Ionosphere Properties and Behaviors - Part 1

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In this series I shall dig a bit deeper into the various ionospheric properties, characteristics and behaviors. These can be in favor or not in favor to our wave propagation and be the cause of strange but often interesting propagation options, modes, and paths. In this month's issue I take a closer look to the signal absorptions and the gyrofrequency property.

Signal Absorption

There are many different types of phenomena that attenuate or reduce the signal strength of a propagating radio wave. Those phenomena types extract energy from the radio wave by converting its energy into heat and electromagnetic noise and are associated with the term **Absorption**.

When referring to the actual propagation of a radio wave through the ionosphere, we have principally two types of ionospheric absorption: the **deviative** and the **non-deviative**.

While a radio signal travels through the upper atmosphere and the lower ionosphere, the effects of electron collisions with neutral particles are much higher, because the density of neutral particles in these regions is still relatively high**.** The resulting collisions absorb energy from the propagating radio wave; see **Collision Frequency**. This form of ionospheric absorption decreases the finally received signal strength by a rather precise amount. Therefore, as with multi-hop modes, the more times the radio wave has to pass through the lower ionospheric regions, the greater the resulting absorptions will be. This form of absorption is known as **non-deviative absorption**.

Collision Frequency.

The collision frequency defines the rate with which electrons collide with neutral particles in the earth atmosphere and ionosphere, **Fig. 51.1.** This value is quite important for accurate calculations of the ionospheric radio wave absorptions or attenuations. The better prediction programs take this into account in their computing algorithm model and are mostly inherently included.

During the day the ionospheric electron density is much increased but recombines also at a quick rate with the ever-present high densities of ions and neutral particles, especially in the lower ionosphere where the gasses are denser than at the higher more rarified regions. This produces stronger levels of ionospheric non-deviating absorption. In contrast, during the night, when the electron densities are substantially lower, the non-deviating absorption decreases. The following equation summarizes empirically the non-deviating absorption:

$$K = 1.15 * 10^{-3} Nv / f^{2}$$

K is the absorption coefficient, **N** is the electron density in the lower ionosphere, **v** is the collision frequency of electrons with neutral particles and **f** is the frequency of the radio wave.

From the above equation we can see that if the electron density **(N)** or the collision frequency **(v)** is increased while the radio frequency **(f)** stays constant, then the absorption level **(K)** will increase, (a higher numerator). However, if the radio frequency is increased, then the effect of non-deviating absorption decreases (a higher denominator). Lower frequencies have a greater or larger wave front than higher frequencies (even when the amplitude is equal). A greater wave front will collide much more with the ions and neutral particles and therefore be more attenuated.

