Wave Propagation Direction Changes

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Just like light rays, electromagnetic radio waves can change the direction of propagation. They can do this in different ways and with different causes and origins. Our radio waves can bend, diffract, reflect, scatter, and refract. Quite a bunch of effects isn't it. We shall discuss these phenomena one at a time.

Bending

The best-known phenomenon of bending radio waves within radio amateur frequencies happens in the VHF bands. Normally our communication distance is limited to the geographical horizon between transmitting and receiving antennas. With certain atmosphere circumstances, that horizon is extended. Our waves are bent in a way that follows the curve of the earth's surface. Communications distance can increase up to 15% when these conditions occur. An atmospheric temperature inversion is the help needed to bend the VHF and UHF signals. A temperature inversion means that we have a layer of colder air closest to the earth surface and a warmer layer on top of it; normally it's the other way around, with warmer close to the surface and colder in higher regions. Those inverse temperature layers duct our waves sometimes and force them to propagate awhile following the earth curve. We will study in more detail this tropospheric propagation mode in a later session.

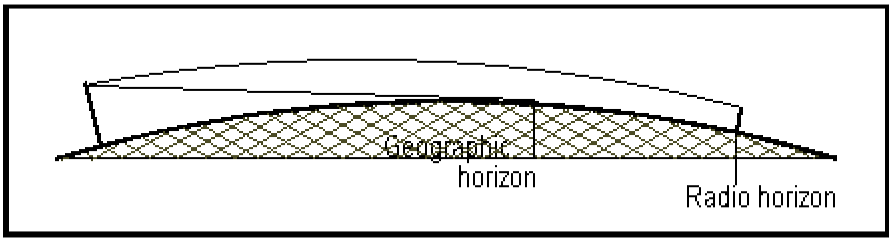

***Fig 2.1**. The radio horizon can be extended by bending beyond the line of sight for a given geographic horizon.*

Bending behind the geographical horizon also happens with waves in the spectrum of LF, MF and to some degree with the lowest frequencies of HF (80 meters band). A propagation speed decrease right at the earth surface level causes a kind of tilt to the wave front, which we shall explore further later on.

Reflection

Reflection occurs at any boundary between materials or mediums having different dielectric constants. We can distinguish two kinds of reflection: the total or direct way in **Fig 2.2** and the scattered way in **Fig 2.3**.

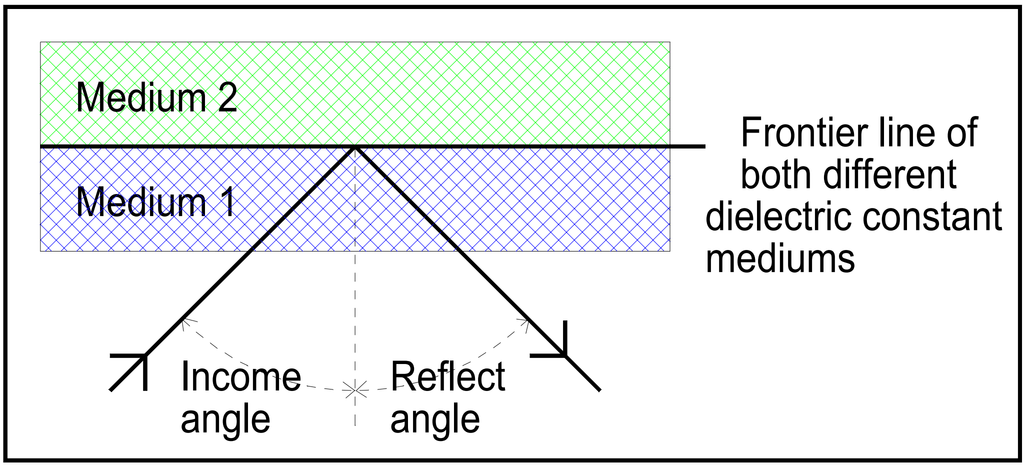

Fig 2.2. *Total reflection: practically no attenuation occurs.*

With direct reflection, the incoming angle of the wave equals the outgoing angle; both angles are equal to each other. Practically no signal attenuation occurs. You can compare this form of reflection with the properties of light waves hitting a flat mirror, with no deformation of the reflected image.

