International Journal of
Engineering Education (IJEE)
e-ISSN : 2540-9808

Analysis the effect of Diffraction Phenomena by Complex Shapes with Hybrid MOM-GTD Method

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***Abstract** - This article deals with a hybrid method combining the method of moments (MOM) with the general theory of diffraction (GTD). This hybrid approach is used to analyse antennas located near perfectly Bodies of arbitrary curved shape. Some examples, e.g. an antenna mounted near a perfect conductor cylinder with two plates, demonstrates that the hybrid approach is the most suitable technique for modelling large-scale objects and arbitrary shapes. This approach allows us to resolve the problem, that the other methods can't solve it alone. Generally, random radiation locates on or near an arbitrary form, can be solved using this technique hence the strong advantages of our method.*

***Keywords** – Diffraction, general theory of diffraction, method of moments.*

Submission: June 17, 2019 Correction: October 5, 2019 Accepted: November 10, 2019

Doi: http://dx.doi.org/10.14710/ijee.1.2.67-73

[How to cite this article: SMendil, S. and , Taoufik, A., (2019). Analysis the effect of Diffraction Phenomena by Complex Shapes with Hybrid MOM-GTD Method. *International Journal of Engineering Education, 1*(2),67-73. doi: http://dx.doi.org/10.14710/ijee.1.2.67-73]

1. Introduction

Although fast computers with large memories are available to antenna design's engineers, it remains difficult to analyse some class of electromagnetic scattering problems, such us, bodies with significant dimensions relative to the wavelength, and complex shapes, requiring, accurate analysis of a radiating. during the past several decades, many theoretical models have been constructed to study the scattering mechanisms. for analyse larges forms, the application of numerical method like moment method (MoM), cannot be taken into account, because of the memory requirements and the CPU time increase proportionally with the frequency. An application of pure asymptotic techniques such as the Diffraction geometric theory (GTD) remains necessary but not enough. A remedy is found in hybrid methods combining (MOM) method, with asymptotic techniques (GTD) general theory of diffraction.

In principle, there is a distinction between asymptotic ray-based techniques, such as GTD techniques, and current-based techniques such as PO. Depending on the structure to be analysed, both have some advantages. a Hybrid MOM / GTD formulations are suitable for problems when we have a structure with large dimension and complex shape e.g. an antenna is located in front of a large scattering body. Our approach is not limited to the bodies of the revolution, but perfectly conducting three-dimensional bodies of arbitrary form can be studied. So, finding an effective method to calculate the electromagnetic scattering by dielectric finite cylinders motivated many authors. An exact analytical solution for scattering from a finite cylinder does not exist, several approximations have been proposed [13]. It approximates the induced current in a finite cylinder by assuming infinite length. this method is valid for a needle-shaped scattered with a radius much smaller than the wavelength. nevertheless, it should be noted that the solutions of such approximate methods, in general, fail to satisfy the reciprocity theorem.

The purpose of this paper is to demonstrate that the use of the diffraction coefficient highlights the geometric shape, simplify the gain in time and required resources. associated with the numerical method MoM give us an effective method to calculate the electromagnetic scattering by dielectric finite cylinders.

1. Hybrid Method

The hybrid technique is used here to solve electromagnetic problems in which antennas or other discontinuities are located on or near a large conductive structure. The basic technique was first introduced in the literature by Thiele and New house [1]. This method involves studying the antenna structure in a moment method format and then modifying the generalized impedance matrix to account for the effects of driving via bodies via GTD.

As a result of the notation used by Thiele and Newhouse, the method of moments is applied to the antenna structure by widening the single current J on the surface a series of basic functions of such:$J_1, J_2, J_3, \ldots$

$$J = \sum_{n=1}^{N} I_n J_n \text{ (1)}$$

A linear operator L is defined to connect the current distributions to their electric fields. A set of weighting functions W1, W2, W is chosen and an internal product is defined so that:

$$\sum_{n=1}^{N} I_n \langle W_n, L(J_n)\rangle = \langle W_m, E^i\rangle \text{ (2)}$$

Where E^i is the incident field on the antenna. This is the same line of the system of N equations described above, by the method of moments. The equation is represented by:

$$[Z](I) = (V) \text{ (3)}$$

The elements of this impedance matrix are those of the impedance matrix of the free space since only the antenna structure has been considered so far.

