

QSB from ionospheric interactions in EME communications at 144 MHz

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doc. n. 24.11 date: May 18th 2011

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Acknowledgments: We are grateful to Franco Giorgi, I2FAK for providing several EME transmission that we displayed in graphic form and compared with ionospheric changes.

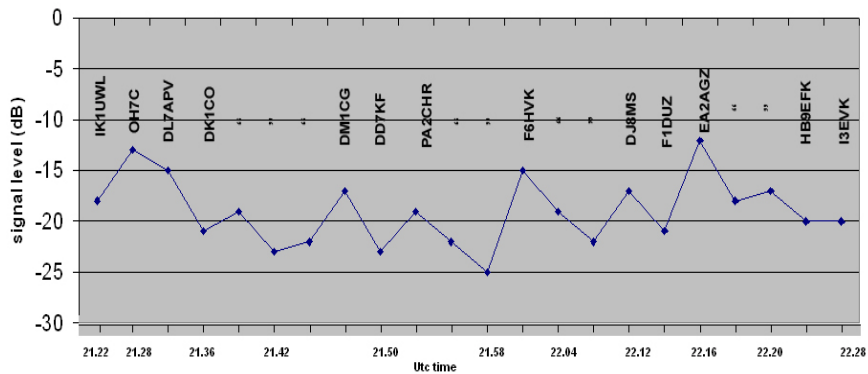
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INTRODUCTION

The present study is born from an experience of Giorgio IK1UWL, who, during his EME activity, noted a significant qsb which could not be related to lunar libration. For several months we have cooperated together with direct experimental observations, alternating echo tests and monitoring of other stations, which have been transformed in diagrams and related to ionospheric variations. Together with this experimental work, we have examined and studied many publications by research institutes, which are mentioned at the end in References.

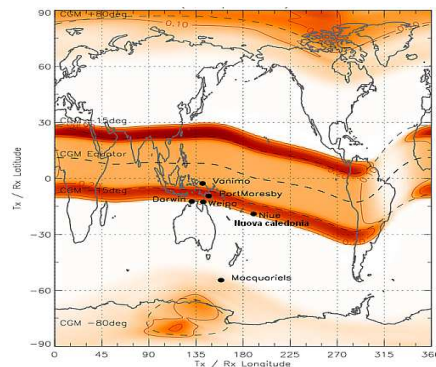
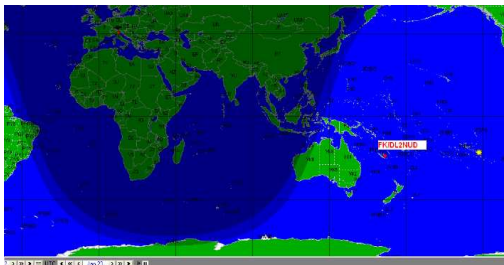
When there was the expedition in FK land (New Caledonia), IK1UWL had a moon window of about one hour, and had the chance of completing a qso at his moonrise. FK/DL2NUD had a very strong signal, and IK1UWL was able to decode him always, also when in qso with other calls, so he continued to monitor the signal, and, after moonset, he built a graph of signal levels of the OOO message in order to have a better overall view of signal levels.



The QSB amounted to 13 dB, not related to Ground Gain which is absent at the IK1UWL qth, and probably absent also at FK, since there were no nulls.

1.1 – Our assumption

New Caledonia is near the geomagnetic equator, which in that area is very much shifted southwards, and so falls in the equatorial region where there is a great ionospheric instability. At that date and time it was fully illuminated by the sun, so the ionosphere was dense and turbulent.



As a factor we have introduced the ionosphere, which, although does not reflect us, must be transversed twice, and which interacts with our signal. We will now speak of its characteristics, applicable to EME signals.

2 – SUN EFFECTS

2.1 – Solar wind

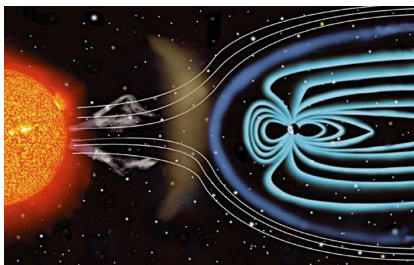
The Sun emits:

a- a particle shower

The particle shower (solar wind) is deviated by earth's magnetic field.

b- wide spectrum radiation.

The ultra-high UV and extreme X radiations, that hit the high regions of the atmosphere, generate the ionosphere.



When Sun activity increases and erupts Solar Flares and CME (Coronal Mass Ejections), the Solar Wind increases in intensity and energy, so that the geomagnetic field is disturbed and distorted and there are heavy repercussions on the ionosphere.

The effects of Solar Storms on the ionosphere:

- SOLAR FLARES and CME

Emit high speed charged particles that in a couple of days reach Earth, causing important perturbations of the ionosphere.

- PROTONIC EVENTS

High energy protons can reach the Earth in 30 minutes after a big flare. Some particles can penetrate the upper atmosphere, causing additional ionization.

