The contribution of EME (Earth-Moon-Earth) in the ionospheric studies

During the dedicated studies on EME propagation, conducted in collaboration with my friend Giorgio Marchi, IK1UWL, we extensively explored the influence of the ionosphere on the transmission of signals (Trans-ionospheric propagation). EME signals intended for the moon undergo traversal through the Earth's ionosphere. Through an analysis of the ionosphere's impact on the phase and amplitude variations of the signal, we observed that the signal's amplitude exhibits an almost periodic fluctuation after the double crossing, as described below. Our investigations were carried out utilizing Joe Taylor's MAP 65 system software, which is specifically designed for EME communications using the JT65 protocol. This software operates in conjunction with an RF system that provides two consistent channels for horizontal and vertical orthogonal polarizations. Through a mathematical algorithm, the software automatically ensures the reception with the correct polarization by managing both polarizations simultaneously. At this stage, the change in signal amplitude remains unaffected by the Faraday effect. This is what our findings reveal:

- We always see a fluctuation of S/N signal levels in decoding.
- We notice a long-term fluctuation with associated shorter fluctuations.
- We believe that fluctuations are caused by focusing/defocusing effects caused by ionosphere ripple.
- Given the magnitude (3-5 dB) there they cannot be attenuations related to the thickening of the ionospheric, caused by the undulations.

Winds and ionospheric waves
Typically, in the ionosphere there are winds of 100-500 m/s, forming waves and vortexes (TIDs).
In the typical wind of 200 m/s = 12 km/min. they correspond to waves of length 1000-1500 km on which smaller waves of length of about 100 km overlap.

The undulation of the layers of E sporadic
The plasma forming the layers of sporadic E is also not uniform but has undulations modulated by the action of ionospheric winds and atmospheric gravity waves (see Note 1). The layers are never flat but can have wavy structures and in some cases even domes.

Fig. Domed shaped clouds by atmospheric winds and gravitational waves. (Photo IK3XTV).

Note:
1- Atmospheric gravity waves (AGW)
Atmospheric gravity waves are elastic oscillations that propagate into the atmosphere because of its thermal stratification. The wavelength ranges from a few hundred meters to hundreds of kilometers, with periods ranging from a few minutes to a few hours. The resulting air oscillations cause small fluctuations in atmospheric variables (pressure, temperature, humidity...) but they have a significant impact on the structure of the Ionosphere. In recent years, scientific research on the Ionosphere and radio propagation has given great prominence to the role of gravitational waves in that they play a decisive

role in the structure of the Ionosphere and therefore in the propagation of radio waves. AGW, interact with the Formation of sporadic E - Tropospheric propagation - influence on F region - Ionospheric disorders - Ionospheric absorption in the D Region - Massing/displacement of ions inside the Ionosphere. The influence of AGW seems more marked in the formation of the night F2 layer, where they would help to provide a small but continuous source of new ionization, contributing to the maintenance of residual night ionization.

2. TID Multipath fading is caused by the presence of different signal paths and therefore signal arrival delays between the transmitter and the receiver. Waves coming from these different paths can interfere constructively or destructively depending on the phase difference at the receiving point. Due to the dynamic nature of the ionosphere, the phase difference between the different waves will vary over time and thus cause evanescence. When the ionosphere is disturbed, the numerous reflective points can produce time-varying evanescencies with periods ranging from a few seconds to tens of seconds, depending on the scale of irregularities. There is another factor that induces fading, due to the focusing effects due to the movement of large scale (LS) irregularities that produce slower fading, in order of tens of seconds. In fact, the movement of LS irregularities in the ionosphere causes a decrease in amplitude unlike the variability of phase interference and the location and shape of irregularities, the ionosphere acts as a mirror for HF waves. When radio waves are reflected from a concave surface of ISO density, the waves will undergo a focus gain; conversely, when the surface is convex, there is a loss by blur effect. The table below shows the scale of irregularities with the phenomena associated with them.

Ionospheric waves

- Winds cause undulations and waves (TIDs), so free electron density varies in space and time.

The Travelling Ionospheric Disturbances (TIDs)

Class	Horizontal wavelenght	Periods	Horizontal phase velocities
LSTIDs Large scale	>1000 Km	0,5..3 h	300..1000 m/s
MSTIDs Medium scale	100..1000 Km	12 min...1h	100..300 m/s
SSTIDs Small Scale	<100 Km	A few minutes	<200 m/s

Ionospheric undulation in trans ionospheric propagation
Signals that must cross the ionosphere twice, such as those signals transmitted to the Moon and Reflected, as in the case of the EME, could be focused/de focused, as they cross the Ionosphere. (Interaction could take place in two ways). On earth there are areas of fading because of focus/de focus effects. Ionospheric irregularities can be seen as a filter that introduces instability in EME signals and is like scintillation phenomenon, which occurs in trans ionospheric communications, as in the case of signals from satellites.