These elements are given by:

$$Z_{mn} = \langle W_m, L(J_n)\rangle \text{ (4)}$$

The scalar product forms a unit space in which;

$$\langle J, aE_1\rangle = a\langle J, E_1\rangle + b\langle J, E_2\rangle \text{ (5)}$$

Where a and b are complex scalars. If aE_1 in equation represents $L(J_n)$ (which is the field due to J_n and if bE_1 in represents a contribution extra field at Z_{mn} (which is also due to J_n but not because of fields arriving directly)

Then:

$$Z'_{mn} = \langle W_m, aE_1 + bE_2\rangle \text{ (6)}$$

$$= \langle W_m, L(J_n) + bL(J_n)\rangle \text{ (7)}$$

Where a=1, b=(m, n).

$$Z'_{mn} = \langle W_m, L(J_n)\rangle + \langle W_m, bL(J_n)\rangle = Z_{mn} + Z^g_{mn} \text{ (8)}$$

The exponent g indicates that one adds to each impedance matrix the term Z^g_{mn} to account for the contributions to the m-th observation point due to J_n scattered fields of the conducting body.

$$[Z'](I') = (V) \text{ (9)}$$

Where Z' is the generalized impedance matrix correctly modified to take into account the presence of the dispersion body, as well as for the antenna itself. Z^g_{mn}elements are found thanks to the GTD. The solution of the equation is

$$(I') = [Z']^{-1}(V) \text{ (10)}$$

The antenna is divided into segments no more than one wavelength. These segments are grouped two by two to form modes. A free-space dipole moment method formulation is first performed assuming a piecewise sinusoidal current distribution in a two-segment mode. This test mode current generates a field E which is reacted with all modes of two segments on the dipole. Each of these reactions gives an impedance matrix term.

$$z_{jk} = -\int_{Rec_k} E^i_j(l).I_k(l)dl \text{ (11)}$$

E^i_j Is the electric field from test mode j to receive mode k.
$I_k(l)$ Is the current expansion distribution also assumed sinusoidal pieces now, we finding the first element of our solution by resolving this integral, it represents our antenna placing only without other objects, after that we propose to calculate the second term Z^g_{mn}.

$$z^g_{jk} = -b_{jk}\int_{Rec_k} E^i_j(l).I_k(l)dl \text{ (12)}$$

finally, the full solution is:

$$z_{jk} + z^g_{jk} = -\int_{Rec_k} E^i_j(l).I_k(l)dl - b_{jk}\int_{Rec_k} E^i_j(l).I_k(l)dl \text{ (13)}$$

2. Analyse of Structure's effect by Hybrid Method

Let considered figure 1 resumes the problem for a cylinder with curved plates, this model complex object with finite curved surface and also two finite plates. figure 2 resumes the diffraction and reflexion mechanism on cylinder and figure 3 resume the same mechanism on the curved plates, some of the studies take some issues : the two curved plates have infinite length assumed to two secondary cylinders, and the main one has an infinite length and radius, in order to reduce the problem to GO Optical Geometry and the complex coefficient b (m, n) is reduced only to Reflexion coefficient. we will compare our solution with the result of these studies.

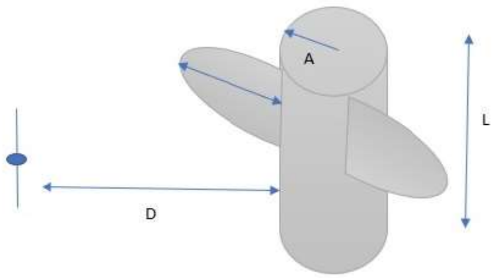

Figure 1. A General Problem.

