SCATTERING OF INHOMOGENEOUS PLANE WAVES BY A CYLINDRICAL REFLECTOR

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SCATTERING OF INHOMOGENEOUS PLANE WAVES BY A CYLINDRICAL REFLECTOR

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

SCATTERING OF INHOMOGENEOUS PLANE WAVES BY A CYLINDRICAL REFLECTOR

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In this thesis, scattering by a cylindrical reflector which has a Perfectly Magnetic Conductor (PMC) surface illuminated by a inhomogeneous plane waves were investigated. The physical optics method (PO), one of the current based methods, has been used in this study. The current induced by the incident wave on the cylindric reflector has been found by aid of the boundary conditions. The obtained current has formed the kernel of the PO scattering integral of the PO scattering integral by the method of stationary phase method (SP), yields the geometrical optics (GO). The edge diffracted fields have been obtaiened by using the edge point method. At first, the solutions were obtained for the homogenous waves. Later on, considering the analytical conditions, the result were extended by interesting the complex angle values instead of real angle values. Lastly, the obtained expressions have been numerically analyzed for the parameters such as the reflectors of different sizes and different complex angle values.

Keywords: Cylindrical Reflector, Geometric Optics, Perfectly Magnetic Conducter, Physical Optics.

ÖZ

SİLİNDİRİK BİR REFLEKTÖR İLE HOMOJEN OLMAYAN DÜZLEM DALGALARININ SAÇILMASI

SARIÇOBAN, Mehmet Ceyhun

Yüksek Lisans, Elektronik ve Haberleşme Mühendisliği Anabilim Dalı

Tez Yöneticisi: Doç. Dr. Hüsnü Deniz Başdemir

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Bu tezde inhomojen dalgalar ile aydınlatılmış mükemmel manyetik iletken yüzeye sahip silindirik reflektörden saçılan alanlar incelenmiştir. Yapılan incelemede, akım bazlı metodların bir tanesi olan fiziksel optik metodu kullanılmıştır. Silindirik reflektor üzerinde gelen alan tarafıdan indüklenen akım, sınır koşulları yardımıyla bulunmuştur. Elde edilen akım fiziksel optik saçılma integralinin çekirdeğini oluşturmuştur. Saçılma integralinin stasyonel faz metoduyla değerlendirilmesiyle geometrik optik alanlar bulunmuştur. Köşe kırınım alanları ise saçılma integralinin köşe noktası tekniği ile değerlendirilmesi sonucunda elde edilmiştir. Başlangıçta homojen dalgalar için elde edilen çözümler, analitik süreklilik göz önüne alınarak, reel açı değerlerinin complex açı değerleri ile değiştirilmesi sonuncunda inhomojen dalga çözümlerine genişletilmiştir. Son olarak, elde edilen ifadeler farklı büyüklükteki reflektörler ve farklı kompleks açı değerleri gibi parametreler için sayısal olarak analiz edilmişlerdir.

Anahtar Kelimeler: Silindrik Reflektör, Geometrik Optik, Mükemmel Manyetik İletken, Fiziksel Optik,

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LIST OF ABBREVIATIONS

PTD	Physical Theory of Diffraction
PO	Physical Optics
MTPO	Modified Theory of Physical Optics
GO	Geometrical Optics
PEC	Perfectly Electric Conducting
UTD	Uniform Theory of Diffraction
GTD	Geometrical Theory of Diffraction
PMC	Perfectly Magnetic Conducting

CHAPTER 1

INTRODUCTION

1.1 Objectives

The current study aims to scrutinize the scattered fields of inhomogeneous plane waves by a cylindrical reflector. For this ultimate aim, the researcher utilized the theory of physical optics(PO) on cylindrical antenna with perfectly magnetic conducting surface. As is known the stationary phase method(SP) and the edge point technique (EPT) are generally preferred to evaluate edge diffracted fields and the geometrical optics (GO). Finally, the homegeneous and inhomegeneous scattered fields were plotted and compared numerically using by Matlab code. The reflecting surface has a Perfectly Magnetic Conductor (PMC) boundary condition.

1.2 Organization of the Thesis

This thesis consists of five chapters. Chapter 1 is an introduction to the study that contains information about objectives, organization of the thesis, background and inhomogeneous waves.

In Chapter 2 the current based methods in the related field are briefly expalined and the current based techniques which are used in this thesis are introduced.

In Chapter 3 our problem and its solution is introduced.

In Chapter 4 includes the numerical analysis of the fields and currents.

In Chapter 5 the conclusion is presented.

1.3 Background

It is generally acknowledged that the homogeneous waves have spatially dependent amplitudes and the real phase functions [1]. Basdemir suggests that inhomogeneous waves have complex phase functions as opposed to homogeneous wave. According to Choudhary and Felsen and Felsen inhomogeneous wave fields, so called evanescent fields [2,3], are generally exposed to perpendicular attenuation toward the direction of propagation [1]. The deatil description of inhomogeneous waves are given below. In this thesis the fields scattered from the cylindric reflectors that has a PMC surface boundary conditions and are illuminated with inhomogenous waves will be analyzed.

1.4 Inhomogeneous Waves

It is widely considered that there is a lack of study conducted on in the field of inhomogeneous wave although techniques utilized for analyzing propagation and diffraction of ordinary high-frequency fields are well developed. Choudhary and Felsen report that inhomogeneous wave fields in lossless media, so called evanescent fields, exist on the dark side of caustics delimiting a region illuminated by geometric optical rays, and on the optically thinner side of dielectric interfaces illuminated from the optically denser side by totally reflected fields [2]. Evanescent fields also characterize phenomena associated with Gaussian beams, with leaky waves, and with creeping waves.

At this vein Kara considers inhomogeneous waves, along with the Gaussian beams, in the category of evanescent waves that have been under investigation for decades [4]. The most important characteristic of these evanescent waves is that because of their rapid fading with respect to the distance, they become negligible in the far field. However, they are considered important in the near field thanks to their contribution.

In addition, Ronchi et al. conducted a study on the scattering of evanescent waves [5]. They used complex angles to express an inhomogeneous wave. Similarly, Keller and Streifer made a study on complex ray application for the Gaussian beams [6]. Besides these researchers, Choudhary and Felsen scrutinized the asymptotic theory for inhomogeneous waves [2]. For the scattering problems, Wang and Deschamps applied complex ray tracing technique [7]. On the otherhand, Shevernev and Kouyoumjian et al. analyzed the diffraction of an inhomogeneous plane wave [8,9] and Bertoni et al. studied on the shadowing of an inhomogeneous plane wave by a wedge [10], Manara et al. analyzed the diffraction of an inhomogeneous plane wave by an impedance in lossy medium where they asymptotically evaluated the rigorous integral representation of the field by utilizing the uniform geometrical theory of diffraction (UTD) [11], wheras Deschamps et al. examined the diffraction of an evanescent plane wave by a half plane [12]. Later, Felsen made a study on evanescent waves [3].

Kouyoumjian et al. are reported to have made a study on inhomogeneous electromagnetic plane wave diffraction by a perfectly electric conducting wedge at oblique incidence [4,13]. The uniform theory, another important theory, was preferred by Umul in which he examined the diffraction of homogeneous and inhomogeneous plane waves by a planar junction between perfectly electric conducting (PEC) and impedance half planes [14]. In additio he also made studies on the diffraction of evanescent plane waves by a resistive half-plane [14]. Scattering of a line source by a cylindrical parabolic impedance surface, and scattering of inhomogeneous plane waves by a resistive half-screen were investigated by Umul [15,16]. On the other hand, Kara is reported to have made a study on the scattering of a plane wave by a cylindrical parabolic perfectly electric conducting reflector [17]. By using PO and Geometrical Theory of Diffraction (GTD), the cylindric reflector that has a perfectly electric conducting (PEC) surface conditions has been examined by Başdemir [1]. In addition to the above mentioned studies conducted by different researchers, this study aims to examine the scattered fields of inhomogeneous plane waves by a cylindrical reflector.

CHAPTER 2

CURRENT BASED METHODS

2.1 Introduction of Methods

In this thesis, our objective is to obtain the scattered fields by a PMC cylinder using PO method. It can be acquired by giving an answer to the Helmholtz equation for basic geometries. The analysis of electromagnetic problems relys on the anlaysis of Helmholtz wave equation by taking into account the coordinates suitable to the problem geometry and the suitable edge conditions. However, the separation of variables of the problem geometry should be obtaiened by different methods. The size of the scattering object is greater than the size of the used wave; namely, under the high frequency conditionsthe high frequency asymptotic techniques are suitable for analysis. The High Frequency (HF) asymptotic techniques can be categorized into two simple groups: (1) ray based techniques and (2) current based techniques. GO, GTD and Unfirom theory of diffraction (UTD) can be taken as the instances for ray based techniques. The theory of PO, the physical theory of diffraction (PTD) and the Modified Theory of Physical Optics (MTPO) are the instances for current based techniques. The high frequency asymptotic condition is satisfied when the multiplication of $k\rho$ is greater than 1, ie $k\rho >> 1$ where k is the wave number and ρ is the distance between the observation point and the orgin. This study is based on evaluation of PO scattering integral to a large extent. Later on evaluated field expressions will be analysed numerically for different parameters.

