Radio waves and Sounding the Ionosphere - Part 3

By Marcel H. De Canck, ON5AU

Most of the information we have gathered worldwide concerning the properties of the ionosphere has come through the direct measurement of quantities by radio soundings. This technique employs the use of a radio transceiver that can transmit and receive vertically incident radio waves. There are several types of ionosondes currently in service of which I will examine some in this episode.

Techniques for Probing the Ionosphere

The technique of probing the ionosphere by using a transceiver was first used, as explained in the previous chapter, by ***G. Breit*** and ***M.A.Tuve.*** Also I already explained that radio waves are refracted or bent when they enter the region of increased electron density in the ionosphere. For each concentration of electron densities there is a plasma frequency below which all radio signals are refracted back to the earth, regardless of the angle of incidence used. For example: if the plasma frequency of the ionosphere above a transmitter is 5 MHz, then all radio signals transmitted vertically to the ionosphere that are less than 5 MHz will be returned back to the earth and all frequencies higher than 5 MHz will pass through the ionosphere into space.

It is this characteristic of the ionosphere that we exploit to probe the properties of the ionosphere. The device used to probe the ionosphere is known as an ionosonde. It consists of a combined radio transmitter and receiver capable to transmit pulses toward the above ionosphere and receiving the same signal pulse as it returns back to the receiver.

Depending on the transmitter power and the wave attenuation during its travel, it is not rare to receive multiple echoes. The returned signal pulse can be reflected back towards the ionosphere by the earth surface and be refracted there again towards the ionosondes. In some cases this might happen a few times. It is self evident that each successive multiple echo pulse signal strength becomes weaker.

The pulsed Ionosonde

This type of ionosonde is the basis for most modern ionosondes. It works by transmitting a series of pulses vertically upwards into the ionosphere. A typical oscilloscope can be used to form a very simple view screen for ionosonde devices, although most modern ionosondes are more complex than this. The time-base of a cathode ray tube is used as a timing device to measure the delay time. When the echo or reflected radio pulse signal is received by the ionosondes, it is fed to the Y-plates of the tube in such a way that the electron beam deviates in direction, **Fig. 65.1** (the A scan method). The position of the pulse on the time base is a measure of the traveling time of the pulse and hence of the virtual height of reflection. The Y-deflection is related to the echo amplitude.

It is also possible to apply the echo pulse to the grid of the oscilloscope to blank out the time base, **Fig. 65.1** (the B-scan method).

The conventional ionosonde for measuring the virtual height of the ionized layers and their respectively critical frequencies is a sweep frequency pulsed radar device. The frequency can range from about 0.1 MHz to 30 MHz with a sweep duration from a few seconds to a few minutes. As the frequency of the transmitted pulses is increased, the path of each pulse through the ionosphere varies. The time taken for the pulse to reach the ionosonde may and can change. Higher frequencies penetrate deeper into the ionosphere and there is also a retardation process (see later).

Slower ramp-up times can increase the resolution of the probed ionosphere and result in better signal to noise ratios, but slow ramp times prevent the ionosonde from following the sometimes rapid changes that might occur in the ionosphere. Rapid ramps in frequency provide a better instantaneous snapshot of the ionospheric layers and state, but suffer from lower signal to noise ratios. So often a compromise has to be taken between better resolution and instant picture.