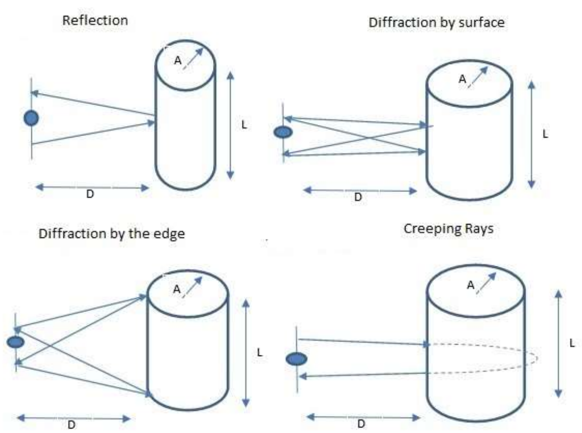

Figure 2. A Mechanism of Diffraction and Reflexion by Cylinder.

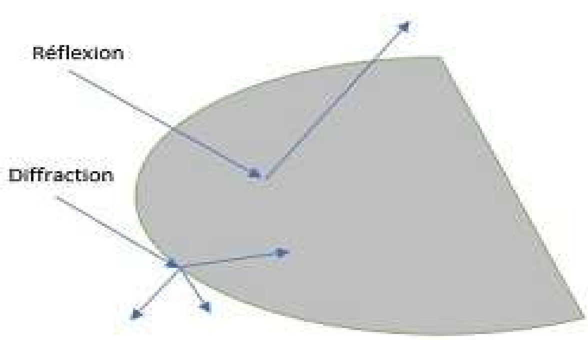

Figure 3. Diffraction and Reflexion Mechanism by plates.

The antenna is divided into segments no more than one wavelength. These segments are grouped two by two to form modes. A free-space dipole moment method formulation is first performed assuming a piecewise sinusoidal current distribution in a two-segment mode. This test mode current generates a field E which is reacted with all modes of two segments on the dipole. Each of these reactions gives an impedance matrix term.

By considering the equation 13, Now we will applicate the hybrid approach, The phenomena of diffraction/ Reflexion by the cylinder and two plates exposed in figure 2-3, introduce some coefficients that will be used in method, and we distinguish :

- A diffraction coefficient by a curved surface
- A diffraction coefficient by a plate surface
- A diffraction coefficient by plate edge
- A diffraction coefficient by curved edge.
- A diffraction coefficient for creeping rays.

The complex coefficient, b in equation (5), will be the sum of all these coefficients

For the reflexion Coefficient R define in figure:

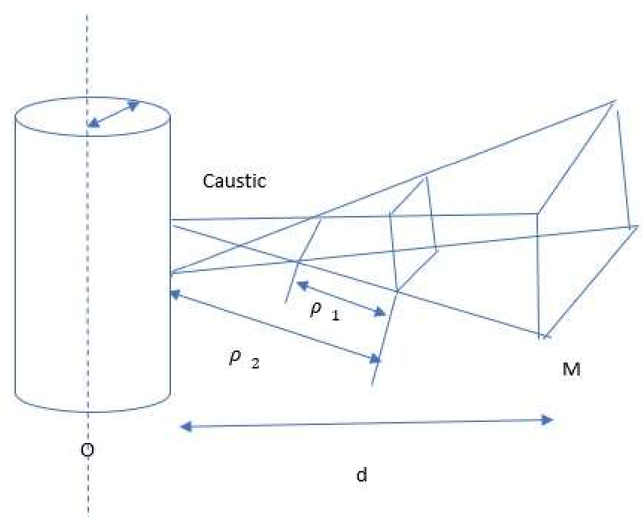

Figure 4. Asigmatic tube of rays.

$$R = \bar{R}\sqrt{\frac{\rho_1^r \rho_2^r}{(\rho_1^r+d)(\rho_2^r+d)}} \quad (14)$$

d= OM, distance from reflexion point in surface and observation point M.

$\bar{R} = \hat{e}_{\parallel}^{i}\hat{e}_{\parallel}^{r} - e_{\perp}e_{\perp}$ is a dyadic Reflexion coefficient as we shown in figure 4.

