# Ionosphere Properties and Behaviors - Part 2

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In the previous issue I explained that gyrofrequency depends on the earth's magnetic field and mentioned that this magnetic field also causes wave deviations and other important propagation path impacts. Not generally known is that the transmitted radio wave signal does split up into two independent components that travel mostly separated paths and also becomes elliptically polarized.

## Ordinary and Extra Ordinary waves

As soon as a transmitted radio signal begins to penetrate the ionosphere, it splits up into two characteristic components due to the earth's magnetic field. These two components are known as the **ordinary** and **extra ordinary** waves.

For the ordinary wave, the E-field accelerates electrons parallel to the magnetic field. This means that the field has no influence, because a magnetic field only imposes a force on charged particles moving perpendicular to the field,

For the extra ordinary wave the E-field of the incident radiation accelerates the free electrons normal to the magnetic field. This means that it exerts a force on the electrons and therefore modifies the motion. This causes the refractive index of the extraordinary wave to be different from the ordinary wave.

The different refractive indices of the two component waves, meaning different velocities, also cause a progressive phase shift between the two components. If the phase shift becomes 90 degrees, then the initial 100% linearly polarized wave has been turned into a 100 % circular polarized wave. For smaller differential phase shifts will the wave becomes elliptically polarized.

Each of these waves, the ordinary and the extra ordinary identified as the **o-wave** or the **x-wave**, travels a completely independent path through the ionosphere. The single radio signal travels as simultaneously transmitted but independent transmissions. Each separate propagating signal component contributes to a different mixture of power level, which totals together the power of the signal before it enters the ionosphere. The individual power level depends upon some complicated relationships between the o-wave and x-wave at the base of the ionosphere, but the x-wave is the weaker of the two.

At higher frequencies the ordinary and the extra ordinary waves often follow very similar paths. At lower frequencies the ordinary and extra ordinary waves will diverge more considerably, see later.

The existence of the ordinary waves, extra ordinary waves, and the gyrofrequency is also clearly noticeable and sounded in ionograms, **Fig. 20.1a 51.1b.** Both waves have different critical frequencies for the different respective ionospheric layers. For example, we find in the F2-layer: respectively **foF2** and **fxF2**. The difference between the two sounded values results in the gyrofrequency as $\mathbf{f_H = 2 * ( fx - fo )}$ or $\mathbf{½\, f_H = ( fx - fo )}$**.** The critical frequency of the extra ordinary wave is ½ $\mathbf{f_H}$ higher than the critical frequency of the ordinary wave. It is obvious that both waves also have their own MUF values as well. The extra ordinary wave MUF will always be higher. Nearly all propagation prediction programs take only the ordinary wave critical frequency into account to compute the MUF and other output parameters. One of the reasons why the experienced MUF might be higher than predicted with these programs can be found in the extra ordinary wave refraction properties.

**MUF = fc / sin (α)**

Where α = angle of incidence and **fc** the critical frequency, either **fo** or **fx** of the considered layer.

Electromagnetic waves propagate through a magneto-ionic medium in the so-called free-space mode as long as $\mathbf{n^2 > 0}$; where **n** is the refraction index. When **n** = 0 then reflection occurs (refracting downward). So we can use the Appleton equation for a vertically propagating signal including the earth's magnetic field and set the refractive index **n** to zero and solve for **X**.

The **Appleton-Hartree** equation describes the complex index of refraction of the ionosphere in terms of the free motion of electrons under the influence of thermal motion, geomagnetic fields, and ionic collisions. Its successful application to the behavior of radio reflection demonstrated that free electrons in the ionosphere's F-layer in fact cause reflection.