The time factor $\exp(jwt)$ is assumed and suppressed throughout the thesis where w is the angular frequency.

2.2 Physical Optics (PO)

McDonald introduced *Physical Optics* (PO) in 1912 [18]. It is a current based technique which depends upon the integration of the induced surface current density that is described on the illuminated side of the scattering object. Since 1950s, PO has been widely utilized in a number of areas as a tool to estimate scattering by military vehicles such as tanks, spacecraft, airplanes, missiles, ships, weapons and in the design of microwave antennas. PO is a significant approach to locate the scattered fields. However, it has a problem to find exact edge diffracted fields. The reason of the problem depends on the shadowed part of the object. In this part of the object, as the surface current density of the shadowed part of the object equalts to zero, the wedge diffraction problem cannot precisely be solved by the PO approach.

As for the solutions to this prpoblem in PO, Ufimtsev put forward a new way in the physical theory of diffraction (PTD) by proposing the addition of a second current component, which is called as the non-uniform or fringe current in order to obtain the correct diffracted field expressions [19]. Similarly, James also proposed a correction factor multiplied by the PO diffraction field instead of summing [20]. Nevertheless, some exact coefficients are needed for such problems. In conclusion, these alternative ways could not be the exact cure of PO. Umul put forward a modified theory of physical optics (MTPO) fort his problem as well [21]. Due to this method it is not required to know a certain solution to obtain scattered fields. In this thesis, transmitted and diffracted fields are obtained by using the physical optics and the geometrical theory of diffraction methods, respectively.

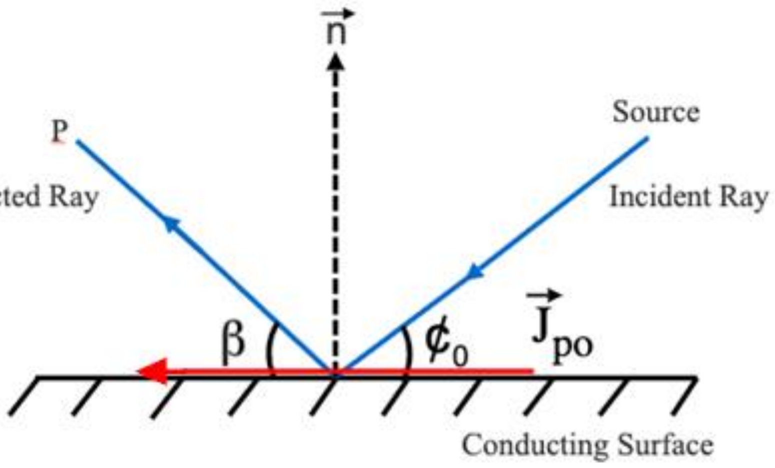

Figure 1 Reflection geometry at point of conducting surface

In the Figure 1 $\vec{n}$ is the unit normal vector, ϕ_0 is the angle of incidence and β is the arbitrary angle of reflection. $\vec{J}_{PO}$ is the PO current densty. The difference between PMC and Perfectly electric conductor (PEC) is that the polorization of the incident field is electric (PEC) and magnetic (PMC) surface. The main idea in PO Method relys on obtaining the scattered fields by integrating the induced current on the diffracted surface. The total electric field obtained in the analysis of an electromagnetic problem

$$\vec{E}_t = \vec{E}_i + \vec{E}_s \tag{2.1}$$

is equal to the sum of the incident electric field $\vec{E}_i$ and the scattered electric field $\vec{E}_s$ as a result of the integration with the object. The ultimate aim here is to find the unknown scattered electric field. The scattering integral gives the scattered electric field. The kernel of the scattered field is equal to multiplication of the induced current on the surface with the Green Function. The induced current on a conducting surface in PO context, if the surface is PC,

$$\vec{J}^{E}_{PO} = \vec{n}x\vec{H}_t \,|_S \tag{2.2}$$

while obtaining under the boundary conditions, if the surface is PMC,

$$\vec{J}^{M}_{PO} = -\vec{n}x\vec{E}_t \,|_S \tag{2.3}$$

It is obtained from the surface boundary conditions. Here, the unit shows the surface perpendicular vector, and the lower indit t shows the sum of the fields coming from the surface and reflected from the surface. Since the reflected wave according to the PO is in the same form with the incident wave and the expressions of $\vec{E}_t$ and $\vec{H}_t$.

$$\vec{E}_t = 2\vec{E}_i \tag{2.4}$$

and

$$\vec{H}_t = 2\vec{H}_i \tag{2.5}$$

It can be given as $\vec{H}_t = 2\vec{H}_i$. In this case, PO currents for PEC and PMC surfaces

$$\vec{J}^{E}_{PO} = 2\vec{n}x\vec{H}_i \,|_S$$

(2.6)

and it can be given as

$$\vec{J}^{M}_{PO} = -2\vec{n}x\vec{E}_i \,|_S . \tag{2.7}$$

2.3 Physical Theory of diffraction

In order to investigate antennas and scattering problems, a high frequency of asymmetric technique that relates to the physical theory of diffraction (PTD) is used. The main focus of this theory is the diffraction of acoustic and electromagnetic waves by perfectly reflecting objects in a homogenous lossless area. The diffracted field is viewed as the radiation caused by scattering currents induced on objects [19]. The ultimate aim is the separation of surface sources into uniform and nonuniform components [19].

The scattered fields in non-uniform currents can be for the sum of fields and currents as

$$\vec{E}_{NU} = \vec{E}_T - \vec{E}_{PO} \quad (2.8)$$

and

$$\vec{J}_{NU} = \vec{J}_T - \vec{J}_{PO}. \quad (2.9)$$

However, in this method, definite field expressions $\vec{E}_T$ and definite flow expressions $\vec{J}_T$ need to be known. However, it is an effective method in the analysis of diffraction fields for solution known problems.

2.4 Modified Theory of Physical Optics

By directly evaluating the scattering problem without the need for a correction term or exact solution, we obtain the correct corner diffraction areas. MTPO is based on three main actions. One of them is to define the scattering angle as a function to the scattering surface. The second is to define variable unit vector $(\vec{n}_v)$ instead of the classical vector definition. The feature of this vector is that it divides the angle between the incoming and scattered beam into 2 equal angles. The last one is to evaluate the opening on the left side of the graph together with its scattering surface.

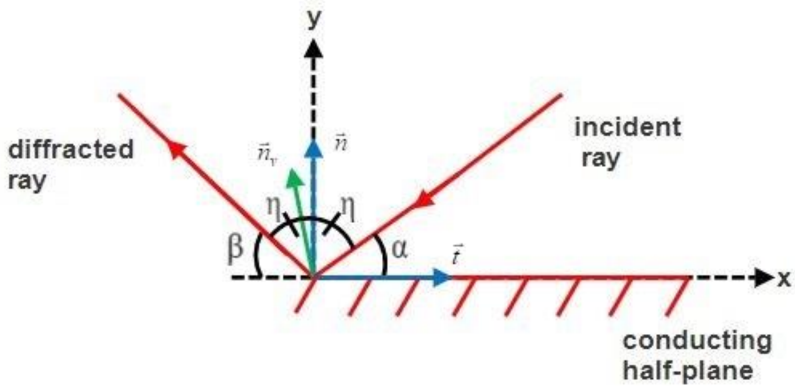

Figure 2 Definition of scattering angle and variable unit vector

Accordingly, the scattering integral is expressed as follows, $\vec{t}$

$$\vec{E} = \frac{-jw\mu_0}{4\pi} \iint_S \vec{J}_{MTPO} \vec{J} ds' \quad (2.10)$$

surface current which is induced on S1 can be defined as

$$\vec{J}_{MTPO} = \vec{n}_v \times \vec{H}_t \,|_S \tag{2.11}$$

The variable unit normal vector $\vec{n}_v$ can be defined as

$$\vec{n}_v = \cos(\eta+\alpha)\vec{t} + \sin(\eta+\alpha)\vec{n} \tag{2.12}$$

Where the angle η is written as

$$\eta = \frac{\pi}{2} - \frac{\alpha+\beta}{2} \tag{2.13}$$

CHAPTER 3

SCATTERING FROM A PMC PARABOLIC REFLECTOR

3.1 Geometry of the Problem

On a cylindrical reflector plane, we will examine the reflection and scattering of electromagnetic waves from a planar source with edge diffraction. The incident wave is considered as a homogenous wave and solely a solution can be obtained. A solution can be achieved for inhomogenous waves by writing complex angle instead of ϕ' according to analytical continuation in the obtained solution.

