Ionosphere Properties and Behaviors - Part 3

By Marcel H. De Canck, ON5AU

Some quite exotic radio signal propagation through the ionosphere can take on diverse forms. They are not as exceptional as you might think and can enhance or degrade the signal performance. **Chordal hopping** and **Inter-layer ducting** are two forms of these exotic propagations that will be discussed in this issue.

Propagation without lossy ground reflections

Multi-hop propagation with intermediate ground reflections has long been the traditional way to explain propagation of radio waves by ionospheric refractions. It was the general opinion that all propagation had to be by means of multihops from the Earth to the ionosphere and then back again. But in the last few decades enthusiastic DXers have made literally thousands of observations of propagation “anomalies” that yield much stronger signals than could be predicted in the traditional way.

These observations spurred propagation scientists to take a closer analytical look. Theoretical research enables us to calculate path losses due to ionospheric absorptions (deviative and non-deviative), free-space attenuation (path distance related) and earth reflection losses (ground or water). The theory of propagation with ground reflections and the knowledge of the attenuation involved at each ionospheric refraction is satisfactory to explain short- and medium-range communications (maximum 10 000 km). Depending on the frequency used and the ionization densities met especially in the D and E-layer, each hop can attenuate the signal strength approximately with 8 to 15 dB. A distance of 10 000 km needs at least a 3F2 mode, but often it might need a 4F2 mode or even a 5F2 mode. The traditional hop-by-hop losses will be high and result in weak signals strength; more than 5 hop modes will be extremely weak and often not decipherable at all. Ground reflection losses can also vary a lot depending on whether they happen via water (sea or ocean), ice or land areas, where land areas attenuate the most and even scatter the signals in mountainous environments. It is well known among DXers that medium distance communication circuits practically entirely over oceans are remarkably stronger than over land.

Those multi ground reflection and ionospheric refraction losses are no longer accepted by most experts as adequately explaining some of the high signal levels obtained over very long distances. There must be other mechanisms involved that compensate for the losses and attenuations that are mostly caused by the D- and E-layer. Some sorts of ***signal ducting*** could well be that mechanism.

Chordal Hop Propagation

A very specific way of signal ducting is called chordal-hop propagation. In this ducting mode, the waves are guided along the concave bottom of the ionospheric layer, acting as a single-walled-duct. Two kinds of chordal-hop modes can be distinguished.

The first one is more a daytime phenomenon and found where the F-region displays two tilted blobs of highly ionized plasma quite some distance apart. The first refraction within a chordal-hop is in fact partly a refraction that does not propagate fully downward, but propagates further along the rather concave ionosphere to meet another region that is ionized high enough to refract it downward to earth. **Fig. 53.1a** below shows an excellent example of how a radio signal can experience a chordal hop. This phenomenon is found practically daily at the equatorial regions known as TEP (Trans Equatorial Propagation). We shall explore TEP in a forthcoming issue.

The second kind of chordal-hop propagation is established by successive chordal-hops. During nighttime the F-region characteristics change rather profoundly. After sunset the F1-layer migrates slowly to a higher height and recombines with the F2-layer. The single existing F2-layer is also migrating to a higher height. The difference between daytime and nighttime height of the F-region can often be more than several hundred kilometers. This process forms a rather concave shaped F2-layer bottom side, which might again act as a single-walled-duct. See **Fig. 53.1b.**

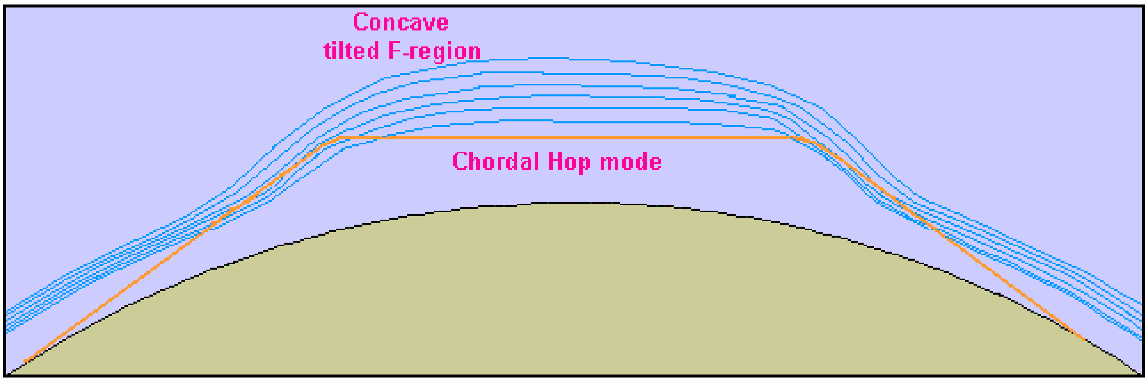

Fig. 53.1a. *A chordal hop propagation mode caused by two tilted highly ionized blobs forming a concave tilted F-region.*