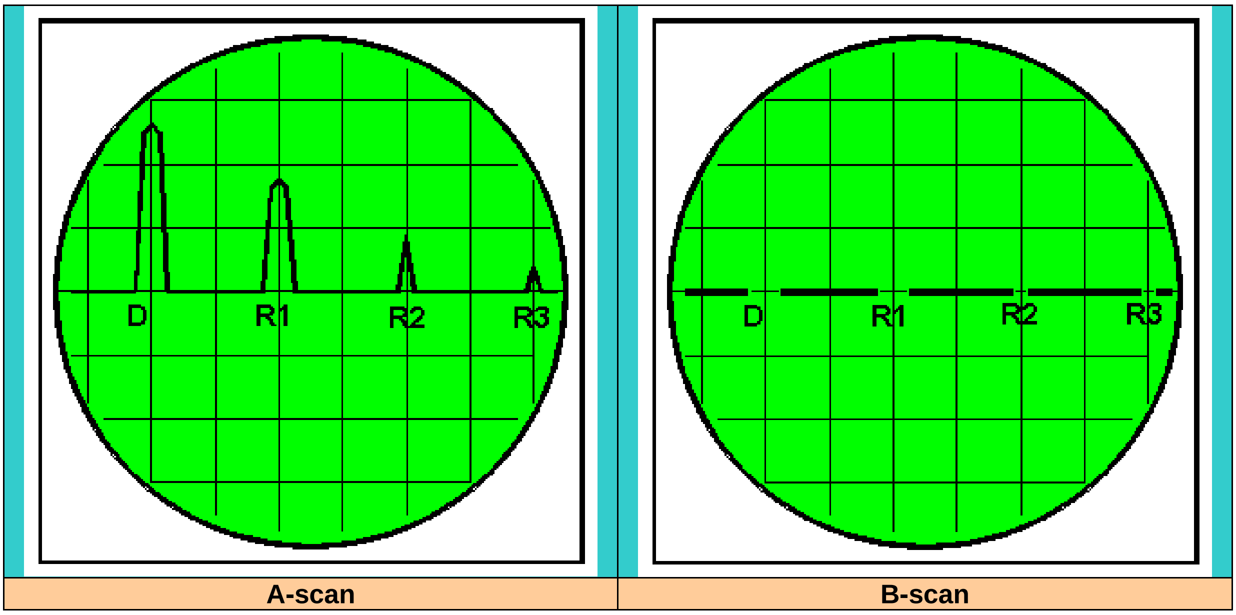

__Fig. 65.1.__ The D pulse is the direct transmitted pulse and R1, R2 and R3 are the received reflected echo pulses. At the left the A-scan method where the pulses are applied to the Y-plates; at the right is the B-scan where the pulses are applied to the grid.

At the early stage before the computer entered into our live, the ionograms were obtained and developed on a slow moving film, **Fig. 65.2a.** Digitalized registering and plotting is the current mode to produce ionograms by ionosondes, **Fig. 65.2b.**

