Propagation column
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Measuring the Ionosphere

The October and November 2005 columns discussed how the ionosphere forms. This month's column will give a brief overview of how the ionosphere is measured. As this will necessarily be brief, I will also point to references that give more details if so desired.

The F Region

The F region of the ionosphere is measured with an ionosonde, which is essentially an HF radar operating in the pulse mode with an antenna that radiates most of its energy straight up (this is also referred to as a vertical sounder). It measures the time from when the pulse leaves the transmitter to the time it returns back to the receiver. This is done as a function of frequency, generally from 1 MHz or so all the way up to 20 MHz if appropriate.

Knowing the up-and-back time of the pulse allows one to calculate the height the pulse reached before being turned around and sent back to Earth – which is simply the roundtrip time divided by two multiplied by the speed of light. This height is known as the virtual height as it assumes the pulse travels at the speed of light for the entire trip. In reality, as the index of refraction in the ionosphere decreases from 1 and approaches 0 as the pulse progresses upward into an ever-increasing electron density, the pulse slows down and refracts (bends) back to Earth. Thus the pulse doesn't really reach the virtual height, and the height it really reaches is called the true height. The true height of the pulse is always lower than the virtual height. Figure 1 shows this concept.

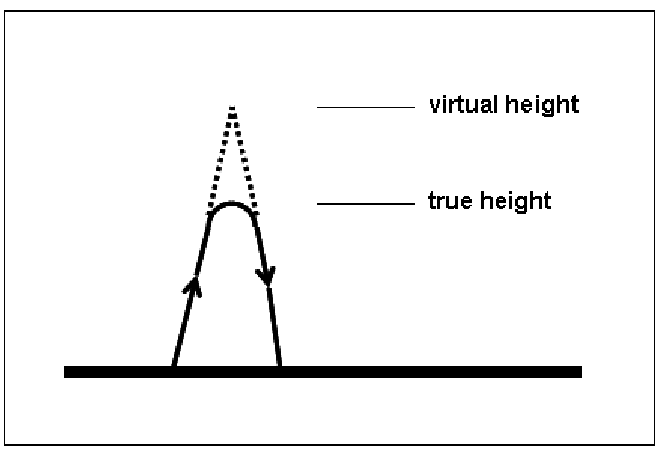

Figure 1 – Concept of Virtual and True Height

The resulting data from the ionosonde is displayed showing the echo delay time on the vertical axis (in terms of the virtual height) as a function of the sounding frequency along the horizontal axis. This plot is called an ionogram. Figure 2 shows a daytime ionogram under quiet magnetic field conditions from the ionosonde at Millstone Hill, MA.

