# The role of Ionosphere in EME communication

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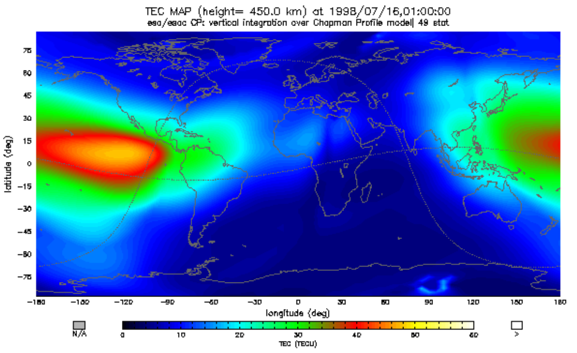
## Abstract

**This document represents a summary of my presentation at the Italian EME conference 2012, organized by ARI  Italian Amateur Radio Association.**

## Earth's Ionosphere

The Ionosphere is a non-homogeneous medium, where the electron density varies with altitude, but there are also horizontal gradients. It is a non-isotropic because the ionized component is immersed in the Earth's magnetic field. In fact we can speak of a magneto plasma. Moreover, the ionosphere presents significant diurnal and seasonal variations mainly related to changes in solar radiation. The ionosphere is turbulent and subject to continuous wave movements.




## The Analogy between electromagnetic waves and optical waves.

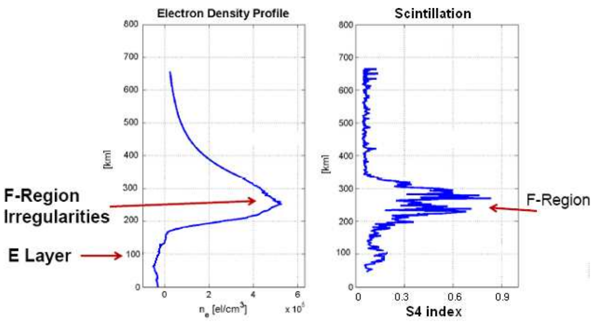
Radio wave does not differ in any way from the optical wave with the exception of the wavelength and hence frequency. Both the units are in fact linked to the C constant (speed of the light) if lambda **increases, must decrease the frequency F.**

$$c = \lambda * F$$

The ionosphere, in general, acts as a refractors for radio waves because it behaves like a dielectric with the constant which is <1 that is less than the dielectric constant of the vacuum.
If the incoming signal through a path in the ionosphere, it is affected by scintillation (fast Fading) there are no any others alternatives, or has gone through a turbulent refractors or  through a refractor, which contained many irregularities.

## Location of the Ionospheric irregularities

The ionospheric scintillations are related to the electron density. The increased electron density occurs at a height between 200 and 300 km (F layer), so it is extremely probable that the majority of disturbances are originating in this area.




## Diurnal variations of TEC (Total electron content)

During the night occurs the recombination of ions and electrons, with decrease of TEC. During the day, the ionization process is predominant,with production of free electrons, with an increase of TEC. Minimums and maximums are offset, however. The TEC begins to rise up before dawn and begins to decrease before sunset. What is the cause? The ionosphere is the seat of very strong winds from East to West.

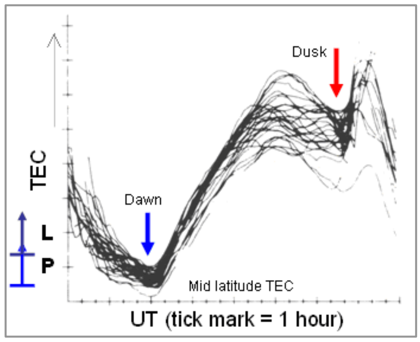



*Fig.3 In this chart we can see a minimum TEC  level before dawn (pre sun rise dip) and a pronounced depression of TEC  before sunset.*

## Seasonal Variations of TEC

We have seasonal variations in total electron content and also variations related to the eleven-year cycle of the sun. Furthermore there may be relevant day to day variations.

