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Araştırma Makalesi - Research Article

Çizgisel Kaynak ile Odak Dışı Beslenen Bir Parabolik Reflektörden Kırınan Alanlar

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ÖZ

Bir çizgisel kaynağın bir silindirik parabolik mükemmel elektriksel iletken (MEİ) reflektör antenden kaynaklanan kırınan alanları Geliştirilmiş Fiziksel Optik'in (Modified Theory of Physical Optics; MTPO) saçınım integrali kullanılarak incelenmiştir. Reflektör, çizgisel kaynak tarafından odak-dışı olarak beslenmiştir. Köşe kırınım alanları, Köşe Noktası Metodu (Edge Point Method) kullanılarak asimptotik olarak hesaplanmıştır. Üniform kırınan alanları elde etmede kullanılan hesaplamada Signum (İşaret) ve Fresnel fonksiyonları yardımıyla üniform olmayan durum ortadan kaldırılmıştır. Toplam saçılan, kırınan ve yansıyan alanlar sayısal olarak, parabol genişliği, çizgisel kaynağın konum açısı gibi problemin bazı parametreleri için çizdirilmiştir.

Anahtar Kelimeler- Çizgisel Kaynak, Parabolik Anten, Odak-Dışı Besleme, Kırınım

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Diffracted Fields by a Parabolic Reflector Offset-Fed by a Line Source

ABSTRACT

Fields of a line source diffracted by a cylindrical parabolic Perfectly Electric Conducting (PEC) reflector are investigated by employing the scattering integral of the Modified Theory of Physical Optics (MTPO). The reflector that is symmetrically located with respect to x-axis is offset-fed by a line source. The line source is lying parallel to the z-axis and off the focus of the reflector. Diffracted fields are evaluated asymptotically by means of the Edge Point Method. An approximate way of expressing uniform diffracted fields is used by utilizing the Signum and Fresnel functions together to overcome the non-uniform situations. Total scattered, diffracted, and reflected fields are plotted numerically for some parameters such as parabola width and location angle of the line source in the problem.

Keywords- - Line Source, Parabolic Antenna, Offset Feed, Diffraction

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I.INTRODUCTION

Offset-fed reflector has long been studied by many researchers. Ingerson and Wong investigated the focal region features of offset fed reflector antennas [1]. The design of a dual-mode corrugated matched feed is also carried out [2]. Adatia and Rudge derived a formula for the squint effect magnitude providing good correlation with computed values of numerical models of offset reflectors and with experimental results as well [3]. A new class of primary-feed antennas is suggested [4]. In the study of Watson, Rudge and Adatia, design and evaluation of a dual-polarised mode is presented [5]. Cross-polar performance of an offset parabolic reflector fed by a rectangular matched feed is examined [6].

Rudge presented a mathematical model providing predictions of principally polarised and cross-polarised radiations for the fields propagated by offset parabolic reflector [7]. Watson examined the field distribution for a finite axially-symmetric parabolic reflector [8]. To obtain far fields of an antenna, Physical Optics (PO) or the ray optics methods are used but they require time consuming integrations. Instead, beam tracking is used by employing the complex-source point or evanescent wave tracking methods both of which are studied for a parabolic antenna whose offset beam feed is located at the focus [9]. Suedan and Jull applied the complex source point technique to parabolic cylinder reflectors and offset parabolic reflector examples [10]. Diffraction-resistant beams are proposed by means of a parabolic reflector and a spherical wave source which is placed near the focus [11].

Scattering and other aspects of parabolic reflectors without offset feed have already been studied for decades. Kennaugh and Ott examined the fields near the focus of a finite parabolic reflector [12]. Rudge derived the principal electric field components for a parabolic reflector by using the scalar wave theory [13]. In the study of James and Poulton, modified half plane diffraction coefficients are used for a plane wave to obtain the field near the parabolic reflector. It was observed that the result was consistent with the method of PO [14]. Knop and Ostertag evaluated the asymptotic PO expression of the scattered fields by a paraboloid [15]. Beam diffraction by a parabolic reflector is examined for a two dimensional case [16]. Umul examined the line source field scattering by a parabolic impedance reflector [17] by means of MTPO integrals [18]. We investigated the scattering phenomenon of an inhomogeneous o plane wave by a cylindrical parabolic PEC reflector [19]. In that study, homogeneous case is also considered. Sarnık and Yalçın examined the fields scattered by PEC parabolic reflector [20]. Yalçın examined scattering from a perfectly conducting cylindrical reflector by the method of the modified theory of physical optics [21].