Diffraction by a curved Edge define in figure 5.1 or 5.2:

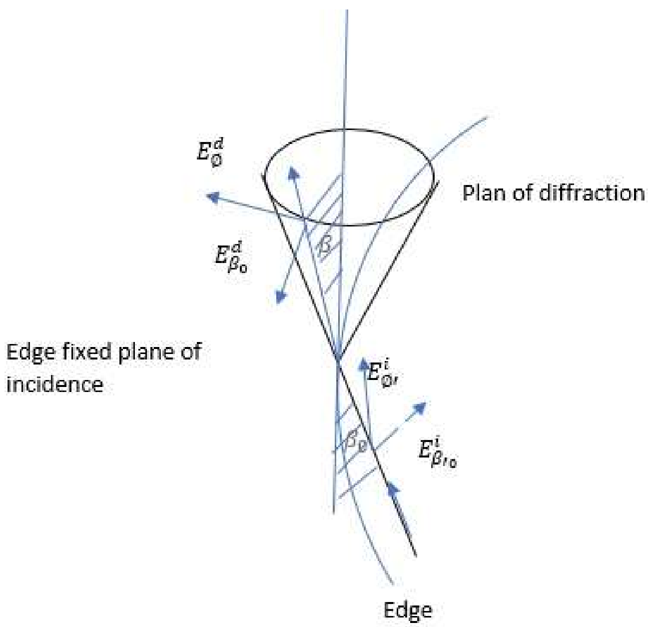

Figure 5.1. Diffraction by Curved edge.

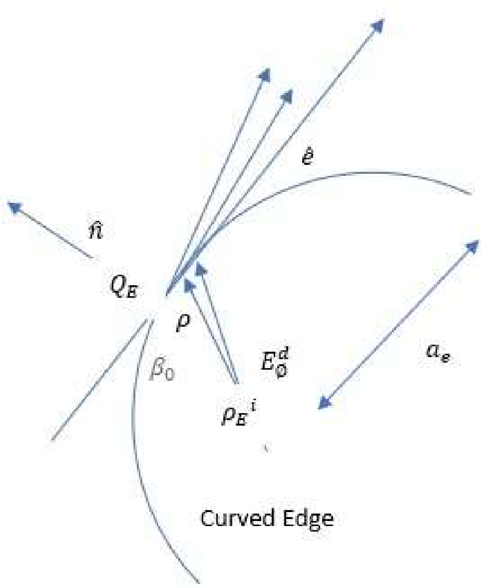

Figure 5.2. Diffraction by Curved edge.

We can introduce now the diffraction coefficient for the curved surface as:

$$D_{s,h}^{surf}(\Phi,\Phi',\beta_0)=\frac{e^{-j\frac{\pi}{4}}}{sin\beta_0}\sqrt{\frac{L}{\pi}}[f(kL,\Phi-\Phi']\,e^{j2kLc\quad^{2}(\frac{\Phi-\Phi'}{2})}$$

$sgn(\pi+\Phi-\Phi')\pm f(kL,\Phi+\Phi']\,e^{j2kLcos^2(\frac{\Phi+\Phi'}{2})}sgn(\pi+\Phi-\Phi')]$ (15)

With $f(kL,\beta]=\int_{\sqrt{2kL}|\cos\frac{\beta}{2}|}^{\infty}e^{-jz^2}dz \quad and \ L=s\,sin^2\beta_0$

For the edge the diffraction coefficient is:

$$D_{s,h}^{edge}(\Phi,\Phi',\beta_0)=-\frac{e^{-j\frac{\pi}{4}}}{2\sqrt{2\pi k}sin\beta_0}[\frac{F[kL^i a(\Phi-\Phi')]}{\cos(\frac{\Phi-\Phi'}{2})}\pm\frac{F[F[kL^r a(\Phi+\Phi')]}{\cos(\frac{\Phi+\Phi'}{2})}]$$

(16)

Angular relationships are expressed by the transition function F (x): $2j\left|\sqrt{x}\right|e^{jx}\int_{|\sqrt{x}|}^{\infty}e^{-jz^2}dz$

The distance parameter associated with the incident and reflection field is given by

$$L^{i,r}=\frac{s(\rho_e^{i,r}+s)\rho_1^{i,r}\rho_2^{i,r}sin^2\beta_0}{\rho_e^{i,r}(\rho_1^{i,r}+s)(\rho_2^{i,r}+s)}$$

The parameter ρ_e^i is the radius of curvature of the wave front incident at the diffraction point Q_E taken in the plane containing the incident ray and unit vector $\hat{e}$ which is tangent to the edge at Q_E. For the case of spherical waves $\rho_e^i=s'$.