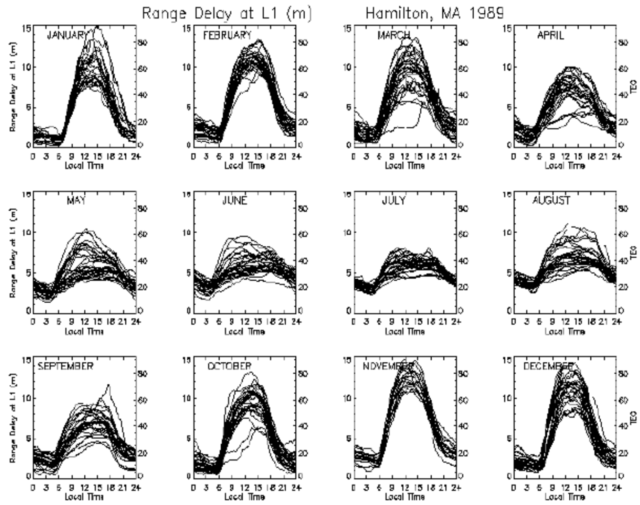



Figure 2.2. Ionospheric TEC variability provides a measure of how the ionosphere varies over Hamilton, Massachusetts during 1989. (One TEC is $10^{16}$ electrons per square meter.) Note the day-to-day and seasonal variation (Borer, 2005).

## Ionospheric Scintillation

Ionospheric scintillation is a rapid fluctuations in amplitude and phase of radio signals passing through the ionosphere due to turbulence causesd by ionospheric irregularities. The irregularities present in the ionosphere cause variations in the refractive index and therefore produce scintillation on the intensity of the signals. The Earth's ionosphere is a plasma by its irregular structure that forms a diffractive screen randomly. Irregularities are always present. The scintillations are caused by agglomerations/plasma bubbles mainly located between the region E and F of the ionosphere in constant motion due to the turbulent nature of the ionosphere. These agglomerations/ionization bubbles act like radio lenses concave/ convex. In EME communication we have a double transit through Ionosphere (ionospheric effects are additive). The amplitude of the scintillation is inversely proportional to the square of the frequency. In VHF the ionospheric component prevails while at higher frequencies, prevails the component due to tropospheric scintillation.

## Reflection Properties of Lunar Surface

A brief note on reflective properties of the lunar surface: As evidenced in the diagram below, the reflection coefficient of the lunar surface decreases with increasing frequency.
(The moon echo is nearly specular in VHF , spread increases at higher frequencies). For a variation from 0.05 to 0.1 of the reflection coefficient the variation in the path loss not exceeding 3 dB (at 144 MHZ)

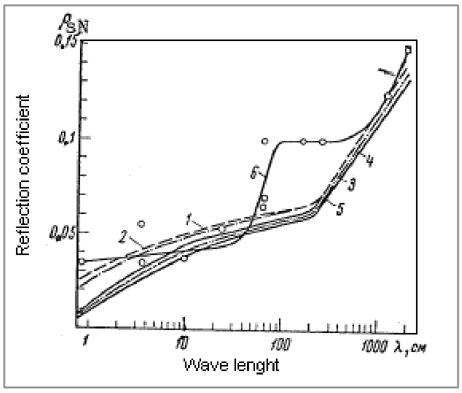



*Fig.5: Trends of the reflection coefficient depending on the frequency. Images Courtesy: NASA National Aeronautics and space Administration, "Radar Studies of the moon" by N.N Krupenio*

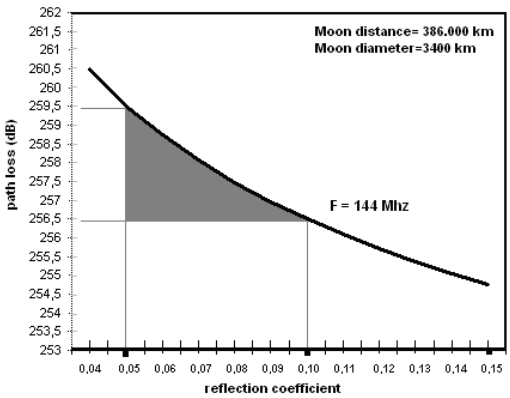



*Fig.6: For a variation from 0.05 to 0.1 of the reflection coefficient, the variation in the path loss not exceeding 3 dB (at 144 MHZ)*

## Libration Fading

The signals reflected from the lunar surface tend to have a fast fading fluctuation known as Libration Fading. It is caused by the irregular surface of the moon, that "oscillates back and forth" compared to an observation from the earth, in addition there is also the movement of rotation and revolution of the Earth. The libration fading can cause fluctuations of the signals above and below the mean level. The fluctuation from Libration Fading is directly proportional to the frequency (the fading is faster with increasing frequency). Then a peak of libration which lasts 3 seconds on 144 MHz, will be only1 second on 432 and 1/3 of a second on 1296. Libration fading: very short period seconds / tens of seconds