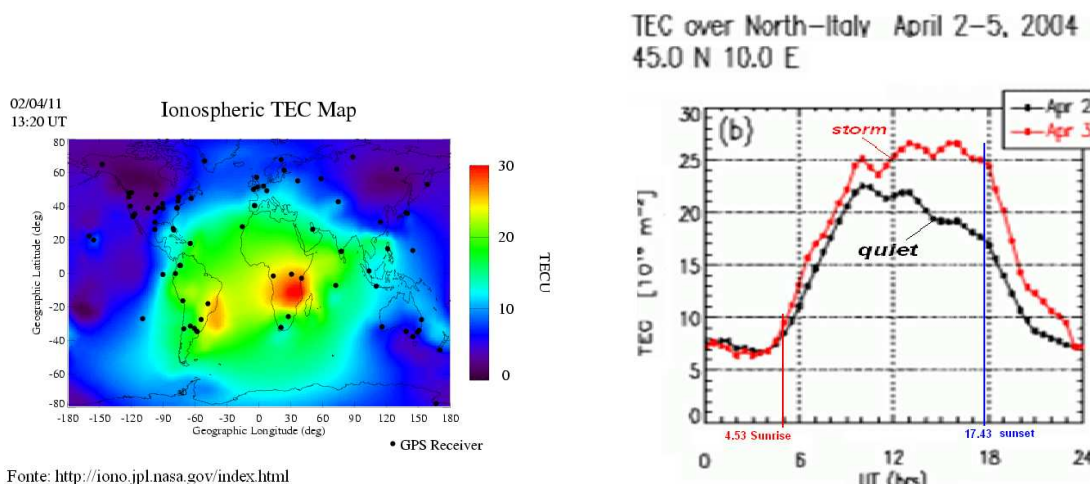
2.2 – The ionosphere

- The ionosphere is a region of the upper atmosphere where there is a plasma of free electrons and ions, generated by the extreme UV and X radiation of the Sun.
- Plasma composition changes with height, because the chemical composition of air changes, the lighter elements rise and various layers are formed.
- The density of the plasma changes with date, local time, and sun activity.
- Ionization rate is higher than recombination rate, so plasma is present also in the regions in darkness.
- The plasma is immersed in Earth's magnetic field, which influences its movements.
- The ionosphere is not almost static, it is subject to turbulence and strong winds.

2.2.1 - TEC (Total Electron Content)

TEC (Total Electron Content) is the key parameter in descriptions of Earth's ionosphere.

It represents the total electron content present along a trajectory, and it is measured in electron number per square meter, with 1 TEC Unit (TECU) = 10^{16} electrons/m². TEC amount determines scintillation amount and phase delay of a radio wave going through it. For the measure of TEC, the GPS satellites are used by measuring their phase delays. TEC changes gradually during the day approximately following zenithal movement of the Sun, but there are also significant local changes due to wave type movements in the ionosphere, turbulences and geomagnetic intensity changes. Minima and maxima are displaced. TEC increases before sunrise and decreases before sunset, with an additional short decrease before sunset. This is caused by the very strong ionospheric winds which flow, at our latitudes, from east to west. Summarising, there is a gradual TEC increase that begins a little before sunrise and reaches its maximum in the early afternoon, then a decrease before sunset, reaching a minimum before sunrise. We can consider three different phases, the increase phase, the daily constant phase, and the decrease phase. There is also an additional decrease phase before sunset, of which we will speak.



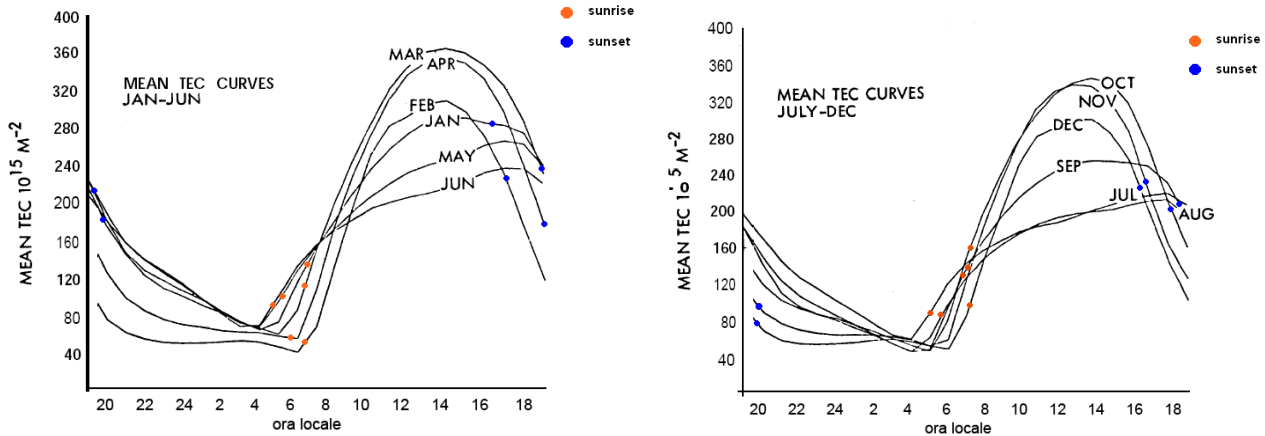
Example: daily curve of TEC, measured in North Italy, with both calm and perturbed ionosphere.

2.2.2 – Daily variations of TEC

At night ions and electrons recombine, so TEC decreases. During the day ionization is predominant, so TEC increases.

But maxima and minima are shifted. TEC increases before sunrise, and decreases before sunset.

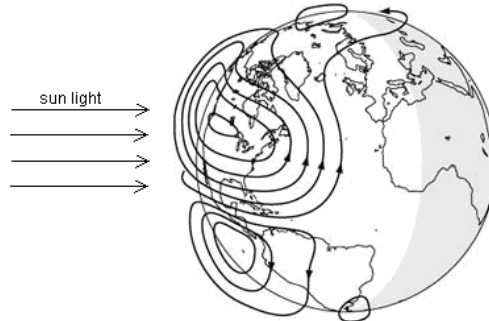
The reason ? There are very strong ionospheric winds, flowing from East to West.



Daily variations of TEC, monthly means of period 1967-1973, measured at Sagamore Hill, MA, by Hawkins and Klobuchar, 1974

2.2.3 – Ionospheric currents system

The daily variation is caused by a system of electric currents that flow in the ionosphere at a height of 400 km. These currents, present in the part of the ionosphere illuminated by the Sun, form two distinct vortices, one in each hemisphere. Viewed from the Sun the rotations are opposed (counter-clock-wise in the northern hemisphere and clock-wise in the southern). The centres are near latitude $\pm 40^\circ$ and very near to the Sun meridian.



2.2.4 – Ionospheric indices

There are indices that are correlated to ionospheric behaviour. They are:

Planetary Kp index

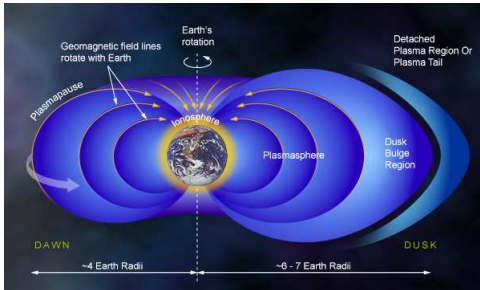
An indication of the level of planetary geomagnetic disturbances is given by this index Kp, which is the average of the K indexes measured in 13 planetary stations. This index is used to separate quiet days from disturbed days.