With scattered reflection, the reflected incoming wave is diffused in different directions. Understandably, we have major attenuation of the signal, since the wave energy is spread around. This form of reflection is comparable to the sunrays hitting a slightly rippled water surface; the water surface ripples spread the sun's rays randomly. The greater the ripples are, the greater the scattering of the light rays.

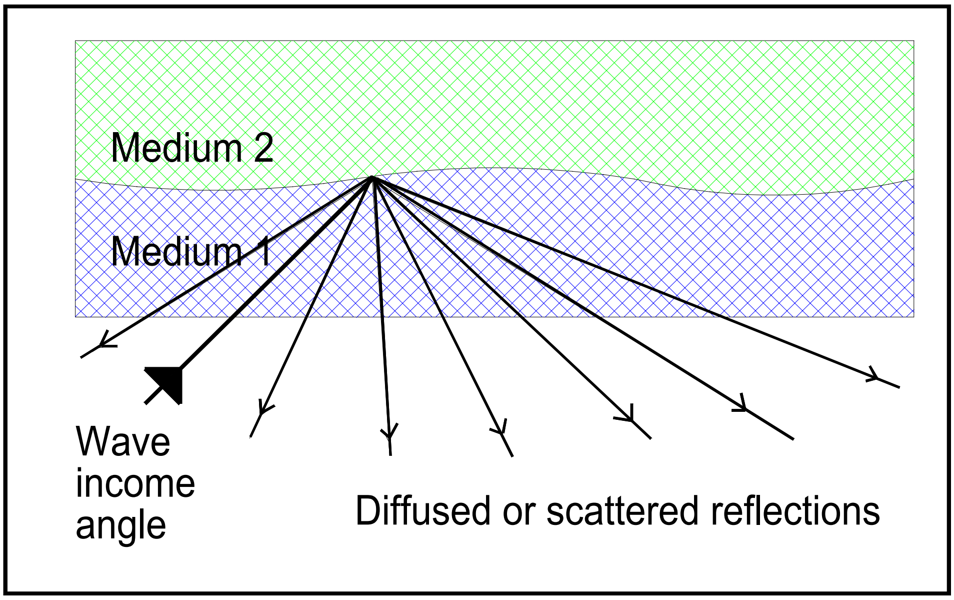

Fig 2.3. *Scattered reflection, high attenuations occur. As can be seen, even backscattering can occur. These phenomena can in some circumstances allow contact to be made which otherwise would be impossible.*

You might think that if our waves are scattered around in many directions, the result might be a total disaster for our communications. Some special exceptions seem to counter this rule. Some of the scattered waves may even be backscattered or side-scattered. Those properties can be positive for exceptional and rare communications, for example, aurora backscatter and crooked paths (which we shall examine more closely later).

Depending on the wavelength, radio-wave paths may be reflected by buildings, mountains, trees, vehicles, the ground, water surfaces, ionized layers in the upper atmosphere, or at boundaries between air layers having different temperatures and moisture content. Radar is a good example of a radio wave reflection application.

At frequencies above 30 MHz we can have more reflections than we might think. But reflections can sometimes bring us benefits. For example, there are some interesting tropospheric propagation possibilities. The line-of-sight distance can be increased if both radio stations can use a common reflecting object. Both stations must beam at the correct angle to the common reflector. The best position for the reflector is not necessarily somewhere halfway the communication path. Contrary to intuitive notions, the most effective reflectors are those closest to one station or the other. The signal strength increases as the reflector approaches one end of the path. Effective reflectors must be many wavelengths in size and have ideally flat surfaces.

Diffraction.