ρ_1^i and ρ_2^i are the principal radii of curvature of the wave front incident to Q_E. Similarly, ρ_1^r and ρ_2^r are the principal radii of the wave front reflected at Q_E, the parameter ρ_e^r is the radius of curvature of the wave front reflected at Q_E taken in the plane containing the ray and e reflected. It is found using:

$$\frac{1}{\rho_e^r}=\frac{1}{\rho_e^i}-\frac{2(\hat{n}\,.\,\hat{n}_e)(\hat{I}.\hat{n})}{a_e sin^2\beta_0}$$

Diffraction by creeping rays:

$$D_{s,h}^{creep}(\Phi,\Phi',\beta_0)=\left.D_{s,h}^{surf}(\Phi,\Phi',\beta_0)\right/2$$

also, for two plates:

$$b_{m,n}^1=2(D^{edge}+R) \quad (17)$$

and for the cylinder:

$$b_{m,n}^{2} = (2D^{edge} + D^{surf} + D^{creep}) \ (18)$$

Finally, the complex coefficient b will be sum for equation 17 and 18.

In the next section, we will present the numerical application of our approach.

3. Application of Hybrid Method

The system presented before in Figure 1 is placed we considered the main cylinder C1 of radius $R1 = 2\lambda$, Length $L1 = 7\lambda$, for the two other curved surfaces of $R2 = \lambda$, $L2 = 2.5\lambda$. the distance of $D = 3\lambda$ from an antenna of length $l = 0.5\lambda$. the frequency f = 3 Ghz for the next subsection.

3.1 Convergence and validation of the method

the radius of antenna a =0.002 λ and the system with the parameter presented at the begin of this section. We take various steps (N) of discretization N = 75, N = 95, N = 100, N=120, N=140. The convergence is obtained at N = 120.

we propose to validate the hybrid method by a reference one, called MoM-eigenfunction [1], The method consists of finding the solution of an axial dipole near an infinitely long, perfectly conducting circular cylinder for our case we use 3 cylinders, the main one placed axially and two others placed perpendicular for modelized the two curved plates . A delta impedance matrix representing the effects of the cylinder is found via a moment method procedure. The method incorporates the cylindrical Green's function in the kernel of the integral equation. To carry out this validation we choose two frequencies at low-frequency f = 600Mhz, and at high frequency for f =3GHz.

for frequency f= 600Mhz,
Distribution current on the antenna:

