Few Case study samples for cost effective numerical modelling

N. S. MurthiSarma, S.P.Venumadhavarao

***Abstract*— This paper focus about introduction of power of numerical modeling in two cases. The case study result encourages the utility of modeling for various purposes.**

***Index Terms*—Power of numerical modeling, study results.**

I. INTRODUCTION

Computational methods in electromagnetics involve rigorous treatment of mathematics that offer cost effective solutions in may situations. Two of such situations are highlighted in this paper. This is to demonstrate the roll of mathematical modeling in antennas and propagation that is one of the frontier areas electronics and communication engineering.

It is well known that the performance of airborne antenna systems is significantly affected by the scattering structure as well as the location of antenna itself. High frequency techniques are suitable for efficiently and accurately analyzing the electromagnetic radiation from antennas in presence of their host environment . Among various high frequency techniques, Uniform theory of diffraction (UTD) is computationally efficient and less demanding on both computer storage and runtime for any antenna located on electrically large bodies [1]. For antenna analysis rocket shaped structure (Fig.1) is chosen, because it is close to satellite launch vehicle and it is the first order approximation of most of the airborne vehicles.The antenna location is assumed at the center of the conical portion of the rocket shaped structure.

Global positioning system (GPS) is a satellite based navigation system used for navigation, position determination and time transfer applications. Monopole, microstrip patch, helical and conical log spiral antennas are most widely used for high performance applications of GPS such as automatic navigation and landing systems. Of all these antennas microstrip antennas are widely used in GPS receivers due to compact size. Hence it is selected for the radiation pattern analysis. Precise Ionospheric and Tropospheric time delay estimation is needed for position fixing, satellite navigation and geodesy The introduction of Global Positioning System (GPS) has led to a major improvement in worldwide navigation and remote sensing facilities. With GPS, excellent navigation solutions can be obtained. As the accuracy being limited by the precision in measuring the time delays and the extent of voluntary degradation (selective ability), various time delay models have been developed to model the ionosphere which would reduce the error to a considerable extent. In this paper a time delay algorithm is proposed based on IRI-90 electron density model and compare this proposed model with Klobuchar's time delay model which is widely used in the GPS receiver, throughout the world. Bent and IRI-90 are two prominent Ionospheric electron density models. The ionospheric models represent the properties of the ionosphere as accurately as possible as functions of geophysical indices, with some statistical description of their variability.

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II. ADVANTAGE OF MATHEMATICAL MODELING OVER REAL TIME EXPERIMENTS OR DATA

The location of the antenna on an aircraft plays a major role in improving the system performance. Real time measurements require wide site requirements along with freeness from other radiating or reflecting sources. As an example at an operating frequency of 3 MHz, an antenna system of one wavelength 10,000 sq.m site is required. Also, it should be free from all other reflecting and other radiating sources. In scaled model measurements operating frequency is increased to reduce the physical dimensions of antenna structure as well as the site area. This will reduce the meaurement cost and complexity to the greater extent. However, it is difficult to realise the stable source at the frequency of scaled model measurements. The increasing complexity in the design of antenna system mounted on an aircraft coupled with ever increasing costs to perform antenna measurements prompts for the use of computer models to aid in the determination of suitable antenna locations on the aircraft. Though indigenous models are commercially available, it is difficult to understand and modify according to requirements. Hence a custom designed algorithm, subject of this paper as one of the case study, is highly economical for testing purposes.

While with Global positioning system receiver, one has to detect the signal from a selected satellite. The path of the signal from satellite to receiver involves atmosphere that comprises of regions such as troposphere, ionosphere. During the travel of signal along the atmosphere

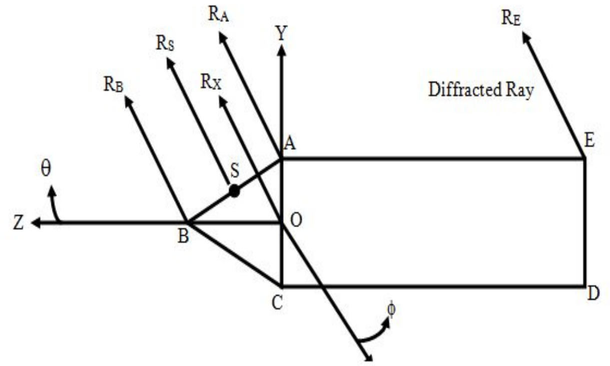

Figure 1: Cross sectional view of rocket shaped structure

the path is deviated from the intended path, which introduces error in calculation of signal

time taken to reach the receiver that indirectly dictates the position computation. The ionosphere introduces major error in delay. Modelling of the ionosphere using experimental or modeled data of ionosphere parameters helps for accurate estimation of delay. However, it is quite difficult to store or use the parameter data at every time of time dealy computation. Prominent time delay model that avoids such problem. Several algorithms are available as universal basis. But they all have less Indian data incorporated. The accuracy of such algorithms to apply for Indian conditions is questionable. The data available at Indian stations is a tool to modify the model to the Indian communications interest.