Diffraction is also a kind of radio wave diffusion that can make some communication path possible. Diffraction can occur if waves pass behind solid objects with rather sharp upper edges, such as a mountain range. This *knife-edge diffraction* phenomenon is easier to comprehend with help of the sketch in **Fig 2.4**. The sharp-edge solid object must be large in terms of a wavelength. The crest of a range of rather steep hills or mountains 50 wavelengths or longer can form a reasonable knife-edge diffractor of radio waves. The waves passing over the edge are refracted slightly downwards and allow reception.

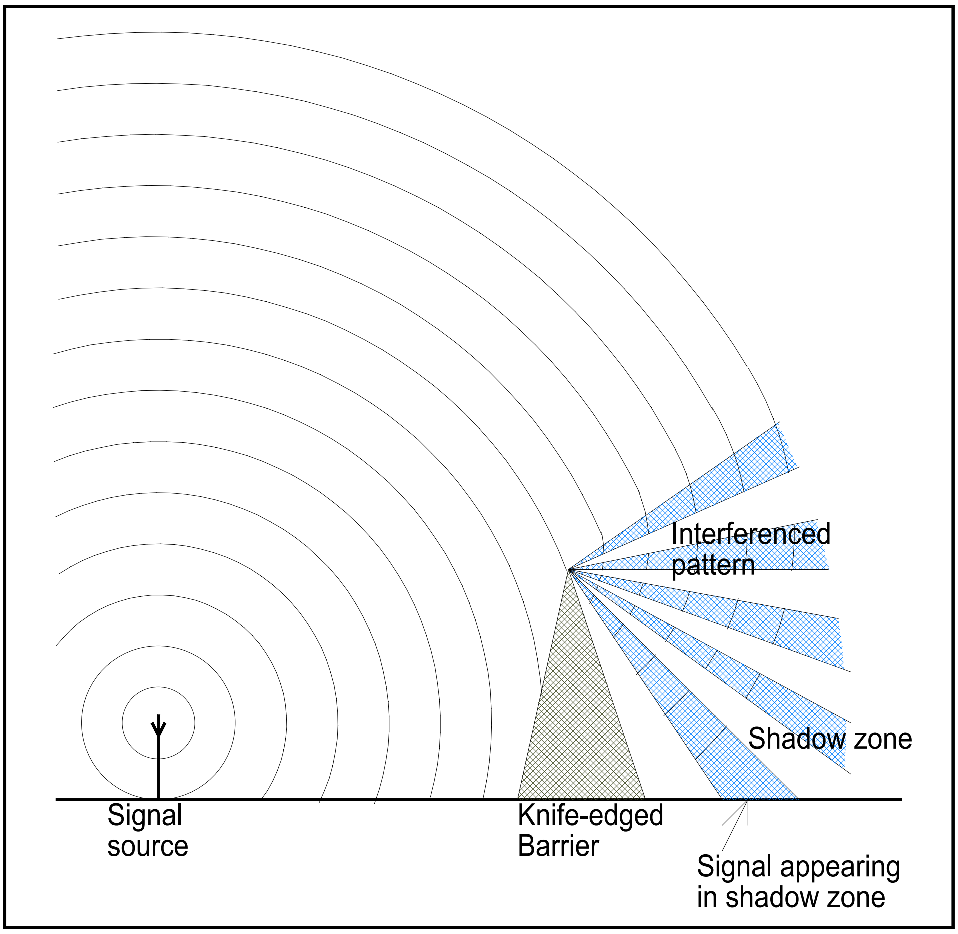

Fig 2.4. *Knife-edged diffraction gives the possibility of communication in the shadow zone of a barrier.*

Refraction

Refraction of radio waves in the propagating direction happens when the wave velocity changes. Changes in wave velocity occur when the wave is traveling from one medium into another medium with a different dielectric constant. When radio waves enter the ionosphere and meet an ionized layer, then the wave paths will be altered. (An ionized layer in itself may consist of a mix of many kinds of smaller sub-layers, each with a different dielectric constant or electron density.) Passing through these small sub-layers causes a process of refraction and alters the wave's course. As an illustration, the same thing happens when you look at a pencil sticking in a glass of water and focus on the boundary of liquid (water) and gas (air). Since the two mediums have different densities, the pencil seems to be bent, and we get the picture of a pencil that is not straight. The electromagnetic light-wave forming the picture in our eyes causes this illusion: the light waves are refracted at the medium boundary.