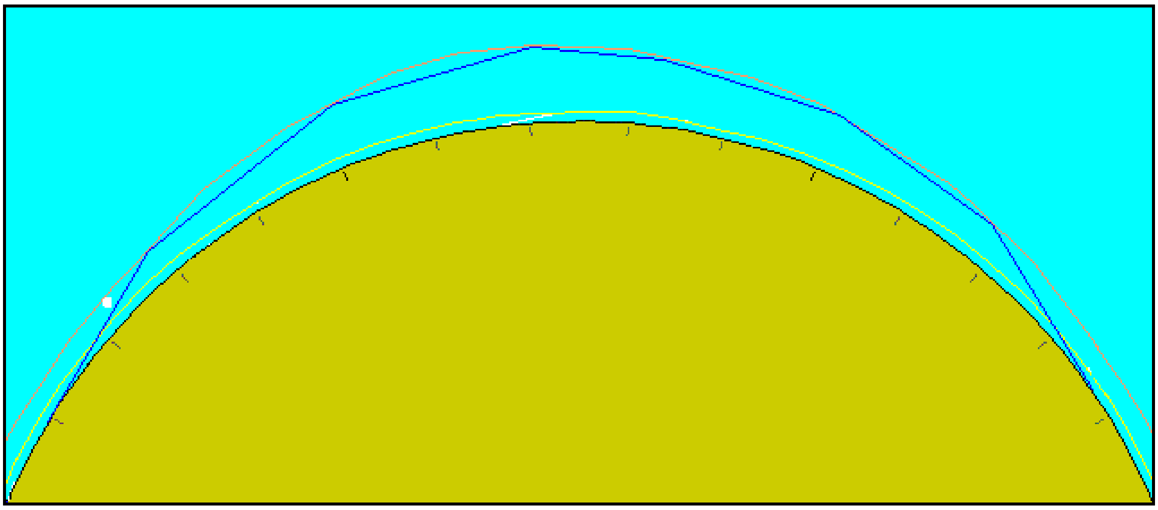

Fig. 53.1b. *Multiple chordal-hops by a concave tilted ionosphere found at the dark side of the globe*

Interlayer Ducting Propagation

Inter-layer ducting is very similar to chordal hop propagation except that the signal does not travel along the base of the ionosphere. Instead, it propagates within the lower E-region and higher F-region. Remember that the ionosphere consists of a depletion of electron density between those two regions. This area of depleted electron density is known as the E-valley region. The E-valley is stronger and capable of ducting radio waves when the area is under sunlight and more strongly ionized. Ducting during nighttime is also possible, but because the E-valley electron density is much weaker, lower frequencies must be used, **Fig. 53.2.**

When the angle of incidence is shallow enough, radio waves might travel within this E-valley, bordered by the top side of the E-layer and the bottom side of the F-layer and ducting may occur. When the angle of incidence is too high then the signal wave will simply pass through the E-layer when returning back toward the earth. When the angle is shallow, the signal will be alternately refracted from the top side of the E-layer to the base of the F-layer and back to the E-layer. This process may repeat numerous additional times until it encounters conditions that would cause the end of the ducting. The signal may encounter an area of irregularity of non-horizontally stratified electron density in the E valley region. This may cause the signal to change direction and increase the angle of incidence with respect to the E- or F-region so that penetration through the layer occurs. Another conditions to end ducting might be that the critical E-layer frequency drops to a level that causes the signal to penetrate this E-layer and return to the earth, **Fig. 53.3.**