Geomagnetic Indices & Conditions

	K Index	Geomagnetic Conditions	HF Noise	Aurora
NORMAL	0	Very Quiet	S1-S2	None
	1	Quiet	S1-S2	None
	2	Quiet	S1-S2	Very low
	3	Unsettled	S2-S3	Very low
	4	Active	S2-S3	Low
STORM	5	MINOR storm	S4-S6	High
	6	MAJOR storm	S6-S9	Very high
	7	SEVERE storm	S9+	Very high
	8	SEVERE STORM	Blackout	Extreme
	9	EXTREME storm	Blackout	Extreme

2.3 - Plasmasphere

Above the ionosphere, for a height of 3 to 6 terrestrial radii, there is a plasma composed principally of ions of oxygen and atomic hydrogen, which flows along the lines of magnetic field of Earth. Its density is around 10^9 electrons/m³, so 100-1000 times less dense, but 100 times more wide, which also contributes to total TEC. Also this region has changes, winds, and turbulences, like the under laying ionosphere.

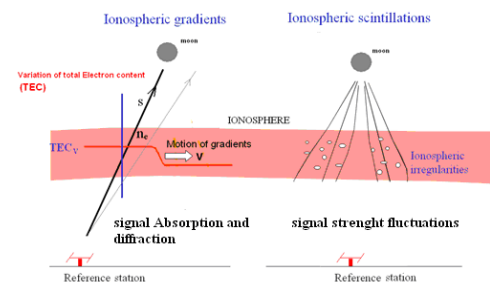
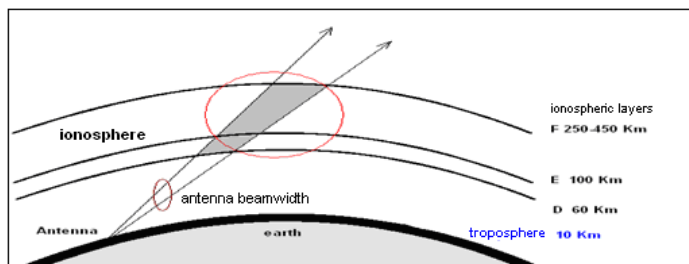


3 –INTERACTIONS WITH A RADIO WAVE

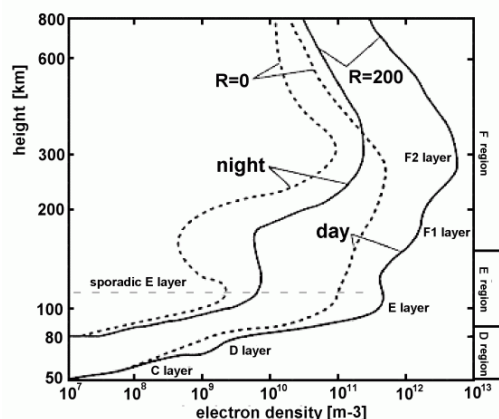
Electrons and ions react to the electromagnetic field of a radio wave absorbing energy, the greatest part of which is given back by reradiation; the result is a weakening, a slowdown and a deviation.

The effects on our signal are:

- 3.1 – Absorption
- 3.2 - Scintillation
- 3.3 – Polarization rotation
- 3.4 – Depolarization
- 3.5 - Deviation



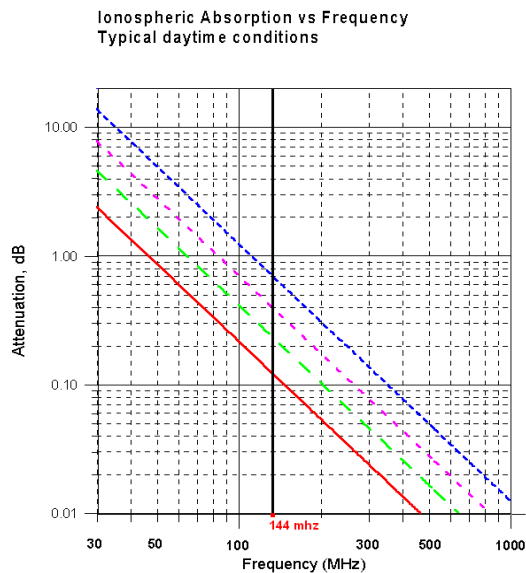
Our study does not concern libration, which is caused only by lunar soil characteristics and its relative movement. Besides, at 144 MHz its effects are secondary.



The greatest effect is caused by electrons, so this is tied to their density (number per m³). Their density changes with altitude since the UV radiation is absorbed starting at high altitudes (see density graph as function of altitude).

3.1 – Ionospheric attenuation

Ionospheric attenuation is proportional to the length of the route through the electron plasma, to the density it encounters, and to the angle of incidence. It is proportional to the inverse of the square of the frequency. Attenuation is additive, greater the route through the plasma, greater the attenuation. The graph here under refers to 100 km of depth. The table covers typical values of total attenuation for a single passage through. Variations in the ionosphere (time of day, solar activity, latitude, turbulences) can increase these values.

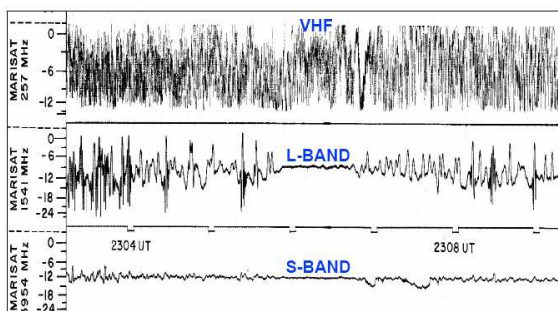
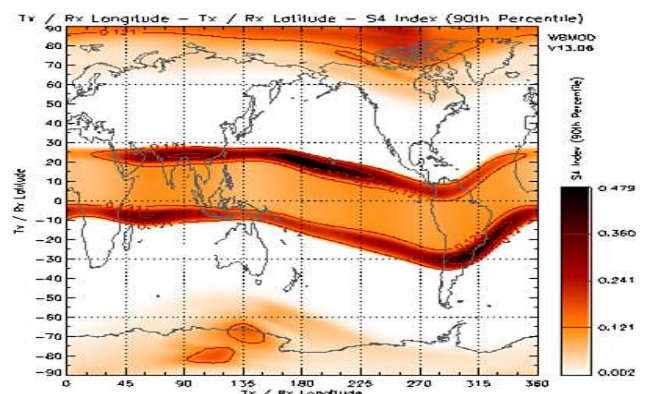
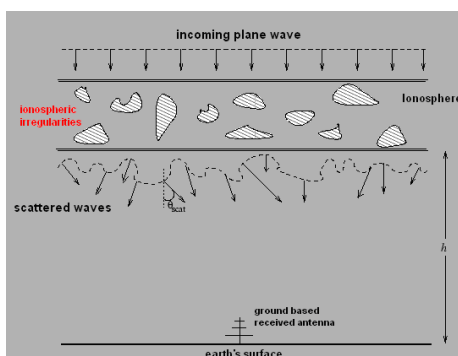


