CRITICAL FREQUENCY

By Marcel H. De Canck, ON5AU

Before reading onward, it would be good to refresh your knowledge about refraction rules in the section on *Refraction* of the earlier "*Wave Propagation Direction Changing"* column.

The degree of refraction of a radio wave in an ionized layer depends on the electron density of that layer and the frequency (wavelength) used. The bending degree is inversely related to the frequency.

At a given frequency, the refraction degree will increase with increased ionization density.

At a given ionization density, the refraction will increase with increasing wavelength, in other words, decreasing with higher frequencies.

A little imagination tells us that we can have two extreme possibilities.

First, with a sufficient ionization intensity (electron density) and a frequency low enough, we have the possibility and the reality that a radio wave, even if it enters the layer perpendicularly to the earth, will be refracted enough to be reflected back to earth.

Second is the converse case: with a high enough frequency and a low enough electron density, a condition can be reached where the refraction is not great enough to return our radio waves to earth, even with the lowest radiating angle. In that case, any wave will continue on its way into outer space and be lost forever.

For many years these principles were used to "sound" the ionosphere to determine the communication potentials at varies frequencies and radiating angles. They are the basic ideas underlying Ionogram charts and propagation models used in propagation predictions. In between those two extremes we have all of the more or less useful varieties of radio wave propagation for our communications.

The first mentioned extreme possibility could give us very interesting information about the properties of the existing ionospheric layers. The technique requires that we transmit 90° upward, perpendicular to the layers, with an increasing frequency signal, until we reach a frequency that will penetrate the layer.

The frequency that just penetrates is known as the ***CRITICAL FREQUENCY****.* Another frequently used term is ***PLASMA FREQUENCY****,* which simply means the critical frequency of a section of ionospheric plasma. A plasma is an ionized gas containing ions and electrons, differing from an ordinary gas in being a good conductor of electricity and in being affected by a magnetic field.

The critical point of returning or not returning our perpendicular propagating radio signal with the given electron density happens also at a certain height, the height of minimum necessary electron density of the layer of interest for that frequency. The height from which total refraction starts is the minimum actual height and is somewhat lower than the virtual height of the layer. See **Fig 6.1**.

The virtual height is the height the wave should reach if it was purely reflected instead of being refracted. The higher the frequency, the higher the virtual height, until we reach the point of maximum Ne of that investigated layer. From that point onward, our wave penetrates the layer and continues its way toward another higher situated layer or, when no more layer are left, finally into space.

The virtual minimum height are denoted as h' D, h' E, h' Es, h' F1 and h'F2.

The height of maximum electron density are denoted as hm D, hm E, hm Es, hm F1 and hm F2.

The critical frequencies are denoted as fo D, fo E, fo Es, fo F1 and fo F2,

Both the critical frequency and the maximum electron density height are very important data to study and calculate radio wave propagation. They are used to determine maximum usable frequencies for obliquely propagating radio waves and other ionospheric general conditions and quantities. This will be discussed in greater detail later.

Summing up: it is at the height of maximum electron density that we find the point of return or no return of radio waves. The frequency at which this happens (critical frequency) depends on the maximum electron density at that time. The critical frequency refers to the location at which maximum refraction occurs, and it also corresponds to the location where we find the maximum electron density for that layer of the ionosphere.

Each ionospheric layer has its own critical frequency, which occurs at its own specific height. The height of maximum electron density and the intensity of ionization vary throughout the day. The hm E resides mostly near 105 km; hm Es varies between 100 and 125 km; hm F1 varies between 150 and 200 km; while hm F2 varies mostly between approximately 220 and 375 km. With extreme ionosphere ionization levels, those mentioned heights might be a bit lower or higher.

