REFLECTIONS

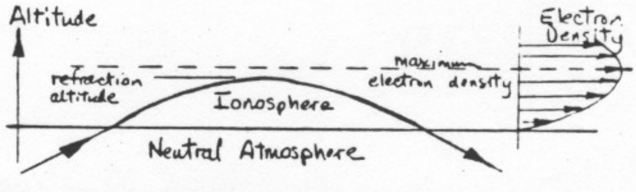

Figure 2. Refraction of a Radio Wave in the Ionosphere.

ON REFLECTION AND REFRACTION
by Randy Seaver

1. INTRODUCTION

A question that is often asked by DXers interested in medium wave propagation is:

"Is reflection or refraction the mechanism by which medium frequency radio waves are propagated by the ionosphere?"

The REFLECTIONS article in the Sept. 23, 1978 DX Monitor discussed night medium wave propagation by means of ionospheric refraction, making no mention of refraction. Some other articles, past and present, in the DX club literature state that reflection is the primary mechanism and discount refraction. As is often the case, there is considerable confusion over one of the most fundamental questions of ionospheric radio wave propagation.

This article will provide some definitions, present a detailed description of reflection and refraction, and will offer the editor's conclusions on this subject.

2. DEFINITIONS

Reflection - This is a wave phenomenon occurring at boundaries between different media (in this case, the neutral atmosphere and the ionosphere) such that the direction of at least part of the oncoming wave is abruptly changed so that it remains in the same medium. Regular reflection occurs at plane boundaries such that the angle of incidence of the wave to the reflecting surface is equal to the angle of reflection from the reflecting surface; for this case, the refractive index of the reflecting medium is sufficient to totally reflect the wave. Partial reflection can occur at a plane boundary in the same fashion as regular reflection if the refractive index of the reflecting medium is not sufficient to totally reflect the wave; in this case, part of the wave energy is reflected back to Earth at the plane boundary and part of the wave energy is refracted at the plane boundary and continues upward into the ionosphere. Diffuse reflection can occur at rough or irregular boundaries; the best example of this is the reflection of waves by a rough ground, such as mountains or valleys where the reflecting surface is uneven.

Figure 1 below shows the cases of regular reflection and partial reflection.

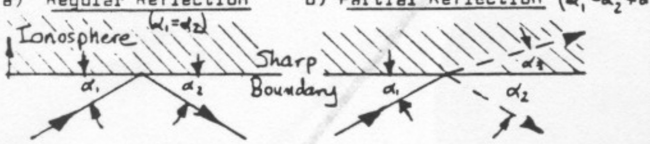

Figure 1. Reflection at a Sharp Boundary

Refraction - This is a wave phenomenon occurring between media or within a medium (e.g., the ionosphere) in which the direction of the wave is modified as the refractive index of the medium changes. In general, a radio wave will enter the ionosphere at an angle of incidence, encounter an increasing number of electrons and be gradually bent until it reaches a peak altitude, continue to be bent until it leaves the ionosphere and returns to Earth. The amount and rate of bending is determined by the refractive index of the ionosphere at the particular wave frequency. Figure 2 below shows a refracting wave in the ionosphere.

Refraction can also occur at a sharp boundary between media if the change in refractive index is not sufficient to cause total reflection; this is shown in the "partial reflection" sketch in Figure 1 above.

Refractive Index - The refractive index is a measure of the bending of a radio wave between or within media. The classical equation for the refractive index is the Appleton formula, which relates the refractive index to the number of electrons, the strength of the Earth's magnetic field, the number of electron collisions, and the wave frequency. The reader should refer to the several excellent technical books available for the derivation of the formula (e.g., Davies, Budden, Al'pert, etc). The simplified Appleton formula was presented in some detail in the 9/23/78 REFLECTIONS article and won't be reproduced here. The value of and the change in the refractive index and the application of Snell's Law determine the amount and rate of bending that a refracting radio wave experiences in the ionosphere. As noted above, the refractive index controls both the reflection and refraction of radio waves, and this will be discussed in more detail below.