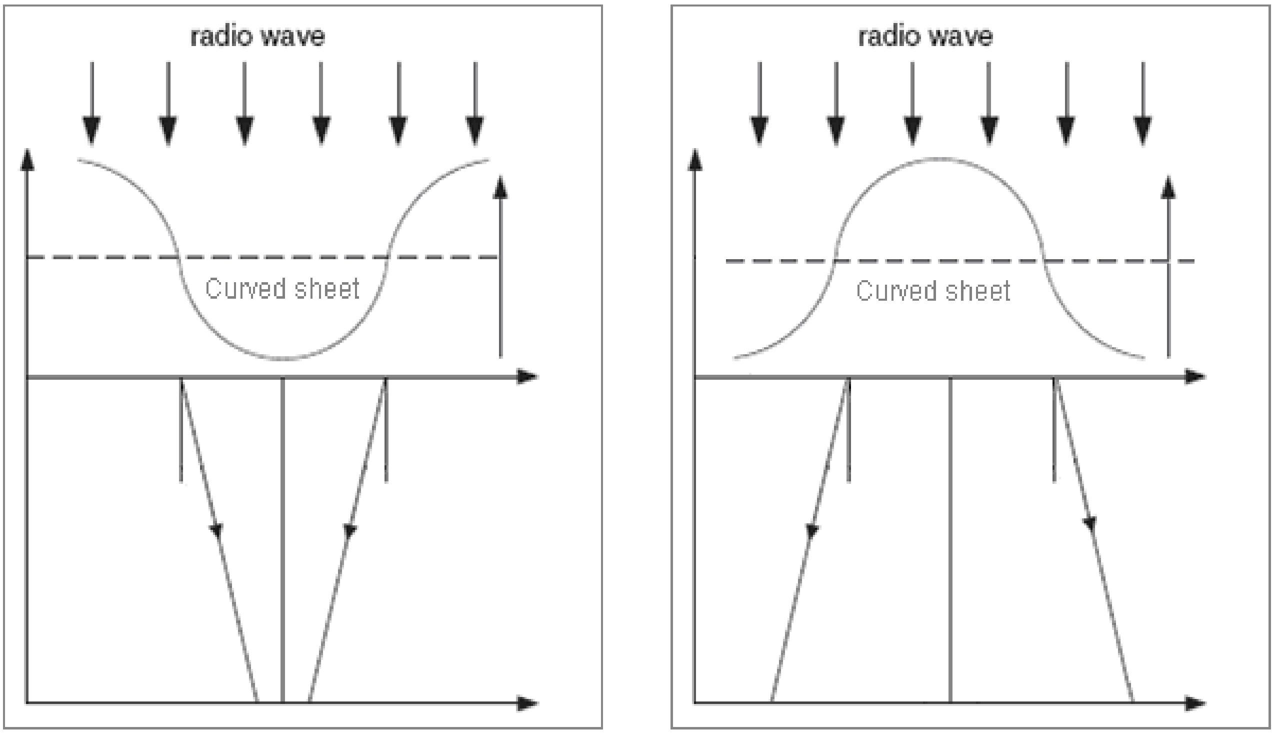


Fig. Model of penetration of radio waves through a sine-shaped ionospheric layer. A radius passing through a curved structure, changes the trajectory of its path. We have a phenomenon of focus or de focusing, depending on the shape of the irregularities (concave / convex).

Ionospheric fluctuation

The effect of TID on the ionosphere, we have seen it by looking at EME signals, which also help us to understand the behavior of the ionosphere for HF frequencies. After we did so many observations and recording on the instability of EME signals, we tried to correlate this Ripple that is always present on the EME signals with the turbulence of the ionosphere. Let us first define the type of Ripple. They are shown below, a couple of real cases with recording signals with seamless decoding every 2 minutes. On long reception periods. The charts show the reception of the signal emitted by a Russian EME station RX1AS, received by PA3FPQ in Netherland.