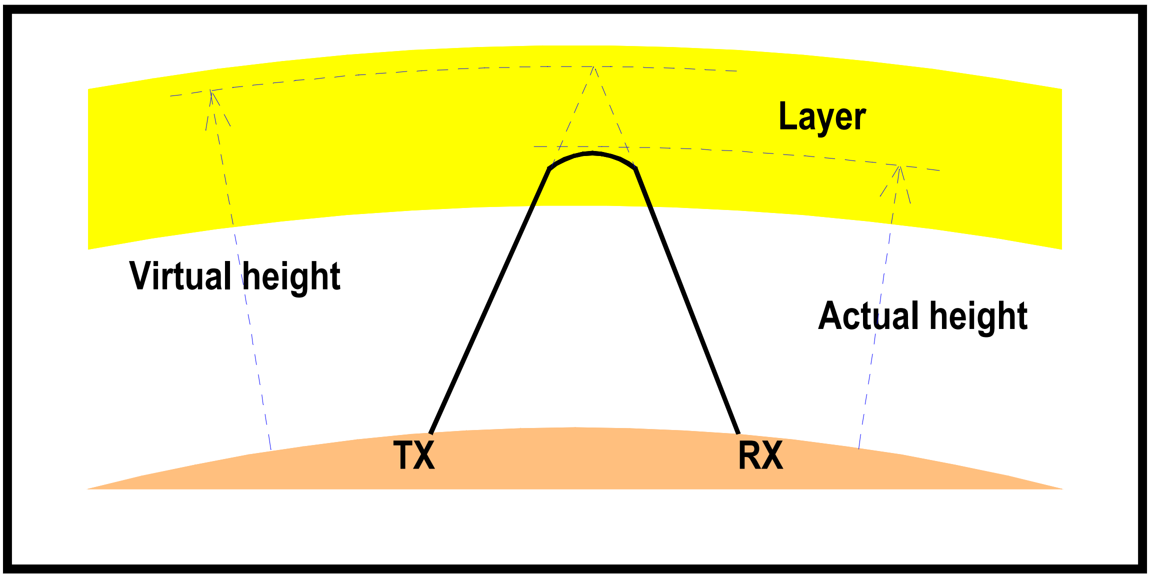


Fig 6.1 *The actual height is the height where the refraction happens. The virtual height is the height the wave should have reached to span the same distance, if it had been purely reflected.*

To illustrate the critical frequency and the height where it happens, we may use PROPLAB PRO-2 to model or simulate this phenomenon. To do this, we pre-compute some data. The prediction software gives us an option in the program main menu to compute certain items of interest. For any location and with a given SSN, A-index, date and time, you can obtain a large amount of data. See **Table 6.1**. Some of the data will be already familiar to you. The unfamiliar parts of the data set will be treated in later columns. We used this same menu option also in earlier columns, to derive data about the electron density and layer height, in the earlier created daily, seasonally and yearly graphs of those data. The process is quite time-consuming, but very educative.

In the following illustrations, I used two different SSN values (50 and 150) for the same location, Brussels Belgium, at 12:00 UTC, 21st of March. First, I give the electron density profile plots and some numeric data about the layers properties. Next comes some different wave tracing diagrams with different frequencies for the different ionospheric layers. See **Fig 6.2a** through **Fig 6.3d** to find the critical frequencies. What we also notice is this: with a higher SSN value we have a higher Ne E, Ne F1, and Ne F2 electron densities and therefore higher fo E, fo F1, and fo F2 critical frequencies. Higher F1, and F2 layer-heights are also noted. We shall discuss and illustrate these matters in depth later.

In the computer models, we simulated a transmitting angle of 89.99° instead of 90°. If we had used the real perpendicular, nothing would be seen, because the plotted line of the returning wave should completely overlay the up-going line. To make the returning wave visual, we need a very small deviation away from perpendicular.

Fig 6.2b - 6.3b. E-layer critical frequency tracing diagrams. The transmitted frequency is just above (higher) the fo E frequency and penetrates the E-layer to be refracted by the F1-layer.

Fig 6.2c - 6.3c. F2-layer critical frequency tracing diagrams. The transmitted frequency is just above (higher) the fo F2 frequency and penetrates the F2 layer to continue its way into space.

Fig 6.2d - 6.3d. F1-layer critical frequency tracing diagrams. The transmitted frequency is above the fo E and below fo F2 and all waves are refracted somewhere in the F1 and F2-layers. The fo F1 is not so clearly defined and distinguishable as are the fo E and fo F2. The F1 critical frequency is somewhere in the vicinity of that strangely shaped refracted wave, propagating some time and distance horizontally before being refracted downward to earth: sharp eyes can distinguish this in **Fig 6.2d** at about 170 km and in **Fig 6.3d** at about 220 km. The same phenomenon of horizontal propagation happens at the frontier of the F2 critical frequency, too. This strange wave behavior will be discussed later and is called a ***Pedersen ray***.