Typical daytime conditions
(single passage through the ionosphere)

Elevation Angle	Attenuation in dB for Height in Km		
	100 Km	300 Km	500 Km
0°	0,6	1,8	3,0
30°	0,2	0,6	1,0
60°	0,12	0,36	0,6

3.2 – Ionospheric scintillation

Rapid fluctuations of the ionospheric refraction index cause scintillation on the signals going through it.. Scintillations are rapid changes in amplitude and/or phase. This effect is well known to GPS system operators, because it can cause significant positioning errors (in some cases even several tens of meter). These effects decrease with increasing frequency (see lower figure). Scintillations are stronger both at high and equatorial latitudes, and during solar storms.



Summing up we have:

- Semi periodic fluctuations, with periods from minutes to tens of minutes, typical of slow movements of plasma masses with consequent slow variation of ionospheric density.
- Very quick variations (quick qsb), with period from fraction of seconds to tens of seconds, caused by turbulence and flow of electron bubbles (typical example is the qsb that happens during a JT65 one minute period, or even on single Morse characters).

3.2.1 - Scintillation (technical investigation)

Prof. Rumsey (California University, San Diego) has authored a theory which can be applied to this kind of physical phenomena, like star brightness twinkling, scintillation of signals going through the ionosphere, flutter fading on polar routes. This theory says that scintillation is a consequence of a space-time fluctuation of the index of refraction of the medium placed between source (Tx) and receiver (Rx).

The characteristic factors of any kind of scintillation are.

-A change of the refraction index, also very small and localized, it is enough to have a change in the space of a wavelength.

The refraction index of a radio wave is a function of electron density, and this last changes if there are magnetic field variations.



Quick QSB is a consequence of ionospheric scintillation. These vary very much from place to place. See image above where two simultaneous EME signals from different stations exhibit very different QSB characteristics.

3.2.2 – Grey Line

A consequence of the pressure from the solar radiation is the non-concentricity of ionosphere and Earth. The shape of the ionosphere changes continuously as can be seen when the Sun sets on a meridian (terminator). In this phase the ionosphere is highly dynamic and its ionization changes drastically after the passage from day to night. The density of electrons in the E layer decreases by a factor 200 to 1, and the F layer by a factor 100 to 1. After sunset the D layer disappears. The signals that goes through these layers for some hundredths of kilometres encounters curved surfaces that are oblique with respect to ground, which can generate focusing effects and can create attenuation and/or phase changes on the signal in transit. From the many tests we have conducted emerges clearly that an EME signal, going through a zone in transformation, are strongly influenced, undergoing attenuation and instability (slow QSB and scintillation).

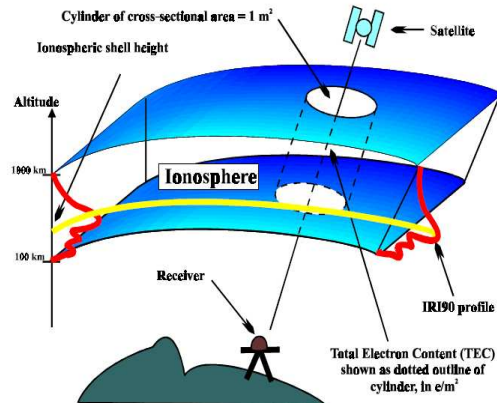
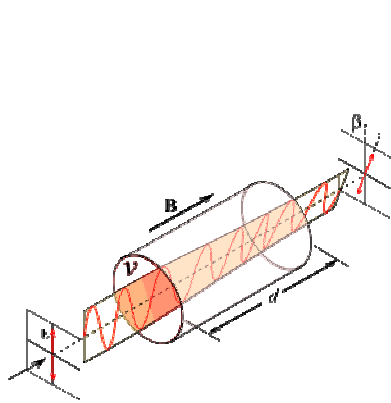
3.3 – Faraday rotation

This is a magneto-optic phenomenon, proportional to the intensity of the magnetic field B and to the index of refraction of the medium gone through, and inversely proportional to the square of the frequency, that rotates the polarization plane of the wave. It is noticeable and important especially on the low EME bands (50 and 144 MHz).

$$\beta = k \cdot B \cdot N_e \cdot d / f^2$$

where:

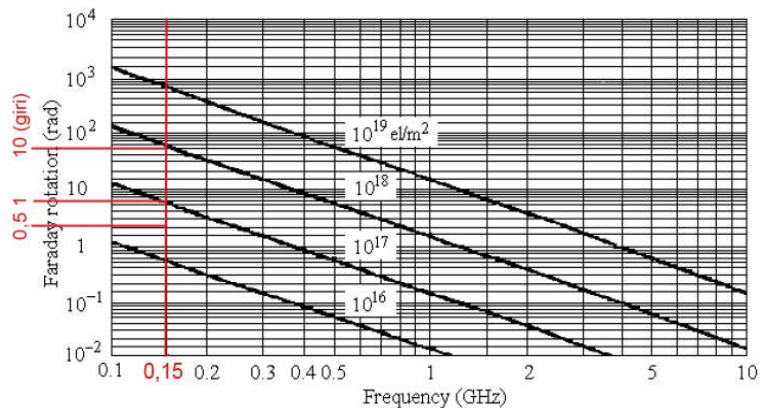
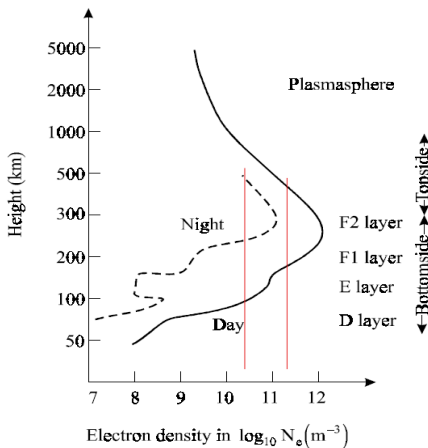
$N_e \cdot d$ (average density of the ionosphere * its thickness) is the TEC (Total Electron Content)