The intensity of ionization and the frequency of the penetrating wave dictate the grade of refraction. Under proper conditions, the wave is refracted enough to head back downward to earth. With the same ionization grade, low frequencies are refracted sooner than higher frequencies, and low incoming angled waves are refracted better than higher angled ones. The incoming angle at a given point in the ionosphere can become too high to allow effective refraction.

The refraction process costs energy. Our waves are attenuated to some degree, and the longer the refraction path through the ionized area the greater the attenuation. So the refracted waves with the lowest incoming angle spend lesser time and distance in the ionized area and therefore will have the greatest signal strength. **Fig 2.5** illustrates the behavior of a wave path modified by refraction laws. Some frequencies and incoming angles are better or preferable for communications. (See our later discussion of MUF, Maximum Usable Frequency.)

What is refraction? When and why does it happen? Radio waves behave more or less like light rays (visible light is also composed of electromagnetic waves, but with a much higher frequency than our radio waves. Law that applies for light (optical physics) will also apply to our electromagnetic radio waves. In particular, Snell's law for refraction is especially pertinent. See **Eq. 2.1.**

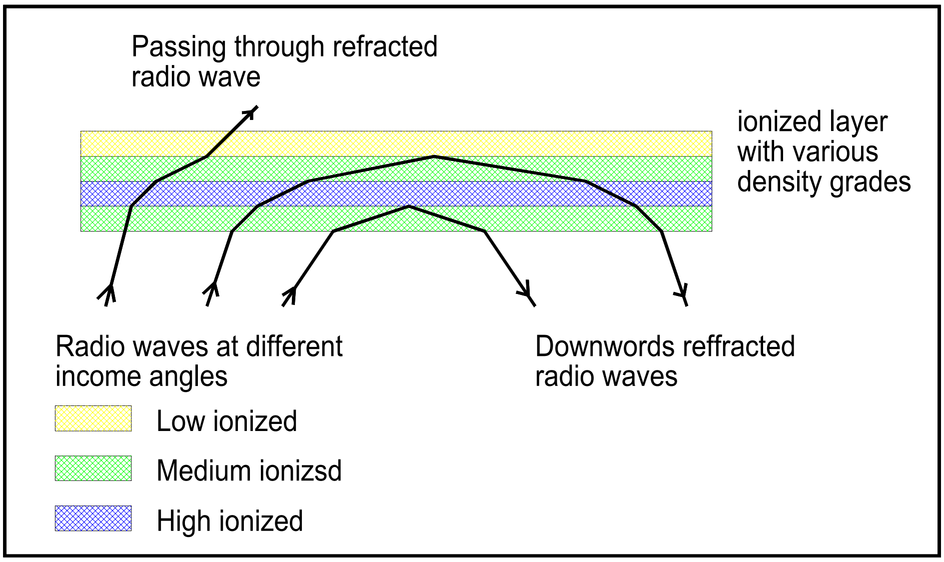

***Fig 2.5**. Different refraction phenomena with different sub-layer properties and different incoming angles.*

The Snell law (By Dutch scientist Willebrord Snell van Royen 1591 - 1626)

Eq. 1.

$$\text{Snell's Law} = \frac{\sin \theta_i}{\sin \theta_r} = n = \frac{v1}{v2}$$

θ I = the angle of incoming ray.
θ r = the angle of outgoing ray.
n = index of refraction of medium 1 in respect to medium 2.
v1 = wave velocity in medium 1.
v2 = wave velocity in medium 1.