**Appleton-Hartree equation**

$$n^2 = 1 - \frac{2X(1-X)}{2(1-X) - Y^2 \pm [Y^4 + 4(1-X)^2 Y^2]^{1/2}}$$

$X = 1$ **the ordinary ( O ) wave**

$X = 1 - Y$ **the extra ordinary ( X ) wave**

$X = 1 + Y$ **the Z – wave**

Where:

$$X = \left( \frac{f_n}{f} \right) \qquad Y = \frac{f_H}{f} \qquad f_n = \sqrt{\frac{N e^2}{m\varepsilon_0}} \qquad f_H = \frac{e\beta_0}{2\pi m}$$

**N, e** and **m** are number density, charge and mass of the electrons, $\varepsilon_0$ is the free space permittivity, $\beta_0$ is the earth's magnetic field, $f_n$ is the plasma frequency and $f_H$ is the gyrofrequency. The **O** and **Z** modes have left hand and the **X** mode right hand polarization with respect to the magnetic field direction. Except at high latitudes the **Z** mode is rarely observed in ionograms. The two prevailing modes **O** and **X**, can be identified by the sense of rotation of the **E-field** vector.

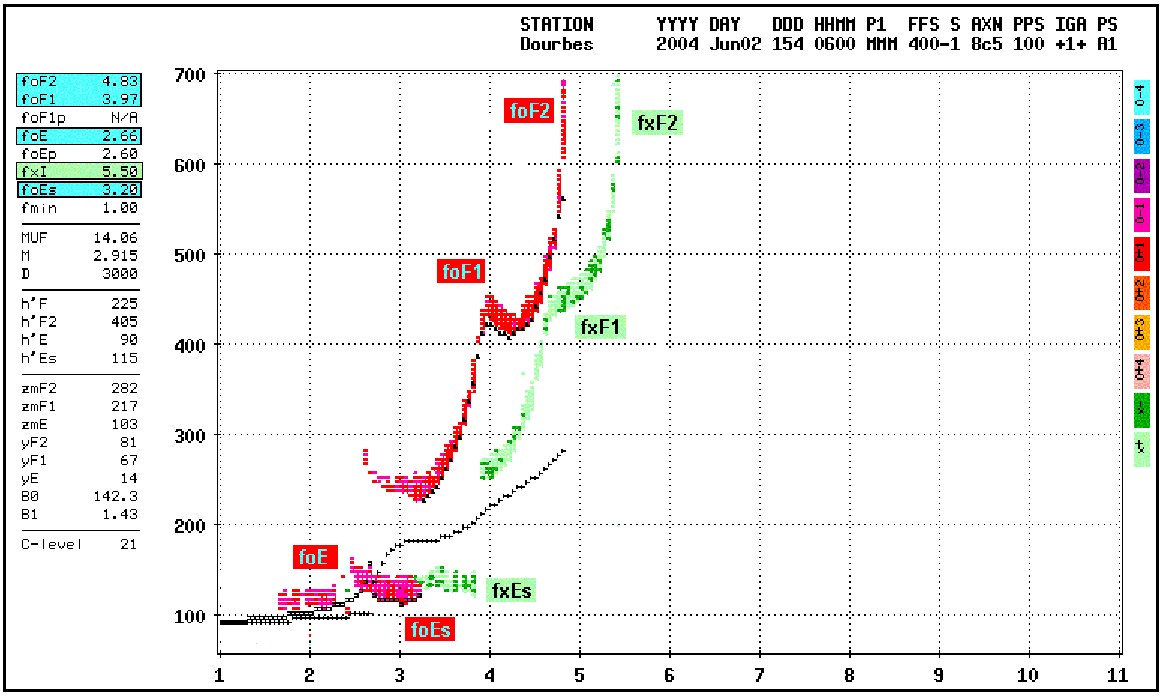


***Fig. 52.1a.*** *A typical summertime mid-latitude ionogram of the ionosonde Dourbes (Belgium). Here is clearly seen by sounding the ionosphere, the difference between the two signal wave components. Both have distinguishable critical frequencies. Not only for the F-region but also with the Es-layer if present.*