III. Description of Scattering Structure Used for Radiation Pattern Analysis

Fig.1. Shows the geometry of rocket shaped structure. The structure is modeled as perfectly conducting circular cylinder of length ‘a’, and diameter ‘2e’ with a cone of length ‘b’ attached at one end of the cylinder and a flat surface at other end.. This approximation facilitates the application of wedge diffraction analysis to estimate the far field at any point on imaginary sphere around the rocket shaped structure. The source is assumed on the cone portion of the structure i.e. at the center of A and B. The location of source is chosen in cone portion because it is one of the prominent locations of satellite launch vehicles, missiles etc., and is difficult to analyze when compared to the location on cylindrical or flat portion of the structure.

IV. Elevation Plane Pattern Analysis of Antenna Mounted on Scattering Structure

The analysis is started with the estimation of elevation plane pattern followed by conical cut patterns. The pattern includes the sum of direct and diffracted fields. Reflected field does not exist as source is sitting on the structure. Diffracted field is product of direct field component and diffraction function that involves diffraction coefficient.

$D_{\parallel}$ and $D_{\perp}$ are diffraction coefficients for parallel (soft) and perpendicular (hard) polarizations[2]

$$D_{\parallel\perp}(\mathrm{L},\psi,\psi_0) = -\frac{e^{-j(\pi/4)}}{2.n\sqrt{2\pi\beta}\sin\beta_0}\Big[\cot\left(\frac{\pi+(\psi-\psi_0)}{2n}\right)F\left[\beta \mathrm{L}a^{+}(\psi-\psi_0)\right]$$
$$+\cot\left(\frac{\pi-(\psi-\psi_0)}{2n}\right)F\left[\beta \mathrm{L}a^{-}(\psi-\psi_0)\right] \quad \Big\{\cot\left(\frac{\pi+(\psi+\psi_0)}{2n}\right)F\left[\beta \mathrm{L}a^{+}(\psi+\psi_0)\right]$$
$$+\cot\left(\frac{\pi-(\psi+\psi_0)}{2n}\right)F\left[\beta \mathrm{L}a^{-}(\psi+\psi_0)\right]\Big\}\Big] \qquad (1)$$

where, n ($0 \le n \le 2$) is the term related to the wedge angle in radians, β_0 is the half cone angle in degrees made by the diffracted ray with phase reference point, ψ and ψ_0 are the angles made by incident and diffracted planes with face of the wedge and L is distance parameter. For a plane wave incidence L is defined as $s.\sin^2\beta_0$, where s is the distance of the diffraction corner from the source. For a argument X, F is represented by,

$$F(X) = 2j\left|\sqrt{x}\right| e^{jX}\int_{\sqrt{X}}^{\infty} e^{-j\tau^2}d\tau \qquad (2)$$

The Fresnel integral factor F(X) may be regarded as a correction to be used in the transition regions. Where

$$X = \beta \mathrm{L}a^{\pm}(\psi \pm \psi_0).$$

X may be calculated for known value of βL, if $a^{\pm}$ as a function of $(\psi \pm \psi_0)$ is known. The factor $a^{\pm}(\psi \pm \psi_0)$ may be interpreted physically as a measure of the angular separation between the field point and a shadow or reflection boundary. To determine $a^{+}(\psi \pm \psi_0)$ and $a^{-}(\psi \pm \psi_0)$ we use

$$a^{\pm}(\psi \pm \psi_0) = 2\cos^2\left[\frac{2n\pi\pi^{\pm} - (\psi \pm \psi_0)}{2}\right] \qquad (3)$$

in which $N^{\pm}$ are the integers such that

$$2\pi N^{+} - (\psi \pm \psi_0) = \pi$$

and

$$2\pi N^{-} - (\psi \pm \psi_0) = -\pi$$

The key steps that involves that uses above set of equations in the pattern estimation are as follows.

