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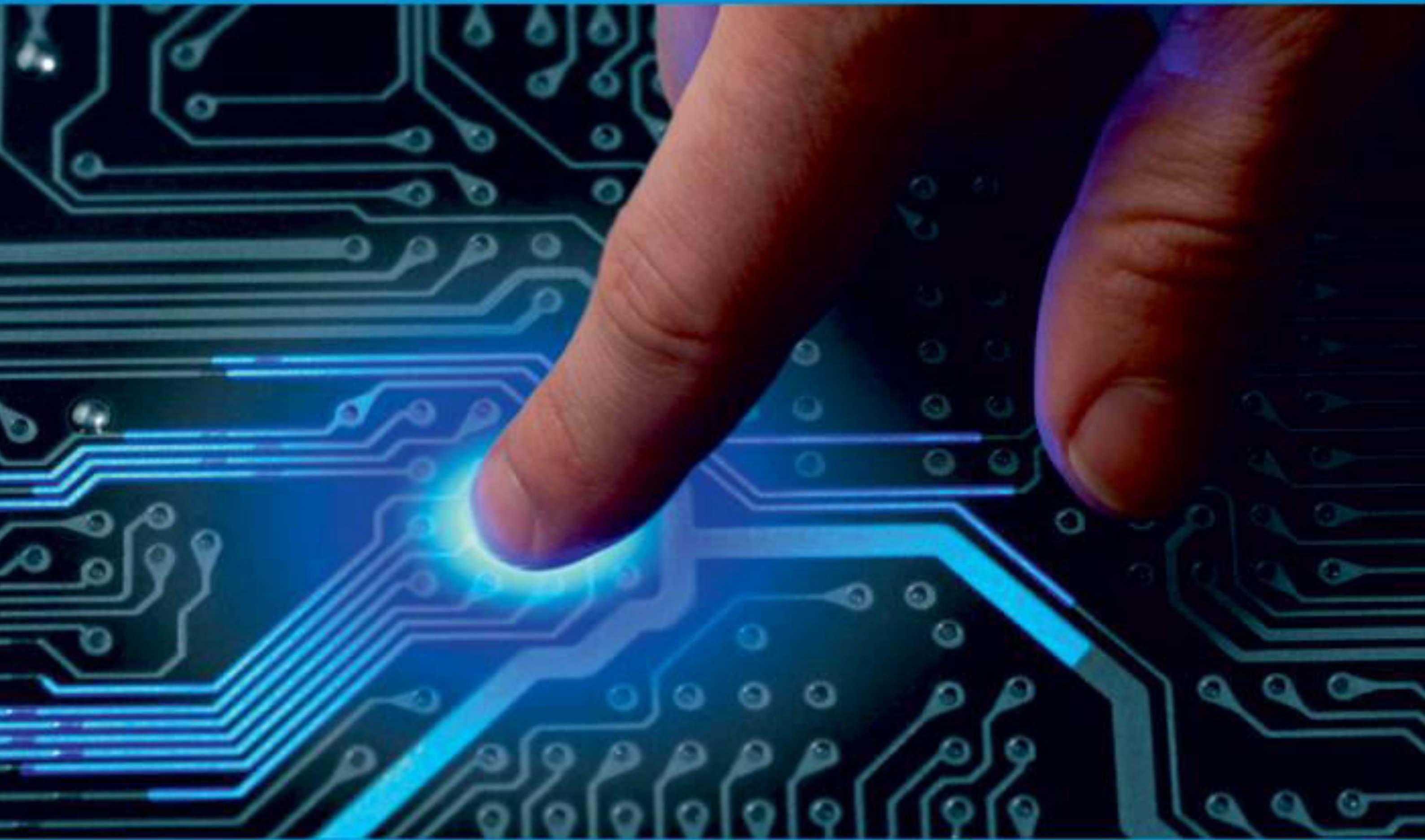

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Ionospheric Layer and its Effects on the Electromagnetic Waves: A Review