TABEL 6.1

UTC Date and Time: 00/03/21 12:00	Origin (Lat, Lon):	+50.850, 355.640
Sunspot Number: 50 A-Index: 5	Profile Location:	+50.850, 355.645

Critical F2-Layer Freq.:	7.000 MHz (Quiet-time),	7.000 MHz (Dynamic)
M(3000)F2:	3.15 (Quiet-time only)	
Maximum F2-Layer Height:	254.99 km (Quiet-time),	254.99 km (Dynamic).
Max. F2 Electron Density:	6.0767e+11 (Quiet-time),	6.0767e+11 (Dynamic)
Critical F1-Layer Freq.:	4.429 MHz	
Maximum F1-Layer Height:	182.09 km.	
Max. F1 Electron Density:	2.4324e+11 electrons / meter^3	
Critical E-Layer Freq:	3.148 MHz.	
Maximum E-Layer Height:	105.00 km	
Max. E-Layer Density:	1.23e+11 electrons / meter^3	
Critical D-Layer Freq.:	0.2460 MHz	
Maximum D-Layer Height:	81.03 km	
Max. D-Layer Density:	7.50e+08 electrons / meter^3	
Solar Zenith Angle:	50.093 degrees (elevation: 39.907 degrees).	
Solar Declination:	0.81 degrees.	
Magnetic Latitude, Lon:	+52.586,	88.519.
Magnetic DIP:	+65.700 degrees.	

SSN 50 A-index 5

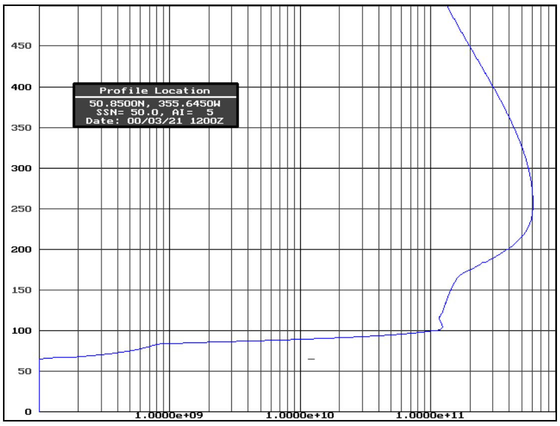


Fig. 6.2a *Electron density profile.*

SSN 150 A-index 5

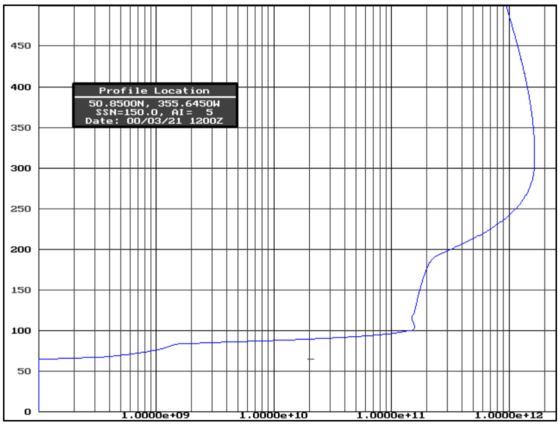


Fig. 6.3a *Electron density profile.*

Layers data with SSN 50 A-index 5		**Layers data with SSN 150 A-index 5**	
Ne E	1.23 E11	Ne E	1.57 E11
Ne F1	2.4324 E11	Ne F1	3.4396 E11
Ne F2	6.0767 E11	Ne F2	1.6552 E12
h' E	105 km.	h' E	105 km.
h' F1	182.09 km.	h' F1	202.47 km.
h' F2	254.99 km.	h' F2	312.29 km.
fo E	3.148 MHz.	fo E	3.559 MHz.
fo F1	4.429 MHz.	fo F1	5.267 MHz.
fo F2	7.000 MHz.	fo F2	11.553 MHz.