The source location is in cone portion of the structure. The far field region around the rocket shaped structure is divided to eight regions. viz., $0° \le \theta \le \beta_B$, $\beta_B < \theta < 90°$, $90° \le \theta \le 180° - \beta_B$, $180° - \beta_B < \theta \le 180°$, $180° < \theta \le 180° + \beta_B$, $180° + \beta_B \le \theta \le 270°$, $270° < \theta < 360° - \beta_B$ and $360° - \beta_B \le \theta \le 360°$. θ is the angle made by the line, joining phase reference point (O) and the receiver (Rx) in clock wise direction with the reference line OZ . β_B is the half of the wedge angle at corner B . Find the corners and the source that contribute to the total field in each of the eight regions. Only the diffracted rays and source rays which see the receiver directly without crossing the structure contribute to the total field. As an example, The total field in the region $\beta_B < \theta < 90°$ is

$$R_T(\theta)=R_S(\theta)+R_A(\theta)+R_B(\theta)+R_E(\theta) \quad (4)$$

$R_S(\theta)$, $R_A(\theta)$, $R_B(\theta)$ and $R_E(\theta)$ are the fields at the source and corners A, B, and E respectively. Fig. 1 shows the corners contributing to total field in the selected region. β_B is given by

$$\beta_B = \cos^{-1}\left(\frac{OG.GA}{|OG|.|GA|}\right) \quad (5)$$

R(θ) is expressed in terms of the free space field of the source F(θ) as

$$R_S(\theta)=\left[\frac{F(\theta)}{\sqrt{r}}\right].PCT_S \qquad \text{for } (0 \le \theta\theta < 180° - \beta_B) \text{ and} (360° - \beta_B \le \theta \le 360°) \quad (6)$$

Where r is the distance from O to the receiver and PCT_S is the phase correction term which is expressed as $\exp(j.k.(s.\hat{r}))$. s is the position vector of the source and $\hat{r}$ is the unit vector in the direction of the receiver from O.

Field at corner A is expressed as

$$R_A(\theta) = \left[R^{(1)}_{A(S)} + R^{(2)}_{A(B)}\right].PCT_A \quad (7)$$

where $R^{(1)}_{A(S)}$ is the field due to the source, $R^{(2)}_{A(BE)}$ are diffracted fields due to source and E respectively and PCT_A is the corresponding phase correction term. The fields at A due to source and E are expressed as

$$R^{(1)}_{A(s)} = \frac{F(\theta = 180^0 - \beta_G)}{\sqrt{|SA|}} v_{B(A)}.RDF_A \quad (8)$$

$$R^{(1)}_{A(B)} = \frac{F(\theta = 360^0 - \beta_G)}{\sqrt{|SA|}} v_{B(AB)}.RDF_{AB} \quad (9)$$

$F(\theta=180°-\beta_B)$ and $F(\theta=360°-\beta_B)$ are values of source field at $(\theta=180°-\beta_B)$ and $(\theta=360°-\beta_B)$ respectively. $v_{B(A)}$ and $v_{B(AB)}$ are the first order and second order diffraction functions at A due to source and B. Diffraction function depends on three variables, viz., distance from source to A (ρ), angle between incident and diffracted planes (ψ-ψ_0) and the term related to the wedge angle. RDF, is the ray divergence factor which is also known as spatial attenuation factor, is proportional to the square root of the area of two cross sections which are under consideration. This is a function of source position, diffraction corner and phase reference point [3]. Fields at other corners and at other regions are estimated similarly.

The elvation plane analysis is then interpreted using vectorial concept for futher processing. Then radiated fields are estimated in the conical cuts parallel to elevation plane at regular intervals. Once this is done, field at any point on the imaginary sphere can be deduced. Detailed description of the analysis is explained elsewhere [4]. By estimating the elevation plane pattern and patterns in various conical cuts, it is possible to construct 3-D radiation pattern.

V. A TIME DELAY ALGORITHM BASED ON PROMINENT IONOSPHERIC MODEL

The International Reference Ionosphere (IRI) is a standard empirical ionospheric model established on behalf of International union of Radio scince(URSI). The IRI-90 model gives only the Electron density values. However, TEC is needed for the estimation of time delay. Therefore, to calculate the ionospheric time delay for a particular station at a particular time, the electron density values from 60 km. to 2000 km. are obtained from the model. The Total Electron Content (TEC) for a transmission path is the integral of the electron density along the path, and thus has the dimensions of number of electron per unit area. Therefore, the area under the curve of Electron density vs. Altitude gives the Total Electron Content. Trapezoidal method is used for the estimation of area. The time delay based on its refractive index is obtained as follows[5].