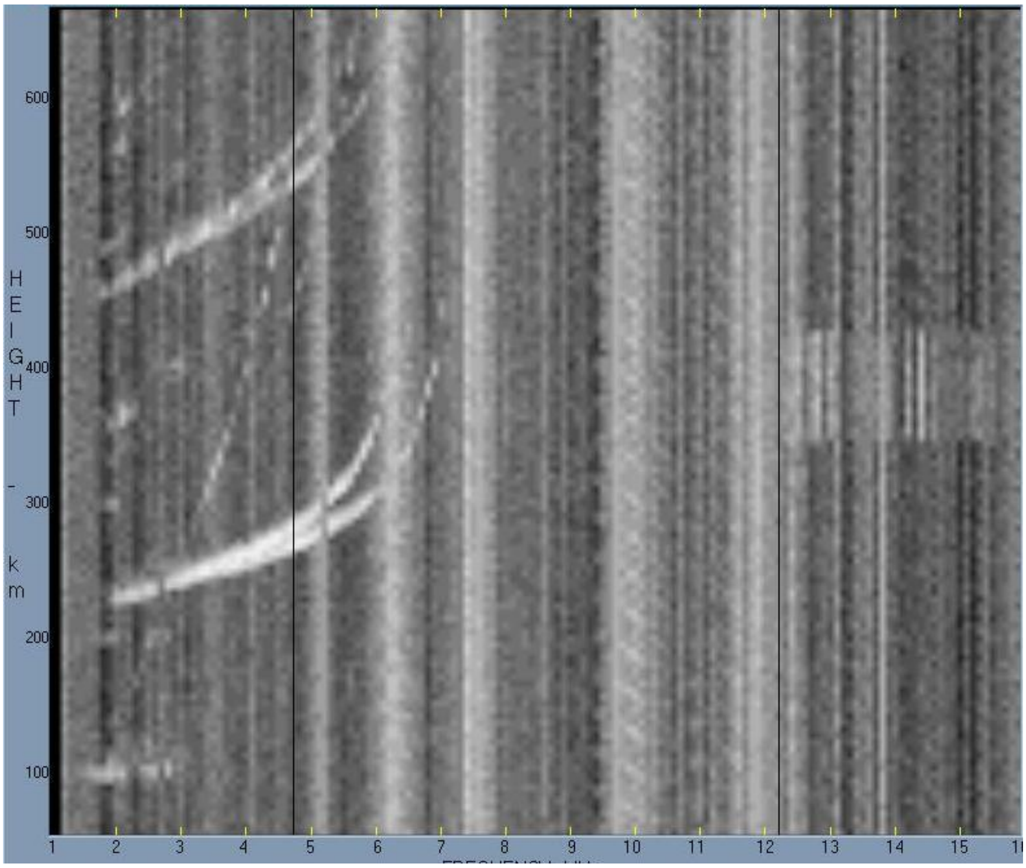

__Fig. 65.2a.__ An ionogram recorded by slow moving film.

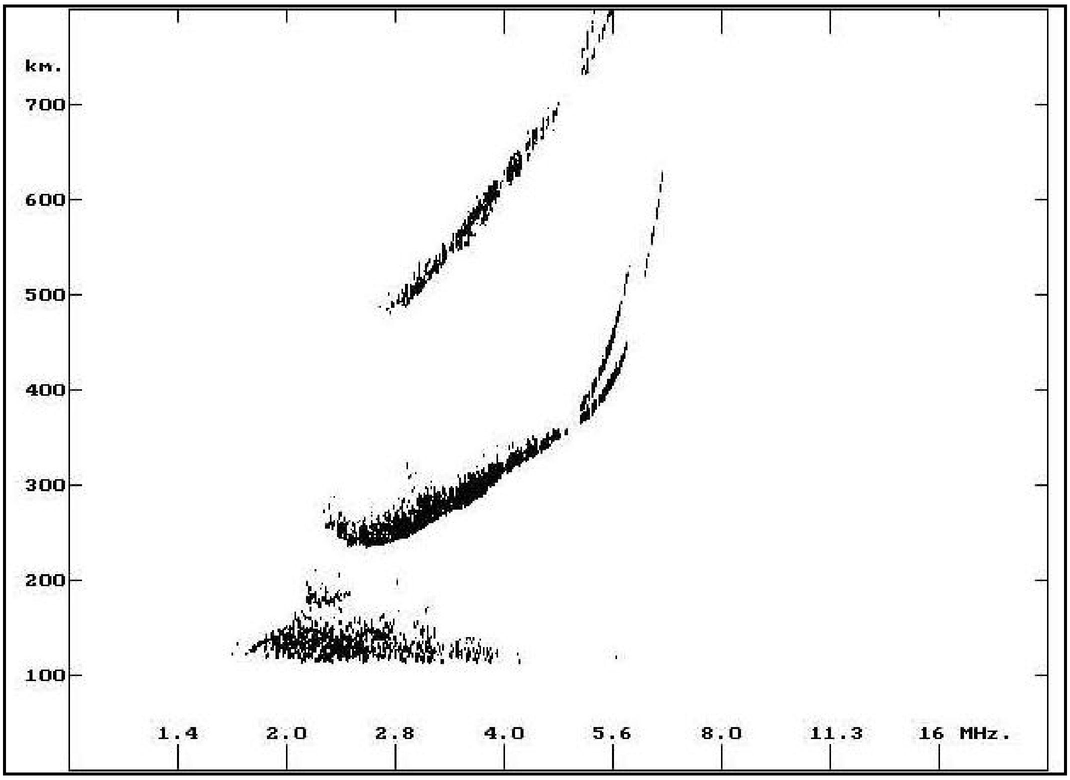

Fig. 65.2b. *An ionogram plotted by a computer program.*

An operational ionosonde can cause considerable interference with other radio communications. Many radio amateurs have heard ionosondes, perhaps without realizing it. Many ionosondes produce an audible sound like a pecking or clicking noise with rapid pulses for certain periods of time and then abruptly cease as the transmission ends or the frequency of the pulses changes.

The Digisonde

A highly sophisticated pulse amplitude sounder is the digisonde. It is capable of measuring a host of additional ionospheric parameters such as the amplitude of returned echoes, the travel time of the reflected echoes, the precise Doppler frequency, the angle of arrival and the separation of the ordinary and extraordinary waves, the wave polarization and the curvation of the wave front of the returned pulses. The obtained parameter values are digitally preprocessed and displayed on a computer monitor or printed on paper.