3. REFLECTION AND REFRACTION

Reflection of a radio wave will occur if the change in the refractive index is great enough to cause the wave to change directions such that the angle of incidence and angle of reflection of the wave to the boundary of the ionosphere are equal. If the change in the refractive index is instantaneous, then the change in the direction of the ray path is instantaneous. Since the refractive index is dependent upon the number of electrons present along the ray path in the ionosphere, the electron density variation with altitude is very important.

Consider a model ionosphere which has an instantaneous increase in electron density (N) at altitude (h), as shown in Figure 3.

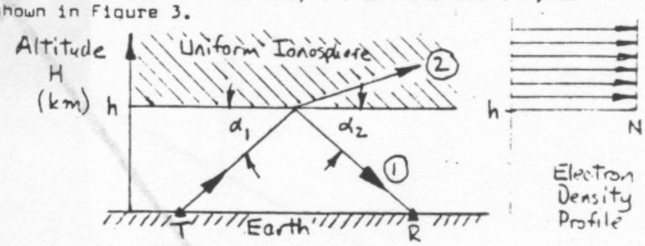

Figure 3. Model Ionosphere with Constant Electron Density.

If the oblique critical frequency of this model ionosphere, as determined by the refractive index and Snell's Law, is greater than the wave frequency, then the wave will be totally reflected back to Earth according to ray path (1) above with equal values of the angle of incidence and angle of reflection (α_1 and α_2 as shown). If the wave frequency is greater than the oblique critical frequency of this model ionosphere, then part of the energy of this ray will be reflected along path (1) and the remainder of the energy will be refracted at the base of the ionosphere and continue upward into the ionosphere along ray path (2). The fraction of energy reflected and refracted depends upon the refractive index.

Now consider a model ionosphere which has a vertical gradient of electron density with altitude up to N_{max} electrons/cu.cm. at altitude h_2, as shown in Figure 4.

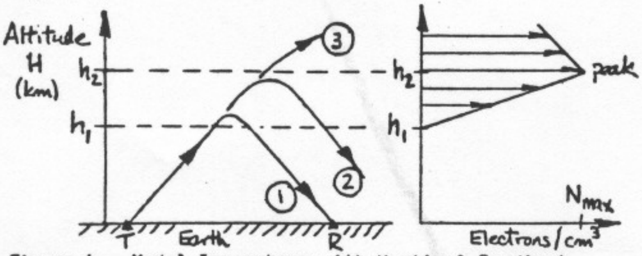

Figure 4. Model Ionosphere with Vertical Gradient

Ray path (1) is for a wave frequency very much below the oblique critical frequency of the model ionosphere. The ray barely penetrates the ionosphere before it is refracted back to Earth. Ray path (2) represents a wave frequency slightly below the oblique critical frequency of the model ionosphere. The refraction altitude of this ray is nearly equal to the altitude at which the peak electron density occurs. Ray path (3) represents a wave frequency far above the oblique critical frequency of the model ionosphere; this ray is only slightly refracted and continues upward into the ionosphere.

The E-region of the night ionosphere usually has a vertical gradient of electron density at the base of the E-region and a series of one or more electron density peaks as shown in Figure 5. Occasionally, one of the peaks will become very pronounced, resulting in a "sporadic E" layer.

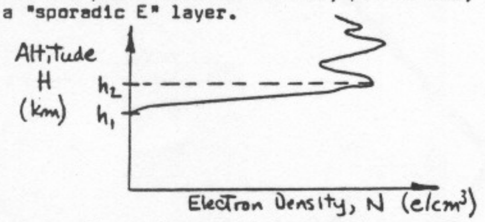

Figure 5. Typical Night E-Region Electron Density Profile.

The base of the E-region denoted by the altitude h_1 is usually between 70 and 90 km. The first peak electron density, h_2, is usually between 90 and 100 km. Several peaks in electron density may occur between 90 and 120 km. altitude.

At wave frequencies near the oblique critical frequency of the night E region, several ray paths between the transmitter and receiver may exist when rays with different angles of incidence refract from the several E-region peaks. This situation may approach a "diffusive reflection" condition. However, experimental and theoretical data shows that ionospheric absorption of radio waves is maximum when the wave frequency and the oblique critical frequency of the E-region are equal. Therefore, this is probably not a viable model for long distance medium wave propagation.