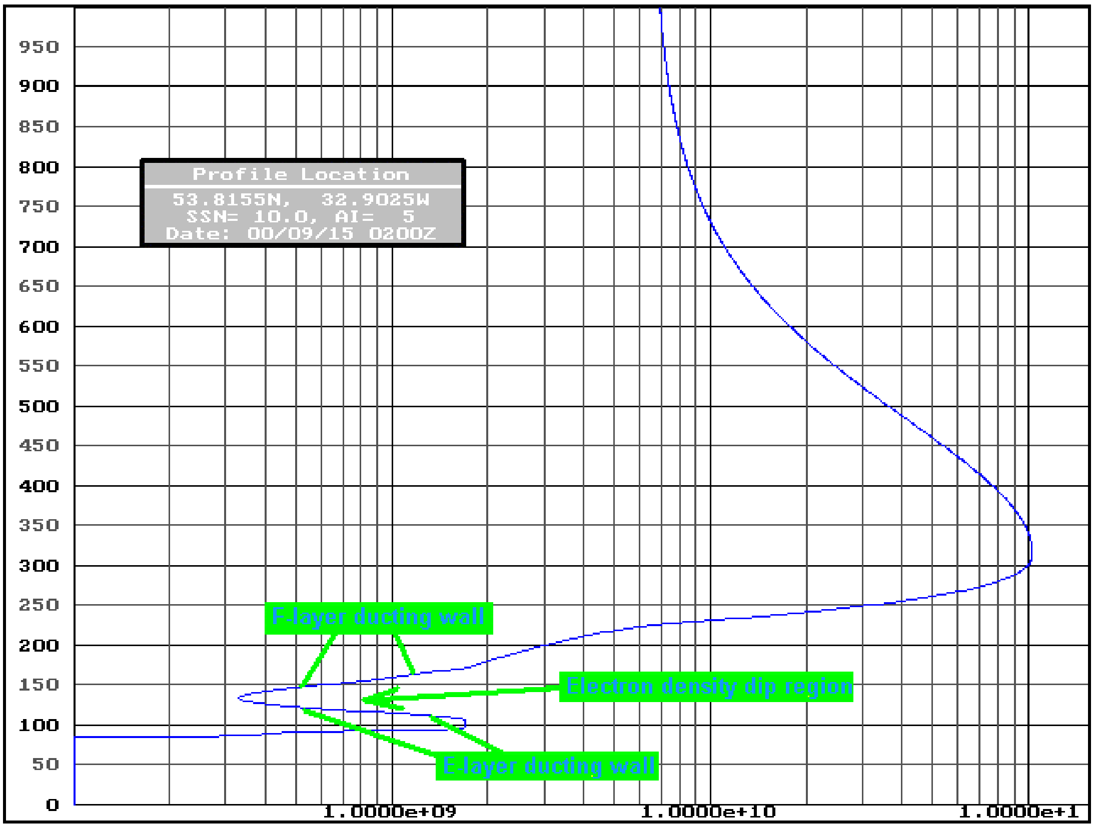

Fig.53.2. *A electron density profile. Notice the dip in the electron density between the E- and the F-layer. This dip is responsible for ducting-guide propagation, with the topside of the E-layer and the bottom-side of the F-layer serving as duct-walls.*

Irregularities such as those involved with or near sporadic-E clouds or other migrating ionospheric disturbances can induce the changes necessary to begin ducting. Non-horizontal gradients in the electron density can also contribute to ducting. Such gradients may be found near sunrise sunset terminators and near areas of anomalously high or low electron density.

The initial conditions needed to get radio wave signals to begin inter-layer ducting is that they encounter refraction conditions altering the trajectory to one that is more parallel with the ionospheric layers. This may be at any part of the propagation path: at the first entrance into the ionosphere or after a few normal earth-ionosphere-earth hops.

- Low transmitted take off angles, as close as possible to the horizon, can be an onset. That is, by the time the radio signal reaches the base of the ionosphere it will intersect it with a respectable large angle of incidence, due to the curvature of the earth and its ionosphere. By using a low angle radiating antenna, usually less then 12 degrees in elevation, the angle of incidence of the signal at the base of the ionosphere will be lower and it will be easier for an irregularity to refract the signal along a slightly different trajectory that commences inter-layer ducting.
- But signals with high angle of incidence entering the E-layer may start inter-layer ducting too. The signal wave can be escaping (penetrating) the E-layer toward the F-layer with a very obtuse angle. So, the angle of incidence when the wave encounters the F-layer is now low enough to start the inter-layer ducting, **Fig. 53.4a.**
- Another option to start inter-layer ducting is that the signal encounters a tilted area at the F-layer which refracts the signal to an angle sufficiently low enough, **Fig. 53.4b.**

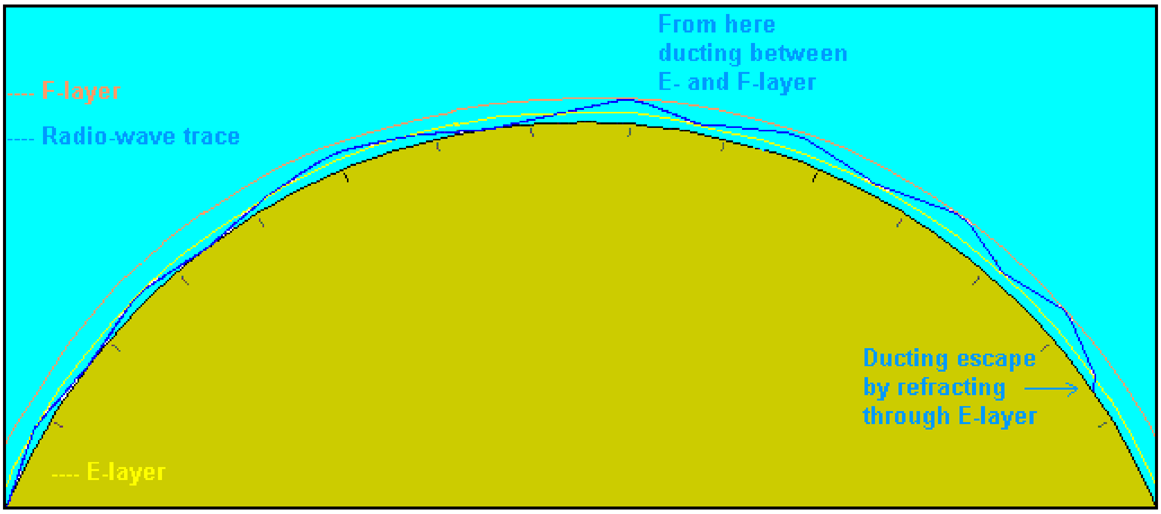

Fig. 53.3. Here the propagation starts inter-layer ducting after a few normal hop modes where conditions were met to obtain the necessary obtuse propagation angel.