The Center for Atmospheric Research at the University of Massachusetts Lowell (UMLCAR) is in the lead for research and development of digisondes. The Lowell Digisondes are the most used worldwide, **Fig. 65.a – 65.b**. The receiver uses an array of crossed loop antennas to facilitate the measurements of the angle of arrival of the ordinary and extraordinary components of the received pulses. An array of four (DSP-1) or seven (DGS-256) of these antennas is used and by switching in the appropriated delay filters, the receiver beam is pointed vertically and in 14 directions arranged in two circles at two angles that are off from the vertical direction, **Fig. 65.c**. Each receiving antennas has a preamplifier (1 – 30 MHz) and is connected by low loss coax cable of identical length with the switching and receiver system. The direction and magnitude of the maximum signal can then be measured. The Doppler shift is also recorded as either positive or negative from normal.

The digisondes include stages of band pass filters capable of filtering out spurious transmissions and interference that could destroy the results. Band pass filters on the order of 400 KHz have been used in many digisonde devices. Digisondes are complex devices, but have been successfully used to uncover many features of the ionosphere. Digisondes can work totally independently and are mostly used remotely. A program and algorithmic activates the transmitter, receiver and antenna switching and computes all the necessary parameters and plots them as an ionogram. Nevertheless, in some cases the automatic interpreting of the data to compute the various ionospheric parameters is not correct (see later).

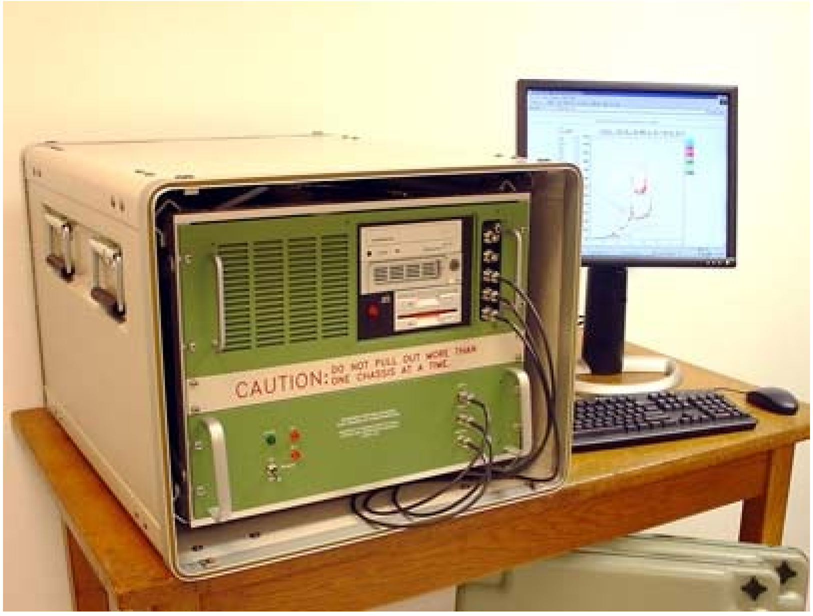

Fig. 65.3a. *The Lowell DSP.1 portable digisonde sounder with low power transmitter of 300 watt*