SSN 50 A-index 5

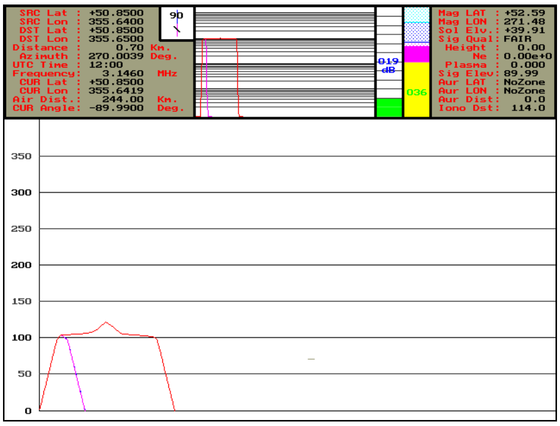


Fig. 6.2b *Wave trace diagram.*
Critical Frequency E-layer
Traced frequencies ***3.145*** *and* ***3.15*** *MHz*

SSN 150 A-index 5

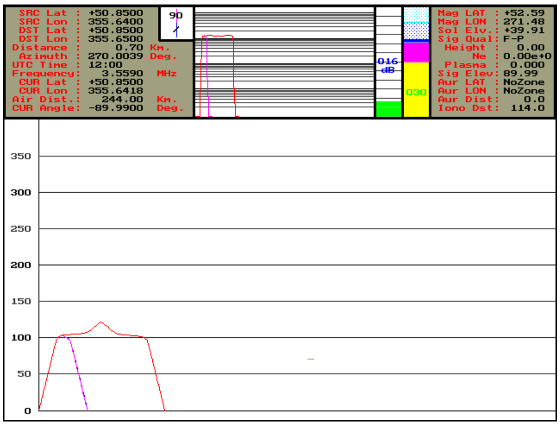


Fig. 6.3b *Wave trace diagram.*
Critical Frequency E-layer
Traced frequencies ***3.555*** *and* ***3.56*** *MHz.*

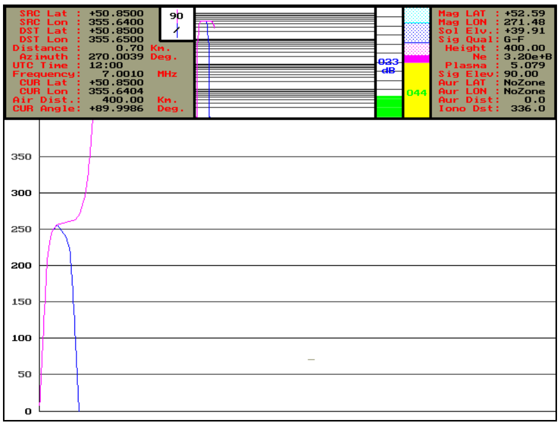


Fig. 6.2c *Wave trace diagram.*
Critical Frequency F2-layer
Traced frequencies ***7*** *and* ***7.005*** *MHz.*

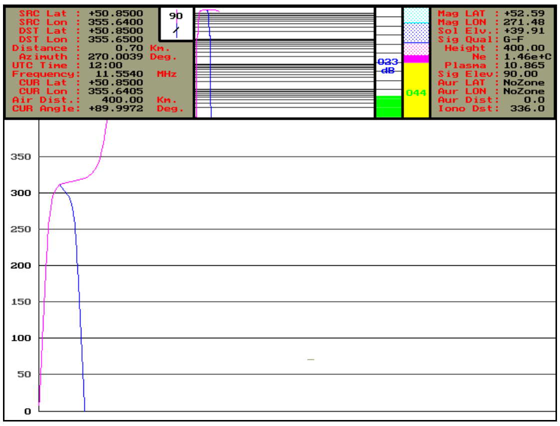


Fig. 6.3c *Wave trace diagram.*
Critical Frequency F2-layer
Traced frequencies ***11.55*** *and* ***11.555*** *MHz.*