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ABSTRACT: Ionosphere layer is a part of earth's atmosphere which plays a major role in the communication of electromagnetic signals from ground to space and vice-versa. The electromagnetic waves transmitted from the earth stations are being affected by the plasma (charged particles) present in the ionosphere as they propagate.Precise estimation of electron density which is usually referred to as Total Electron Content (TEC) parameter is very much essential in order to fully understand the behavior of electromagnetic wave in plasma. The density of electrons in the ionosphere layer differs with geographical location, season, local time, latitude & longitude and with solar & magnetic environments.This paper discusses the ionospheric layers and variation of Total Electron Content with different conditions and to overcome the propagation effects caused which are useful for radar and navigation applications.

KEYWORDS: Ionosphere, TEC, propagation effects, SAR, Faraday rotation

I. INTRODUCTION

The Earth's ionosphere is an ionized medium formed by the ionization effect of the solar radiation on the upper atmosphere, ranging from 50 to 1000 km[1][2].

At frequencies such as 10 GHz and beyond, the effect of ionosphere can be ignored, but at lower frequencies, particularly at radio frequencies and microwave frequencies (~300MHz to 5GHz), the effects can be relatively dominant[3].Also the unpredictable and dispersive properties exhibited by the ionosphere layer, considerably disturbs the propagation of the electromagnetic waves[1][2].

Ionospheric layer, consist of free electrons and positive ions of equal ratio, in an electrically neutral medium. The charged particles exhibit a great impact on the electrical properties of the medium also their existence brings about the possibility of radio communication over longer distances by making use of one or more ionospheric reflections[4]. The solar radiation results in ionization of the atmosphere constituents their by creating group of free electrons and ions which affects propagation of radio waves. Since the amount of ionization depends on the amount of radiation received from the sun, the ionosphere state has day time and seasonal variations in accordance with the sun position [12].

Identification of the effects caused by the ionosphere layer needs to be considered, namely dispersion, group delay, refraction and Faraday rotation due to background ionosphere and others such as refractive index fluctuations, pulse broadening, clutter and amplitude scintillation due to irregularities in the ionosphere. These effects are collectively considered because they all depend on the integral of electron density along the ray path (or total electron content, TEC) over the ionosphere. The result of these effects, seriously affect the radar imaging by causing image shift, range resolution degradation etc.[5]

II. TOTAL ELECTRON CONTENT (TEC)

Total electron content (TEC) is defined as the integral of the density of electrons over the perpendicular path from the earth surface to the upper ionosphere. Electron density and solar activities are closely related as the TEC value changes with solar activities, and the variations can be of the order of 103. Various techniques are used to quantify the TEC value of the ionosphere. Both satellites and high-altitude rockets were used to get the ionosphere profiles[6].

Without giving much importance to the terrestrial magnetic field and the electron collision, the refractive index of the ionosphere is proportional to the frequency[7] of the radar signal, which can be expressed as

$$n = 1 - \frac{f_e^2}{2f^2} = 1 - \frac{KN_e}{f^2} \qquad (1)$$

where $f_e$refers to plasma frequency, f is the carrier frequency, and $N_e$is the electronic concentration. K is the classical electron parameter stated as K = e2/8π2ε0m = 40.28 m3/s2, [1]where e is the elementary charge, m is the mass of the electron, and ε0 refers to dielectric permittivity of the free space.

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Because of the dispersion, the delay caused by the ionosphere is given by an integral equation as

$$\triangle l = \int (n-1)dl = -\frac{K}{f^2} * TEC \qquad (2)$$

Where TEC = $\int N_e dl$ is the total electron content along the vertical ionosphere path, and the TEC's unit (TECU) is 1016 electrons/m2. The corresponding phase advance of the round-trip can be represented as

$$\triangle \varphi = \frac{4\Pi K}{cf} * TEC \qquad (3)$$

where c is the velocity of light. Equation (3) shows that the ionosphere phase advance is a function of frequency, which is directly proportional to the TEC experienced by the electromagnetic waves propagating a round trip in the ionosphere.