Fig. 65.3b. *The Lowell DGS256 a 10KW digisonde used at Dourbes (Belgium).*

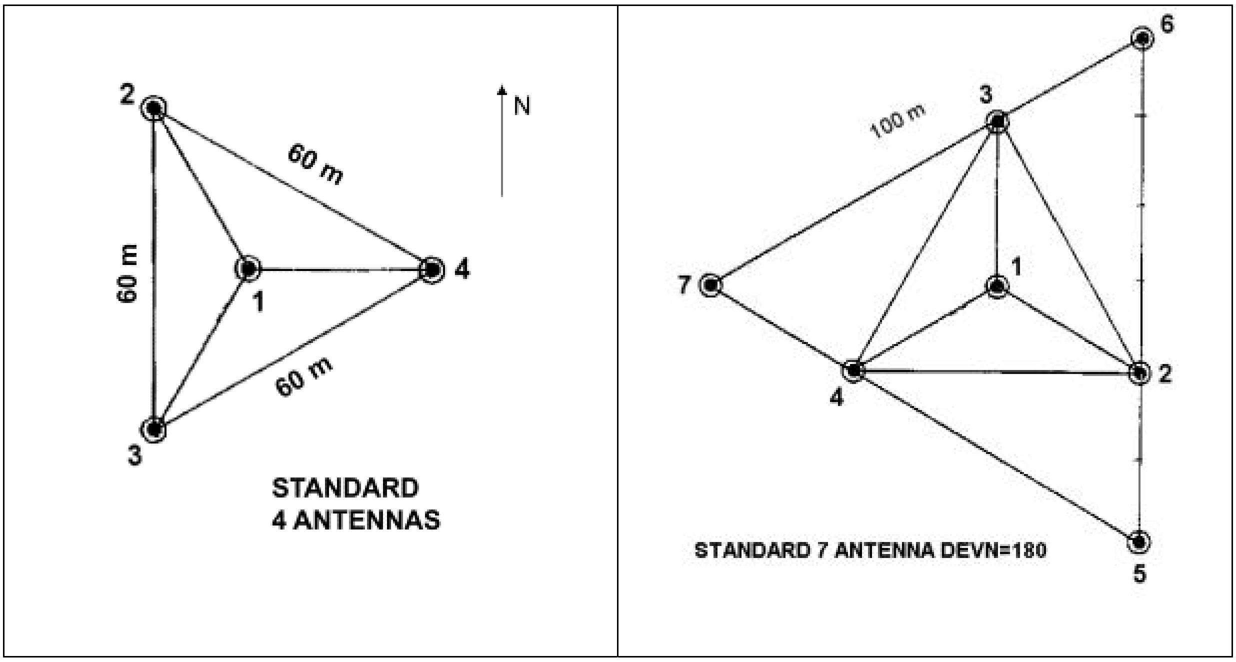

Fig. 65.3c. *The layout of respectively a four and a seven receiving antenna array type used by Lowell digisondes.*

Fig. 65.3d. *One of the crossed loop receiver antennas of a seven array type. In the background is a second one. Sheep are here often the lawn mower, and fences were put around the antennas for protection.*

Fig. 65.3e. *The entrance of the digisonde station at Dourbes. The 42-meter supporting mast for the vertically pointing asymmetrical rhombic transmitting antenna is clearly seen on top of the digisonde station.*

Fig. 65.3f. *A detail of the broadband asymmetrical rhombic transmitter antenna of the Dourbes digisonde. The asymmetrical rhombic is constructed with three wires and terminated at the top with a 600 ohm resistor.*

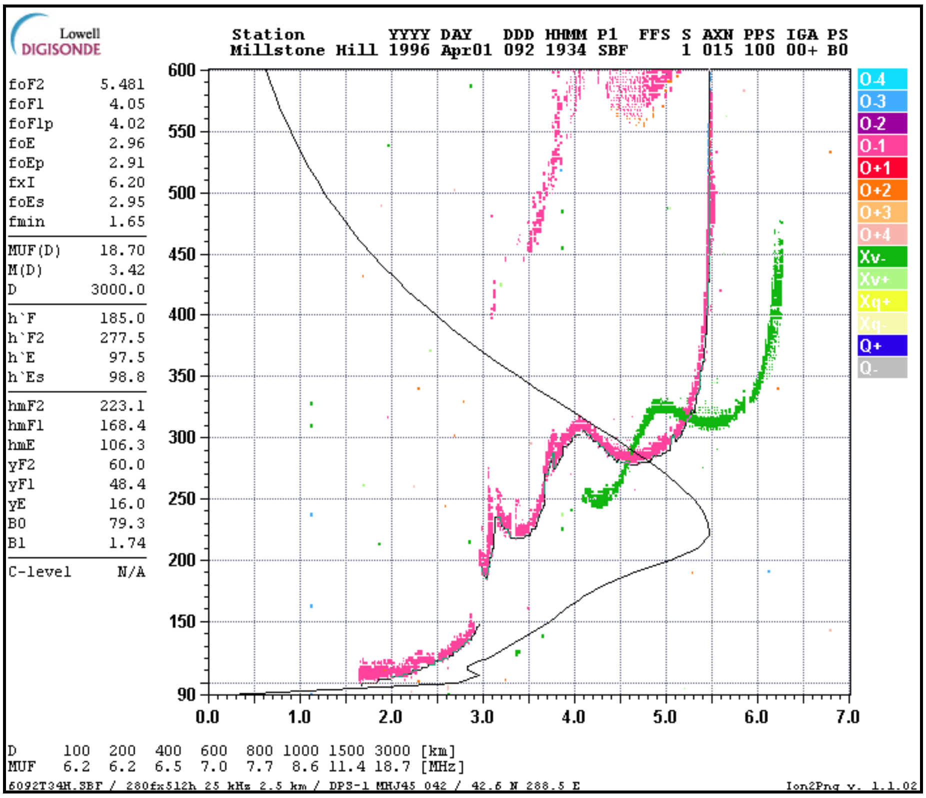

Fig. 65.3g. *A typical ionogram of a digisonde. I shall explain later how to read and interpret various ones.*