You should imagine this cylinder as a tube, with a unitary section (1 m^2), that represents our road going through the ionosphere. The above equation should be written with an integral sign before it, from 0 to d , because the ionosphere is not homogeneous along its height. As a first approximation we can consider a uniform magnetic field and density. In quiet Sun conditions, TEC varies between 10^{17} and 10^{18} m^{-2} , with $1 \text{ turn} < \beta < 10 \text{ turns}$. In perturbed Sun conditions, with turbulence, and on the Grey Line, we get very quick changes of rotation angle, which contribute to scintillation.

From the graph here under:

Average diurnal $N_e = 3 \cdot 10^{11} \text{ m}^{-3}$, average thickness $2 \cdot 300 \text{ km}$, $\text{TEC} = 2 \cdot 3 \cdot 10^5 \cdot 3 \cdot 10^{11} = 1,8 \cdot 10^{18} \text{ m}^{-2}$
 Average nocturnal $N_e = 3 \cdot 10^{10} \text{ m}^{-3}$, average thickness $2 \cdot 250 \text{ km}$, $\text{TEC} = 2 \cdot 2,5 \cdot 10^5 \cdot 3 \cdot 10^{10} = 1,8 \cdot 10^{17} \text{ m}^{-2}$



At 144 MHz there is always more than 1 turn of rotation

3.4 – Depolarization

A linearly polarized wave is the combination of two circularly polarized waves, one cw and the other ccw. These two waves do not propagate through the ionosphere, along the lines of the magnetic field, in the same manner; so, when they emerge from the electron plasma, their recombination is no more a linearly polarized wave, but slightly elliptical. This effect is very slight at 144 MHz, where the orthogonal component is 15 dB lower, but increases with increasing frequency.

3.5 - Refraction

The deviation of a wave that goes through the ionosphere is a function of electron density N_e and of frequency. There is a critical frequency

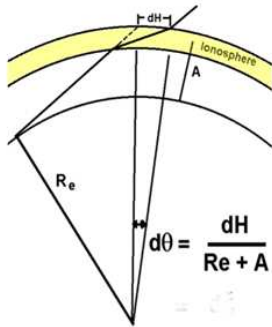
$$f_c \simeq 9\sqrt{N}$$

which divides the frequency field in two parts:

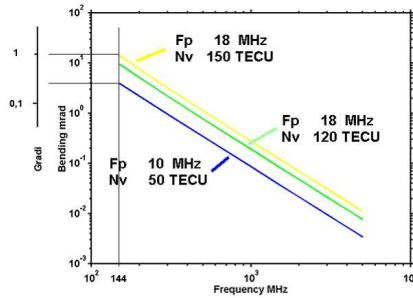
- for frequencies lower than f_c the wave is reflected, with whatever angle of incidence.
- For frequencies higher than f_c the reflection happens only under a certain angle of incidence (which is frequency dependent).

For frequencies higher than f_c there is never reflection, only deviation.

For evaluating deviation entity, we use some simplifications in considering the ionosphere as a curved shell formed by the F layer (the densest).



**Bending From
Horizontal Displacement**



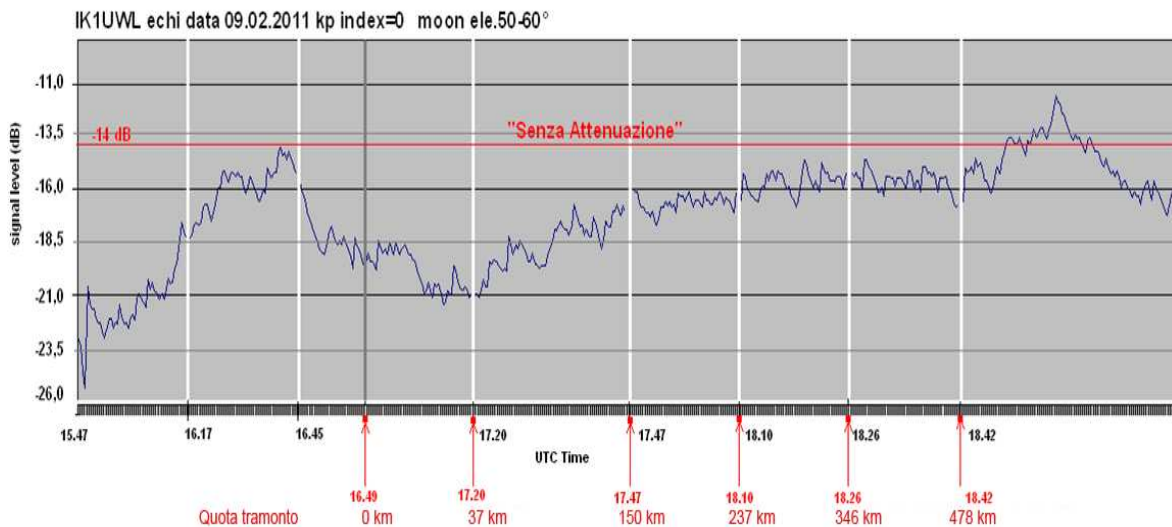
**Bending for Shell Ionosphere
Ground Elevation Angle 0 Degrees**

Depending on local time and solar cycle season, this density varies; let's consider three conditions corresponding to night and day at solar minimum, and day at solar maximum. At 144 MHz we find respectively 0°25, 0°6 and 1°, happily small values with respect to antenna lobe aperture. At higher frequencies it is surely negligible.

4 – ECHO TESTS

These echoes have been made by IK1UWL, transmitting with circular polarization and receiving in H pol. They are therefore exempt from the Faraday effect, so the scintillation present is caused by attenuation and diffraction.