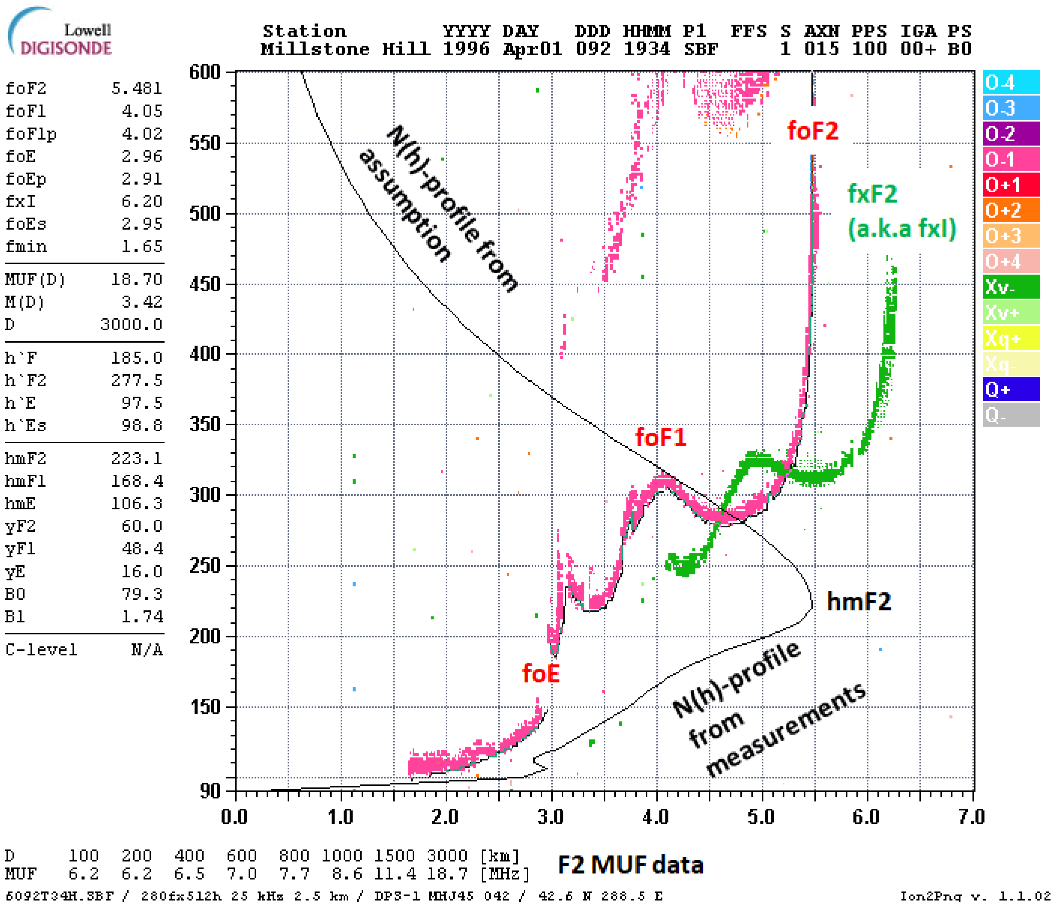

Figure 2 – A Sample Ionogram

This ionogram shows echoes from the E region, the F1 region, and the F2 region. Following the trace from its beginning around 1.6 MHz (which is designated fmin = 1.65 MHz), we see that the virtual height steadily increases as frequency increases. Just before 3 MHz the trace rises steeply – this is the E region critical frequency (annotated as foE = 2.96 MHz), indicating that the E region electron density at this frequency is not dense enough to turn the pulse back to Earth.

Similarly, another steep rise in virtual height is seen around 5.5MHz – this is the F2 region critical frequency (annotated foF2 = 5.481 MHz). Note the slight hump in the trace around 4 MHz – this is the F1 critical frequency (annotated as foF1 = 4.05 MHz). There is no steep rise in virtual height as seen with foE and foF2 because the F1 region does not have an electron density peak as do the E and F2 regions – the F1 region is more of an inflection point in the electron density.

Note that two traces show up beginning just above 4 MHz. The two traces are the ordinary wave (the red trace) and the extraordinary wave (the green trace) as discussed in the May 2007 column (an up-going wave couples into an ordinary wave and an extraordinary wave upon entering the ionosphere). The difference in refraction between the ordinary wave and the extraordinary wave is quite obvious. As predicted by theory, the extraordinary wave F2 region critical frequency (annotated fxI = fxF2 = 6.20 MHz) is higher than the ordinary wave F2 region critical frequency (foF2 = 5.481 MHz) by about one-half the electron gyro-frequency (the electron gyro-frequency is around 1.5 MHz over the Millstone Hill ionosonde).

Also note the black trace annotated ‘N(h)-profile’. This is the electron density profile as deduced from the measured ordinary wave parameters (along with making some important assumptions with respect to the shape of the profile). The profile is up to the F2 region peak height (hmF2 = true height = 223 km). Since an ionosonde can’t “see” above the maximum F2 region electron density (there are no return echoes), we have to make an assumption of the electron density profile above the F2 region peak. This assumption is based on data from satellites (also known as topside sounders), indicating that the electron density decays exponentially above hmF2. This exponential decay is what is plotted above hmF2.