The Chirp Sounder

Chirp sounders operate differently by broadcasting continuous modulated and linearly ramped signals into the ionosphere. The signal is reflected and returns back to the ionosonde receiver. Meanwhile, the transmitter frequency will have increased by an amount proportional to the time that has elapsed for the returning signal. When the transmitted frequency is subtracted from the echoed signal then an audio frequency is the result (chirp sound). The frequency of the chirp tone is proportional to the time delays of the signal. By applying Fast Fourier Transformations to this data, time delays and therefore reflection heights can be determined relatively accurately.

Chirp sounders are in favor over other types of sounders because they require very low transmitter power to function, usually in the range of 10 to 100 watt. The Doppler and phase components are fairly easily determined by use of the Fourier transformations of the received and differenced echo signal. The adjacent picture illustrates a typical commercial 50W FM/CW (chirped) ionospheric sounding transmitter.

However, chirp sounders have the disadvantage of taking longer time to complete a frequency sweep. A chirp sounder may require as much as 10 minutes to complete a sounding of the ionosphere if the resolution of 3 kilometers in height is required over a frequency range from 1 to 30 MHz. Often substantial ionospheric characteristics changes may occur during this time and therefore chirp sounding is only practical when the state of the ionosphere is fairly constant over time periods from 5 to 10 minutes

Collecting very interesting ionospheric properties is possible by means of chirp sounders from locations much further from the sounder station. G3PLX developed a very interesting project to investigate the ionosphere by yourself. An HF receiver, a GPS clock giving 1 pulse/sec, a PC with a sound board, and some software is all you need. See the below links:

http://jcoppens.com/radio/prop/g3plx/index.en.php
http://homepages.ipact.nl/~pa1are/index.html

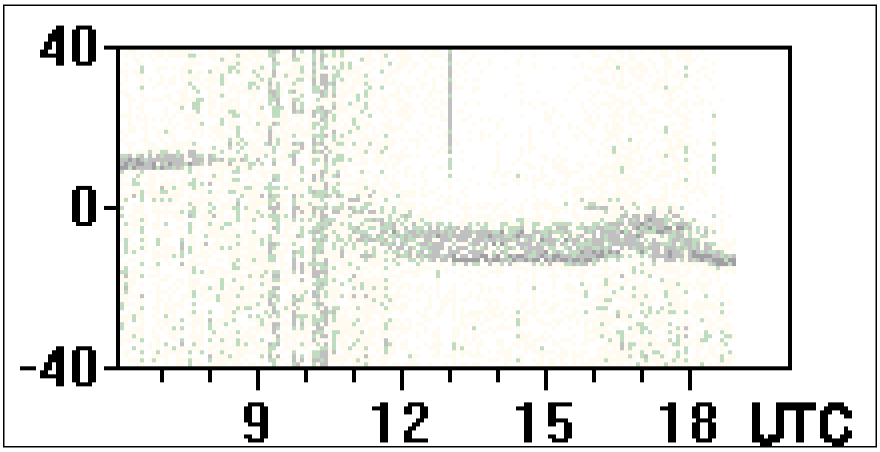

Fig. 65.4. *A plot of transmission from a in Cyprus located chirp sounder and received in New Zealand (ZL1BPU), showing long path (left) and short path (right). Vertical scale is milliseconds.*

Oblique sounding

The above handled ionosondes are used to collect data of the ionosphere right above the ionosonde location and to give a good picture of the ionospheric properties. They were and are the source for the empirical data about the ionosphere used in propagation studies and prediction programs. Although these ionosonde stations are located worldwide, there are locations where it is not easy to operate one, like oceans, deserts and other remote places. Knowing the ionospheric properties and behaviors at these parts of the world is also very important to know. The oblique sounding technique is one method to achieve this and reach those locations.