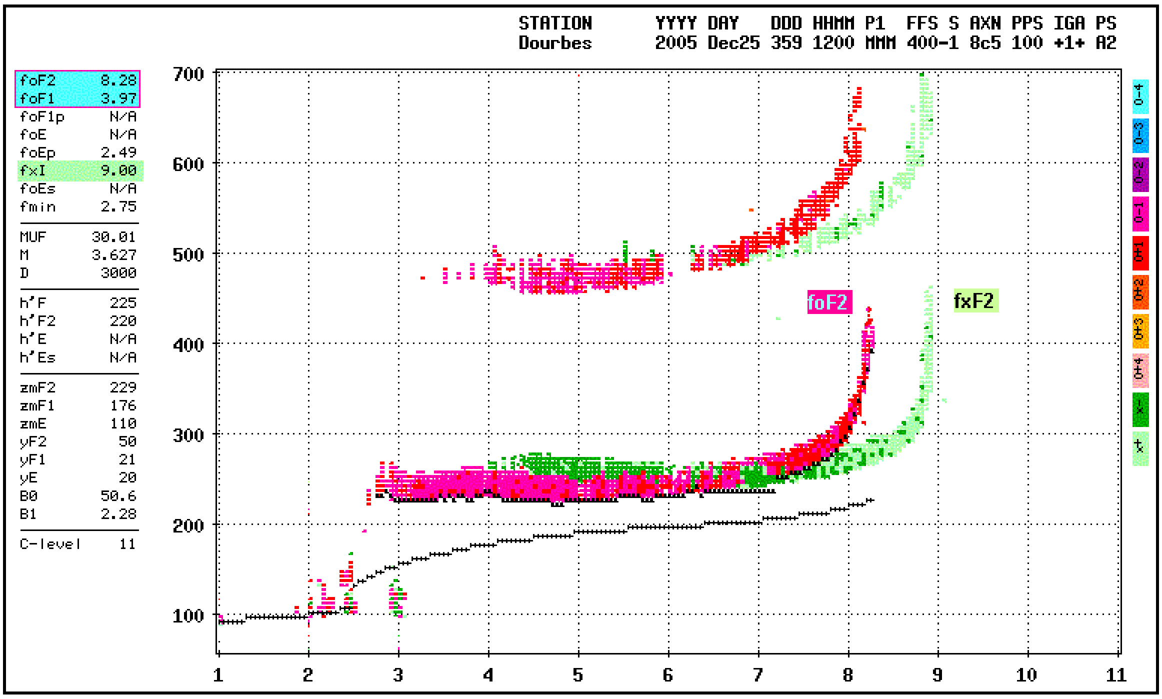


***Fig. 52.1b.*** *A typical wintertime ionogram from the same ionosonde.*

### Deviation from great circle path

The illustrations **Fig. 52.2a 52.2e** help also to display another important property of ordinary and extra ordinary waves. The influence of the earth's magnetic field causes them to split but also to divergence away from the great-circle path. The ordinary wave diverges toward the magnetic pole while the extra ordinary waves diverge toward the equator. This can be observed in the ground-track plots of these two signal components. **Note:** the divergence can also be cause **additionally** by ionospheric tilts