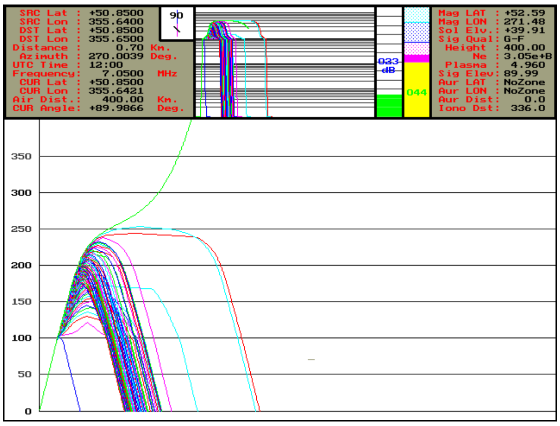


Fig. 6.2d *Wave trace diagram.*
From E-layer critical frequency to F2-layer critical frequency
Traced frequencies from:
3.145 to 7.005 *MHz.*

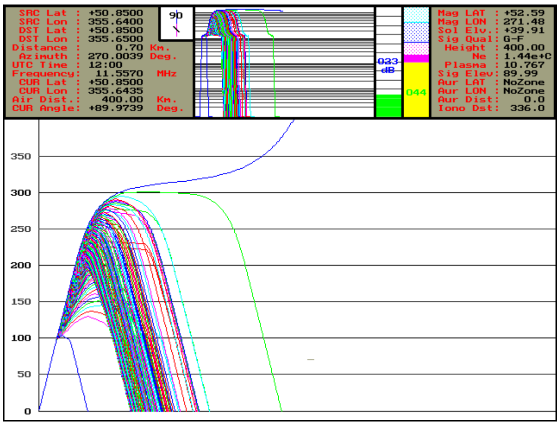


Fig. 6.3d *Wave trace diagram.*
From E-layer critical frequency to F2-layer critical frequency
Traced frequencies from:
3.555 *to* ***11.555*** *MHz.*

Several other options with the PROPLAB PRO-2 program can give you additional information about the structure of the ionosphere and the different plasma frequencies at their respectively heights, for any location of the world. A transverse plasma frequency map or slice is one option and can be produced between any two points. See **Map 6.1a-b-c-d**. Also, global maps can be produced giving information about the foE (E-layer critical frequencies), foF2 (F2-layer critical frequencies) and the hmF2 (F2-layer layer maximum density height)**.** In the next column, we shall handle these options in detail.

In the plasma frequency transverse maps are the contour lines of the plasma frequencies of the ionosphere; they are essentially critical frequencies at specific heights of the ionosphere. Take as an example the critical frequency at the 2500-km point in the 18:00 UTC map (midday) at a height of 100 km. The E- layer has a critical frequency of 2.2 MHz: this means that this E- layer would refract a vertically propagated wave below 2.2 MHz, while at frequencies above 2.2 MHz the wave would penetrate that E- layer and continue its journey upward. As long the plasma frequency it meets is higher than the operation frequency, the wave will be refracted. Once both frequencies are equal, we reach the critical point of return or no return, being refracted or penetrating. In the same example, the same phenomenon will happen at a frequency of 8.2 MHz at a height of approximately 270 km. Higher-frequency waves than 8.2 MHz penetrate that region and are lost into space. Remember that we are talking about 90 degrees vertically upward radiated waves.

The left side of the Transverse Plasma Frequencies maps at 0 km is the location N 40 W 130 (Western USA Pacific Ocean); the right side at 5005 km is location N 40 W 70 (Eastern USA Atlantic Ocean); the point at 834 km is the location of the meridian W 120; the point at 2085 km is the location of the meridian W 105; the point at 3336 km is the location of the meridian W 90; and the point at 4587 km is the location of the meridian W 75. These are the points to watch closely at equinox dates 21 March and 21 September for sunset, midnight, sunrise and midday. For W 90 (point 3336 km), These times occur, respectively, at 00:00, 06:00, 12:00 and 18:00 (UTC). Take a close look at this point in the four different transverse plasma maps for date 21 March.

The critical frequency is related to the electron density. High critical frequencies mean high electron density. At 00:00 UTC you can notice the start of a decreasing density (sunset) and at 06:00 UTC a stable low density (midnight). At 12:00 UTC you can notice the start of an increasing density (sunrise) and at 18:00 UTC we find a stable high density (midday). Also look at the increasing and decreasing hmF2 (maximum density heights) of the F2 layer along the path at the different given times. The grayline zone on the maps for sunset 00:00 UTC and for sunrise 12:00 UTC is also good to distinguish. The sun is moving along the path from east (right on the map) to west (left on the map). In reality, our globe is rotating counterclockwise, looking from the North Pole. At the end of this column, you can download a Wizard with an hourly animation and gain a good insight into the hourly changing ionosphere properties.