Rather than the rather stringent definition of reflection given above, most references state that "reflection" of radio waves occurs if the wave is refracted back to Earth in a distance of one wavelength. For the night E-region, this criterion is satisfied for two conditions:

a) Very low frequency waves that barely penetrate the base of the E-region, since only a few electrons are required to refract these waves back to Earth, and are refracted within a distance of one wavelength.
b) Some sporadic E layers with large electron density gradients may refract medium or short waves back to Earth within a wavelength.

Both of these examples produce regular reflections.

Medium wave ray paths can be modelled by simply assuming that the ray is effectively "reflected" from an "effective height" of the night ionosphere such that the takeoff and arrival angles are equal. While, in a pure sense, this is not what really happens as the wave passes through the ionosphere, it is an adequate approximation for most ray paths. The "effective height" of waves with low medium wave frequencies will be lower than that of high medium wave frequencies, since more bending occurs as the wave frequency approaches or exceeds the oblique critical frequency of the E-region. For E-region refraction, the "effective height" is in the range of 90 to 110 km. If the ray penetrates the E-region the "effective height" of the ray refracting from the F-region will usually be well below the altitude at which the peak electron density of the F-region exists; typical "effective heights" of rays refracted from the F-region are usually in the range of 200 to 300 km.

It is difficult to be more precise for the general case because there are many factors to account for; the real ionosphere, under the influence of the Earth's magnetic field, has geographic and temporal variations in the electron density profile.

4. CONCLUSIONS

The general conclusions that can be drawn from the above discussion include:

a) The ray path of radio waves in the ionosphere is controlled by the refractive index, which is a function of the electron density of the ionosphere and the wave frequency.

b) The two basic criteria for reflection are that it occurs at plane boundaries and that the angle of incidence and the angle of reflection are equal. These criteria are satisfied only for long wavelength waves and some "sporadic E" layers at medium wave and short wave frequencies.

c) The lower part of the night E-region of the ionosphere usually exhibits a vertical gradient of electron density with altitude. Consequently, ionospheric refraction is the general rule, and reflection is the exception.

d) The classical magnetoionic theory encompasses both reflection and refraction in a unified theory. Reflection is actually a special case of refraction.

e) A model of reflection from an "effective height" is usually assumed to greatly simplify range and elevation angle calculations with little loss in accuracy.

DEPARTMENT STORE RADIO

by Cary Simpson

In the early days of radio, hundreds of stations were put on the air by department stores and radio supply houses or stores. There was a very specific reason for this. The stores wanted to sell radios, and without a station to pick up, people wouldn't buy their radios.

Thus, even before the Department of Commerce began to issue licenses, many communities already had local outlets operating very informally, but enough hours so that customers of the stores could tune in. It was all a matter of pastime, or a hobby in those days. There was no news on the radio, no live music except at the larger stations.

In Philadelphia, stations were put on the air by John Wanamaker Store (WOO), Lit Brothers (WLIT), Gimbels (WIP), Strawbridge & Clothier (WFI) and several other department stores. WFI and WLIT were merged into WFIL, and WIP remains today. WOO was taken off the air because the owners of Wanamaker's saw no future for this "gimmick" that radio seemed to them to be.

In Chicago, WLS was operated by Sears, Roebuck and Company, in New Orleans, Maison Blanche operated WSMB, and the list could go on and on. Gene Martin should research this sometime and give us a list of all of them he can remember.

In the central Pennsylvania area, Gables Department store operated WFBG for 31 years before selling it to Triangle Publications in 1955. That was 24 years ago, but many people in and around Altoona, who were raised on a steady diet of "Gables Radio" do not today refer to WFBG as that, but still call it "Gable's". The habit is too great to break.

In those early days, the station was devoted to promoting the department store throughout much of its broadcast day. So, it's no wonder the public was brainwashed. They used to announce the time as "Ten minutes to nine. Only ten more minutes before Gable's opens for business." Then, at 9:00, a fanfare, and an excited announcer practically screamed "It's now 9:00 and the doors swing open on the biggest and best department store in all of Pennsylvania!"

The station had its "Crystal Studio" in the store's Arcade and shoppers could watch the programming from the rug department.

Can any other "old-timers" recall days of "department store radio"? How about the old Yankee Network? Or The Outlet Stores in Providence?