In this study, we will investigate the diffraction effects of a parabolic PEC reflector offset-fed by a line source. The edge point method will be used to evaluate the diffracted fields which plotted for the parameters, such as offset angle of the source location, observation and source distances to the origin of the geometry.

II. THEORY

The scattering integrals of the MTPO used in [17] can be adapted for the parabolic PEC reflector shown in Fig. 1 as

$$E_{scattered} = \frac{e^{-jk\rho_3}}{\sqrt{k\rho_3}} + \frac{ke^{j\frac{\pi}{4}}}{\sqrt{2\pi}} \int_{-\varphi_e}^{\varphi_e} f(\alpha,\beta)\, \frac{e^{-jk\rho_1}}{\sqrt{k\rho_1}} \frac{e^{-jk\rho_2}}{\sqrt{k\rho_2}}\, \rho' \,\frac{d\varphi\prime}{\cos\left(\frac{\varphi'}{2}\right)} \tag{1}$$

where k is the wave number which is equal to $2\pi/\lambda$, and λ is the wavelength. $\rho_1$is the distance between the source and reflection point Q. ρ_2 and $\rho_3$are defined in Fig. 1 as the distances of source point and reflection point Q to the observation point P respectively. Reflector is located symmetrically with respect to the horizontal line ($\varphi' = 0$).

$$f(\alpha,\beta) = \sin\left(\frac{\beta+\alpha}{2}\right) - \sin\left(\frac{\beta-\alpha}{2}\right), \tag{2}$$

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where α and β are the angles between the surface normal, and ρ_1 and ρ_2 respectively. The first term in Eq.(2) represents the reflected field while the second term determines the incident-diffracted field of the scattering integral given in Eq.(1). Surface equation of the parabola is written as

$$\rho' = \frac{f}{cos^2\left(\frac{\varphi'}{2}\right)} \quad , \tag{3}$$

where f is its focus.

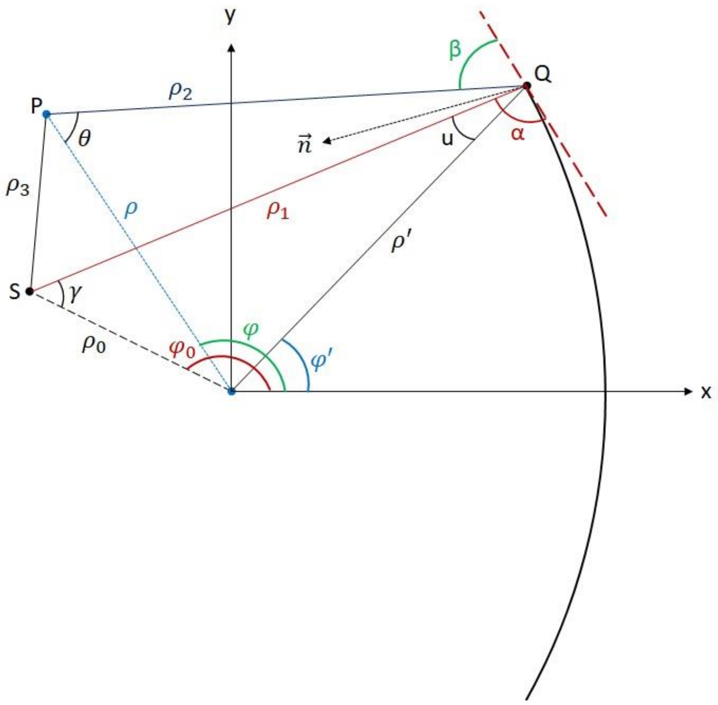

Figure. 1. Geometry of the problem.