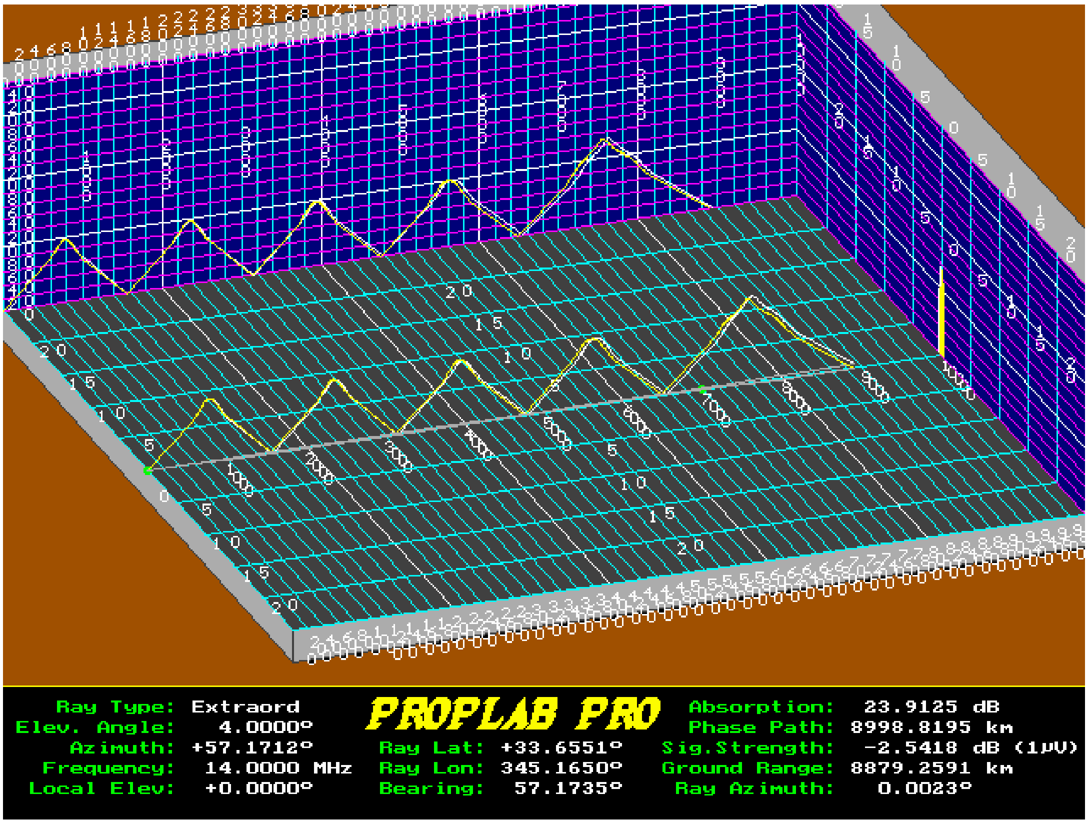
At frequencies lower than the peak plasma frequency (critical frequency) the ordinary wave deviates more pole-ward than the extra ordinary wave equator-ward defection does. The most deviation of the ordinary wave occurs also at or near the point of reflection.

### 3D Wave path projection

In many previous issues, I often used PROPLAB PRO 2 to illustrate wave propagations in a 2-dimensional ray tracing mode, explicitly using the ordinary waves. But this program has also a comprehensive or complex technique to trace additionally the extra ordinary waves while propagating. Using this comprehensive method traces more accurately and precisely how and where the ordinary and extra ordinary signals are traveling. Some different 3-dimensional setups and/or definings are available within the PROPLAB options, but for this issue's purpose I shall use only one takeoff angle to keep matters a bit orderly.