The surface of the reflector is considred as PMC surface. PMC indicates total magnetic field on the tangential plane, is equals to zero.

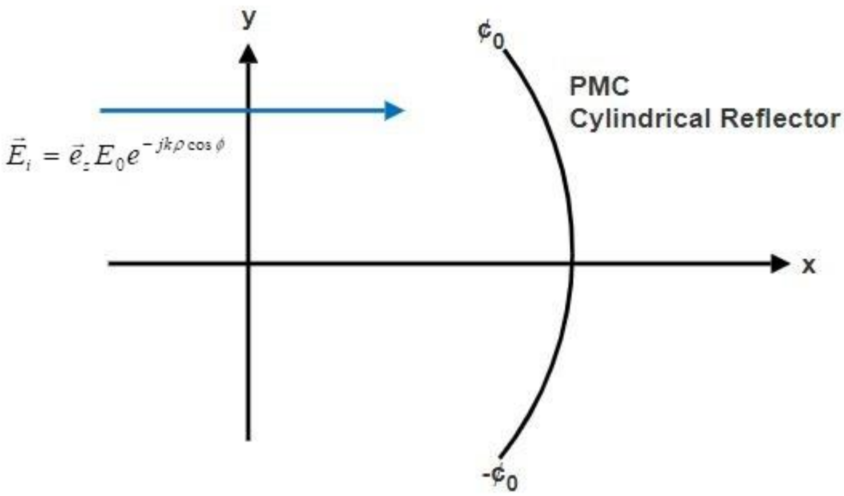

Figure 3 The Geometry of the PMC cylinder

The geometry of the cylindrical reflector is shown in Figure 4 and the reflector is lying between the values of ϕ_0 to $-\phi_0$ and the radius of a. Here the cylendrical coordiantes are represented as (ρ, ϕ, z). This figure has a several parameters. $\rho^{'}$ is the diameter of the cylendrical reflector and $\phi^{'}$ is the incident angle, p is the observation point. β is the arbitrary angle of reflection, respectively. The cylindrical coordinate parameters ρ and $2\pi - \phi$ define the position of the observation point (P) relative to the starting point at incident wave. R means the ray path that is a distance between P and the cylndrical antenna. Incident and reflection angles are $\left(\phi^{'}, \beta\right)$, respectively.

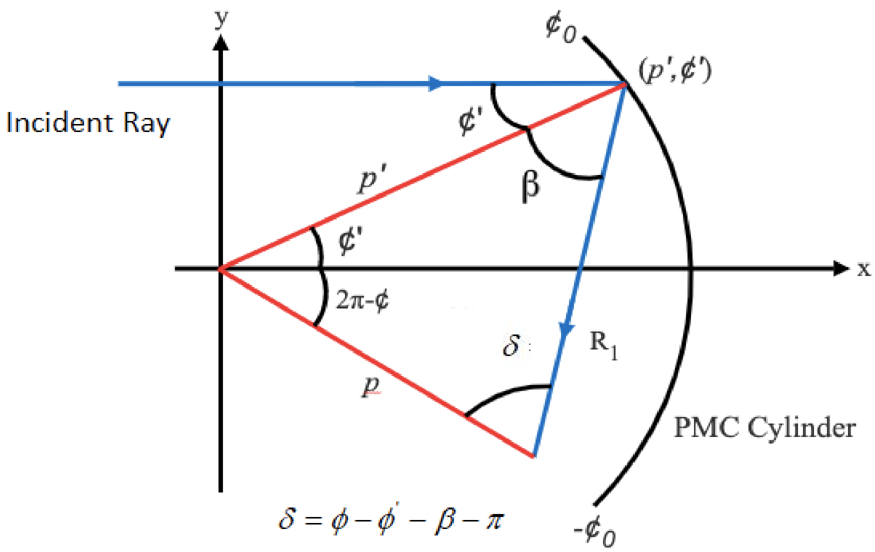

Figure 4 The geometry of reflected field

The new geometry of the problem with the related quantity is given in Figure 4.

3.2 Scattring Integral

The PMC cylinder is illuminated by the plane wave of

$$\vec{E}_i = \vec{e}_z E_0 e^{-jk\rho\cos\phi} \tag{3.1}$$

where E_0 is the complex amplitude and the incident wave is *z* polarized. The induced electrical surface current can be defined as

$$\vec{J}_{PO}^{M} = -\vec{n}x\vec{E}_t|_s \tag{3.2}$$

Since the reflected wave, according to PO, is in the same form as the incident wave $\left(\vec{E}_r = \vec{E}_i\right)$, unit vector is equal to $2\vec{n}$ .The induced electrical surface current can be written as

$$\vec{J}_{PO}^{M} = -2\vec{n}x\vec{E}_i|_s \tag{3.3}$$

where $\vec{n}$ is the unit normal vector and equal to $\vec{e}_\rho$. Thus, the Equation (3.3) is rewritten as

$$\vec{J}_{PO}^{M} \cong -2\vec{e}_\phi e^{-jka\cos\phi'} \tag{3.4}$$

Magnetic field component using Maxwell-Faraday equation induced surface current can be obtained. The electric vector potential can ben defined as

$$\vec{F} = \frac{\varepsilon_0}{4\pi}\iint_{S'} \vec{J}_{PO}^{M} \frac{e^{-jkR}}{R} ds' \tag{3.5}$$

where ε_0 is the free space permittivity and R is the three-dimensional ray-path equals to $\left[\rho^2 + a^2 - 2\rho a\cos(\phi - \phi') + (z - z')^2\right]^{\frac{1}{2}}$. The scattered magnetic field, taking into account the HF condition is given as

$$\vec{H} \cong -j\omega\vec{F} \tag{3.6}$$

and by using Eq(3.5). Scattering integral takes the form as

$$\vec{H}_s \cong -\frac{j\omega\varepsilon_0}{4\pi}\iint_{S'} \vec{J}_{PO}^{M}\frac{e^{-jkR}}{R}ds' \tag{3.7}$$

according to Maxwell Faraday equation $\vec{E}$ can be determined as

$$\vec{E} \cong \frac{1}{j\omega\varepsilon_0}\nabla x\vec{H} \tag{3.8}$$

Thus, after the application of Maxwell-Faraday to the Eq(3.7) scattering integral for electric field is obtanined as

$$\vec{E}_s \cong -\frac{1}{4\pi}\iint_{S'}\nabla x\left(\vec{J}_{PO}^{M}\frac{e-jkR}{R}\right)ds' \tag{3.9}$$

Then, by inserting Eq(3.4) in to the Eq(3.9), the ultimate scattering integral takes the form as

$$\vec{E} \cong -\frac{\vec{E}_0 a}{2\pi}\int_{\phi'=-\phi_0}^{\phi} e^{-jka\cos\phi'}\nabla x\left(\vec{e}_\phi\int_{z'=-\infty}^{\infty}\frac{e^{-jkR}}{R}dz'\right)d\phi' \tag{3.10}$$

The geometry is symmetrical with respect to z' so Green's function is reduced to the 2D frame. The 2D Green’s function is defined as

$$\int_{z'=-\infty}^{\infty}\frac{e^{-jkR}}{R}dz' = \frac{\pi}{j}H_0^{(2)}(kR_1) \tag{3.11}$$

Where R_1 is equal to $\left[\rho^2 + a^2 - 2\rho a\cos(\phi-\phi')\right]^{\frac{1}{2}}$. Thus, the scattering integral to rewritten as

$$\vec{E} \cong -\frac{\vec{E}_0 a}{2j}\int_{\phi'=-\phi_0}^{\phi} e^{-jka\cos\phi'}\nabla x\left[\vec{e}_\phi H_0^{(2)}(kR_1)\right]d\phi' \tag{3.12}$$