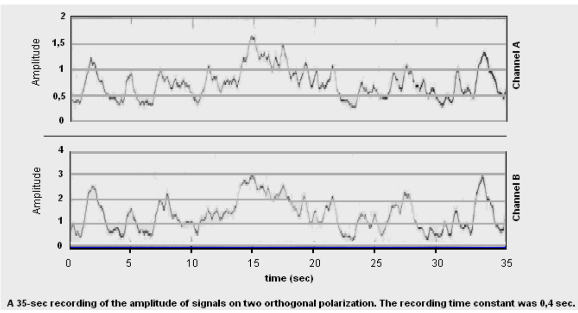



Fig.7: This test was carried out at a frequency of 488 MHZ. *The level of the fading is approximately 8 dB. With decreasing frequency decreases the fading due to libration and tends to increase the fading component due to ionospheric turbulence Image courtesy: NIST National Institute of standard and Technology Radio science department*

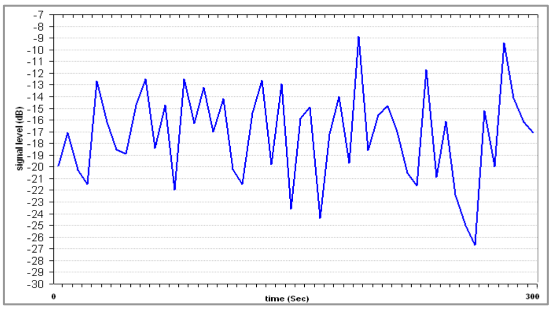



Fig.8: Comparison with WSJT at 144 MHZ. We found a mean variation in the order of 12-13 dB mainly due to ionospheric scintillation (at 144 MHz the libration fading is about 3db) Tests realized by IK1UWL with 4x16 elements long Yagi with circular polarization (quiet ionosphere). Echoes with WSJT "no avg" . This is the special version without average.

## Fading by Ionospheric Absorption

The fading by ionospheric absorption is characterized by a very slow Period: a few minutes / tens of minutes. It is due to the turbulent and unstable nature of the Earth's Ionosphere

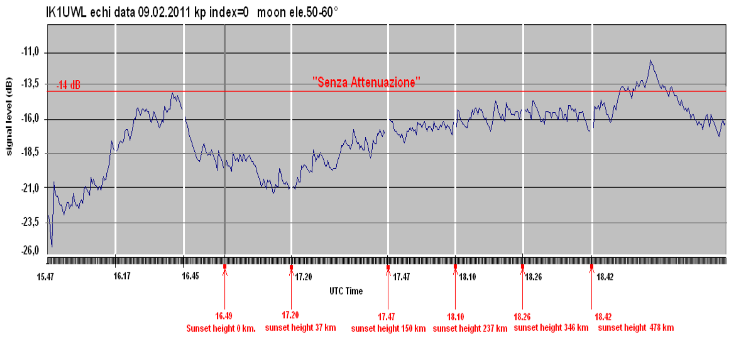



*Fig.9:The graph illustrates the performance of EME signals in the range of about 3 hours. Can be noted significant changes in signal strength. This Test has been realized by IK1UWL with WSJT9.0 with average function, during quiet Ionospheric conditions.*

## Faraday rotation and F0F2

The Faraday rotation depends on the TEC and in good approximation by f0F2. Therefore a daily monitoring of f0F2 can give important information on the intensity of rotations

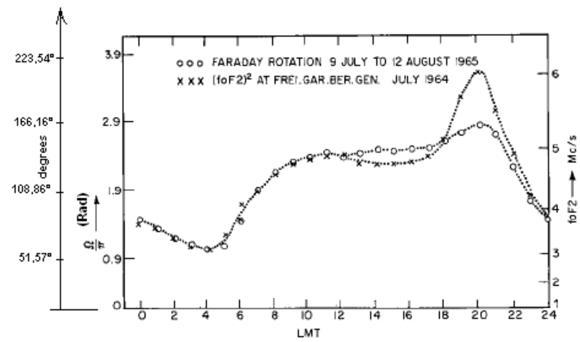



*Fig.10: Median diurnal Variation of the f0F2 (Crosses, right hand scale-squared) and the observed Faraday rotation (circles, left hand scale, adjusted by best fit method)*

## Focusing and defocusing effects in the Ionosphere

Local variations in electron density can act as a radio lens that can cause ionospheric phenomena of focusing/defocusing.