Edge diffracted field is calculated by the Edge Point Method as

$$E_d \cong \frac{1}{jk} \frac{e^{jkg(\varphi_e')}}{g\prime(\varphi_e')} f(\varphi_e') \tag{4}$$

where the $g(\varphi_e')$ is the phase function and expressed as the sum of ρ_1 and ρ_2 at the edge point as

$$g(\varphi_e') = \rho_{1e} + \rho_{2e} \ , \tag{5}$$

and $g'(\varphi_e')$ is the first derivative of $g(\varphi_e')$.

f_e is given as

$$f_e = \frac{ke^{j\frac{\pi}{4}}}{\sqrt{2\pi}} f(\alpha, \beta) \frac{\rho_e'}{cos\left(\frac{\varphi_e'}{2}\right)} \frac{1}{\sqrt{k^2 \rho_{1e}\, \rho_{2e}}} . \tag{6}$$

ρ_1 and ρ_2 can be expressed as

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$$\rho_1 = \rho_0 cos\gamma + \rho' cosu, \tag{7}$$

and

$$\rho_2 = \rho cos\theta - \rho' cos(u - \alpha - \beta) \tag{8}$$

For the first derivative of Eq. (4) we write

$$\frac{\partial \rho_1}{\partial \varphi'} = -\rho_0 sin\gamma + \rho' \frac{sin\frac{\varphi'}{2}}{cos\frac{\varphi'}{2}} cosu \tag{9}$$

and

$$\frac{\partial \rho_2}{\partial \varphi'} = -\rho sin\theta + \rho' \frac{sin\frac{\varphi'}{2}}{cos\frac{\varphi'}{2}} cos(u - \alpha - \beta)\,. \tag{10}$$

Phase function derivative is obtained as

$$g'(\varphi') = \frac{\partial \rho_1}{\partial \varphi'} + \frac{\partial \rho_2}{\partial \varphi'} = \frac{\rho' cos\alpha - \rho' cos\beta}{cos\frac{\varphi'}{2}}\,. \tag{11}$$

At the edge point Eq. (10) is written as

$$g'(\varphi_e') = \frac{\rho_e'(cos\alpha_e - cos\beta_e)}{cos\left(\frac{\varphi_e'}{2}\right)}\,. \tag{12}$$

As a result, diffracted field is reduced to

$$E_d = \frac{1}{\rho_e'} \frac{e^{j\frac{\pi}{4}}}{\sqrt{2\pi}} \frac{e^{jk(\rho_{1e}+\rho_{2e})}}{\sqrt{k^2 \rho_{1e}\, \rho_{2e}}} \frac{f(\alpha,\beta) cos\left(\frac{\varphi_e'}{2}\right)}{cos\alpha_e - cos\beta_e}\ , \tag{13}$$

or

$$E_d = \frac{1}{\rho_e'} \frac{e^{j\frac{\pi}{4}}}{\sqrt{2\pi}} \frac{e^{jk(\rho_{1e}+\rho_{2e})}}{\sqrt{k^2 \rho_{1e}\, \rho_{2e}}} \frac{f(\alpha,\beta) cos\left(\frac{\varphi_e'}{2}\right)}{2\sin\left(\frac{\beta+\alpha}{2}\right) sin\left(\frac{\beta-\alpha}{2}\right)}\ . \tag{14}$$

Diffracted field can be expressed by the Signum and Fresnel functions to avoid non-uniform field plots as

$$E_d = \frac{cos\left(\frac{\varphi_e'}{2}\right)}{\rho_e'} \frac{e^{jk\rho_{1e}}}{\sqrt{k\rho_{1e}}} \left(e^{jk\rho_{1e}\cos(\beta_e - \alpha_e)} sign(t_1) F[|t_1|] - e^{jk\rho_{1e}\cos(\beta_e + \alpha_e)} sign(t_2) F[|t_2|]\right) \tag{15}$$

where

$$t_1 = \sqrt{2k\, \rho_{2e}} \sin\left(\frac{\beta_e - \alpha_e}{2}\right), \tag{16}$$

$$t_2 = \sqrt{2k\, \rho_{2e}}\, sin\left(\frac{\beta_e + \alpha_e}{2}\right), \tag{17}$$

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and the Fresnel function is defined as

$$F[x] = \frac{e^{j\frac{\pi}{4}}}{\sqrt{\pi}} \int_x^{\infty} e^{-jt^2} dt. \tag{18}$$

Sign(x) is the Signum function which is 1 for $x > 0$, and -1 for $x < 0$.