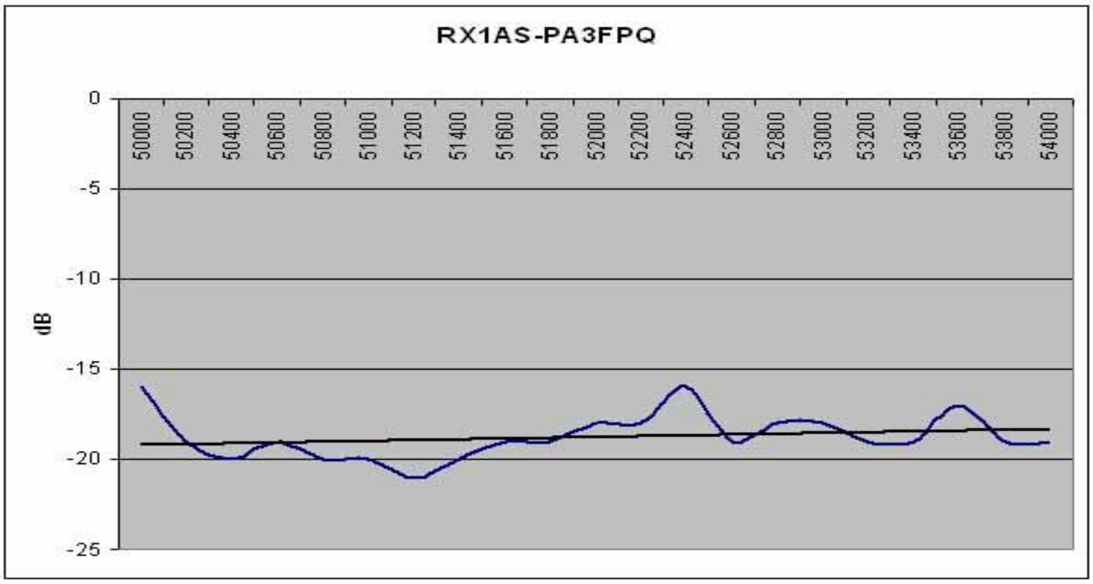


Fig. EME signal transmitted by RX1AS and received by PA3FPQ. The fluctuation was equal to 5dB, from -21 dB to -16 dB and you can see both periods of 4 minutes and period of 24 minutes.

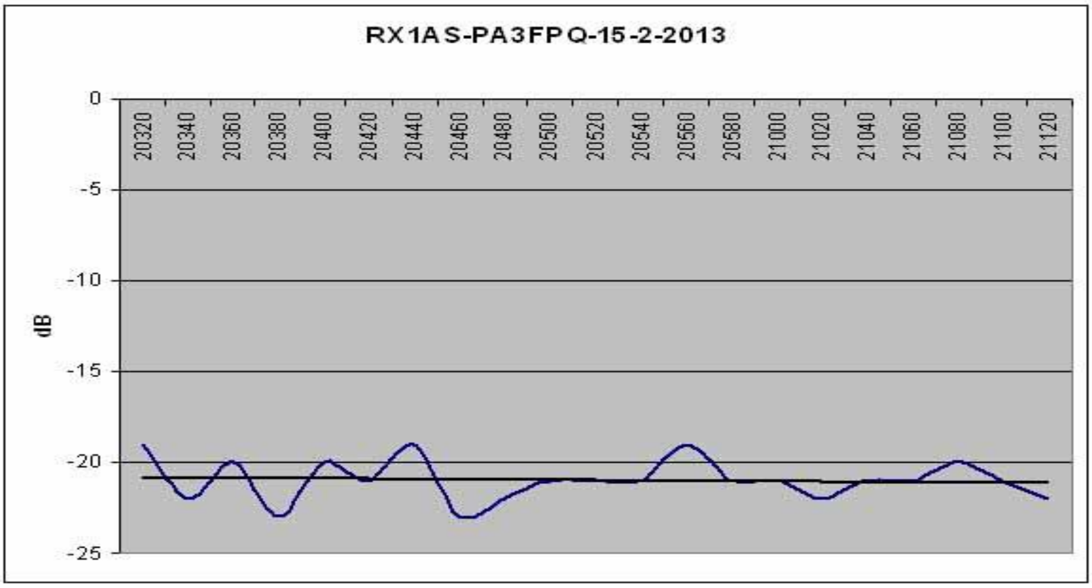


Fig. Another registration on another date. The fluctuation was from -19 to -23 dB and periods of both 4 minutes and 12 minutes are noted. As in rough seas, we see short waves superimposed on longer waves. We know that zonal ionospheric winds have speeds of the order of 50-100 m/s.