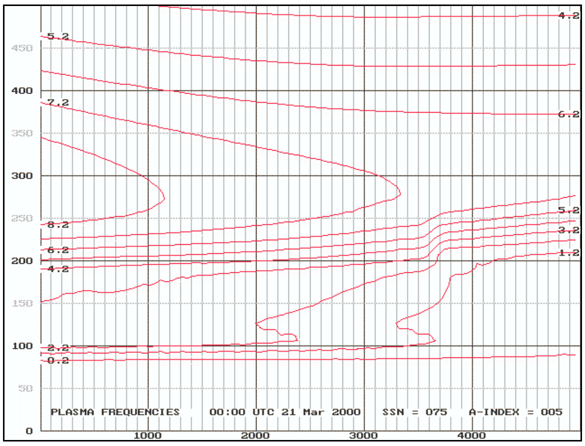
As mentioned before, the plasma frequency is related to the electron density. When we know the plasma frequency (critical frequency), we can compute the electron density by using the following equation, **Eq 6.2**:

Eq 6.2

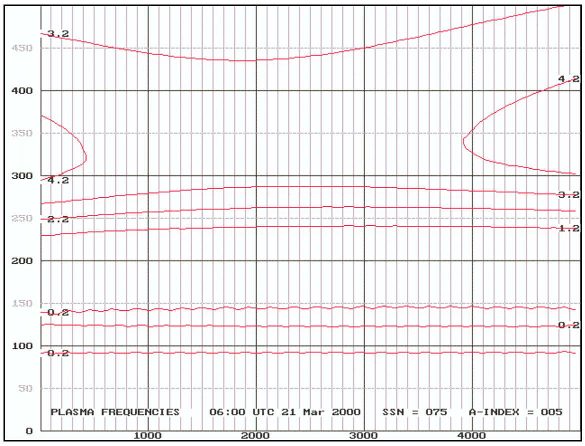
Density = (1.24×10^{10}) * Plasma Freq
Ne = 1.24 E10 * fo (layer region)

The electron density is in electrons per cubic meter and the plasma frequency in MHz. In the above example for the date 21 March, time 18:00 UTC, with an F2 layer plasma frequency of 8.2 MHz, the electron density Ne F2 = 10.168 E10.

Transverse Plasma Frequencies Maps
Circuit Location: USA N 40° W 130° to N 40° W 70°.
Date: 21 March.
Times: 00:00 - 06:00 -12:00 and 18:00 UTC.
Extra data: SSN 75 and A-index 5.