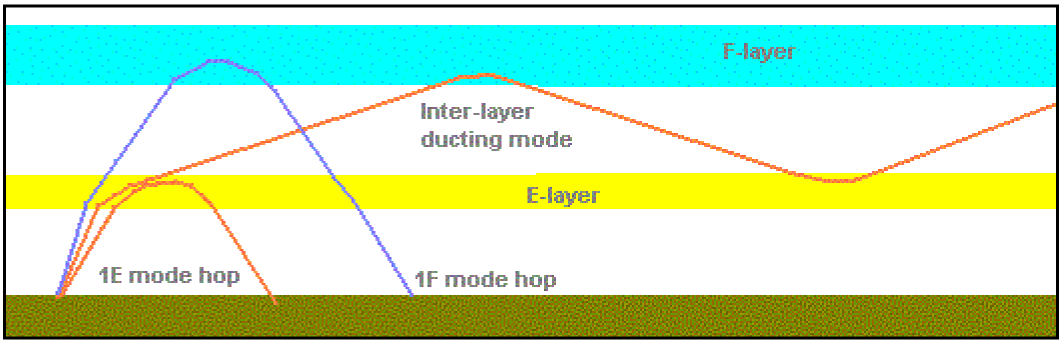

***Fig. 53.4a.** The E-layer can refract the signal path to an angle obtuse enough to start inter-layer ducting.*

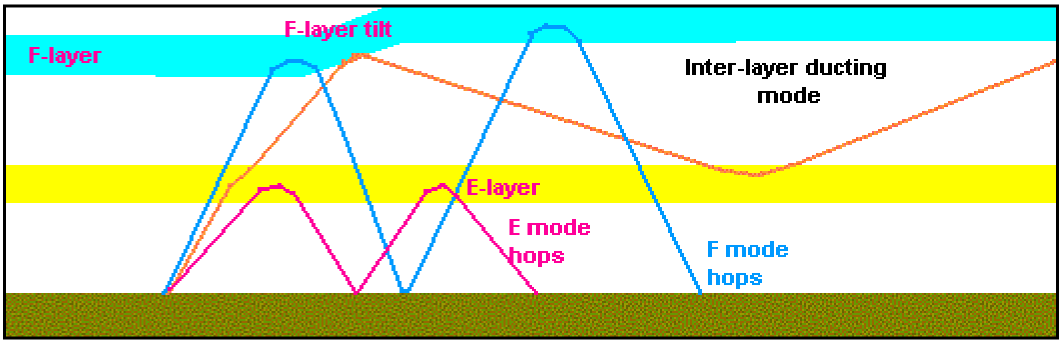

***Fig. 53.4b.** A tilt at the F-layer may also be the onset to inter-layer ducting, at bit similar as the onset to a chordal hop.*

More properties and characteristics

Inter-layer ducted radio signals are practically impossible to control. The mechanisms (ionospheric irregularities) that start the process of inter-layer ducting are difficult if not impossible to reliably predict. Also, slight changes in transmitted signal elevation or azimuth can have a large impact on how much radio signal energy enters the duct.

The true path a radio signal takes through the ionosphere during the ducting phase may also be completely unexpected and not in line with the great-circle path. When a signal begins ducting, then small changes in the horizontalness of the base of the F-layer or the top of the E-layer can have a strong bearing on the path signals take.

Chordal hop and particularly inter-layer ducted radio signals often take on a “whispering gallery” characteristic caused by the spreading and scattering of the radio signals energy in different but similar directions to the main trajectory of the signal. It is roughly analogous to what happens when you yell into a hollow pipe. The sound waves are scattered and reflected off rough surfaces and re-reflected in a way that cause the signal wave of sound energy to be converted into myriad of different wave-fronts that arrive at your ear at slightly delayed times.

Inter-layer signal ducting can strongly degrade the radio signal quality but the signal strength compared to travel distance is much higher and may be sufficient to permit complete around-the-world propagation. Many cases are known in which communications around the world via inter-layer ducting were done with a transmitter power less then 100 watts. So it is quite normal that you are able to communicate with a rather nearby station a few hundred km away, that normally should not be possible, because it is otherwise located in the skip zone of the short path normal hop mode.

Chordal and inter-layer ducted radio signals can appear suddenly and varnish just as quickly. Propagation via chordal hop or inter-layer ducting is heavily dependent upon the irregularities that cause the signals to be refracted more parallel to the ionospheric layers. These irregularities may move rapidly from one location to another. Once the irregularity leaves the area where your radio signal is penetrating the ionosphere, the conditions that permitted chordal hopping or inter-layer ducting may break down rapidly. Once the irregularity has passed, your signal would travel into the ionosphere via normal hop modes. A distant radio listener may detect this change as a sudden loss of signal.

Signal reciprocity of chordal hopped or inter-layer ducted radio signals is not always observed. In order for reciprocity to work, the transmitted signal from the listener would have to follow exactly the same path from the listener back toward the originator of the signal. Often this is not observed and the radio propagation becomes one-way only. You hear the station calling but he does not hear at all your reply.