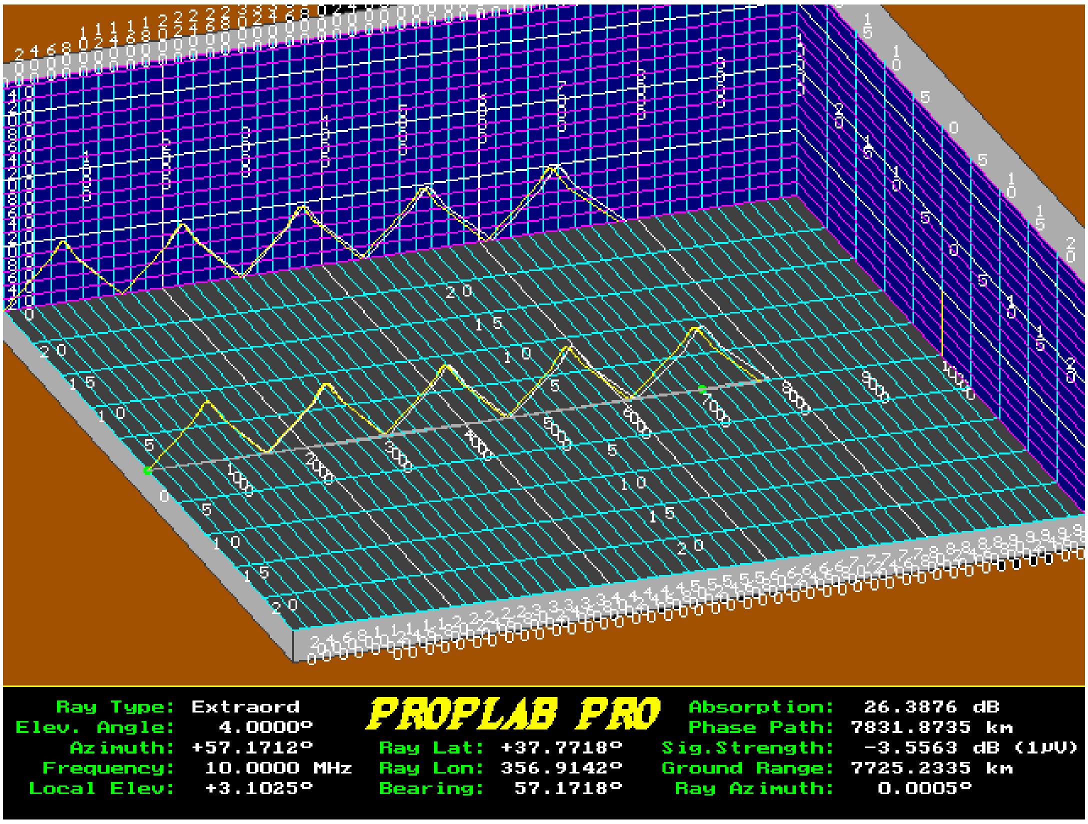
The 3-dimensional grid should be viewed as follows. Imagine a box with the left and front sides removed. The bottom is the earth's surface for a defined area, but interpreted as being flat. The left-most green dot is the tranceiver location and the green dot on the zero line some distance away from the TX is a defined receiver location, in the examples here about 7 000 km distant. The far side of the box forms the **"Altitude wall"**. This wall shows the altitude of the traced rays in the ionosphere. The right side of the box forms the **"Lateral deviation wall"** and shows you the extent to which the rays will be deviated laterally away from the great circle path. This great circle path is the zero kilometers lateral deviation line connecting the TX and RX locations. The traced wave-traveling lines, curving above and along the base of the grid indicates the true path the waves take through the ionosphere. It is obvious that the waves being deviated away from the great circle path by ionospheric tilt and the interactions with the earth magnetic field will be noticeably traced.

All distances on the 3-dimensional grid are labeled in kilometers. In the illustrations below the earth's surface area is 10 000 km long and 50 km wide and the altitude wall is 350 km high. The white trace lines are the ordinary wave paths and the yellow ones are the extra ordinary wave paths. The gray lines projected at the bottom grid indicate the respective deviated paths for both waves.



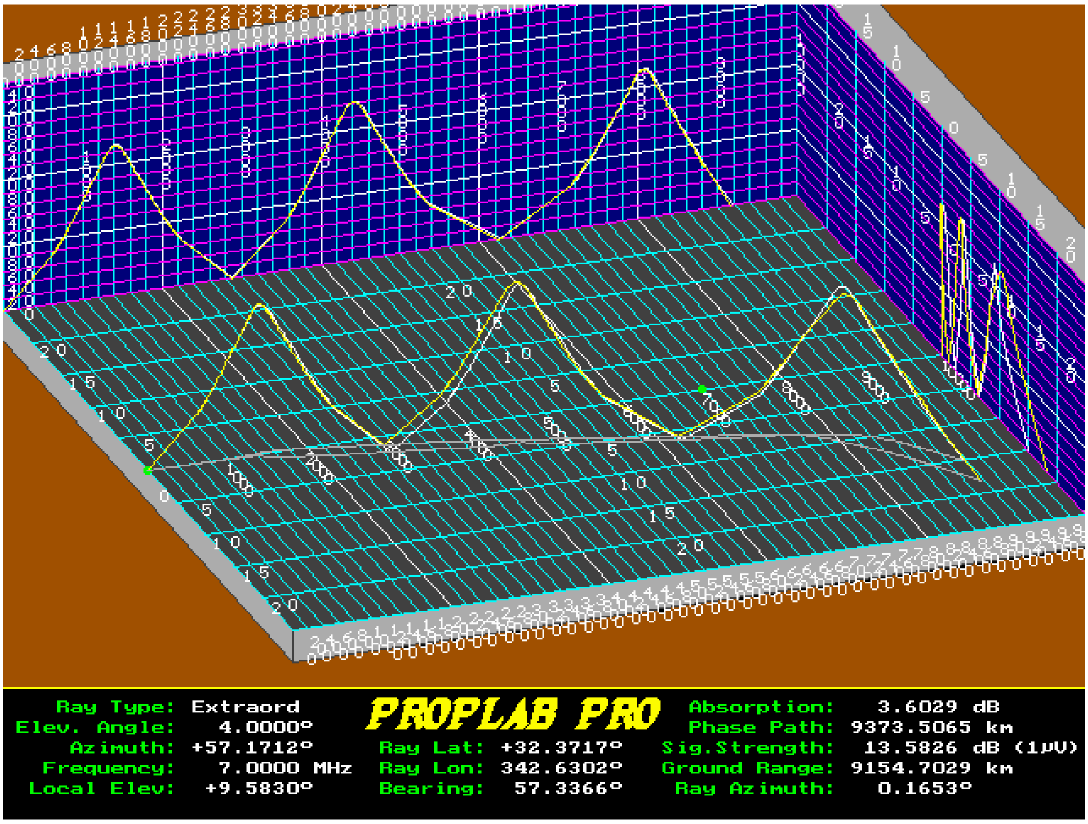
```
     Ray Type: Extraord                     Absorption:  23.9125 dB
  Elev. Angle:   4.0000°                   Phase Path: 8998.8195 km
      Azimuth: +57.1712°  Ray Lat: +33.6551°  Sig.Strength:  -2.5418 dB (1µV)
    Frequency:  14.0000 MHz Ray Lon: 345.1650°  Ground Range: 8879.2591 km
   Local Elev:  +0.0000°  Bearing:  57.1735°   Ray Azimuth:   0.0023°
```