III. CHALLENGES IN SAR IMAGING

The test to acquiring valuable information from a satellite-borne Very-High-Frequency (VHF) Synthetic-Aperture-Radar arises from two issues. The first is to dismiss the impact of scattering, by adjusting the radar waveform using the inclination TEC towards the focal point of the imaged area at each gap location. This requires a model of the ionosphere that is a decent match to the conditions that the information are acquired in. In any event, one would need to know the vertical TEC at the satellite area. Such readings may be acquired from the satellite itself; for instance, one may probably utilize the nadir projection of the SAR as a sounder which related to altimeter information could be utilized to estimate group delay and vertical TEC. The second test is to make up for any non-consistencies in the ionosphere, for example, those delivered by acoustic-gravity waves (Traveling Ionospheric Disturbances) which results in index of refraction over the components of the aperture. Such varieties will corrupt the image, which will fluctuate in time and location [6].

IV. CONDITIONS APPLIED TO OVERCOME SAR IMAGE DEGRADATION DUE TO INHOMOGENEOUS IONOSPHERE

Non uniform nature of the ionosphere must be taken in to count when evaluating the SAR image degradation under 500MHz, also a precise numerical model will be fundamental as it is difficult to include the spatial and temporal changes of the ionosphere in an analytical model. When a perpendicular structure[8] of the ionosphere is considered, further image degradation and shift results due to the effect of ray bending.

Ray bending causes a normal path length change of 500 MHz and an image shift of 6 meters for an ionosphere with an average TEC value (5 TECU) which tells that ionospheric impacts are irrelevant for an ionosphere with low normal TEC (under 5 TECU).

The SAR image degradation brought about by layered ionosphere is frequency dependent and its effect diminishes to an irrelevant level for frequencies above 600MHz.

One method to control the SAR image degradation is by acquiring the information during the time when the ionosphere is generally stable. To moderate the SAR image degradation, it is essential to perform detailed analysis of the ionosphere structure [8].

V. IONOSPHERIC EFFECTS

A. DUE TO THUNDERSTORM

Tropospheric thunderstorms have been accounted for to aggravate the lower ionosphere, at heights of 65–90 km, by convective climatic gravity waves and by electric field changes created by lightning discharges. Hypothetical predictions recommend that lightning electric fields elevated the electron attached to O2 and decrease the electron thickness in the lower ionosphere. Such perceptions typically found in the evening ionosphere over a little rainstorm [7]. The electron thickness in the lower ionosphere diminished because of lightning releases. The degree of the decrease is firmly related in reality to the rate of lightning releases, supporting that the improved electron connection is in charge of the decrease [7].

In the previous two decades, various hypothetical examinations have been accounted for on the electrical coupling forms among lightning and the lower ionosphere, concentrated for the most part on the commencement of high altitude releases. Some studies anticipated that hasty lightning field changes (∼100 µs) diminish the electron thickness at 75–85km attributable to electron connection to O2 and increment the electron thickness at 85–95km inferable from ionization of N2 and O2. The rate of the thickness change relies upon the adequacy and span of the lightning pulse, and on the first electron profile. Reenactments with different pulse amplitudes and electron profiles demonstrate that the electro-n thickness is decreased by ∼60% close 80km and expanded to different degrees at 85–95km by an arrangement of 20 lightning impulses.

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The lightning strikes are known to regularly create more extensive field changes at lower frequencies. The compelling pulse width at the ionosphere is then restricted by the in situ conductivity unwinding time, in terms of milliseconds at 75–85km resulting in re-ionization. This re-ionization would refill the expelled electrons within minutes, so repeated lightning releases happening within minutes can collectively evacuate the electrons [7].