Then, Debby asymptotic form of he Hankel function can be expressed as

$$H_0^{(2)}(kR_1) \cong \sqrt{\frac{\pi}{2}}e^{j\pi/4}\frac{e^{-jkR_1}}{\sqrt{kR_1}} \tag{3.13}$$

when $k\rho >> 1$ and j is equal to $e^{-j\pi/2}$ so we added Eq(3.12) in Eq(3.11) and then rewritten as Eq(3.11) is equal to

$$\vec{E} \cong -\frac{\vec{E}_0 a}{\sqrt{2\pi}} e^{-j\pi/4} \int_{\phi'=-\phi_0}^{\phi_0} e^{-jka\cos\phi'} \nabla x\left(\vec{e}_\phi \frac{e^{-jkR_1}}{\sqrt{kR_1}}\right) d\phi' \tag{3.14}$$

where R_1 is the ray path is equal to

$$R = \left[\rho^2 + a^2 - 2\rho a \cos\left(\phi - \phi'\right)\right]^{\frac{1}{2}} \tag{3.15}$$

The rotational process is made according to the coordinates of the observation point and this asypmtotic function can be expressed as

$$\nabla x\left(\vec{e}_\phi \frac{e^{-jkR_1}}{\sqrt{kR_1}}\right) = \begin{vmatrix} \vec{e}_\rho & g\vec{e}_\phi & \vec{e}_z \\ \frac{\partial}{\partial_\rho} & \frac{\partial}{\partial_\phi} & 0 \\ 0 & \rho \frac{e^{-jkR_1}}{\sqrt{kR_1}} & 0 \end{vmatrix} \tag{3.16}$$

where it is easy to note that the result comes only from the third column of determinant operation, as a result it can be obtained as

$$\nabla x\left(\vec{e}_\phi \frac{e^{-jkR_1}}{\sqrt{kR_1}}\right) = \vec{e}_z \frac{e^{-jkR_1}}{\sqrt{kR_1}} \left(\frac{1}{\rho} - \frac{jk(\rho - a\cos(\phi - \phi'))}{R_1}\right) \tag{3.17}$$

where $\frac{1}{\rho}$ can be neglected because of $k\rho >> 1$. As a result, Eq(3.14) can be obtained as

$$\vec{E} \cong \vec{e}_z \frac{E_0 ak}{\sqrt{2\pi}} e^{-j\pi/4} jk \int_{\phi'=-\phi_0}^{\phi_0} \frac{\rho - a\cos(\phi - \phi')}{R_1} e^{-jka\cos\phi'} \frac{e^{-jkR_1}}{\sqrt{kR_1}} d\phi' \tag{3.18}$$

and j is equal to $e^{j\pi/2}$. If j is replaced by $e^{j\pi/2}$, $\vec{E}$ is obtained as

$$\vec{E} \cong \vec{e}_z \frac{E_0 ak}{\sqrt{2\pi}} e^{j\pi/4} \int_{\phi'=-\phi_0}^{\phi_0} \frac{\rho - a\cos(\phi - \phi')}{R_1} e^{-jka\cos\phi'} \frac{e^{-jkR_1}}{\sqrt{kR_1}} d\phi' \tag{3.19}$$

3.3 Asymptotic Evaluation of the Scattering Integral

3.3.1 Stationary Phase Method

The scattering integral in Eq(3.19) will be asymptotically evaluated utilizing the stationary phase (SP) and edge point methods. SP evaluation GO fields. First of all, SP method will be presented. The general form of an integral is defined as

$$I = \int_{-\phi_0}^{\phi_0} f\left(\phi^{'}\right) e^{-jkg\left(\phi^{'}\right)} d\phi^{'} \tag{3.20}$$

where $\phi^{'}$ is the integral variables, $f(\phi^{'})$ and $g(\phi^{'})$, indicate the integral amplitude function and the phase function of the integral, respectively. $-\phi_0$ and ϕ_0, are the upper and lower limits of the integral. As a result, $f\left(\phi^{'}\right)$ and $g\left(\phi^{'}\right)$ equal to

$$g\left(\phi^{'}\right) = a\cos\left(\phi^{'}\right) + R_1 \tag{3.21}$$

and

$$f\left(\phi^{'}\right) = \frac{\rho - a\cos\left(\phi - \phi^{'}\right)}{R_1} \frac{1}{\sqrt{kR_1}} \tag{3.22}$$

The value that makes the first derivative of the phase function zero is the point at which the phase is constant. The value of ϕ in the stational phase point is ϕ_S .

According to this, Eq(3.20) can be rewritten as

$$I = e^{-j\pi/4} \sqrt{2\pi} \frac{f\left(\phi_s\right)}{\sqrt{kg^{''}\left(\phi_s\right)}} e^{-jkg(\phi_s)} \tag{3.23}$$

where the ray path is shown “ R_1 ” symbol as below

$$R_1 = \left[\rho^2 + a^2 - 2\rho a\cos\left(\phi - \phi^{'}\right)\right]^{\frac{1}{2}} \tag{3.24}$$

the first derivative of R_1 according to $\phi^{'}$ can be written as

$$\frac{\partial R_1}{\partial \phi'} = \left[\frac{1}{2}\left[\rho^2 + a^2 - 2\rho a\cos(\phi - \phi')\right]^{\frac{1}{2}} - 2\rho a\sin(\phi - \phi')\right] \tag{3.25}$$

the last version of R_1 is obtained as

$$\frac{\partial R_1}{\partial \phi'} = \frac{\rho a\cos(\phi - \phi')}{R_1} = a\sin\beta \tag{3.26}$$

If Eq(3.26) is written in Eq(3.21), the first derivative of the phase function is obtained as below

$$\mathrm{g}(\phi') = a\cos\phi' + a\sin\beta \tag{3.27}$$

then, the second derivative of the phase function is calculated

$$g''(\phi'') = -a\cos\phi' + a\cos\beta\frac{\partial\beta}{\partial\phi'} \quad \text{is obtained} \tag{3.28}$$

As to the application of the method, it begins with the definition of the phase function as it relys on the expansion of Taylor series first three terms. The stationary phase point can be shown as ϕ_S. An evaluation of the stationary phase point of the integral can be $\phi_s = \phi$, $\beta_s = \phi_s$ and $\beta_s = \pi - \phi_s$ by equating Eq(3.27) to zero.

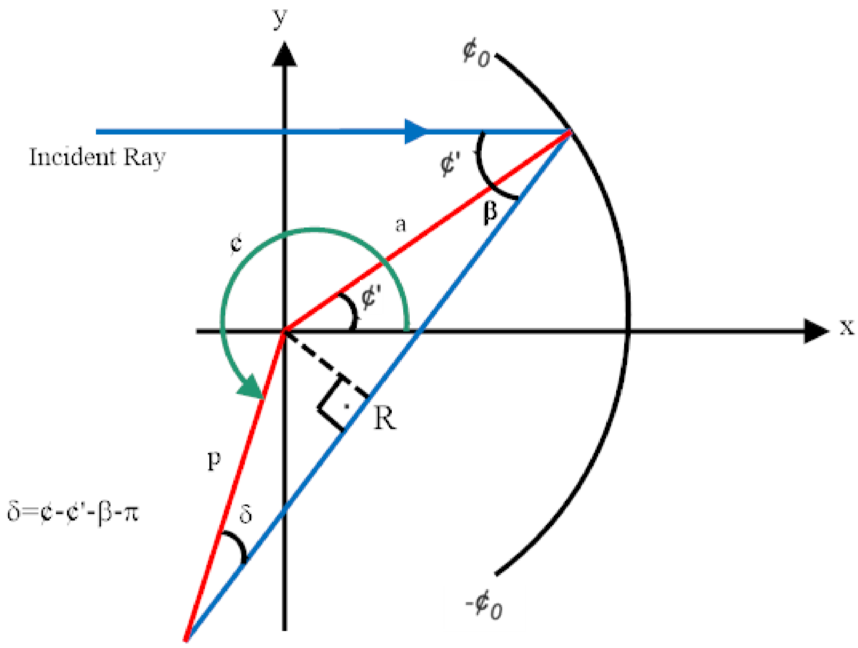

Figure 5 Reflection Geometry, β is the reflected field

By using the geometry given in Figure 5, the derivative of β by $\phi^{'}$ according to sine rule can be found. The sine rule can be written as

$$\frac{a}{\sin\left(\phi-\phi^{'}-\beta-\pi\right)}=\frac{\rho}{\sin(\beta)} \tag{3.29}$$

then $\frac{d\beta}{d\phi^{'}}$ can be rewritten as

$$\rho\sin\left(\phi-\phi^{'}-\beta-\pi\right)=a\sin(\beta) \tag{3.30}$$

If the first derivative of β by $\phi^{'}$ in both sides of the above equation is obtained,

$$\frac{\partial\beta}{\partial\phi^{'}}=\frac{-\rho\sin\left(\phi-\phi^{'}-\beta-\pi\right)}{\rho\sin\left(\phi-\phi^{'}-\beta-\pi\right)+a\cos\beta} \quad \text{can be obtained.} \tag{3.31}$$