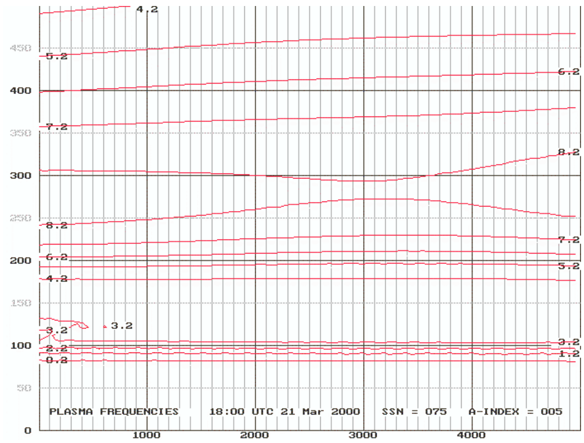


***Map 6.1a** 00:00 UTC. Sunset*
W 90° midday is at point ± 3300 km



***Map 6.1b** 06:00 UTC. Midnight*
W 90° midday is at point ± 3300 km

***Map 6.1d** 12:00 UTC. Sunrise*
W 90° midday is at point ± 3300 km

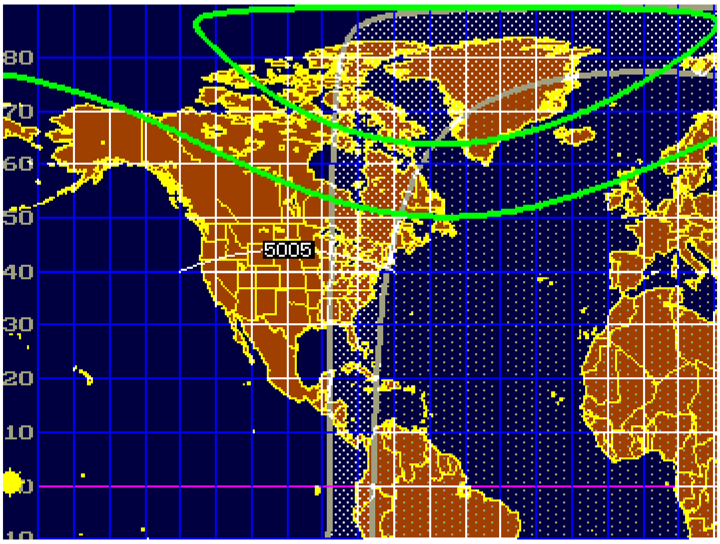


***Map 6.1d** 18:00 UTC. Midday*
W 90° midday is at point ± 3300 km.

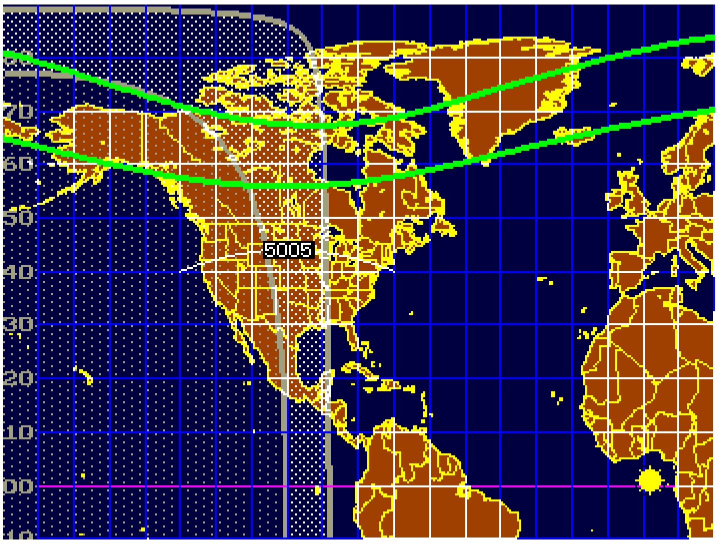
The two following maps give you an insight on where to situate the above transverse plasma frequencies maps (slices). The circuit path is the slightly bent line labeled as 5005 km.

Map 6.2a gives you a better idea of the grayline location and the before sunrise twilight zone for 12°.
Map 6.2b gives you a better idea of the grayline location and the after sunset twilight zone for 12°.

The grayline is shown on the maps as the solid gray colored line closest to the sun symbol. The second solid gray colored line defines the regions where the sun is exactly 12° below the horizon, the end or the beginning of the evening or morning twilight.



Map 6.2a *Gray line at W 90 sunset at 00:00 UTC 21 March*
Great circle path from N 40 W 130 to N 40 W 70. Distance 5005 km.



Map 6.2b *Gray line at W 90 sunrise at 12:00 UTC 21 March.*

Starting with this month's column, you will have the opportunity to download **Presentation Wizards**. What's hidden in this name? Each wizard has a presentation of illustrations and animated pictures. By use of these wizards, with their inherent animations, it is my goal to give you a live picture of the continuously changing propagation and ionosphere properties. Together with the wizards you will have the opportunity to download a PDF document as well. This document is a hard copy of the illustrations you find in the wizard. By printing out these documents, you can make a library of propagation information. Download them and find out yourself. We, the publisher of ***antenneX*** and I, would like to hear your thoughts, suggestions and comments about these wizards and documents, so that we can improve them better to meet your needs. **30-**

Transverse Plasma Frequency Map's during 24 hours. N40 W105 – N40 W70 circuit. March 21	**Size: 1.432 Mb 0.590 Mb**	**CLICK Wiz06a Doc06a**