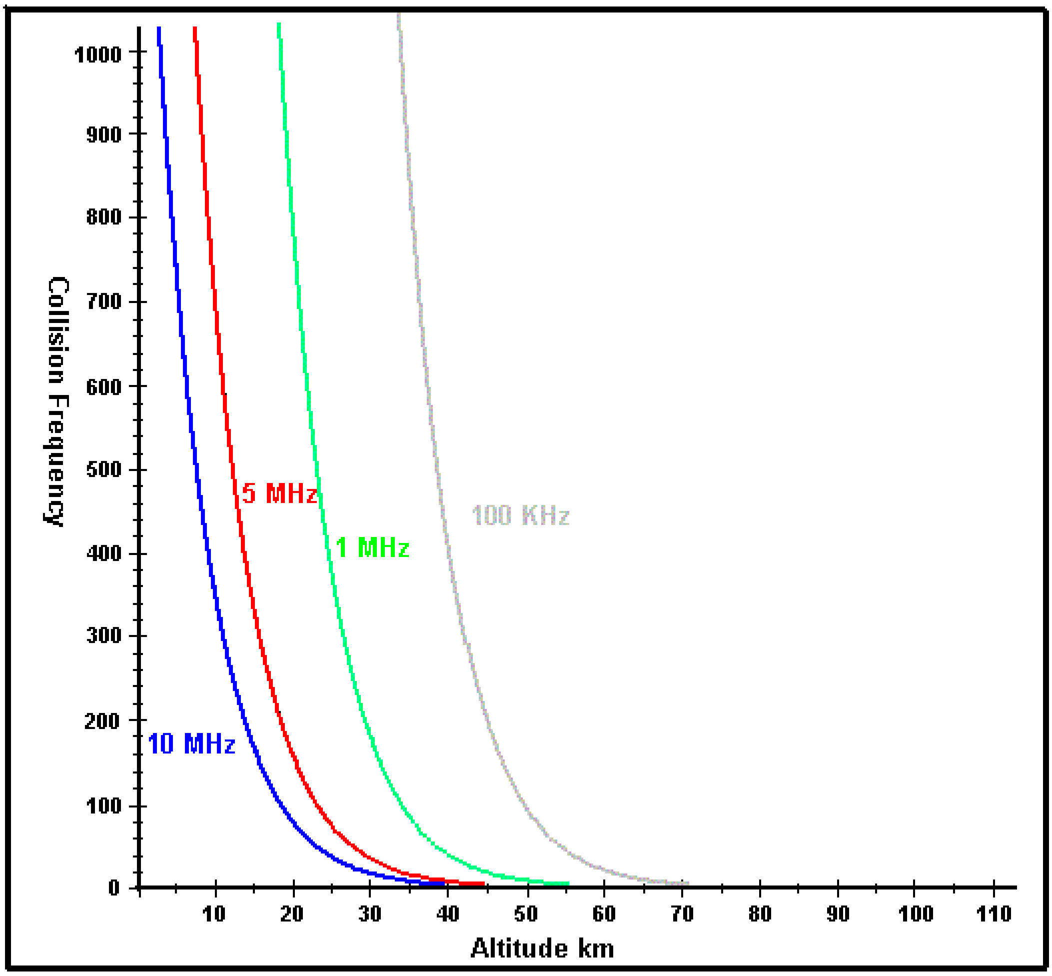

Fig. 51.1. *Collision Frequency Profiles using 2-exponential terms for transmitting frequencies from 0.1 to 10 MHz at the higher atmosphere or lowest ionosphere. As can be seen, when the frequency of the radio wave is increased, then the effect of the collision frequency decreases. Higher frequencies do not play a role as large in collisions as low frequencies do. (From the manual of Proplab Pro-2 of STD)*

During strong solar flares periods and at the earth daylight side the non-deviative absorption can increase very considerably. Those flares radiate strong X-rays, which can penetrate deeply into the earth ionosphere, where they increase the electron density of the D-layer region. Long and strong X-ray flare events might even more ionize the D-region by a magnitude factor of 10. In such cases the increased D-layer electron density can thicken this layer, lower its base, and influence even VLF signals. However, the primary effect with a large X-ray solar flare, coincident with a stronger ionized and thicker D-layer, is a proportional increase of non-deviative absorption. Such events are known as blackouts for certain communications frequencies, only associated with the daylit hemisphere of the ionosphere. The stronger the X-ray emissions from the sun, the greater are the electron densities in the lower ionosphere. This implies that non-deviative absorption is proportional to X-ray intensity. This proportionality relies also upon the angle of incidence of the X-rays to the lower ionosphere. Regions of the earth that are near sunrise or sunset will have lesser non-deviative absorption then regions of the earth where the sun is higher into the sky. The absorption during blackouts is roughly proportional to $\cos^n(\chi)$, where n is usually in the neighborhood of 0.75 and χ is the angle of incidence.

During very weak solar flare event periods and when the sun is directly overhead, a 5 MHz radio signal can be attenuated by as much a 7 dB. With higher frequencies (more used during daylight communications) the attenuations are less problematic. But non-negligible levels of absorption can occur with very large solar flares, even on the higher HF frequencies. Such large solar flares are capable of producing attenuation levels as much as 45 dB on 5 MHz radio signals when the sun is directly overhead. This is enough absorption to completely absorb the lower HF radio signals. X-class solar flares are capable of producing radio blackout conditions for most radio signals with frequencies below 12 to 15 MHz, which is quite a large fraction of the HF spectrum.

Non-deviative absorptions vary also with season, time of the day, (diurnal) or the phase of the solar cycle, (cyclical). The diurnal variation is strongly related to the sun inclination angle, the cyclical variation to the sun activity, that is, more or less violent solar flare occurrences. The term "non-deviative" comes from the fact that this type of absorption is the heaviest near the base of the ionosphere where the effects of refraction on the propagating wave are very small. The signals traveling through this absorbing medium will travel practically in a near straight line, a non-deviating path. Therefore, it's called non-deviative absorption, because the signal is not being bent in any direction while it is being attenuated.