The simplified version of this equation can be given as

$$\frac{\partial\beta}{\partial\phi^{'}}=-1+\frac{a\cos\beta}{R_1} \tag{3.32}$$

If Eq(3.32) is written in Eq(3.28), the second derivative of the phase can be redefined as

$$g^{''}\left(\phi_s^{'}\right)=-a\cos\phi_s+a\cos\beta_s+\frac{a^2\cos^2\beta}{R_1} \tag{3.33}$$

As a result, we know that the values of $f(\phi_s)$, $g(\phi_s)$ and $g^{''}\left(\phi^{'}_s\right)$. After we rewrite these values in Eq(3.23), the new stationary phase method is as fallows.

$$I=e^{-j\pi/4}\sqrt{2\pi}\,\frac{\dfrac{\rho-a\cos(\phi-\phi_S)}{R_S}\dfrac{1}{\sqrt{kR_S}}e^{-jk\left(a\cos\phi_S+R_S\right)}}{k\left(-a\cos\phi_S+a\cos\beta_S+\dfrac{a^2\cos^2\beta_S}{R_S}\right)} \tag{3.34}$$

Later, in order to find the part of the transmitted field according to the geometric optics (GO) $\beta_s=\pi-\phi_s$ is used, whereas $\beta_s=\phi_s$ is utilized in order to find the reflected fields. Now, let us evaluate the transmitted field that is shown in Figure 6. Writing

$\pi - \phi_s$ instead of β_s in Eq(3.34) to reevaluate the equation the following can be obtained.

$$I = e^{-j\pi/4}\sqrt{2\pi}\,\frac{\dfrac{\rho - a\cos(\phi - \phi_S)}{R_S}\dfrac{1}{\sqrt{kR_S}}e^{-jk(a\cos\phi_S + R_S)}}{k\left(-a\cos\phi_S + a\cos(\pi - \phi_s) + \dfrac{a^2\cos^2(\pi - \phi_s)}{R_S}\right)} \tag{3.35}$$

If we want to simplify the above equation, the new version can be written as

$$I = e^{-j\pi/4}\sqrt{2\pi}\,\frac{\dfrac{\rho - a\cos(\phi - \phi_S)}{R_1}\dfrac{1}{\sqrt{kR_1}}e^{-jk(a\cos\phi_S + R_S)}}{k\left(-a\cos\phi_S - a\cos(\phi_s) + \dfrac{a^2\cos^2(\pi - \phi_s)}{R_S}\right)} \tag{3.36}$$

The value of Eq(3.36) equals to the integral value in Eq(3.19). As a result, if we reevluate Eq(3.19), the equation below can be obtained.

$$\vec{E}_t^{GO} = \vec{e}_z E_0 ak(\rho - a\cos(\phi - \phi_S))\frac{e^{-jka\cos(\phi_S)}}{R_S}\frac{e^{-jkR_S}}{\sqrt{kR_S}}\frac{1}{\sqrt{k\dfrac{a^2\cos^2(\pi - \phi_S)}{R_S}}} \tag{3.37}$$

After some simplification processes, $\frac{\rho - a\cos(\phi - \phi_S)}{-R_S}$ can be equal to $\cos\delta_S$. Then Eq(3.37) can be rewritten as

$$\vec{E}_t^{GO} = -\vec{e}_z E_0 \frac{\cos\delta_S}{\cos\phi_S} e^{-jka\cos\phi_S e^{-jkR_S}} \tag{3.38}$$

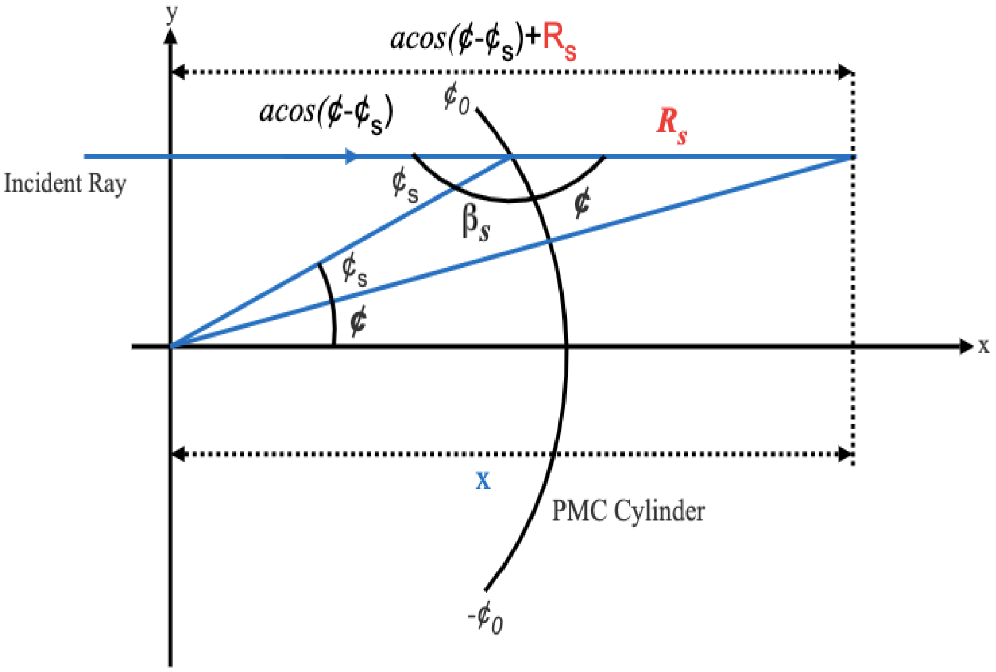

Figure 6 The geometry for transmitted field

Next, the reflected field is evaluated (Figure 7). Writing ϕ_s instead of β_s in Eq(3.34) to reevaluate the equation the following can be obtained.

$$I = e^{-j\pi/4}\sqrt{2\pi}\,\frac{\dfrac{\rho - a\cos(\phi-\phi_S)}{Rs}\dfrac{1}{\sqrt{kR_S}}e^{-jk\left(a\cos\phi_S + R_S\right)}}{k\left(-a\cos\phi_S - a\cos\phi_S + \dfrac{a^2\cos^2\phi_S}{R_S}\right)} \tag{3.39}$$

The value of Eq(3.39) equals to the integral value in Eq(3.19). As a result, if we reevluate Eq(3.19), the equation below can be obtained.

$$\vec{E}_t^{GO} = \vec{e}_z E_0 ak\left(\rho - a\cos(\phi-\phi_S)\right)\frac{e^{-jka\cos(\phi_S)}}{R_S}\frac{e^{-jkR_S}}{\sqrt{kR_S}}\frac{1}{\sqrt{k\left(-2aR_S\cos\phi_S\right)+\dfrac{a^2\cos^2\phi_S}{R_S}}} \tag{3.40}$$

After some simplifications and then again $\frac{\rho - a\cos(\phi - \phi_S)}{R_S}$ can be equal to $\cos\delta_S$. As a result, it can be rewritten as

$$\vec{E}_t^{GO} = -\vec{e}_z E_0 \cos\delta_S \sqrt{\frac{a}{\cos\phi_S}} \frac{1}{\sqrt{a\cos\phi_S - 2R_S}} e^{-jka\cos\phi_S} e^{ijkR_S} \tag{3.41}$$

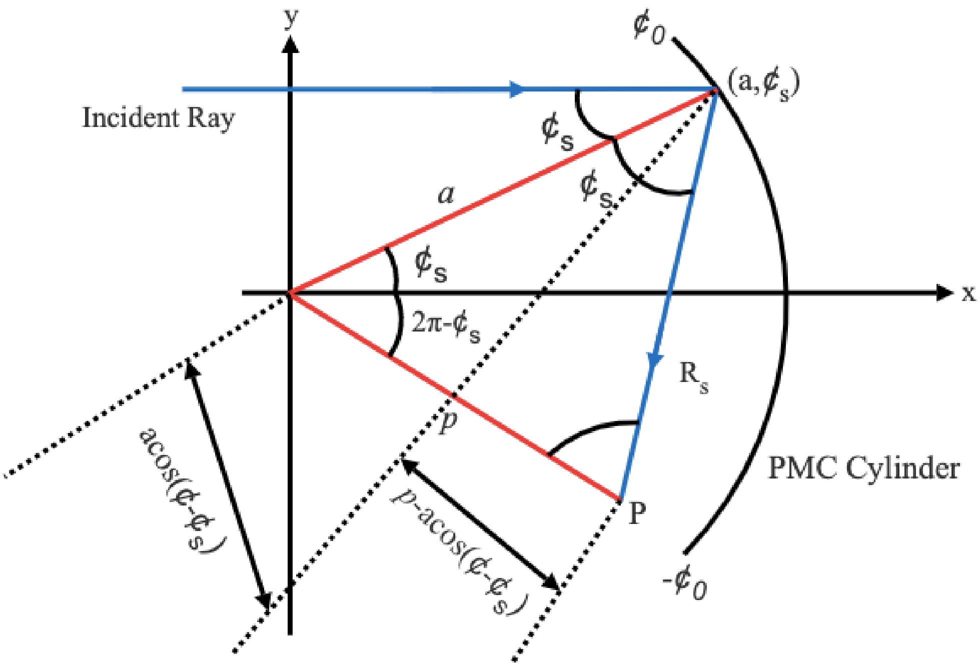

Figure 7 Stationary phase geometry of the reflected field

3.3.2 Edge Diffracted Waves

Here the edge point technique is utilized in order to evaluate the nonuniform edge diffracted fileds for the related geometry. This method is used in limiting the integral, one edge of which is a limited zone. When applied in the scattered integral, it gives us the definition of the reflected fields by an object, one edge of which is limited.