With oblique sounding the transmitter and the receiver locations are far apart from each other, even thousands of kilometers or miles. An often used distance is around 3 000 km but is not a must; it may be more or less depending on what area is wanted to be investigated. The illustration, **Fig. 65.5**, gives an idea of such an oblique sounding geometry. It is obvious that not as many ionospheric parameters can be collected compared with vertical sounding. But oblique sounding has also its own specific advantages to study ionospheric and propagation properties. These are multiple paths, with their different delay times and the **MOF** (**M**aximum **O**bserved **F**requency) or the highest supported frequency for a given communication circuit or hop mode. I strongly recommend reading my issue of the series ***"A Communication Circuit study - Part 3 - November 2003,"*** where I explained oblique ionograms simulated with the program PROBLAB – PRO2.

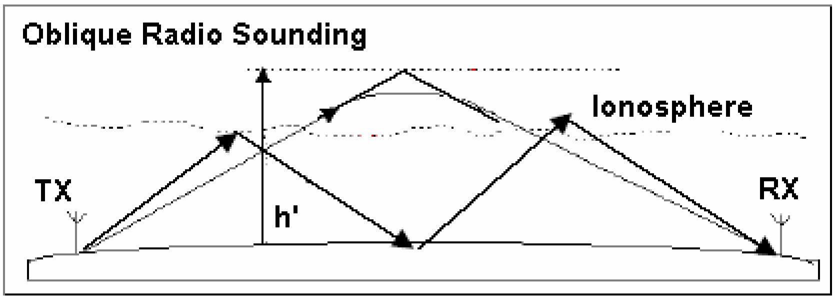

Fig. 65.5. *The geometry of an oblique sounding setup.*

Fig. 65.6. *The IRIS (Improved Radio Ionospheric Sounder) transmitter and receiver used at Svalbard and Chilton.*

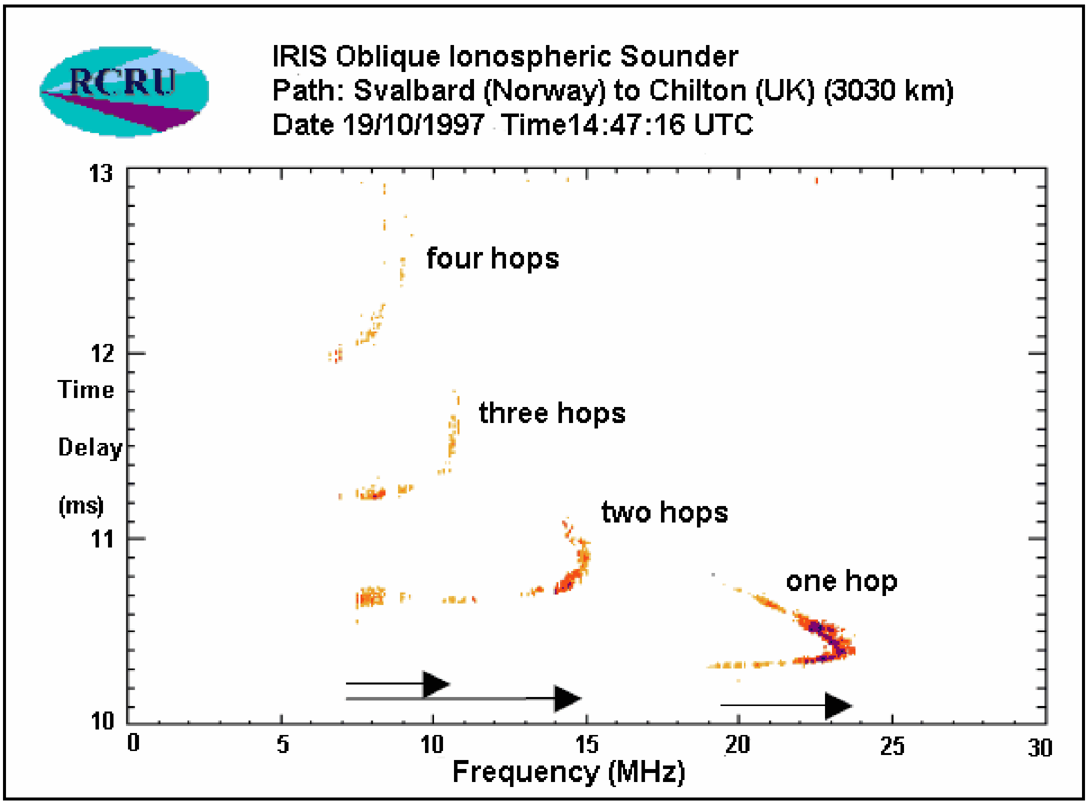

Fig. 65.7. *This is a typical ionogram of an oblique ionospheric sounder. Here the locations are TX Svalbard (Norway) and RX at the Chilton station (UK) a ground distance of 3 030 km.. The multiple propagation paths and hop mode possibilities are clearly seen with their respectively propagating*