Deviative absorption is a type of absorption that occurs when the signal spends a longer period of time within the absorbing medium and meanwhile is refracting. The deviative absorption coefficient depends heavily upon the refractive index of the signal and the frequency of electron collisions with neutral particles. The deviative absorption is greatest wherever the signal wave deviates the strongest from its expected straight-line path. This occurs typically at and near the signal wave refection point.

Each time a signal is refracted in the ionosphere, deviative absorption occurs. Refractions in the lower ionosphere regions, where the electron collision frequency is rather high, experience greater absorption and can be rather high, particularly the frequencies in the lower HF spectrum. If the sun also illuminates the communication circuit, then the effects of non-deviative absorption will take an additional toll on the signal strength, **Fig. 51.2.**

Deviating absorption is usually not as strong as non-deviative absorption but plays nevertheless an important role

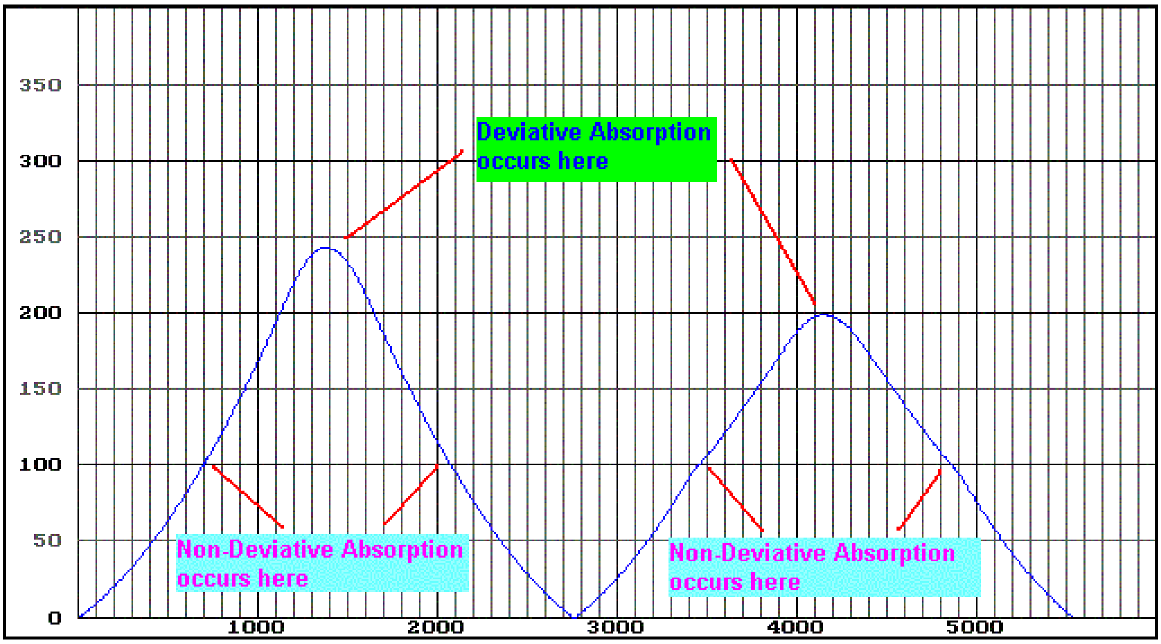

Fig. 51.2. *Regions where the non-deviative and deviative absorptions occurs.*

Gyrofrequency

Another important ionospheric term is the gyrofrequency, the relationship of which to propagation properties is not commonly known (see a forthcoming issue). The free electrons, the ions and other charges particles are attracted by the earth's magnetic field. As they come under the influence of that magnetic field, they will begin to spiral around a magnetic field line and its path will change so that it follows the direction of the magnetic field, **Fig. 51.2.** The rate or frequency with which these electrons and ions gyrate around the magnetic field lines is known as the angular gyro magnetic frequency or the **gyrofrequency**. The electrons generally cannot move perpendicular to the magnetic field lines, but can travel freely in a direction parallel to it through the spiraling action. The direction is towards the magnetic poles, northward at the northern and southward at the southern hemispheres.