The refractive index(n) any medium is given by

$$n = \frac{c}{v_p} \tag{9}$$

where c and v_p are the velocity of electromagnetic signal in free space and the medium of interest respectively. However, the same is expressed in terms of permittivity (ε) as

$$n = \sqrt{\varepsilon} \tag{10}$$

In general the effective conductivity of the ionosphere can not be neglected, but at the higher frequencies where the em signal is propagating, reflection takes place in 'F" layer of ionosphere where collision frequency is small and the conductivity is correspondingly low. Therefore, for the first approximation, one can neglect the effects of conductivity and ε in above equation may be replaced with dielectric constant(ε_r). At greater heights where collision frequency(ν) is significantly smaller than the signal angular frequency(ω), the dielectric constant can be written as

$$\varepsilon_r = \left(1 - \frac{Ne^2}{\varepsilon_0 m\omega^2}\right) \tag{11}$$

If electron has charge(e)1.59x10^{-19}Columbs and mass(m)9x10^{-31}Kg, above equation is reduced to

$$\varepsilon_r = \left(1 - \frac{80.6N}{f^2}\right) \tag{12}$$

Where f is operating frequency in Hz. Using this,

$$n = \sqrt{1 - \frac{80.6N}{f^2}} \tag{13}$$

Also the velocity(v in m/s) of the em signal based on this reduces to

$$v = \frac{1}{\sqrt{1 - \frac{80.6N}{f^2}}} \tag{14}$$

Using binomial theorm The time delay (τ) in sec is calculated from the standard formula

$$\tau = 40.3\frac{N}{cf^2} \tag{15}$$

Two of the prominent time delay algorithms were based on above equation. A sample result that high lights our developed algorithm is discussed in the following section.

VI. RESULTS AND DISCUSSION

The proposed techniques are applied to the antenna pattern and time delay estimation problems.

A. Elevation pattern analysis

Several radiation pattern measurements were made in an RF Anechoic Chamber in DLRL, Hyderabad. The detailed description of experimental set-up is given in reference [6]. The operating frequency used in our analysis is 8.895 GHz. The radiation patterns are given only for $0^0 \leq \theta \leq 180^0$ as these are meant for hemispherical coverage.

The theoretical and practical elevation plane pattern of a rectangular patch antenna[7] of dimensions (0.3196λ x 0.3196λ) on the rocket shaped structure is as shown in Fig.2. It is evident from the figure that the experimental pattern closely follows the theoretically estimated pattern. The deviation of the experimental pattern from the predicted results in the region $0^0 \leq \theta \leq 90^0$ is of maximum 3 dB and could be due to reflections from the walls of the anechoic chamber. The estimated radiation pattern of rectangular patch for 80^0 conical cut is iss also carried out similarly. Conical cut is a plane parallel to the elevation plane. It is designated by the half cone angle of the cone subtended at center of the sphere.

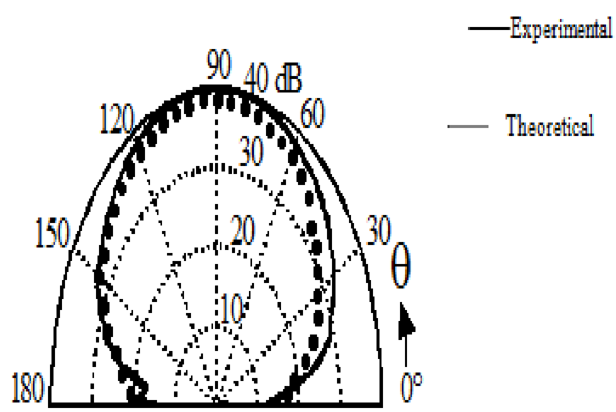

Figure.2 Elevation radiation pattern of a rectangular microstrip patch antenna mounted on cone portion rocket shaped structure at a distance of 10.1520 inches (7.6997λ) from A.

B. Time delay estimation

Fig.3 shows the various time delay models that based on Eq.15. For the data obtained from a GPS station located at NGRI (Hyderabad), The subionospheric latitude and longitude for the data taken here 26.1042^0 N and 73.1518^0 E respectively. The SF is 2.62. For the noted subionospheric latitude and longitude, the IRI-90 model's ionospheric time delay is estimated for all the 24 hours. This delay is multiplied by SF, inorder to obtain the slant delay and plotted. Both the models, one due to Klobucha model[8], a model based on bent model a non relvant model to India and other based on IRI-90 electron model [9] without any time delay modelling are plotted in Fig. Klobuchar model is taken as it is currently under use of many GPS users. The third plot is obtained by using the coefficients that are exclusively derived for Indiansubcontinent using the procedure described in the previous section. From

Figure the following points may be noted.