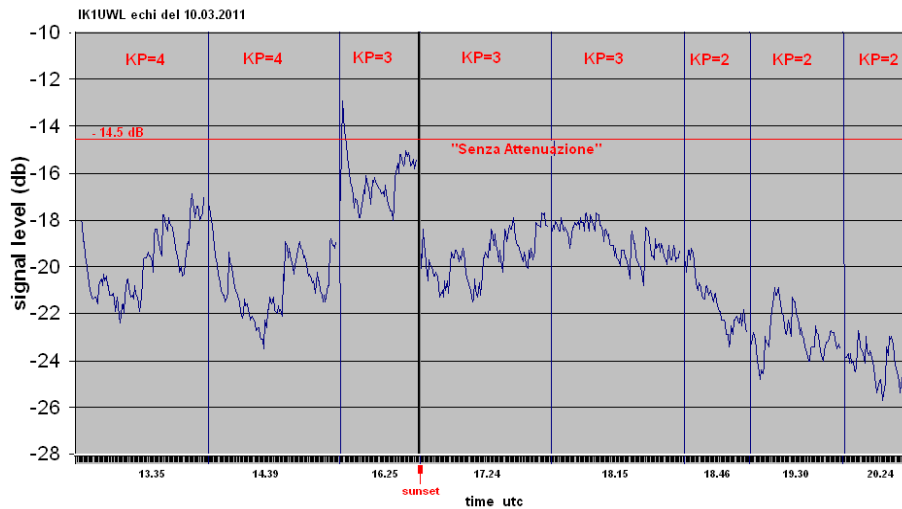
They are not averaged (WSJT, Echo mode, Avg=0). In ideal conditions, without ionospheric absorption and without cosmic noise (degradation), for that station the echoes should have a -10 dB level. On each graph there is a line corresponding to -10 + degr.



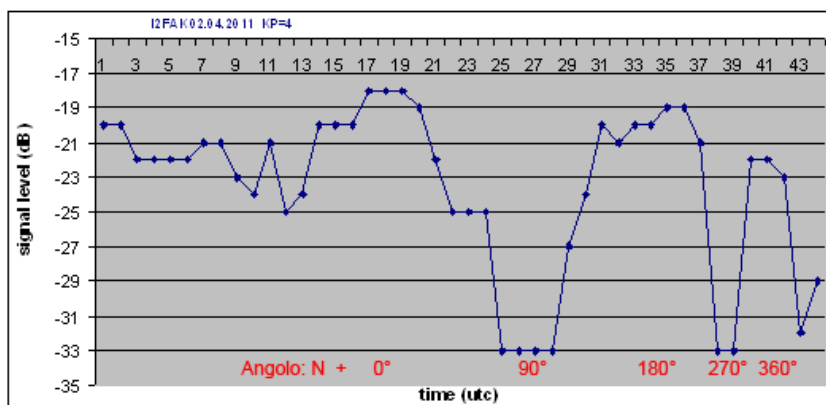
This is a test with quiet Sun ($Kp=0$), which is representative of normal ionospheric conditions.

Before sunset one can see the TEC attenuation caused by the winds that move the plasma westward.

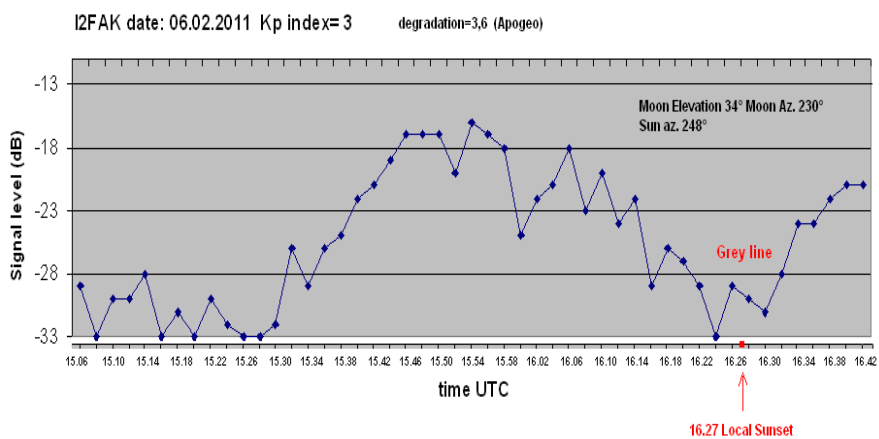
After sunset there is the displaced plasma cloud which attenuates again the signal, attenuation that gradually decreases during the night hours in which predominates recombination, making the plasma less dense. A scintillation of some dB is always present, and there is a case of focalization where the signal exceeds the ideal level.



This above is an echo test made with perturbed solar conditions due to a CME (Coronal Mass Ejection). The ionosphere has an anomalous behaviour, attenuation is much higher, only the peak before sunset is still there, sign of very strong winds. This peak is present in all the tests.

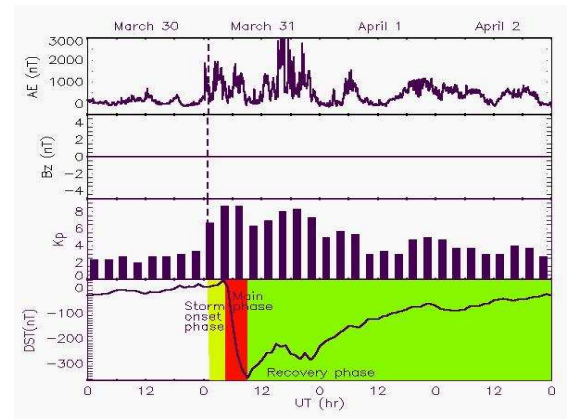
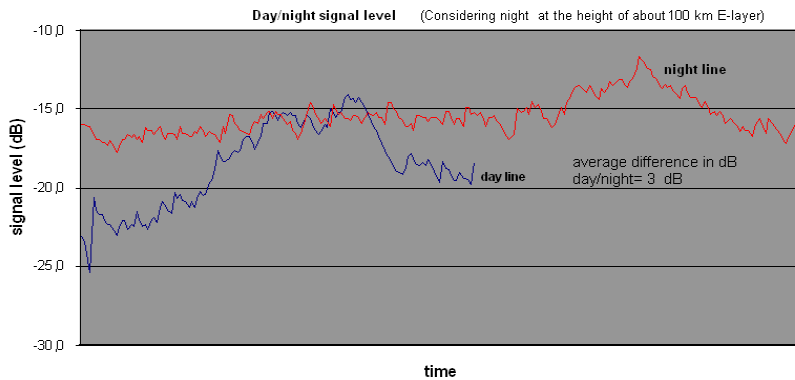


Here one can see rapid Faraday rotations with perturbed ionosphere, Kp=4. IK3XTV monitored for a long time the signal of I2FAK with his horizontal array. Every dot is spaced two minutes. In 10 minutes the signal disappeared (90° rotation), in the succeeding 10 minutes the signal returned to full value (180° rotation). The situation repeated with the same speed.