The **electron gyrofrequency** can be determined by the following equation:

$$f_H = \frac{\frac{e}{m}\,\beta_o}{2\pi}$$

f_H is the angular frequency, **e** is the charge on an electron, **m** is the mass of the electron and β_o is the magnitude of the imposed magnetic field in **tesla** units. By precomputing the constants the equation simplifies to:

$$f_H = 2.799224693 \times 10^{10}\ \beta_o$$

An example: when the strength of the magnetic field is 0.6 $\times 10^{-4}$ teslas, then the electron gyrofrequency is approximately $2.8E^{10}$ x $0.6E^{-4}$ = 1 680 000 Hz or 1.68 MHz.

The electron gyrofrequency lies within the MF band, between approximately 600 and 1800 KHz. The 160 meters band can be rather influenced in certain areas of the globe by it.

The **ion gyrofrequency** is determined by:

$$f_{Hion} = \frac{e}{2\pi\, M}\ \beta_o$$

It is related to the electron gyrofrequency by:

$$f_{Hion} = \frac{m}{M}\, f_H$$

m is the mass of an electron, **M** is the rest mass of the ion and f_H is the electron gyrofrequency.

A close study of the above equations tells us that the much higher mass of the ions results in a much lower ion gyrofrequency compared to the electron gyrofrequency. For example, the typical gyrofrequency of a **O^+** ion in the ionosphere is only about 48 Hz and has no effect on radio-wave propagation.

How close the electron gyrofrequency is to the HF lower frequency bands depends on your geographical location. The earth's magnetic field intensity is quite different at different geographical locations. **Fig. 51.3** illustrates this by plotting lines of equal gyrofrequencies. The units are in kHz and are valid at an altitude of 90 km, near the base of the ionosphere.