Low frequency bands can be refracted more effectively at higher angles of incidence than signals at higher frequencies can be. From the launching point of such a duct path, refraction occurs when the signal travels through the E-layer, resulting in bending of the wave path into a lower angle (without complete refection). The wave is propagating further at the required angle to start ducting. For these low frequencies relatively high launched angles from the earth are required to punch through the D- and E-layer, so that the wave can finally be reflected up into the E-F region. This may be an explanation why higher wave-angle transmit antennas sometimes beat out very low angle antennas, especially at 160 and 80 meters.

To sustain a ducting path between E-layer and F-layer, the valley between these two regions must be present all along the path. Even modest increases in electron density in the ducting region will fill up the valley and halt the ducting mechanism. The required density levels in this valley are levels that will barely increase signal attenuation. It is also found that inter-layer ducting conditions are more frequent during low SSN activity. At higher SSN level periods, this valley is higher and may be ionized to an electron density that prevents the ducting process.

Both signal components, the ordinary and the extra ordinary wave, do not necessarily start chordal hopping or inter-layer ducting with the same angle of incidence. Nor may the ducting begin in the same ionospheric area. More often, they may follow quite very different and separated paths. To illustrate this I modeled some 3-dimensional wave tracings with PROPLAB PRO-2. See **Fig.53.5a** to **53.5g.** The tracing were done with TOA between 4 and 6 degrees and increasing steps of 0.1 degrees. Higher TOAs were also tested but did not display E-F ducting. The example 3-D wave tracings display how inter-layer ducting might be quite different for the ordinary and the extraordinary waves. Even with very small differences of the angle of incidence into the ionosphere the picture can be totally different.

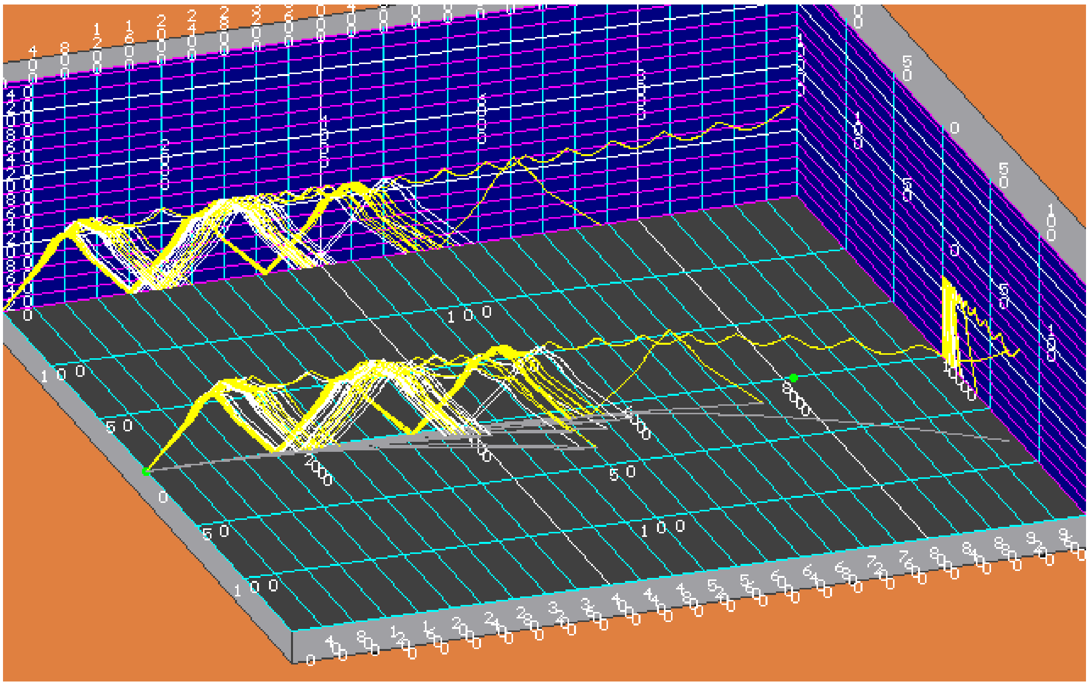

Fig. 53.5a. *The total trace picture of ordinary and extra ordinary waves with TOA from 4 to 6 degrees and increasing steps of 0.1 degrees*