III. NUMERICAL ANALYSIS

In this section, we will examine the scattering characteristics of the offset-fed parabolic reflector for some parameter values. The total scattered field given in Eq.(1), reflected and diffracted fields will be plotted numerically. The focal length f is taken as 6λ. The value of ρ is equal to 3λ, and $\rho_0 = 5\lambda$ where the wave number λ is taken as 0.1 meter. Reflected and diffracted fields given in Eq. (19) and Eq. (20) respectively will be used for the plots.

$$E_r = \frac{ke^{j\frac{\pi}{4}}}{\sqrt{2\pi}} \int_{-\varphi_e}^{\varphi_e} \sin\left(\frac{\beta+\alpha}{2}\right) \frac{e^{-jk\rho_1}}{\sqrt{k\rho_1}} \frac{e^{-jk\rho_2}}{\sqrt{k\rho_2}} \rho' \frac{d\varphi'}{\cos\left(\frac{\varphi'}{2}\right)} \ . \tag{19}$$

Diffracted field is

$$E_{diffracted} = \frac{e^{-jk\rho_3}}{\sqrt{k\rho_3}} - \frac{ke^{j\frac{\pi}{4}}}{\sqrt{2\pi}} \int_{-\varphi_e}^{\varphi_e} \sin\left(\frac{\beta-\alpha}{2}\right) \frac{e^{-jk\rho_1}}{\sqrt{k\rho_1}} \frac{e^{-jk\rho_2}}{\sqrt{k\rho_2}} \rho' \frac{d\varphi'}{\cos\left(\frac{\varphi'}{2}\right)} \ . \tag{20}$$

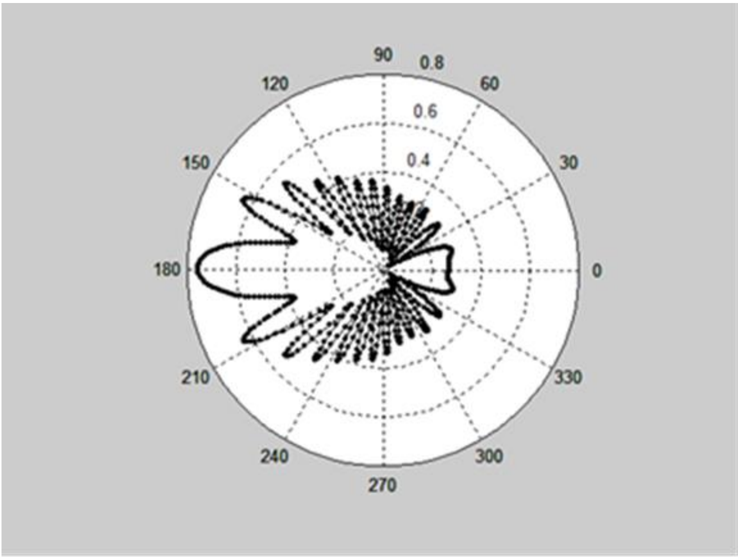

Figure 2. Total scattered field for $\varphi_0 = \pi$.

Total scattered field is the combination of the reflected and diffracted fields. When $\varphi_0 = \pi$ total scattered field is symmetrical with respect to the horizontal line of polar configuration as shown in Fig. 2. This is expected due to the geometry of Fig. 1.