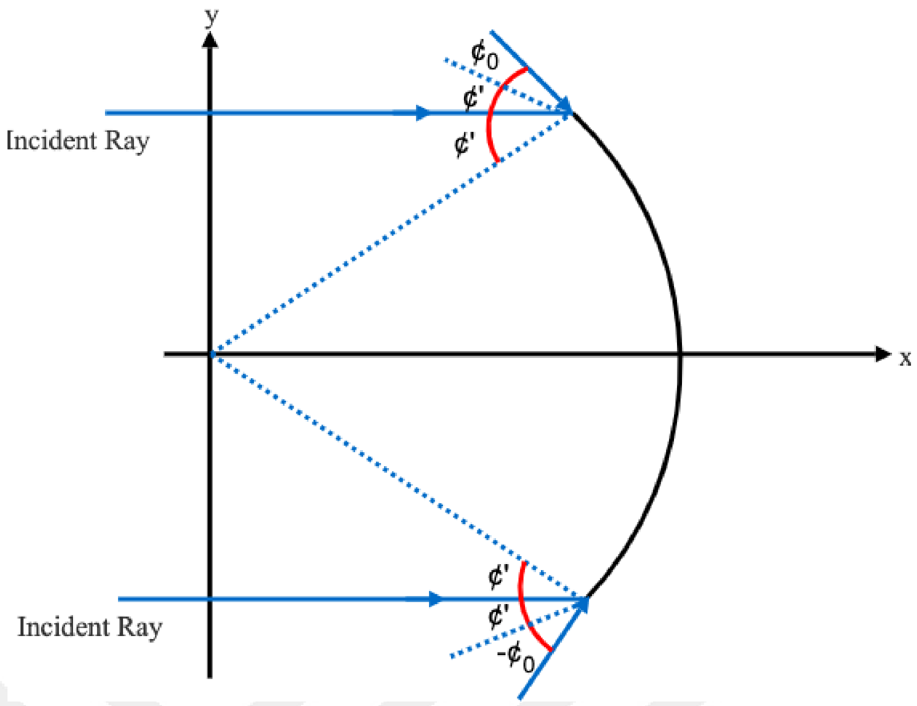

Figure 8 Edge diffraciton geometry of the cylndric reflector

The edge diffraction geometry of the cylndric reflector is shown in Figure 8. ϕ_0 is the edge boundry angle of the reflector because the reflector is situated between the angles of $[-\phi_0, \phi_0]$. As a result of the edge point technique evaluation for general equation, it is possible to evaluate the edge diffracted fields. The edge diffraciton will be defined by E_d. Firstly, By utilizing Eq(3.17) and Eq(3.32), Eq(3.17) can be written for edge diffracted

$$I = \int_{\phi_0}^{\infty} f(\phi') e^{-jkg(\phi')} d\phi' \tag{3.42}$$

where $f(\phi' = \phi_0)$ and $g(\phi' = \phi_0)$, Eq(3.42) can be rewritten as

$$I = \frac{1}{jk} \frac{f(\phi' = \phi_0)}{g(\phi' = \phi_0)} e^{-jkg(\phi' = \phi_0)} \tag{3.43}$$

and Eq(3.42) can be rewritten as

$$I=\frac{1}{jk}\frac{\frac{\rho-a\cos(\phi-\phi_0)}{R_S}\frac{1}{\sqrt{kR_S}}}{-a\sin\phi_0+a\sin\phi_S}e^{-jk(a\cos\phi_0+R_S)} \tag{3.44}$$

and j is equal to $e^{j\pi/2}$ .The value of Eq(3.44) equals to the integral value in Eq(3.19). As a result, if we reevluate Eq(3.19), the equation below can be obtained.

$$\vec{E}_{d1}=\vec{e}_z\frac{E_0ak}{\sqrt{2\pi}}e^{j\pi/4}\frac{1}{e^{j\pi/2}k}\frac{e^{-jkR_S}}{\sqrt{kR_S}}\frac{e^{-jka\cos\phi_0}}{R_S}\frac{\rho-a\cos(\phi-\phi_0)}{-a(\sin\phi_0-\sin\phi_S)} \tag{3.45}$$

where $\frac{\rho-a\cos(\phi-\phi_0)}{R_S}$ can be equal to $\cos\delta_S$ and then which can be simplified as

$$\vec{E}_{d1}=-\vec{e}_z\frac{E_0}{\sqrt{2\pi}}e^{-j\pi/4}\frac{e^{-jkR_S}}{\sqrt{kR_S}}\cos\delta_S\frac{e^{-jka\cos\phi_0}}{\sin\phi_0-\sin\phi_S} \tag{3.46}$$

Secondly, edge diffracted point can be evaluated with $f(\phi'=-\phi_0)$ and $g(\phi'=-\phi_0)$ angle point and Eq(3.44) can be rewritten as

$$I=\frac{1}{jk}\frac{\frac{\rho-a\cos(\phi+\phi_0)}{R_S}\frac{1}{\sqrt{kR_S}}}{a\sin\phi_0+a\sin\phi_S}e^{-jk(-a\cos\phi_0+R_S)} \tag{3.47}$$

and j is equal to $e^{j\pi/2}$ .The value of Eq(3.47) equals to the integral value in Eq(3.19). As a result, if we reevluate Eq(3.19), the equation below can be obtained.

$$\vec{E}_{d2}=\vec{e}_z\frac{E_0ak}{\sqrt{2\pi}}e^{j\pi/4}\frac{1}{e^{j\pi/2}k}\frac{e^{-jkR_S}}{\sqrt{kR_S}}\frac{e^{jka\cos\phi_0}}{a(\sin\phi_0+\sin\phi_S)}\frac{\rho-a\cos(\phi+\phi_0)}{R_S} \tag{3.48}$$

where $\frac{\rho - a\cos(\phi + \phi_0)}{R_S}$ can be equal to $\cos\delta_S$ and then which can be simplified as

$$\vec{E}_{d2} = \vec{e}_z \frac{E_0}{\sqrt{2\pi}} e^{-j\pi/4} \frac{e^{-jkR_S}}{\sqrt{kR_S}} \cos\delta_S \frac{e^{jka\cos\phi_0}}{\sin\phi_0 + \sin\phi_S} \tag{3.49}$$

Finaly, Total edge diffraction is equal to $E_{dt} = E_{d1} + E_{d2}$, so E_{dt} it can be written as

$$\vec{E}_{dt} = -\vec{e}_z \frac{E_0}{\sqrt{2\pi}} e^{-j\pi/4} \frac{e^{-jkR_S}}{\sqrt{kR_S}} \cos\delta_S \left[\frac{e^{-jka\cos\phi_0}}{\sin\phi_0 - \sin\phi_S} - \frac{e^{jka\cos\phi_0}}{\sin\phi_0 + \sin\phi_S} \right] \tag{3.50}$$

CHAPTER 4

NUMERIC ANALYSIS

As to the numeric analysis, scattering process for inhomogenous and homegenous waves by the cylindrical reflector is scrutinized for reflection, transmission and the nonuniform diffraction. The distance between the observation point and the origin will be taken as 6λ that is constant for all plots and λ is the wavelength. Radius of the cylinder *a* will be taken as 2λ for all plots. The incident wave variation regarding the angle of observation according to the complex angle ϕ_b between the 0° and the $3\pi/180^\circ$ is shown in Fig. 9. It is clear that when the value of the complex angle is zero, with a perfect symmetry the incident field has an amplitude value. As long as the complex angle value increases, the perpendical field in the direction of the propagation attenuates. The amplitude of the incident field having the complex angle values increases at 270°.