In the above monitoring test with Kp=3, scintillation is even more evident.

IK1UWL eme echo test 09.02.2011 IONOSPHERIC KP index= 0 (very quiet)

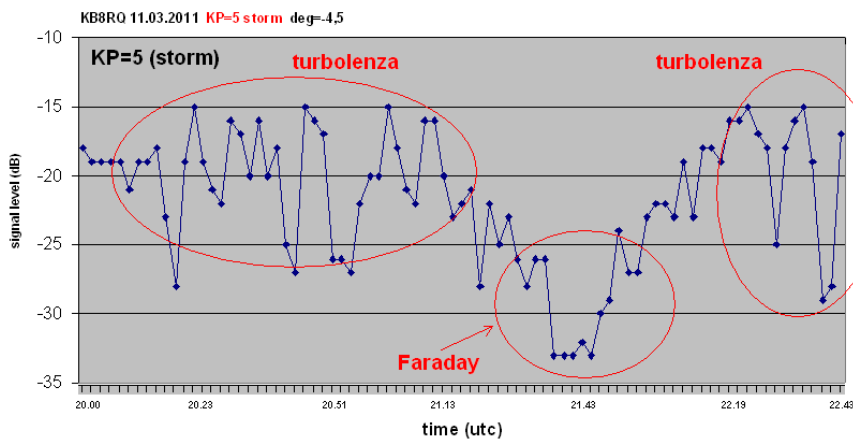


Above left diagram: with normal ionosphere we have seen from echo tests the different attenuation between day and night conditions.

Above right diagram: After an intense solar event, one can notice that ionosphere has an hysteresis in returning to normal conditions. The needed recovery phase time varies from some hours to days, depending on the event

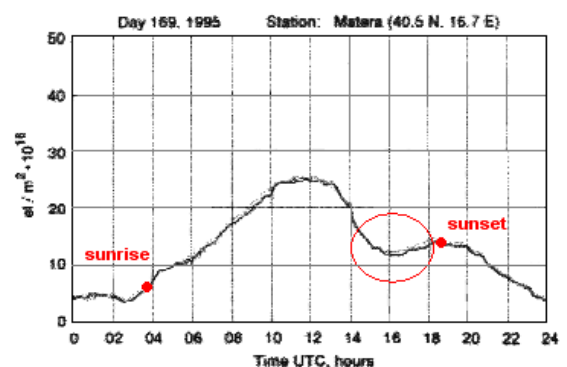
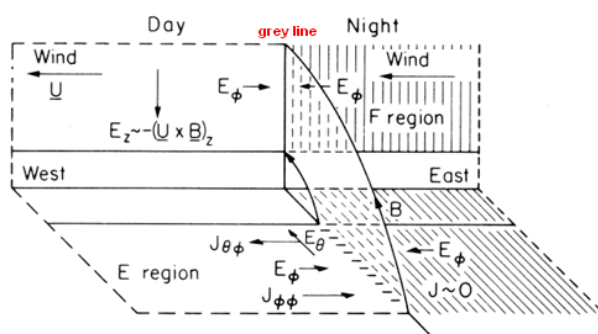
4.1 – Ionosphere perturbed by a CME

A strong solar flare (class X1.5), happened at 23.23 utc of 9th march 2011, caused an intense ionospheric perturbation with index Kp risen to level 5. The graph here under refers to a monitoring test made during the ionospheric perturbation, and shows signal variations up to 12 dB in few minutes caused by turbulence. This test was made with IK3XTV in night conditions and full day conditions in USA (KB8RQ).



4.2 – The peak before sunset

We found it always; our explanation: the strong ionospheric winds displace and clear temporarily the ionosphere creating a window in the total TEC, with the result of an attenuation decrease. In the diagram here under you can notice a subsidence of TEC before sunset, which correlates with the signal peak we have always found. The diagram was made at the ionosphere measuring station of Matera (Italy)



5 – Negative QSB ?

A QRPP qso with I2FAK

This qso:

EME with I2FAK was made by IK3XTV with 2 W output power.

Frequency :144.125 Mhz

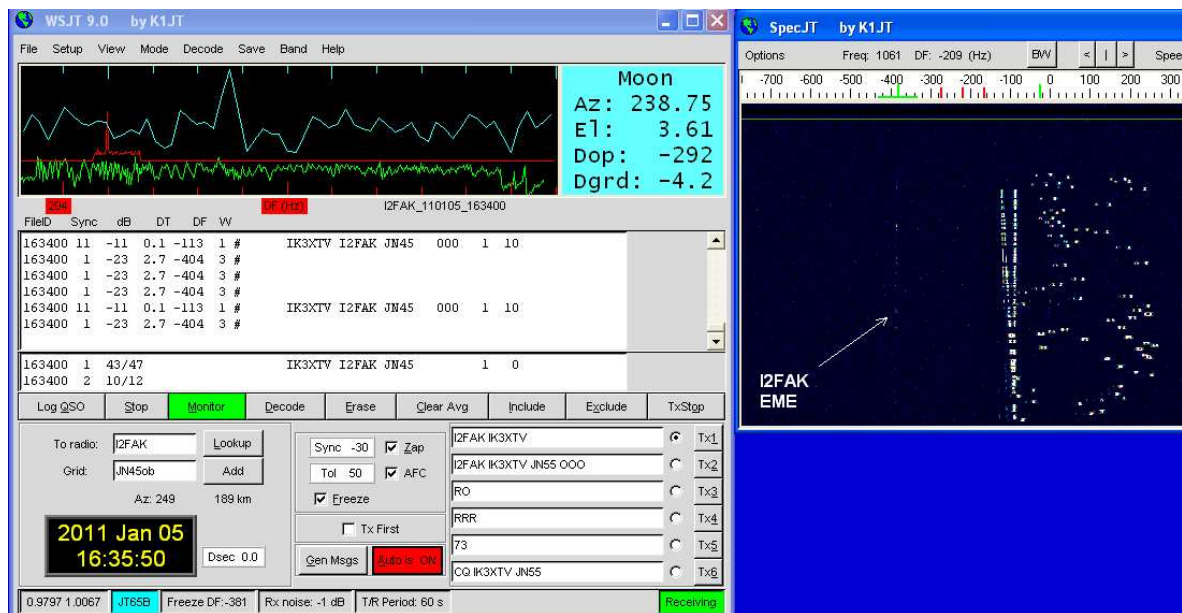
Date:05.01.2011 16.35 Utc

Kp index=0 (quiet)