We know that in the ionosphere there are mobile disorders, called T IDs. Let us review them in a brief:
Polarization fading occurs due to the rotation of the wave polarization plane, a process known as the Faraday rotation. Two characteristic waves, the ordinary (O) and the extraordinary (X), cross the ionosphere with a slightly different path and phase velocity, since they are circularly polarized and in the opposite direction, the resulting wave arriving at the receiver will have a different polarization than that of the initial wave. The dynamic nature of the ionosphere causes the constantly evolving polarization of the wave arriving at the receiver, resulting in fading effects. Another fading mechanism is amplitude fading, which is caused by the movement of large-scale irregularities in the ionosphere. Depending on the location of the irregularities, the ionosphere will effectively become a concave or convex reflection layer for HF radio waves, which causes focusing or defocusing effects on the received signal. In these graphs, the two phenomena we are dealing, are perfectly described and summarized. Staying on the levels. In addition to zonal winds, we know that TIDs have wavelengths from 100 to 1000 Km and speeds of 1000 m/s. We can deduce that in general a wind of 100 m/s produces waves of wavelength of 1000 Km in the ionosphere. (100 m / sec = 6 km / min. = 24 km / 4min = 72 km / 12min = 144 km / 24min) The periods of 4 ', 12' and 24 'observed in the two graphs seem to be related to the passage of waves with length waveforms of 24, 72, 144 km, superimposed on each other. They are the same values that are given for the TIDs and represent a situation of wave motion like what we see on the sea, scaled by the different density.

Another mechanism of variation in signal amplitude is caused by the movement of large-scale irregularities.
Inside the Ionosphere there are some disturbances, they are called (TID Traveling ionospheric disturbance). Depending on the location of the irregularities, which cause ripple in the ionosphere with the effect that the ionosphere will become concave or convex for the HF radio wave, this causes a focus or defocus on the received signal. These irregularities are constantly moving and cause changes in the intensity of the received signal. These effects are highlighted in the figure on the next page.

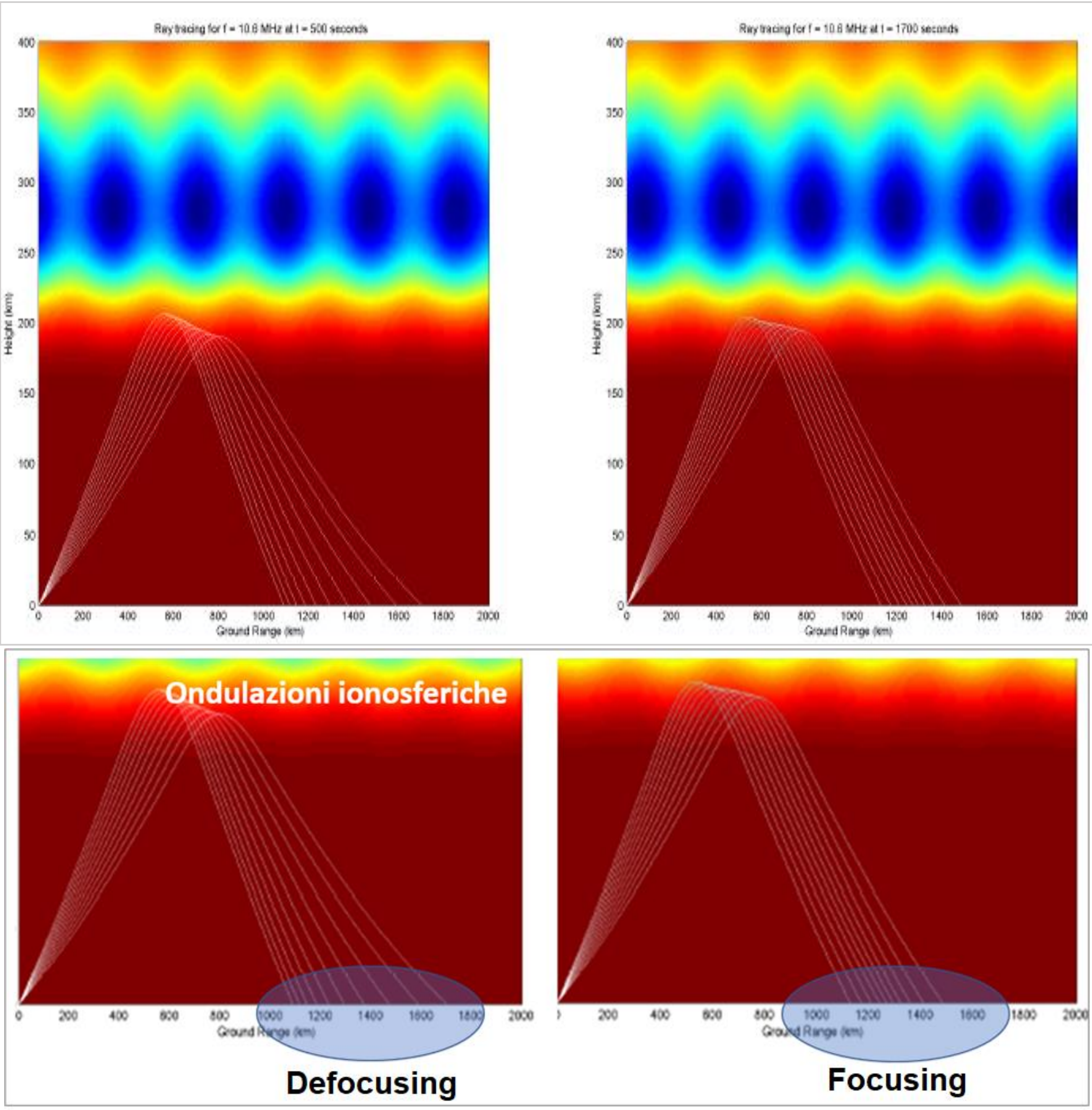
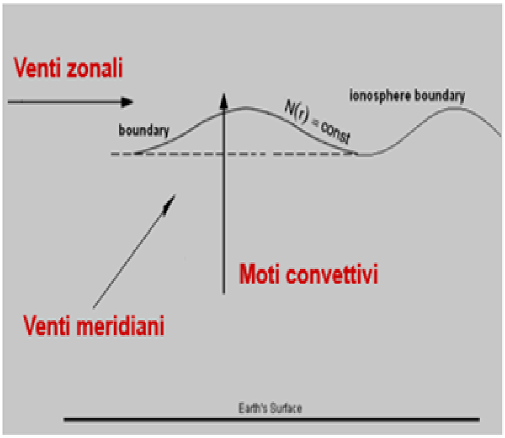