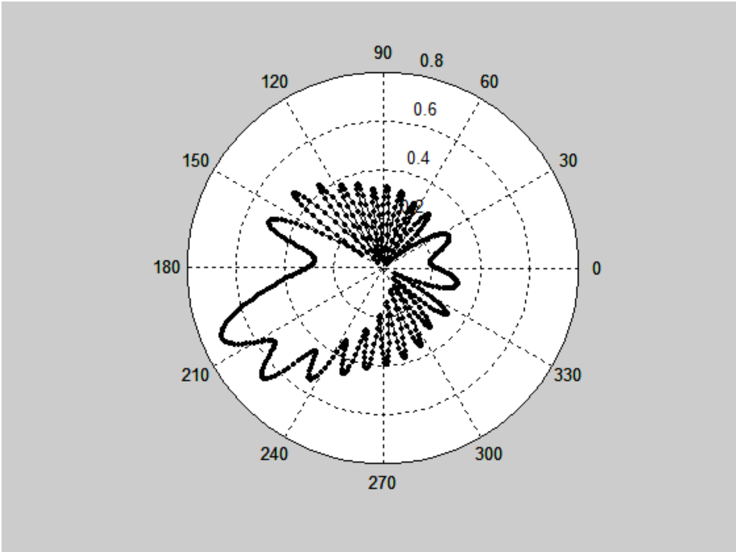

Figure 3. Total scattered field for $\varphi_0=7\pi/6$.

When the source is located on the place with an angle of $7\pi/6$, total scattered field pattern is oriented approximately in that direction as shown in Fig.3.

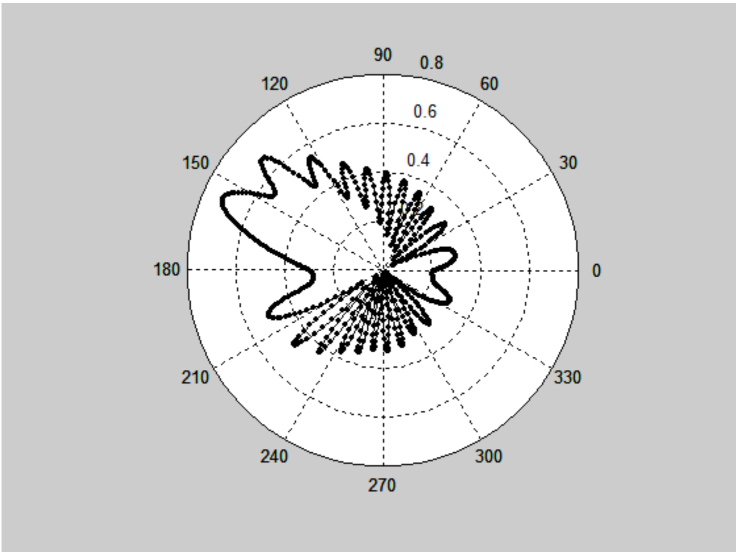

Figure 4. Total scattered field for $\varphi_0=5\pi/6$.

Similarly, total scattered field is obtained in Fig. 4 when the source is located at $\varphi_0=5\pi/6$.

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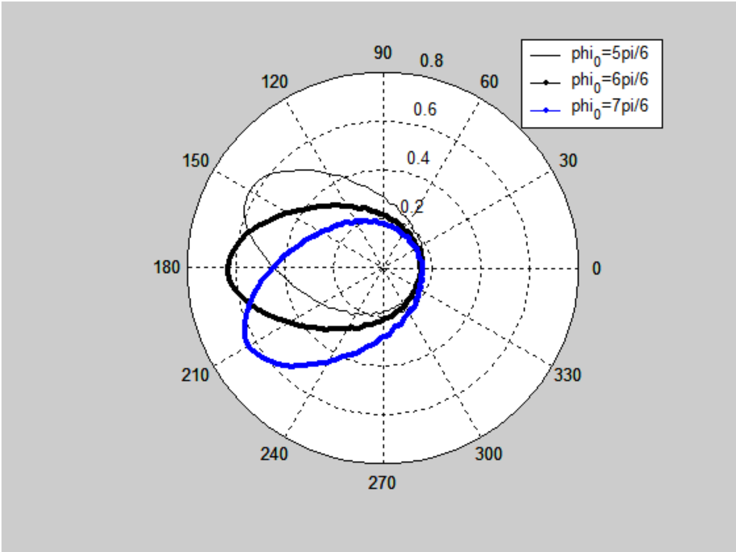

Figure 5. Total diffracted field variation for some φ_0 values.

Total transmitted field and diffracted field variations for some φ_0 values are depicted in Fig. 5 and Fig. 6 respectively. Total transmitted field is the summation of the incident and diffracted fields. As can be seen from Fig.5 that incident field determines the total transmitted field orientation. Because diffracted field occurs almost in all directions as depicted in Fig. 6. Also its contribution to the total transmitted field is much less than the incident field which can be seen from Fig. 6 as well.