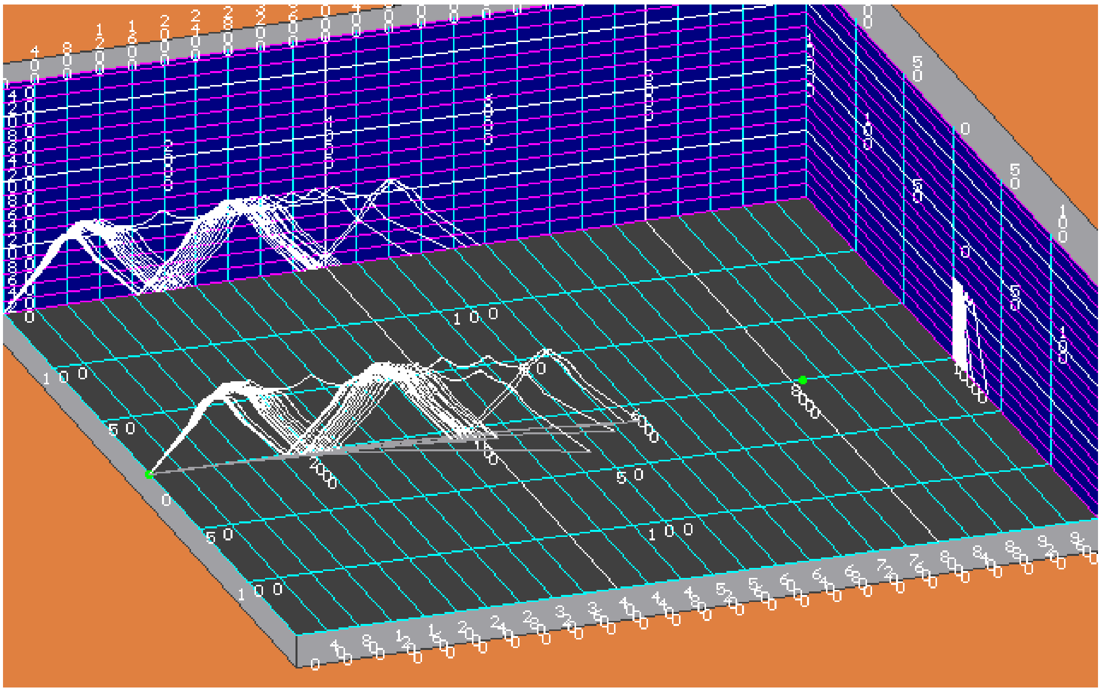

Fig. 53.5b. *The picture of ordinary waves only, with TOA from 4 to 6 degrees and increasing steps of 0.1 degrees.*

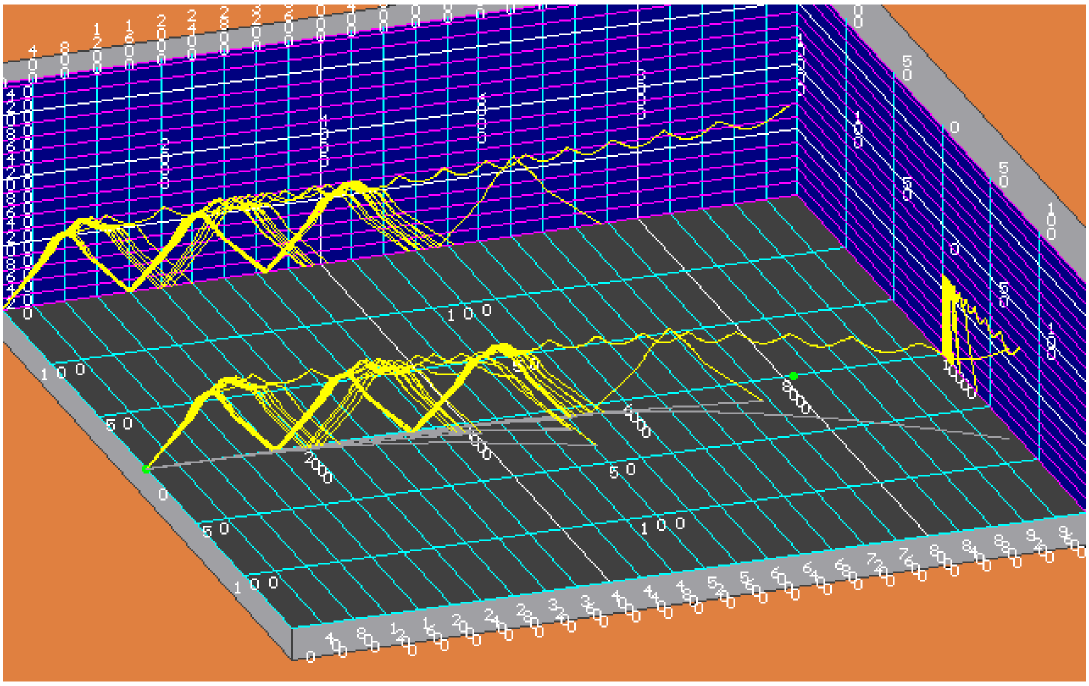

Fig. 53.5c. *The picture of the extra ordinary waves only, with TOA from 4 to 6 degrees and increasing steps of 0.1 degrees. With this circuit and time the extra ordinary waves seems to duct more than the ordinary waves seen* ***at Fig. 53.5b****. One TOA is even propagating beyond the 10 000 km distance.*