***Fig. 52.2a.*** *An example at frequency 14 MHZ (20 meters band). A daytime circuit propagating from West to East. The refractions occur during 4 hops via the E-layer and the last one via the F1-layer. Both wave components travel rather equal paths and only deviate very little from the great circle path.*



```
   Ray Type:  Extraord                      Absorption:   26.3876 dB
Elev. Angle:    4.0000°                     Phase Path:  7831.8735 km
    Azimuth:  +57.1712°    Ray Lat: +37.7718°  Sig.Strength:  -3.5563 dB (1µV)
  Frequency:   10.0000 MHz Ray Lon: 356.9142°  Ground Range: 7725.2335 km
 Local Elev:   +3.1025°    Bearing:  57.1718°   Ray Azimuth:    0.0005°
```

***Fig. 52.2b.*** *An example at frequency 10 MHZ (30 meters band). A daytime circuit propagating from West to East. Here the refractions happen only at the E-region and only the two last hops displays the ordinary and extra ordinary waves minor different propagation paths.*



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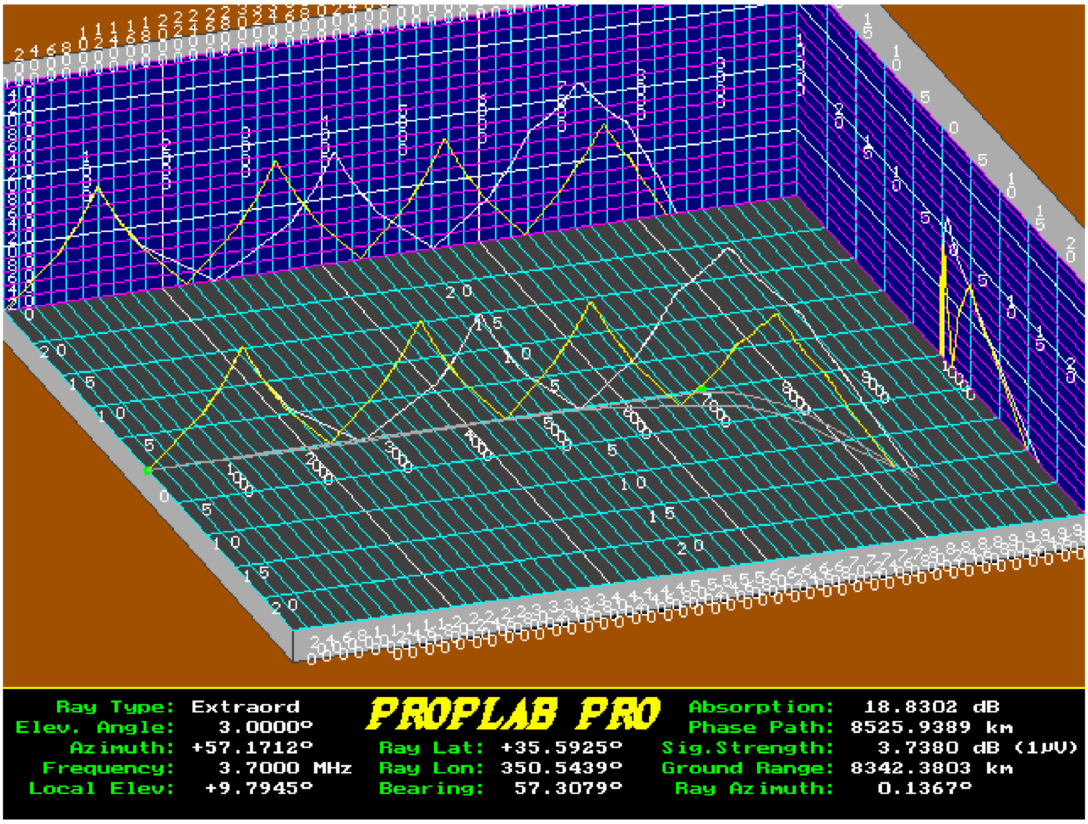
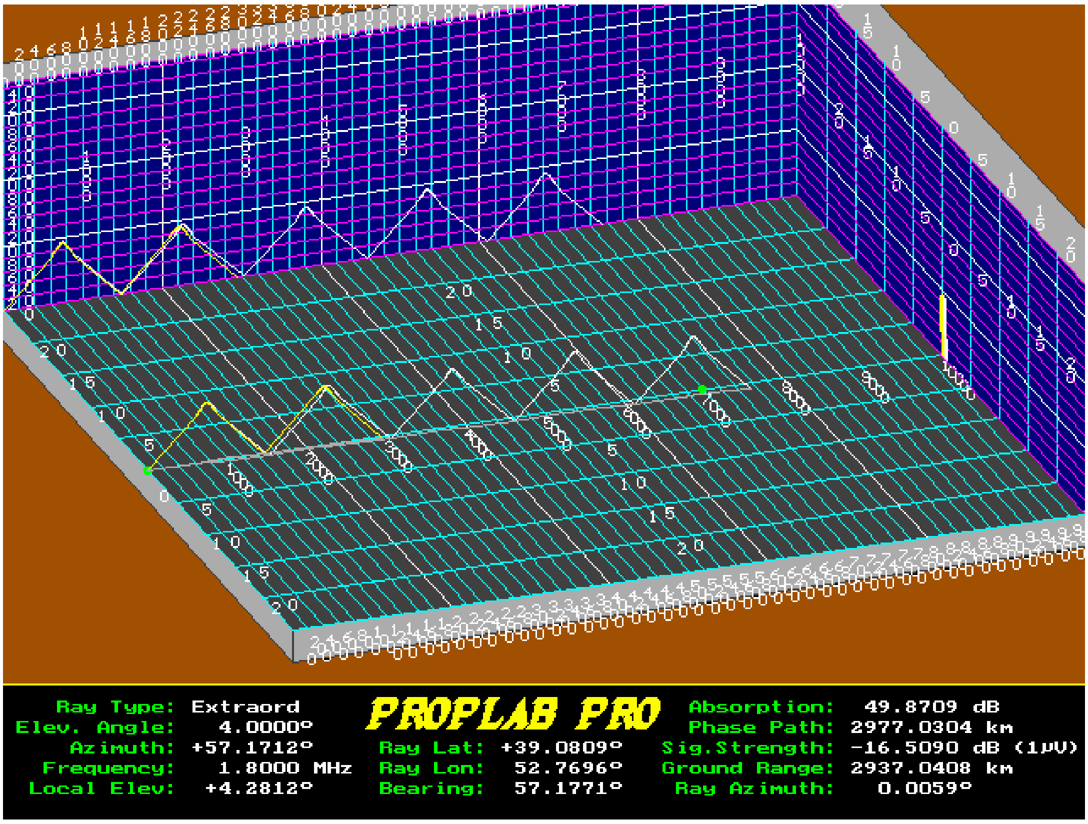
   Ray Type:  Extraord                      Absorption:    3.6029 dB
Elev. Angle:    4.0000°                     Phase Path:  9373.5065 km
    Azimuth:  +57.1712°    Ray Lat: +32.3717°  Sig.Strength:  13.5826 dB (1µV)
  Frequency:    7.0000 MHz Ray Lon: 342.6302°  Ground Range: 9154.7029 km
 Local Elev:   +9.5830°    Bearing:  57.3366°   Ray Azimuth:    0.1653°
```

***Fig. 52.2c.*** *An example at frequency 7 MHZ (40 meters band). Here a nighttime circuit propagating from West to East was chosen. The ordinary and extra ordinary wave does propagate in a bit more separated paths and deviate both from the great circle path.*



