-17.5	4	2.25	4	-16.5	4
LBFA	2.5	4	-18.75	4.25	2.5	4	-17	4.25