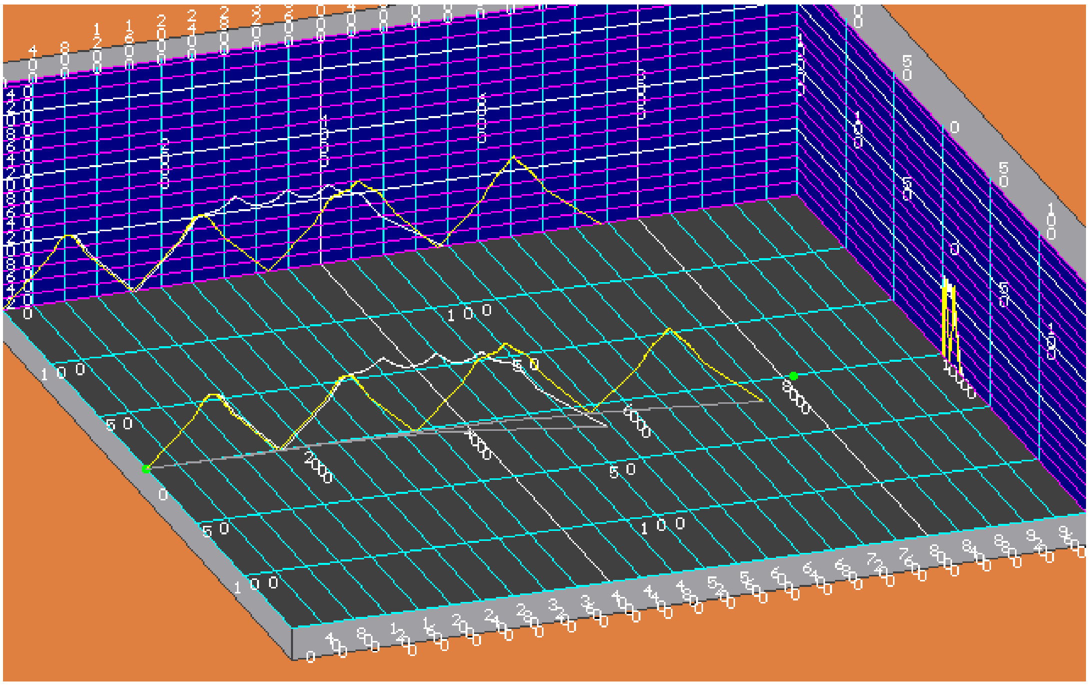

Fig. 53.5d. *Here at a given TOA angle of 4 degrees, only the ordinary wave experienced inter-layer ducting.*

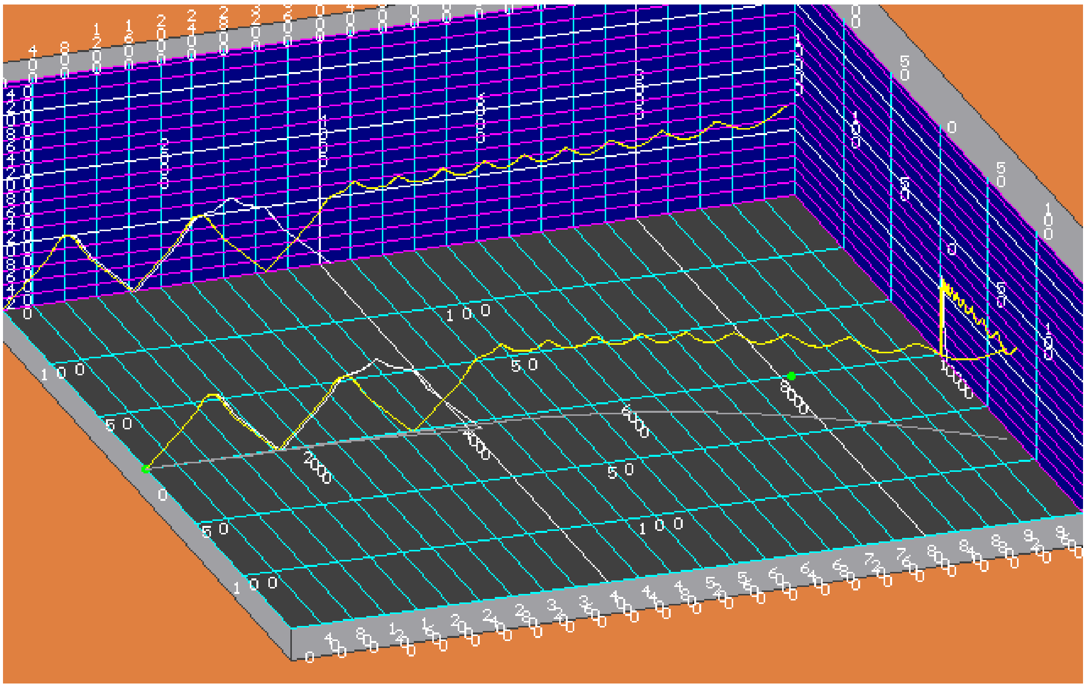

Fig. 53.5e. *Here at a given TOA 4.2 degrees, only the extra ordinary wave experienced inter-layer ducting and did not finish or escape the ducting at 10 000 km yet.*