Fig. Representation of medium-scale itinerant ionospheric disorders (TID) and effects on radio waves An electromagnetic beam is directed towards a receiver situated 1220 km away from the transmitter. In the image on the left, you see a defocus effect, while in the image on the right you *see* a focus effect on the signal on *the ground. (Focusing and defocusing of radio waves due to movement of large-scale ionospheric structure).*
(Image credits and permission: School of Electrical and Electronic Engineering, The University of Adelaide, South Australia 5005, Australia).

Ionospheric model
Wave model: the ionospheric layers are not homogeneous; they are continuously shaped by strong ionospheric neutral winds that can have zonal movements (east-west direction) along the parallels and meridian movements (north-south direction along the meridians). In addition, there are vertical turbulences with convective motions and AGW (atmospheric gravitational waves) that constantly shape the layers. The ionosphere is therefore an "ocean" in continuous movement.

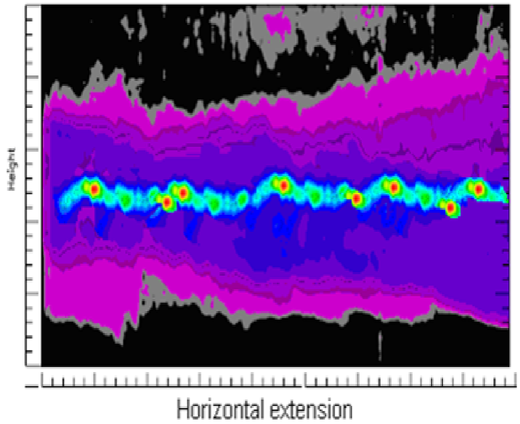
Ionospheric undulations

Ionospheric Layers



- Wave pattern: The ionospheric layers are not homogeneous, they are continuously shaped by the strong ionospheric neutral winds that can have zonal movements (east-west direction) and meridian movements (north-south direction along the meridians).

- Furthermore there are vertical turbulences with convective motions and AGW Atmospheric gravity waves, which constantly shape the layers.



We can have:

- Small-scale irregularities (some wavelength size)
- Large-scale irregularities (dimensions in the order of 100 Km)
- Irregularities tend to line up along the lines of the Earth's magnetic field

My take on DX: Never give up

These ripples in ionospheric communications can have both negative and positive effects. If you're having trouble establishing contact with a DX station, don't give up immediately. Keep trying, as the opportune moment can arise unexpectedly. The undulations create phenomena of defocusing and focusing, and eventually, your turn will come as well. Even with limited power and modest resources, focusing can assist you, even without a nuclear power plant. Arm yourself with patience, as it is said to be the key to paradise. Sometimes, time and patience can be more valuable than immense power.