The refraction index depends on the frequency and on the density properties of the two mediums. The refraction index dictates a change of traveling direction caused by a change of the wave velocity, when that wave crosses a frontier between two mediums with different density properties.

The refraction grade, or “index,” depends of the electron density of the two media and the frequency. The refraction index can therefore be interpreted as a gradient of ionization, **Eq. 2.**

$$n = \sqrt{1 - K\frac{N_e}{f^2}}$$

Eq. 2.

n = refraction index.
K = positive constant with value 80.5.
N_e = electron density (electrons / cubic meter).
f = frequency of incoming wave expressed in Hertz.

Because the factor *K* is a positive value, the factor *n* must be smaller than 1. From the equation we can also derive that the refraction decreases with increasing frequency. The higher the frequency, the more difficult it is to refract the wave in the ionosphere. With higher frequencies, we need higher electron densities to maintain an equal refraction index. With a frequency of 2 MHz we need approximately 4.0 E+10 electrons / cubic meter to get a refraction index of 0.5. With a frequency of 10 MHz, we need 4.0 E+12 electrons / cubic meter, and at 25 MHz we require a density of 5.0 E+12 electrons / cubic meter. These figures illustrate the dependency of the refraction index on frequency and electron density.

The refraction index of an ionized layer changes continuously within the layer, due to a continuous change of the ionization intensity. Looking from the bottom frontier line of the ionized layer upwards, we have a continuously increasing electron density with height until we meet a point of highest ionization grade. From that point upward, the ionization density decreases continuously to a level of no importance for refraction properties. A radio wave of a given frequency that penetrates the ionized layer with a given incoming angle will be refracted more and more when traveling higher and higher until it will be refracted enough to be in a horizontal propagating direction. From that moment, it will be further propagated and refracted downwards to earth, as in **Fig. 2.6. I**f the wave is refracted but not yet be propagating horizontally when it reaches the point of maximum electron density, the wave will be refracted upwards again and continue its way to a next layer or into outer space. See **Fig. 2.7**.