B. IONOSPHERE EFFECT ON A SPACE-BORNE SAR

Distinctive distribution patterns of the electron density results in significant image distortion brought about by the ionosphere. When the electron density is distributed linearly, the image distortion becomes more prominent and the change in resolution can be up to 300%. To accomplish the desired image resolution under the state of an organized ionosphere, the framework may need to alter its effective aperture size. In the arbitrary appropriation case, which is nearer to the real situation, results in an increasingly more image distortion. There is a significant image shift because of Ray-bending at P-band (less than 500MHz) or lower frequencies [9].

C. FARADAY ROTATION DUE TO IONOSPHERIC EFFECT

In the event that the electromagnetic wave is propagated in the ionosphere along the geomagnetic field, two circularly polarized waves gets generated, and accordingly if a linearly polarized wave is occurring on the ionosphere, it parts into right and left handed polarized waves. After propagation, these two waves recombine to give a linearly polarized wave with the plane of polarization turned in extent to the geomagnetic field and the propagation distance. This pivot of polarization is known as the "Faraday rotation" and has been utilized to determine the TEC of the ionosphere [5].

FR is an impact of radio signal traversing in a charged plasma as found by Michael Faraday in 1845. Its magnitude is relatively proportional to total electron content (TEC) along the radio beam path [10]. The Faraday rotation (FR) impact is exceptionally critical at P-band, yet the ellipticity change is unimportant, and the change in the direction of orientation is the primary to the Faraday rotation [5].

It ought to be noticed that Faraday rotation is influenced by regulation of magnetic field along the radio beam. In Earth remote detecting observations, the modulation differs with latitude because of the variation of geo-magnetic inclination. This regulation diminishes or limits the FR impact close to the magnetic equator where the radio wave vector of a side-looking SAR framework is about opposite to the geomagnetic field. Then again, the effect of geomagnetic field on the ionospheric-induced signal phase advance is immaterial at L-band. The FR impact is relative to TEC/f2 while ionospheric-induced signal phase advance is corresponding to TEC/f, where 'f' is the radio frequency. This makes the FR impact more fragile than the phase effect for a similar radio signal and same TEC. Hence, ionospheric estimations utilizing L-band SAR signals are more sensitive to phase than to FR at low latitudes [10].

D. EFFECT OF IONOSPHERE ON GEOSAR IMAGING

The aperture of geosynchronous synthetic aperture radar (GEOSAR) is acquired with a clear movement of the geosynchronous satellite initiated by non-zero inclination and eccentricity of the orbit. The fundamental difficulties for GEOSAR originate from the long range (around 36 000 km) between the geosynchronous satellite and the Earth's surface and wide coverage. The environmental impacts, including both tropospheric and ionospheric impact, will be a standout amongst the most significant variables affecting the GEOSAR performances [11].

The spatial variation of the background ionosphere results in GEOSAR image to shift. The vertical structure of the ionosphere makes the image to move in the z-direction, and the deviation about 40.3 × TEC/f02, where f0 is the frequency of the GEOSAR signal. The dispersion effect and the resolution degradation are irrelevant for L-band GEOCSAR with data transfer capacity under low frequency. Since aperture length of GEOCSAR anticipated onto the ionosphere is for the most part around many kilometers [11].

VI. CONCLUSION

Following are the conclusions drawn after reviewing the effects caused by ionosphere layer on the electromagnetic signals.

- Ionospheric electron density variations corresponding to lightning discharges needs to be considered while simulating the ionosphere.
- Precise estimation of total electron content (TEC) is very much essential for mitigating different propagation effects caused by the ionospheric plasma on the electromagnetic signal.

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- The lower ionosphere layer will be affected more in the presence of thunderstorm, and gets recovered once the storm stops.
- The low frequency or very low frequency signals cannot be probed once they enter deep in to the ionospheric height say 85-95 km distance.
- The dispersion effect and range resolution degradation of L-band SAR signals become negligible at lower bandwidth (less than 100 MHz).

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BIOGRAPHY

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