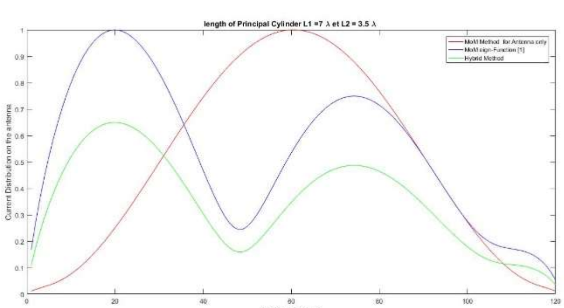

Figure 6. Current Distribution in bas Frequency

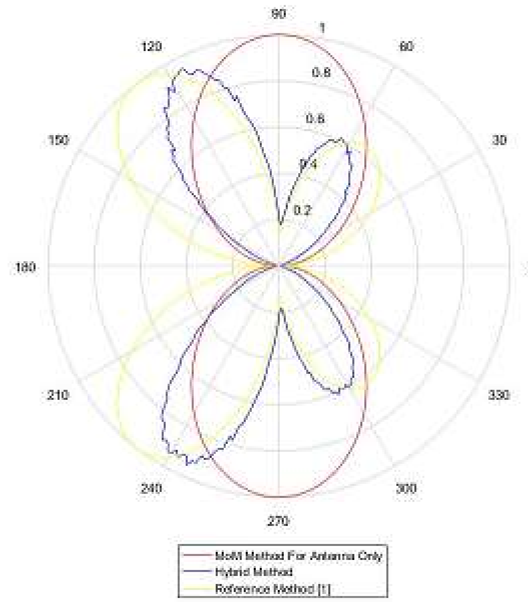

Figure 7. Pattern Diagram in bas Frequency

we notice in figure 6 and 7 a difference between the two curves, the hybrid method (green line) and the other, the reference method (blue line), this difference is due to the fact that at low frequency, the value of the wavelength is not enough small relative to the parameters of the object (total length is in order of $ 7 \lambda $ and total width is $ 3 \lambda $ including radius of the main cylinder and the two curved plates). A small part of the rays diffracted by the object arrives on the antenna, and the other, the larger one disperses in space. this is very visible when one sees the distribution of the current on the antenna, this is also explained because the greater intensity of the rays merges their influences are remarkable on the upper part of the antenna. the geometric shape of the object allows that (Figure 1). the rays that arrive on the upper part of the two secondary cylinders will be redirected either by diffraction on the antenna and the rays arriving on the lower part of the secondary cylinders dispersed in space.

for high frequency f=3Ghz:

Distribution current on the antenna:

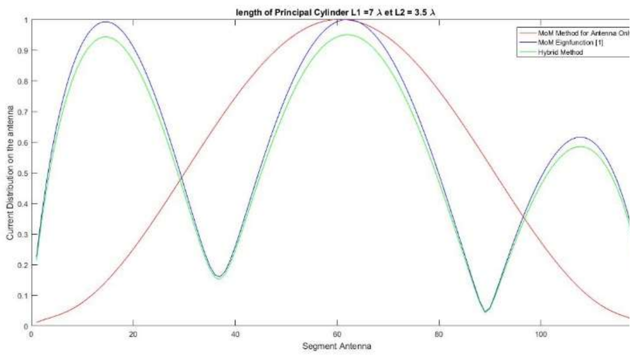

Figure 8. Current Distribution in high Frequency

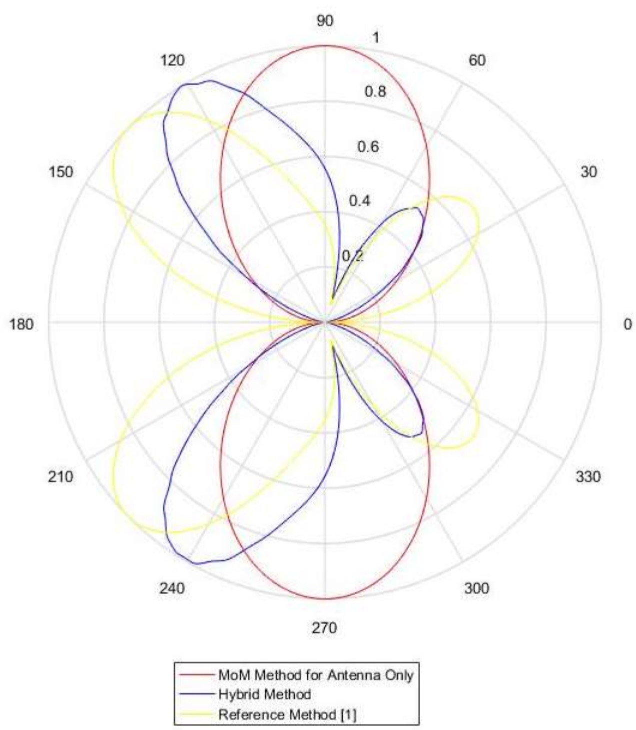

Figure 9. Pattern Distribution in high Frequency

Figure 8, 9 shows that the gaps observed at low frequency between the Reference and Hybrid method disappear at high frequency, the two curves are superimposed , we also notice the appearance of a small hump in the shape of the current distribution , it has a half maximum of the two others, as well as the antenna becomes a more directive.

in the next subsection, we analyse the effect of object dimension on the antenna.