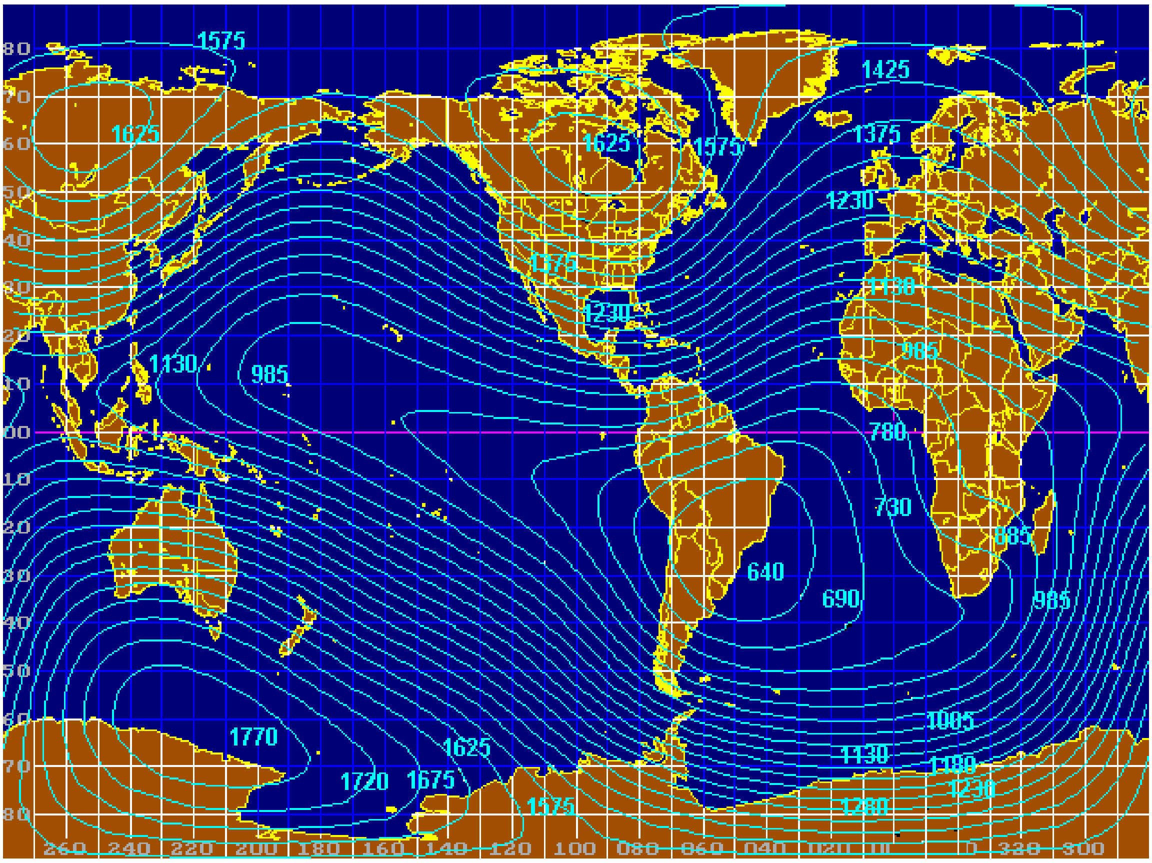

Fig. 51.3. *World map indicating the gyrofrequencies (KHz) found at the base of the ionosphere at an altitude of 90 kilometers.*

Ions have a larger mass than electrons; therefore, the radius of their gyration around the magnetic field line is larger. This larger gyro radius is simply due to the fact that they have a higher momentum. Imagine an analogous happening when you swing a ball fixed by an elastic band around you. The larger or more massive (weight) the ball is, the larger the radius will be that the ball circles around you. It will additionally circle slower if you should use a ball having a greater mass. Using a lighter ball should results in corresponding smaller and faster circle traces.

The direction of gyration is different for electrons and positive ions. This direction can be determined by using the simple thumb rule: the direction of rotation of electrons and negative ions is determined by the fingers of the right hand when the thumb points in the direction of the magnetic field. The direction of gyration of positive ions is in the opposite sense, Fig. **51.4.**

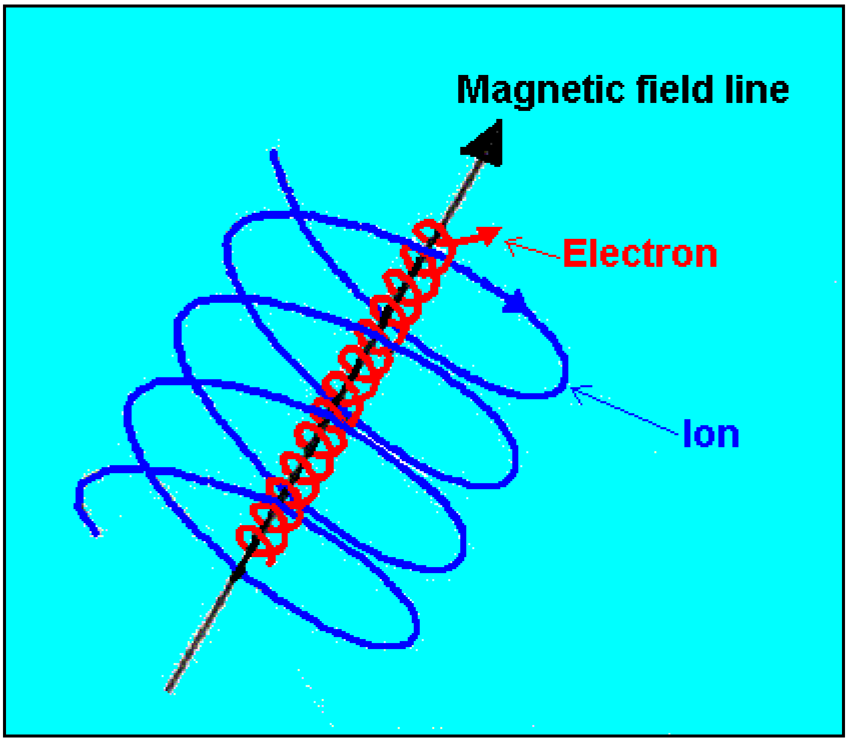

Fig. 51.4. *The different gyration properties of electrons and ions.*

The electron gyrofrequency has an important impact to the critical frequency properties of the ionospheric layers. Also to the propagating path the radio signals might follow. More to follow about this phenomenon in the next issue. Stay tuned. **–30-**