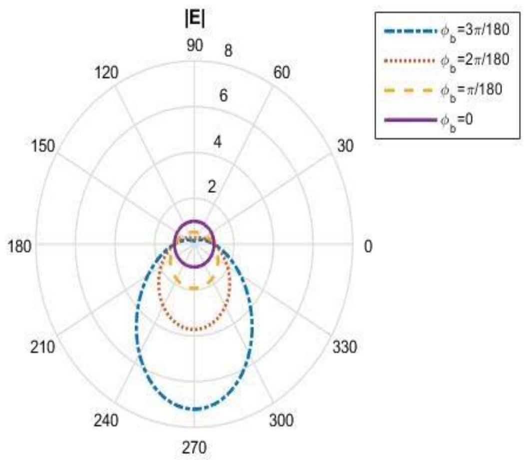

Figure 9 Incident wave for various complex angle values

In Figure 10 the plot indicates the different values of inhomogenous wave lenght. As long as the inhomogenous waves increase, the scattered area attenuates perpendically in the direction of the propagation. Therefore, the perfect symmetry disappears between 0° and $3\pi/180^\circ$. As the complex angle value increases, the scattered area attenuates perpendically in the direction of the propagation and increases in the opposite direction.

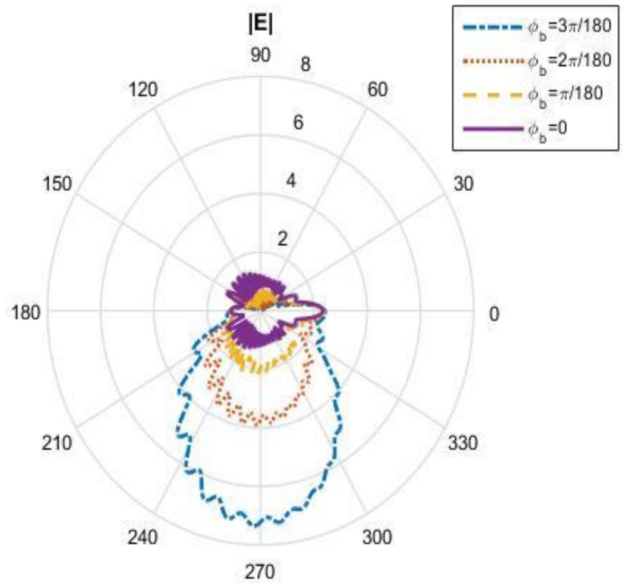

Figure 10 Total wave for different values of complex angles

Figure 11 shows the incident field, the scattered field, and their total variation according to the observation point. When various ϕ values are employed, Fig. 12 shows the scattered fields in the luminous areas between 90° and 270°. In the shadow region we cannot observe such a kind of amplitude variation for the real life. However, the evaluation of the scattering integral yields such a kind of nonactual fields. When we add the incident wave to the evaluated scattered integral, the actual field variation can be observed.

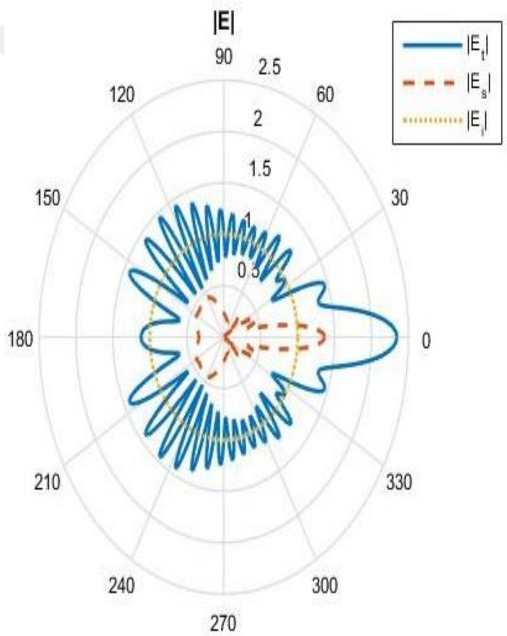

Figure 11 Total, incident and scattered fields

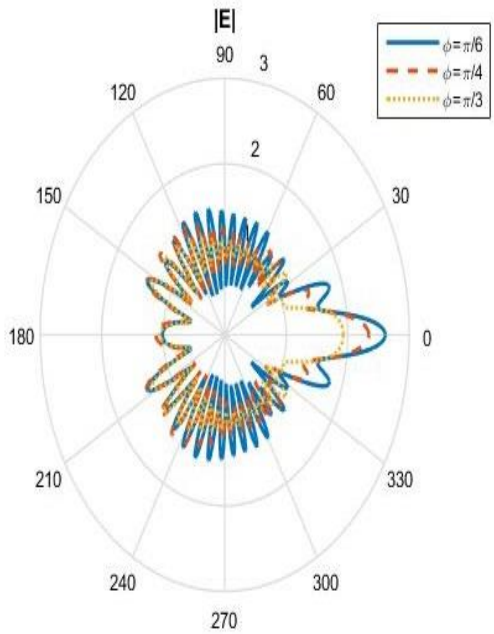

Figure 12 Total scattered fields for different values of ϕ_0

In Figure 13 it is shown that as the complex angle is constant and the ϕ angle of the sylindirical reflector value increases from $\pi/6$ to $\pi/3$ the total scattered field effect increases, too.

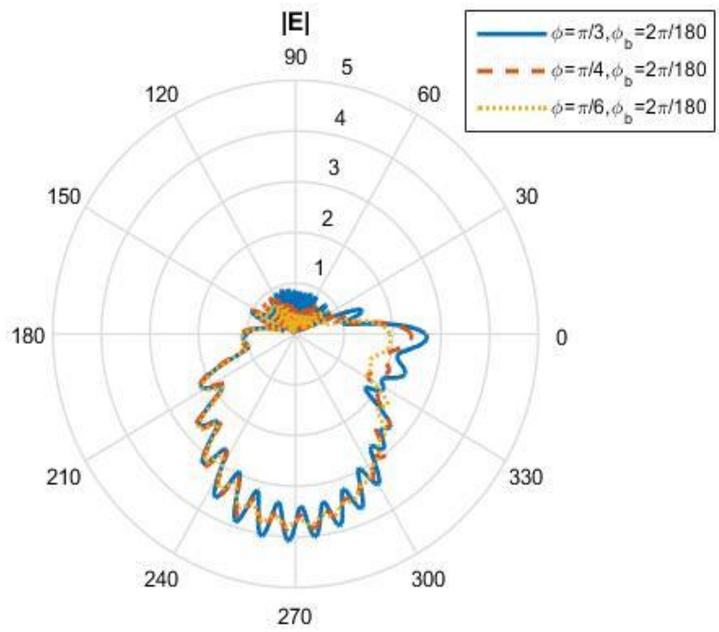

Figure 13 Total wave for different values of ϕ_0

The complex angle value of π is shown in Fig. 14, whereas this value is 2π as is shown in Fig. 15. Both figures show the incident fields, reflected fields that are perpendical in the direction of propogation and total scattering fields attenuate between 90° and 270°.