3.2 Electric characteristic of the antenna

In this section, we propose to determine some technical characteristics of our antenna (current distribution and radiation diagram) by varying the dimension (length) of the structure presented before figure 1.

When we vary Length L1 = from 10 to 10000 λ as length of principal cylinder and L2 = 0.5 λ length of the two secondary curved plates.

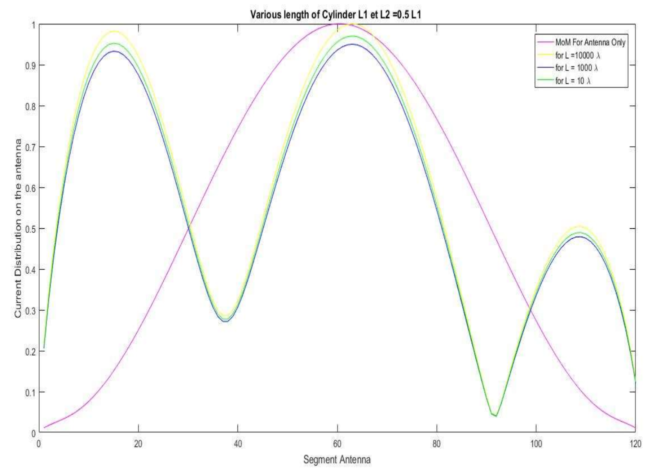

Figure 10. Current Distribution by changing Cylinder length

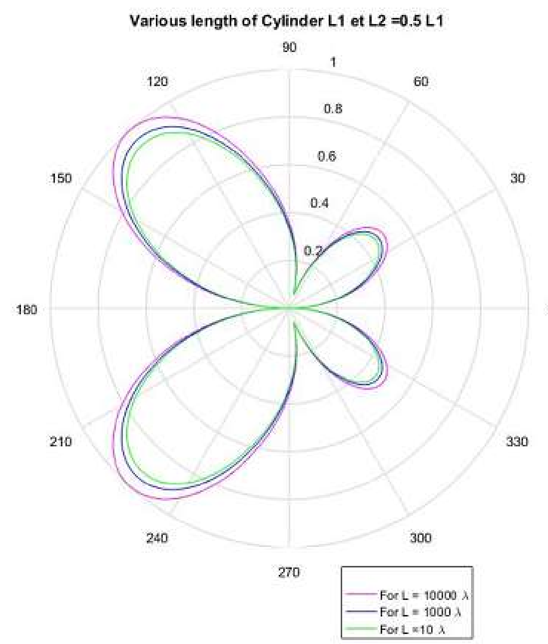

Figure 11. Pattern Distribution

According to figure 10 and 11, by varying the lengths of the cylinders, it is noted that the intensity of the currents (figure 13) increases in proportion with the lengths of the cylinders L = 10 $ \ lambda $ (line blue) at L = 10000 $ \ lambda $ (yellow line). this is well explained, since the variation of the variables L1 and L2 act as the phenomenon of reflection. the radiation diagram also proves our result.

4. Conclusion

A based hybrid method has been presented that combines MOM with an asymptotic method and GTD. Even though the approach is one of the most important in terms of the shape and size of the scattered, we have the scope of application in this paper to antennas mounted near curved convex surfaces. This particular geometry requires special and complicated features to model if we use another method based on the current flow of the curved convex body and the wire antenna. The asymptotic Method (GTD) has been used to determine the behaviour of electric fields. in which we highlight the importance of Diffraction coefficients for curved edge and curved surface, in our case, and the importance of the use of this coefficient in general case. we were given a solution for calculating the electromagnetic scattering by a dielectric finite cylinder. also, we were given a new hybrid approach, that benefice from the advantage of a numerical method (MoM) and asymptotic one (GTD).

The purpose of this paper is achieved and we demonstrate that the use of the diffraction coefficient highlights the geometric shape, simplify the computation, we gain in time and required resources. associated with the numerical method MoM give us an effective method to calculate the electromagnetic scattering by dielectric finite cylinders.

Acknowledgments

The authors would like to thank ENIT for providing scholarship during the study.

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