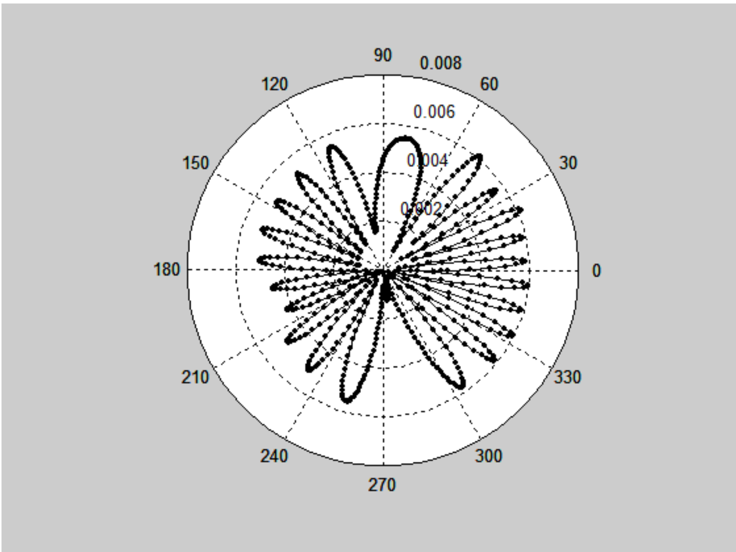

Figure 6. Diffracted field variation for $\varphi_0=5\pi/6$.

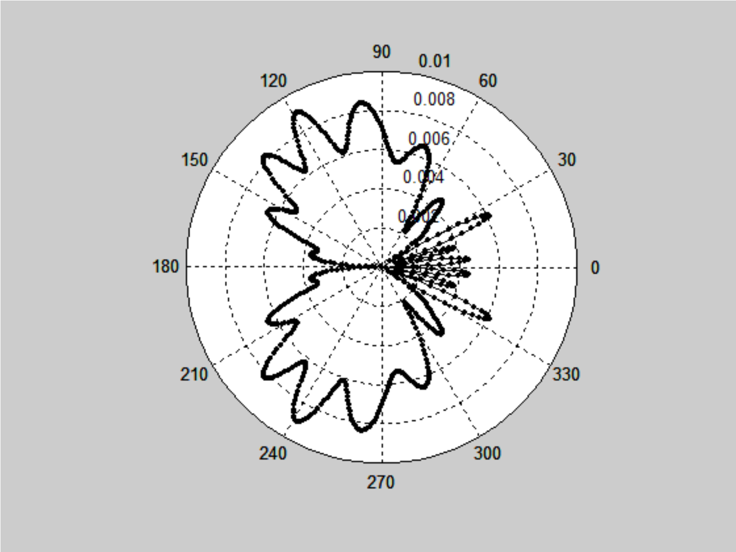

Figure 7. Reflected field variation for $\varphi_0=\pi$.

In Fig. 7, two main lobes of the reflected field that are symmetrical due to the source orientation are seen when the source is located on the horizontal line ($\varphi_0=\pi$).

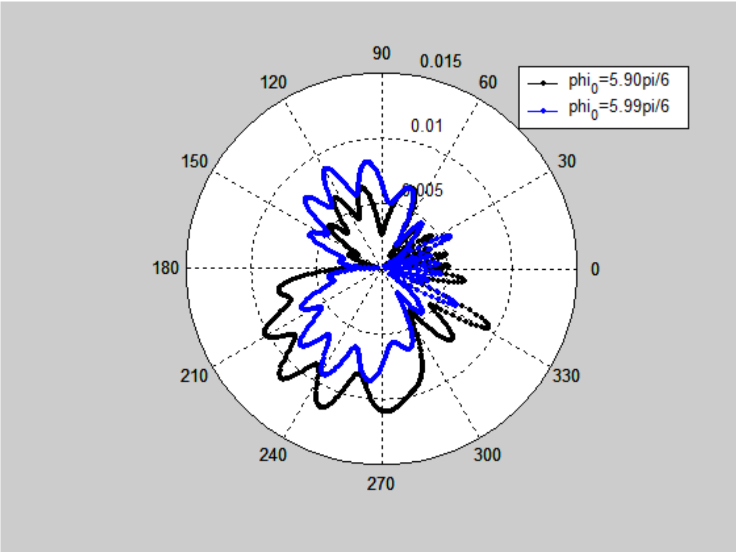

Figure 8. Reflected variations for some φ_0 values.