1. The maximum time delay from IRI-90 is 120 ns. At certain timing of the day the difference between these two plots can be as 30ns.
2. A wide discrepancy exists between the time delay based on IRI-90 model and Klobuchar's model time delay during night times i.e. from 0 to 5 Hrs, The reason for this discrepancy is Klobuchar's cosine model considers the constant time delay as 5 ns at night times. But according to IRI-90 model the ionospheric time delay ranges from 20 ns to 40 ns at night times. The Klobuchar's model clearly underestimates the delay in the early hours of the day.

It is evident from the figure, that the proposed model is more nearer to IRI model and is expected to give more accurate time delay. The Klobuchar's time delay model is not suitable for Indian conditions and especially when we are interested in particular region of the world.

The results obtained emphasizes the important of mathematical modeling in antennas and propagation, one of the frontier areas of electronics and communications engineering. However, many other methods are equally competent in other areas of electronics and communications Engineering.

CONCLUSIONS

Computational methods in electromagnetics involve rigorous treatment of mathematics that offer cost effective solutions in may situations. Case studies for two different problems in one of the frontier areas of electronics and communications are outlined in this paper. The developed theory is validated with published and experimental results. The results emphasizes the significance of the computational methods for offering the cost effective solutions

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REFERENCES

[1] A.D. Sarma, B. Balakrishna, S. Srikanth and L.N. Merugu, "Uniform geometrical theory of diffraction for the analysis of on-Aircraft antennas A mini-Review", IETE . Tech. Rev., Vol.3, pp.191-202, May-June, 1998.

[2] P.H. Pathak, "High-Frequency Techniques for antenna Analysis", Proceedings of IEEE, Vol.80, No.1, pp, 44-65, Jan.1992.

[3] Murthy Sarma N.S and A.D. Sarma, ‘‘ Analysis of a monopole antenna on a Rocket shaped structure’’, Electromagnetic and Compatibility Journal, Vol.12, No.1&2, pp.8-11, April & October, 1999.

[4] A.D. Sarma and N.S. Murthy Sarma, " 3-D analysis of modeling Antennas mounted on cuboid using wedge diffraction analysis", , Electromagnetic and Compatibility Journal, Vol.13, No.1&2, pp.8-11, April & October, 2000

[5] Jordan and Balamin, "Electromagnetic waves and Radiating systems", PHI,1995.

[6] Murthy Shama N.S, A.D. Sarma, and B.Rama Krishna Rao, " A novel technique of modeling GPS antennas mounted on a rocket shaped structure using wedge diffraction analysis", IETE. Tech.Rev., Vol.18, Nos.2&3, pp.159-168, March-June, 2001

[7] Padro N, J.J. Orthosia, J. Poaker, M. Iskander and B. Thornberg, " Comparative study of high frequency performance GPS receiver antenna designs ", IEEE. Trans. on A & P, Vol. AP-20, pp.474-476, July 1972.

[8] Klobuchar J.A. `` Ionospheric time delay algorithm for single frequency GPS users," IEEE Transactions on Aerospace and Electronic Systems, Vol. 23,), 325 – 331, May, 1987

[9] A.D.Sarma and N.S.Murthy sarma, ‘‘ A Time Delay Model Based On IRI-90 Electron Density Model For GPS Applications In The Indian Subcontinent’’ Journal of Indian Geophysical Union, Hyderabad, pp. 23-26, Vol.2, No.1, Nov.1998.

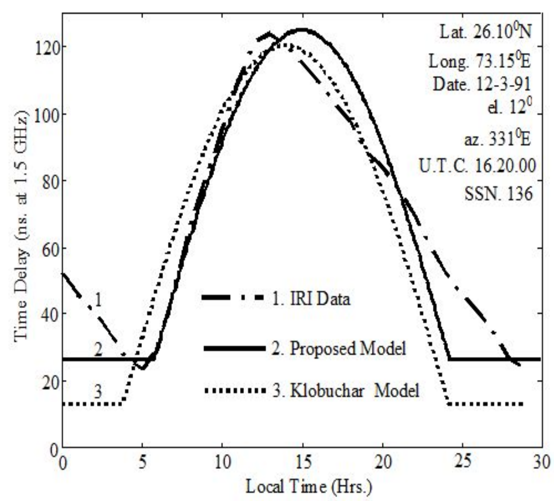

Figure 4: Time delay estimation based on various time delay models