With ionosondes running worldwide and running for many years, the characteristics of the F region versus time of day, month, and solar phase allow a data-based model of the F region to be developed. Translating this vertical data to oblique paths is relatively easy, and this then forms the basis for our propagation prediction programs. For example, at the bottom of the ionogram is tabular data for the MUF (maximum usable frequency) over the ionosonde assuming it’s the midpoint of various distances from 100 km to 3000 km. The F2 region MUF at low elevation angles is about 3 times foF2, while the E region MUF at low elevation angles is about 5 times foE.

One comment on ionosonde data is in order. Getting pertinent data from ionograms can be very tasking. The ionogram in Figure 2 is pretty benign. If you’re interested in more information on interpreting ionograms, download *UAG-23A: URSI Handbook of Ionogram Interpretation and Reduction (second edition)* from the Australian IPS website at **www.ips.gov.au/IPSHosted/INAG/uag_23a/uag_23a.html**. This is a 10Meg file, and it gives you a 137 page document. Yes, 137 pages – as I said, interpreting ionograms can be very tasking with geomagnetic field activity thrown in along with other phenomenon!

The E Region

As can be seen in Figure 2, data on the daytime E region also comes out of the ionogram. But ionosondes are not as important for our understanding of the quiet daytime E region as they are for the F region. The reason for this is the E region is under direct solar control. In other words, the daytime E region critical frequency under quiet geomagnetic field conditions can be modeled with good accuracy simply by knowing the solar zenith angle (the angle measured from straight up to where the Sun is) and the smoothed sunspot number (see equation 5.1 in *Ionospheric Radio* by Kenneth Davies for this relationship). On the other hand, the F region is not under direct solar control – yes, it is formed by solar radiation, but it is influenced by a slower recombination rate and winds at the higher F2 region altitudes, and results in the F2 region maximum electron density peaking a bit later in the afternoon local time as opposed to local noon for the E region.

But there is a problem at night in measuring the E region – the E region critical frequency is usually below the low-frequency limit of an ionosonde. The low-frequency limit is determined by output power, antenna gain, and system receive sensitivity of the ionosonde (not unlike what limits us on our lower bands). So how do we know what the E region is doing at night? This is where real radars at higher frequencies come into play. They can be used to determine the electron density of the nighttime E region (the nighttime E region critical frequency is around 0.4MHz, and varies a couple tenths of a MHz over a solar cycle). They also confirm that there is indeed a nighttime valley in the electron density above the E region peak – the valley that appears to be an important player in ducting on 160m at night. And they can also help us understand the E region under disturbed geomagnetic field conditions.

The D Region

Measuring the D region, whether at night or in the daytime, poses the toughest problem for scientists. Again it’s due to an ionosonde not being able to detect a return signal at low frequencies. Thus radars again play an important role in measuring the D region, as do rocket flights. As one would expect from these limited availability techniques, our understanding of the D region and its variability leaves a lot to be desired. Not having a good understanding of the D region (at least not as good as our understanding of the E and F regions) has the biggest impact to propagation on the lower frequencies – where absorption dominates in determining propagation.

There is another interesting technique used to deduce D region electron densities. The low frequency energy in an electromagnetic wave generated by a lightning discharge propagates in the Earth-ionosphere waveguide – that is, between ground and the D region. A receiving station can record the spectral characteristics of this propagating energy, and this technique then varies a model of the D region electron density to match its predicted spectral characteristics to the measured spectral characteristics.

Summary

Most of our understanding of the F region comes from data taken by ionosondes. Computer models, radars, rockets, and the spectral characteristics of lightning propagation add to this understanding for the E region and the D region. For a more detailed discussion of measuring the ionosphere, I recommend the book *Radio Techniques for Probing the Terrestrial Ionosphere* by R. D. Hunsucker (Springer-Verlag, 1991). By the way, R. D. Hunsucker was one of us – he was Bob AB7VP (now an SK).