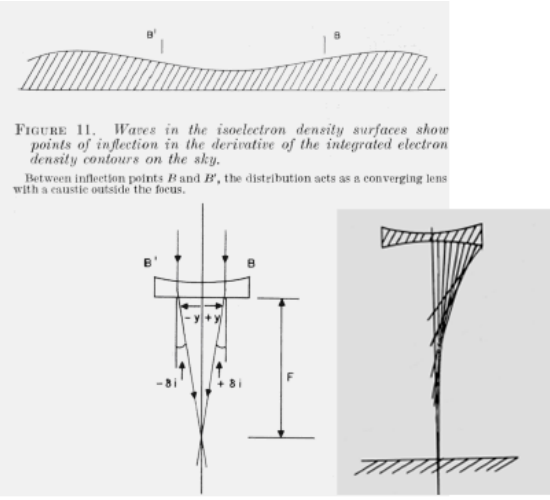



*Fig.11: Lenticular structures due to changes in electron density in the ionosphere. In this shape, the Electronic distribution has the correct properties of radio converging lens. Iso electronic surfaces in the ionosphere are modelled by sinusoidally internal movements of the ionosphere. In the right panel: Caustic formed by a converging lens.*
*Image: Courtesy of Radio Science (Journal of Research) – "Radio Star Scintillations from Ionospheric waves" J.W.Warwick*

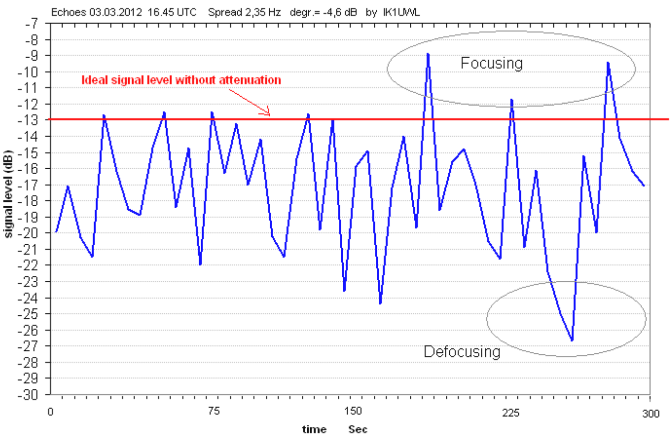



*Fig.12:Tests realized with WSJT no average. In addition to the strong ionospheric scintillation there are some peaks of 4 dB above the ideal line, and some negative deep peaks due to defocusing effects.*

## Undulations in the Ionosphere

Wave model: the ionospheric layers are not homogeneous, they are continuously shaped by strong winds that may have neutral ionospheric movements , zonal movements (east-west) along the parallels and meridians movements (north-south) along the meridians. Also there are vertical convective turbulence and AGW (Atmospheric gravity waves) that constantly shape the layers. We can have: Irregularities on a small scale (size of a few wavelengths). Irregularities on a large scale (size of order 100 km).The irregularities tend to align along the lines of the earth's magnetic field.

## The ionospheric irregularities (focusing/defocusing): Shape and structure

The presence of lenticular cylindrical structures in the ionosphere is a result of the vertical distribution of electron density.
The phenomenon is due to multiple iso-electronic surfaces interconnected inside the ionosphere and mainly distributed in the vertical direction.

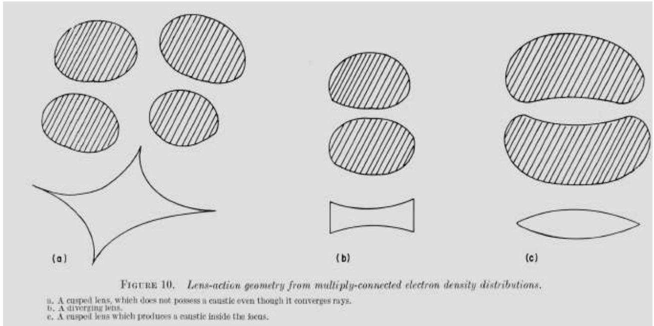



*Fig.13: Various shapes of lenses due to multiple distributions of electron density with multiplicative effect. Regions of greatest electron density with cylindrical symmetry (vertical) can act as a converging lens.*
*Image Courtesy:* Courtesy: Radio Science Journal of Research NBS/USNC-URSI

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