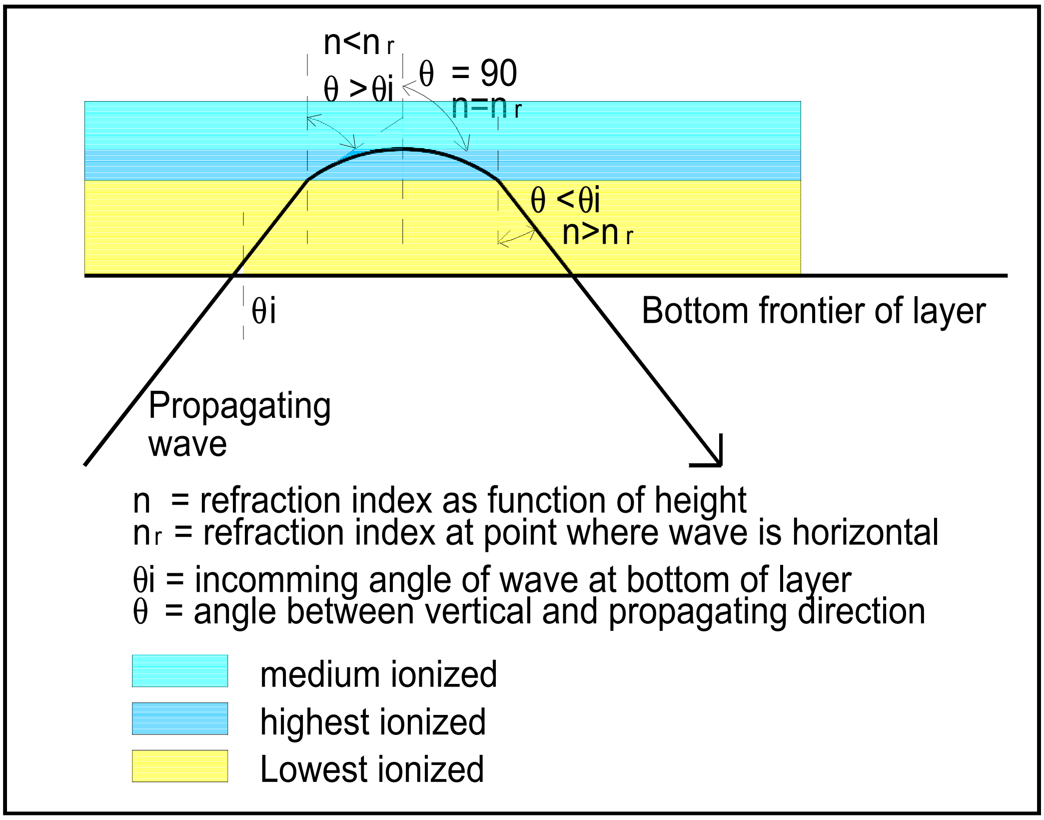

***Fig. 2.6**. Refraction until the wave is bent downwards.*

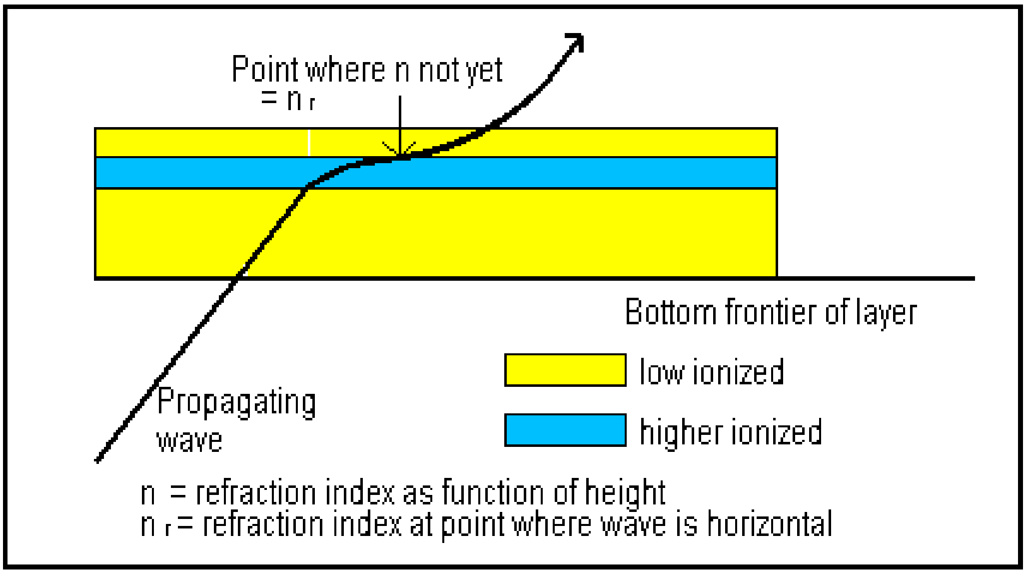

***Fig. 2.7**. A wave that is not refracted enough to be bent downward. The wave penetrates too deeply and encounters a lesser ionized sub-layer.*

I hope that some of your questions about changes in the direction of a propagated wave have been answered by this survey of various phenomena. However, I am sure new ones have come up. For example, what is ionization? What causes ionization? How do we measure ionization, and how do we know the ionization grade? How and when do we know that a wave with a given frequency and radiating angle is the right one to propagate to the desired location? Quite possibly some jargon used in the propagation trade has sneaked into our account, and some of the terms may seem a bit mysterious. However, please be patient. We shall look at the phenomena of propagation and at the language we use to describe it in greater detail as we move along. We hope to answer all of the questions that we just raised in future columns—and to make the language of propagation equally clear and familiar. **–30-**

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