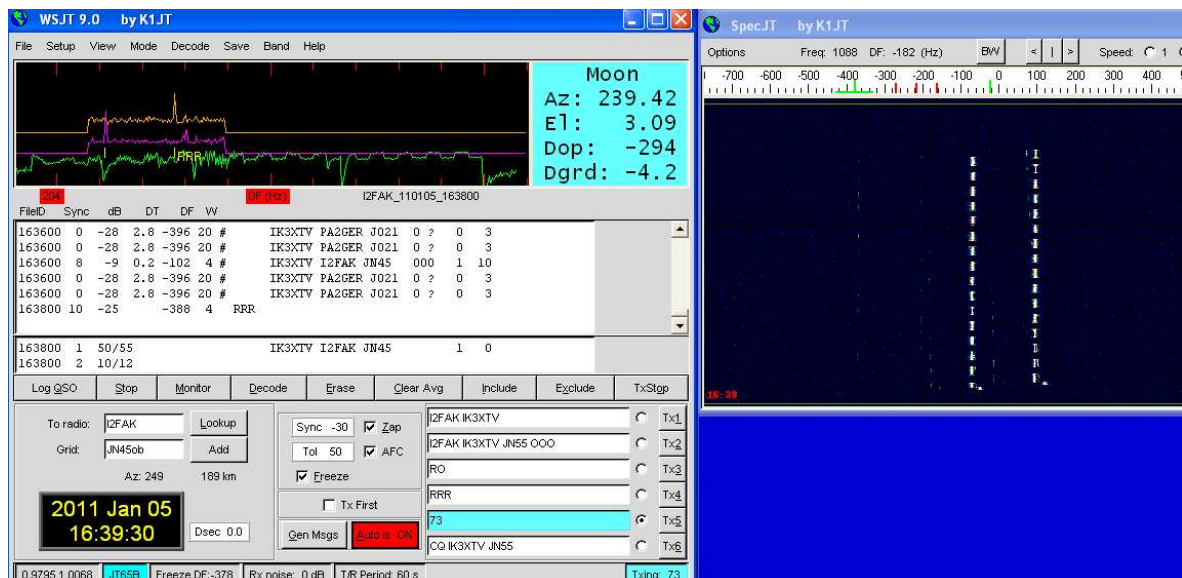
On the logger Flavio got this report from I2FAK : 163300 3 -28 2.5 105 0 * I2FAK IK3XTV 1 0

Flavio relates his qso:

I called I2FAK for a long time (10-15 minutes). I had removed from Tx1 my locator with the intention of simplifying the message (bad choice, in this way I could not be decoded by Deep Search). Surprise: at 16.34 I get OOO from I2FAK, but since I could not decode his EME trace (although -23) but only his tropo trace, I waited the next sequence hoping to get an EME decode.



Since the problem persisted, at 16.37 I sent my RO (with 2 watts) , which also was decoded by I2FAK who sent RRR at 16.38..



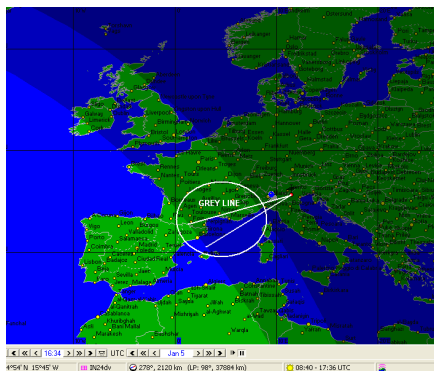
Assesments:

I had made several qsos with I2FAK using my normal power of 250 W. The best report I had got was -21 dB. In this case I had called him with 2 W, which is 21 dB lower. That day, with that azimuth and elevation I had Ground Gain (about 4 dB), So my signal normally would have arrived with level -21-21+4=-38 dB. Since he received me at -28 level, something increased my signal by 10 dB.

A possibile hypothesis:

A focalization effect on the Grey Line

Solar radiation pressure places the ionosphere in a non concentric position with Earth. This causes a continuous ionospheric change especially when the Sun sets on a meridian (terminator). In this phase the ionosphere is highly dynamic and its ionization changes drastically during the passage from day to night. The signal that goes through the ionosphere for hundreds of kilometres may go through denser lenticular formations that can cause focalization effects (the scientific literature mentions that focalization effects can reach 10 dB or even more). Note that my difficulty in decoding the EME signal of I2FAK (which was also abnormally lower than usual) may have been caused by the complementary defocusing effect of nearby zones.



INGV Istituto nazionale di Geofisica e Vulcanologia Italia

Darrel Emerson National Radio Astronomy Observatory Campus Building 65 949 N. Cherry Avenue Tucson, AZ 85721)
<http://science.nrao.edu/alma/index.shtml> (Fonte per assorbimento Ionosferico)

Wikipedia

National Institute of Information and Communications Technology (Giappone)

DLR Deutsches Zentrum für Luft und Raumfahrt

Stanford University, Electrical Engineering (Stanford California)

Institut für Geophysik und Meteorologie Universität Graz

Ionospheric Bending of Radio Signals: A Rough Shell model approximation by James R. Clynch

LESIA, CNRS-Observatoire de Paris France

ESA European Space Agency (prediction of ionospheric scintillation)

Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China

Dr. Keith Groves Monitoring Ionospheric Scintillation with GPS Space Weather Center of Excellence Air Force Research Laboratory Hanscom AFB,
MA Colloquium

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doc. n. 24.11 date: May 18th 2011