In Fig.8, as φ_0 tends to move clockwise away from π, main lobe start to occur in the lower part of the coordinate system due to the reflection phenomenon. Also, the upper part lobe gets smaller gradually. In a similar manner, main lobe occurs in the upper part in Fig. 9.

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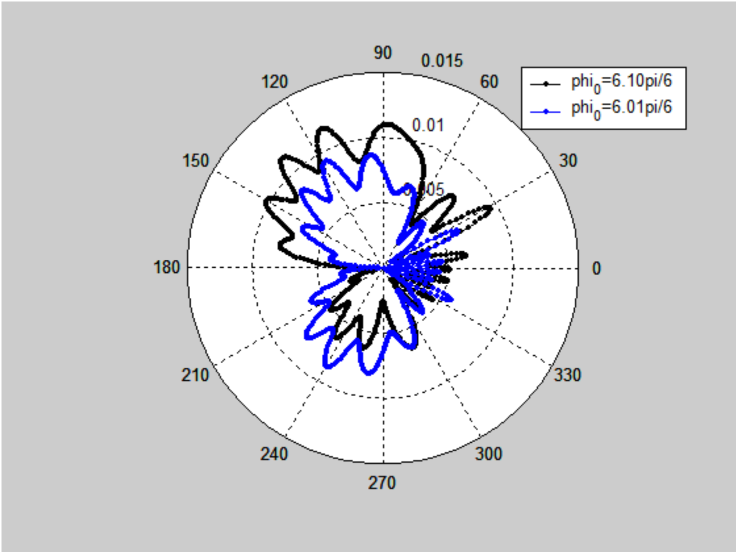

Figure 9. Reflected field variations for some φ_0 values.

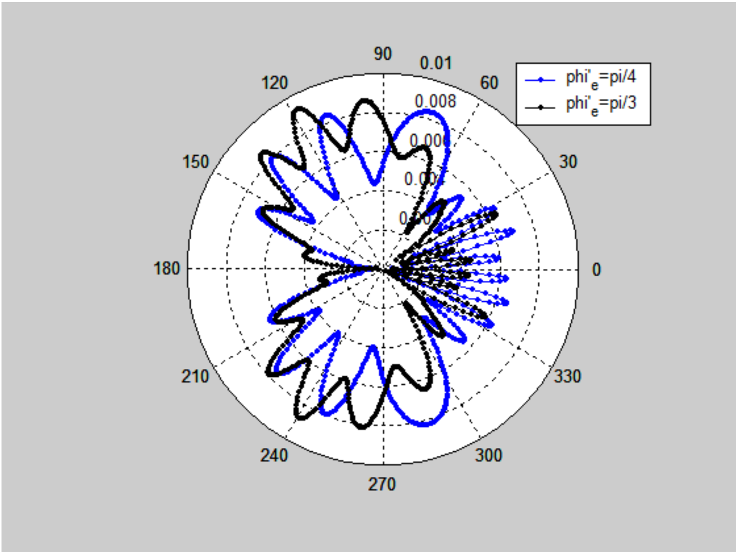

Figure 10. Reflected field variations due to reflector width.

Fig. 10 shows the variations of the reflected field due to the parabola width. It is seen that as the parabola width increases, scattering at the back side direction of the parabola decreases. Meanwhile, reflected field amplitude at the parabola front increases.

IV. CONCLUSION

Scattering integral, obtained via the surface integrals of the MTPO, of a line source field by a parabolic PEC reflector is employed to find the diffracted fields asymptotically. The parabolic reflector is considered with an offset feed by a line source placed off its focus. Diffracted field is obtained by the Edge Point Method and rewritten by means of Signum and Fresnel functions to avoid non-uniform field expression. Reflected and diffracted field variations and orientations are plotted numerically according to some parameter values. It is observed that as the width of the parabolic reflector increases, reflection to the front side of the reflector increases as well. However, reflected field at the back region of the parabola decreases.

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