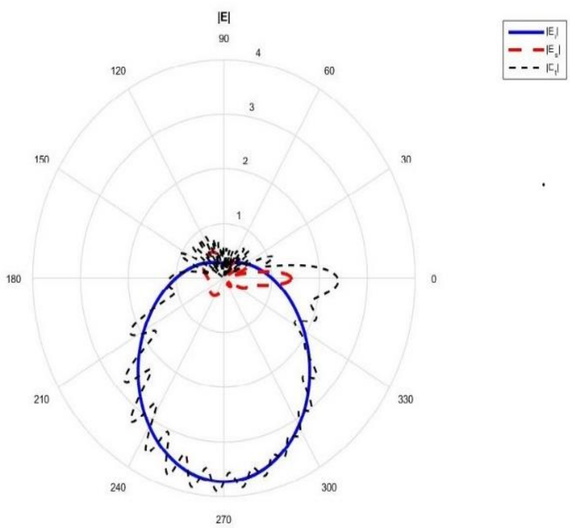

Figure 14 Scattered fields for π

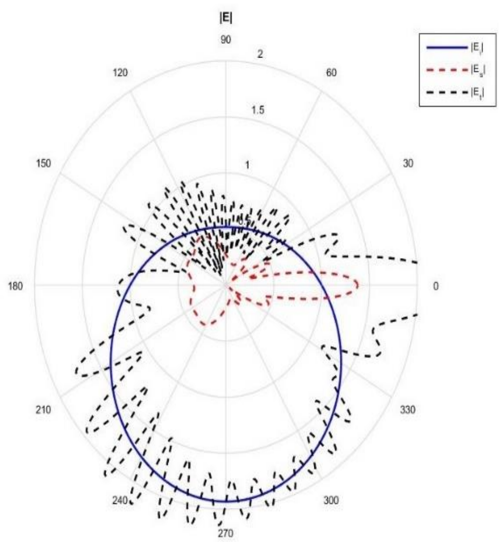

Figure 15 Scattered fields for 2π

CHAPTER 5

CONCLUSION

It is widely known homogenous and inhomogenous wave have different characterstics in that homogeneous waves have spatially dependent amplitudes and the real phase functions, while inhomogeneous waves possess complex phase functions. In some of the related studies like the one by Deniz inhomogeneous wave fields are described to have generally been exposed to perpendicular attenuation toward the direction of propagation [1]. In this study the fields scattered from the cylindric reflectors that has a PMC surface boundary conditions and are illuminated with inhomogenous waves have been analyzed. The reason why this topic has been the lack of such studies in the field of inhomogeneous wave although techniques for analyzing propagation and diffraction of ordinary high-frequency fields are well developed.

Inhomogeneous wave fields in lossless media are known to exist on the dark side of caustics that delimite a region illuminated by geometric optical rays. This is a case usually on the optically thinner side of dielectric interfaces illuminated from the optically denser side by totally reflected fields [2].

In this thesis the scattering process of homogenous and inhomogenous waves from a cylindrical reflector with a perfect magnetic conductor surface is scrutinized by PO method. The stationary phase method was used to evaluate the geometric optical fields scattered from the cylindrical reflector, whereas the edge point method was used to evaluate the edge diffractions. The kernel of the scattered integral was obtained by the evaluation of PO current on Perfectly Magnetic Conduct surface under the suitable boundary conditions. With various complex angle and reflector angle values, the incident, the scattered, and the total scattered fields were analyzed. The numerical findings indicate that as the complex value increases, the field amplitudes scattered from the reflector, as is expected, attenuate perpendically in the direction of propogation.

REFERENCES

1. **Başdemir H. D. (2015),** "*Scattering of inhomogeneous plane waves by a truncated cylindrical cap*", Journal of Modern Optics, 62:19, 1555-1560, DOI:10.1080/09500340.2015.1051149

2. **Choudhary, S., and Felsen, L.B. (1973)**, Asymptotic theory for inhomogeneous waves, IEEE Transactions on Antennas and Propagation, 21, 827-842, DOI:10.1109/TAP.1973.1140598.

3. **Felsen, L. B. (1976)** Evanescent waves, Journal of Optical Society of America, 66, 751-760, DOI:10.1364/JOSA.66.000751.

4. **Kara, M. (2019)**, "*Asymptotıc Evaluation of Scattering of Inhomogeneous Plane Waves by a Perfectly Electric Conducting Half Plane*", Uludağ University Journal of The Faculty of Engineering, Vol. 24, No. 2., pp.697-709, DOI: 10.17482/uumfd.428378.

5. **Ronchi, L., Russo, V., Di Francia, G. T., and Zaccagnini, C. (1961)** Scattering of evanescent waves by cylindrical structures, *Optica Acta*, 8, 281-299.

6. **Keller, J.B., and Streifer, W. (1971)** Complex rays with an application to Gaussian beams, Journal of Optical Society of America, 61, 40-43, DOI:10.1364/JOSA.61.000040.

7. **Wang, D., and Deschamps, G.A. (1974)** Application of complex ray tracing to scattering problems, *Proceedings of IEEE*, 11, 1541-1551.

8. **Shevernev, V. I. (1976)** Diffraction of an inhomogeneous plane wave by a half-plane, *Radiofizika*, 19, 1854-1861.

9. **Kouyoumjian, R. G., Manara, G., Nepa, P., and Taute, B. J. E. (1996)** The diffraction of an inhomogeneous plane wave by a wedge, *Radio Science*, 31, 1387-1397, DOI:10.1029/96RS02192.

10. **Bertoni, H. L., Green, A. C., and Felsen, L. B. (1978)** Shadowing of an inhomogeneous plane wave by an edge, *Journal of Optical Society of America*, 68, 983-989, DOI:10.1364/JOSA.68.000983.

11. **Manara, G., Nepa, P., Kouyoumjian, R. G., and Taute, B. J. E. (1998)** Diffraction of an inhomogeneous plane wave by an impedance wedge in lossy medium, *IEEE Transactions on Antennas and Propagation*, 46, 1753-1755, DOI: 10.1109/8.736640.

12. **Deschamps, G. A., Lee, S. W., Gowan, III, E., and Fontana, T. (1979)** Diffraction of an evanescent plane wave by a half plane, *Wave Motion*, 1, 25-35, DOI:10.1016/0165-2125(79)90023-4.

13. **Kouyoumjian, R. G., Celandroni,T., Manara, G., and Nepa, P. (2007)** Inhomogeneous electromagnetic plane wave diffraction by a perfectly electric conducting wedge at oblique incidence, *Radio Science*, 42, RS003680, DOI:10.1029/2007RS003680.

14. **Umul, Y. Z. (2007**) Diffraction of homogeneous and inhomogeneous plane waves by a planar junction between perfectly conducting and impedance half-planes, *Journal of Optical Society of America A*, 24, 1786, DOI:10.1364/JOSAA.24.001786.

15. **Umul Y. Z., (2008),** "*Scattering of A Line Source by A Cylindrical Parabolic Impedance Surface*", J. Opt. Soc. A., vol. 25, pp. 1652-1659.

16. **Umul, Y.Z. (2013)** Scattering of inhomogeneous plane waves by a resistive half-screen, Optics Letters, 38, 5102-5105, DOI: 10.1364/OL.38.005102.

17. **Kara, M., (2016)** Scattering of a plane wave by a cylindrical parabolic perfectly electric conducting reflector, *Optik*, 127, 4531–4535, doi: 10.1016/j.ijleo.2016.01.146.

18. **McDonald H. M., (1913),** "*The Effect Produced by An Obstacle on A Train of Electric Waves*", Phil. Trans. R. Soc. Lond., Ser. A., Math. Phys. Sc., vol. 212, pp. 299-337.

19. **Ufimtsev P. Ya.**, **(2007),** "*Fundamentals of The Physical Theory of Diffraction*", Wiley, New Jersey.

20. **James, G. L.**, **(1979),** "Geometrical Theory of Diffraction for Electromagnetic Waves", Peter Peregrinus Ltd. on behalf of Institution of Elecrical Engineers, United Kingdom.

21. **Umul Y. Z.**, **(2004),** "*Modified Theory of Physical Optics*," Opt. Express, vol.12, no. 20, pp.4959–4972.

APPENDIX A

MATLAB CODES

Physical Optics Total Scattered Field

```
lambda=0.1;
k=2.*pi./lambda;
a=2.*lambda;
rho=6.*lambda;
fi=0:0.01:2.*pi;
fi0=pi./4;
fib=2.*pi./180;
fic=fi+j.*fib;
ei=exp(-j.*k.*rho.*cos(fic));
 N=1000;
sum=0;
asinir=0;
usinir=fi0;
delta=(usinir-asinir)./N;
for i=0:N
    fii=asinir+(i.*delta);
```

```
    R=sqrt((rho.^2)+(a.^2)-2.*rho.*a.*cos(fic-fii));
    Epo=((rho-a.*cos(fic-fii))./R).*
    exp(-j.*k.*a.*cos(fii)).*(exp(-j.*k.*R)./sqrt(k.*R));
    sum=sum+Epo;
end
f2=sum.*delta;
sum1=0;
asinir1=2.*pi-fi0;
usinir1=2.*pi;
delta1=(usinir1-asinir1)./N;
for i=0:N
    fii1=asinir1+(i.*delta1);
    R1=sqrt((rho.^2)+(a.^2)-2.*rho.*a.*cos(fic-fii1));
    Epo1=((rho-a.*cos(fic-fii1))./R1).*exp(j.*k.*a.*cos(fii1)).*(exp(-
j.*k.*R1)./sqrt(k.*R1));
    sum1=sum1+Epo1;
end
f3=sum1.*delta1;
Es=((exp(j.*pi./4).*k.*a)./sqrt(2.*pi)).*(f2+f3);
Et=Es+ei;
polar(fi, abs(Et));
title('|E|')
hold on
```

CURRICULUM VITALE

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