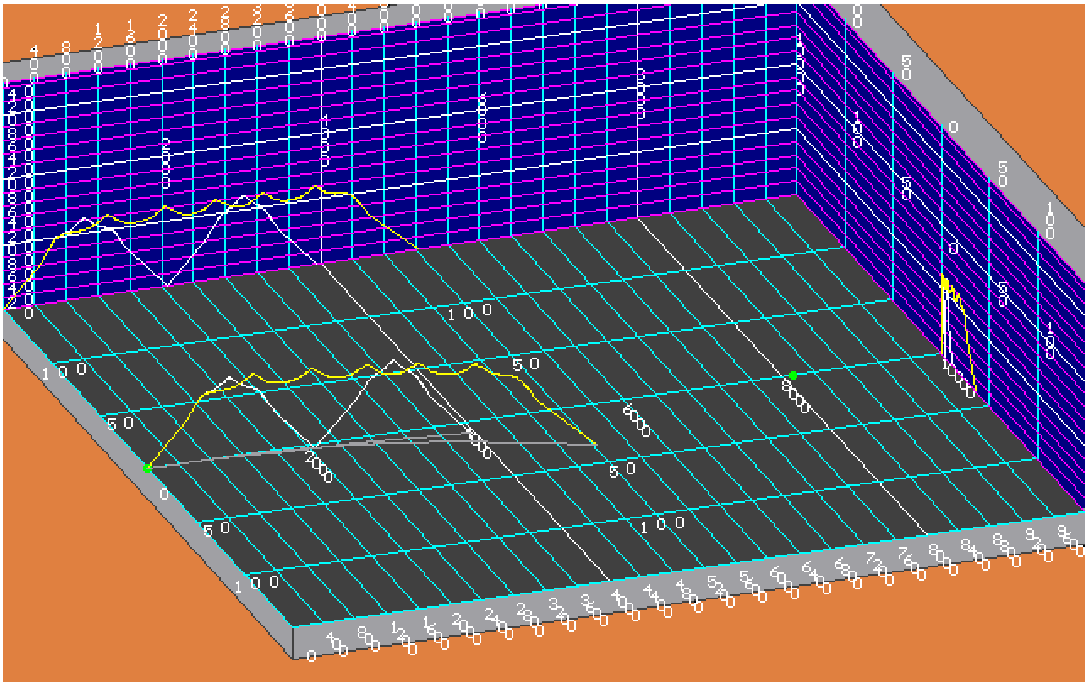

Fig. 53.5f. *Here at a given TOA of 4.9 degrees, only the extra ordinary wave did inter-layer ducting.*

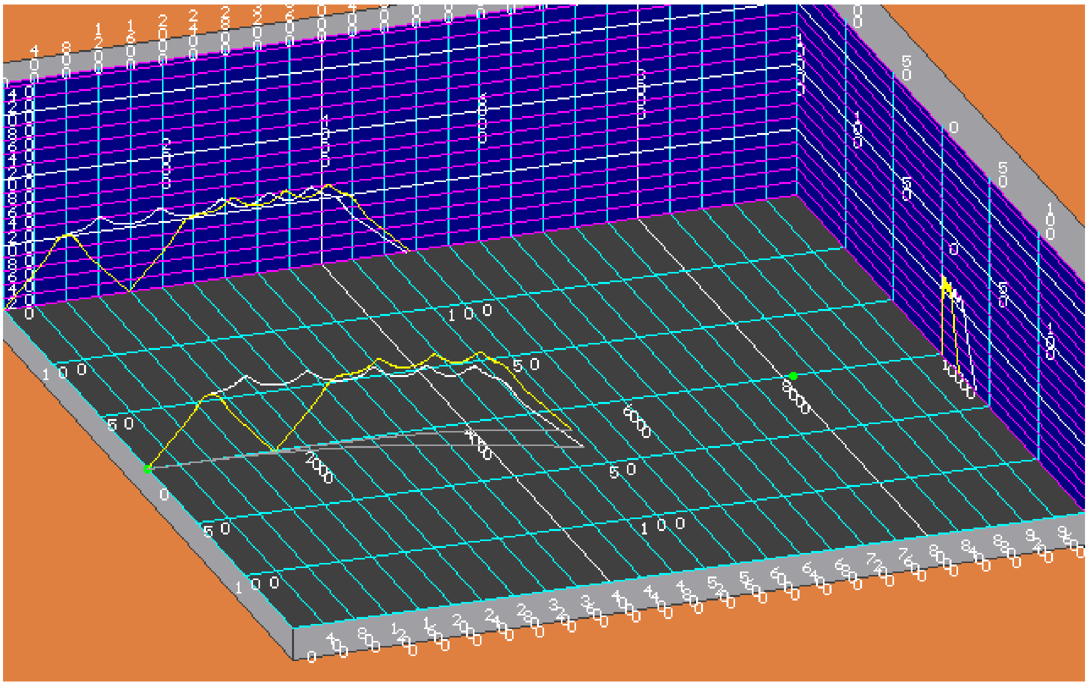

Fig. 53.5g. *Here at a given TOA of 5.4 degrees, both the ordinary and the extra ordinary wave did inter-layer ducting, but did not start at the same area.*

In the next issue, we shall examine some more specific ionospheric properties and behaviors, so stay tuned. **–30-**