```
   Ray Type: Extraord      PROPLAB PRO   Absorption:  18.8302 dB
Elev. Angle:   3.0000°                   Phase Path: 8525.9389 km
    Azimuth: +57.1712°   Ray Lat: +35.5925°  Sig.Strength:   3.7380 dB (1µV)
  Frequency:   3.7000 MHz Ray Lon: 350.5439°  Ground Range: 8342.3803 km
Local Elev:  +9.7945°    Bearing:  57.3079°   Ray Azimuth:   0.1367°
```

***Fig. 52.2d.*** *An example at frequency 3.7 MHZ (80 meters band). A nighttime circuit propagating from West to East. Here we notice clearly that the ordinary and the extra ordinary waves travel completely different paths. To reach approximately the same area does the ordinary signal need only 3 hops where the extra ordinary signal propagates via 4 hops. The deviation from the great circle path is with this example the greatest at the last hops. This happens most likely by a more tilted ionosphere in this area.*



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  Ray Type:  Extraord     PROPLAB PRO    Absorption:    49.8709 dB
Elev. Angle:    4.0000°                  Phase Path:  2977.0304 km
   Azimuth:  +57.1712°  Ray Lat: +39.0809°  Sig.Strength: -16.5090 dB (1µV)
 Frequency:    1.8000 MHz  Ray Lon:  52.7696°  Ground Range: 2937.0408 km
Local Elev:  +4.2812°   Bearing:   57.1771°   Ray Azimuth:    0.0059°
```

***Fig. 52.2e.*** *An example at frequency 1.8 MHz (160 meters band). Here the refractions occur at the E-layer. Not much deviation from the great circle path is noticed here because the path lies entirely in the dark side, so no considerable ionospheric tilt were encountered. The E-region is also very thin and weakly ionized during the nighttime, but is still sufficient enough to refract the lower frequencies, MF (Medium Waves). Notice also that the extra ordinary wave propagates only 2 hops and the ordinary 5 hops. This happens because the extra ordinary wave is much weaker then the ordinary wave and sooner absorbed.*

The above 3D wave-tracing plots are kept simple for clearness sake and do not at all display completely what is happening to all the propagating waves. Lower or higher TAO (Take Off Angles) quite often behave differently. The circuit location, distance and time (or date) show mostly a completely different propagating picture of both signals.

Quite some more radical and exotic propagation paths are possible. For instance, the ordinary wave may start ducting in-between the F- and E-region, while the extra ordinary wave continues to experience the normal ground hop mode. In extreme cases with propagation path within a tilted ionosphere, the non-great-circle deviation can affect of the ordinary and extra ordinary wave divergence, resulting in wide separations between both signal components; see forthcoming issues. It is not exceptional at all, that the signal you receive is only an extra ordinary wave, but if this is the case, it will be rather weak compared to when the connection is achieved by an ordinary wave signal.

In next issue I shall explore some more of these exotic propagation path; stay tuned. **–30-**