delay times. Frequencies between 19 and 24 MHz are one hop modes, between 12 and 15 MHz are two hop modes and between 7 and 11 MHz are principal possible via two, three and four hop modes. By knowing the ground distance between the two stations and the measured delay time of the various hop modes it is simple to compute the refraction heights.

Fig. 65.8 shows many Svalbard-Chilton ionograms recorded over several days in 1997. Here each ionogram has been plotted as a single time point to produce a plot of frequency against time. In this way the observed spectrum occupancy for this propagation path can be seen very easily.

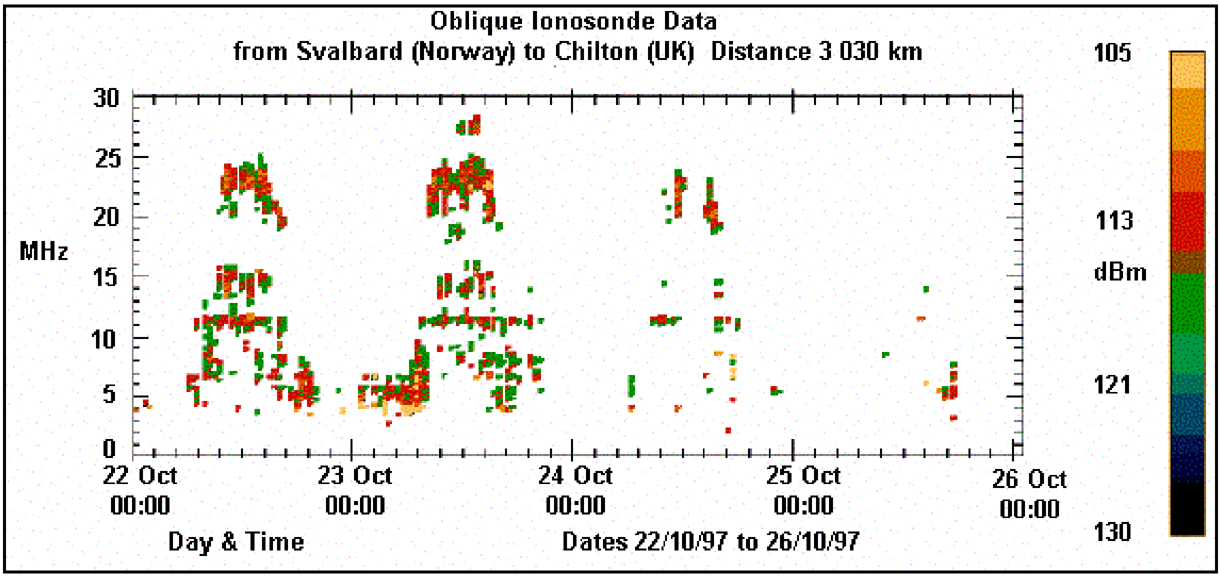

Fig. 65.8. *An spectrogram of the IRIS data recorded at Chilton from the chirp transmitter located on Svalbard . The diurnal variation of the available bandwidth can be clearly seen in the first 2 days of the four days plotted. However, ionospheric absorption disrupts this pattern for the latter two days. The bandwidth of each of the multiple hops can be clearly seen for this trans-auroral oval path. Between 20 and 25 MHz propagation is only via a single ionospheric F-layer reflection, the 1F MOF. Yet below 15 MHz the multiple F-layer reflections can be seen to extend the available bandwidth. The 2F MOF, 3F MOF and even 4F MOF are all available during certain conditions on the 22nd and 23rd. There is evidence of scatter propagation above 25 MHz at noon on the 23rd. Increased auroral absorption prevented propagation on 25th October 1997, which is coincident with an increase in geomagnetic activity on the 24th and 25th.*

Ionograms are often complex to interpret properly. Even in a 15-minuts period they can differ completely from the foregoing or next one. Also great variations are found from day to day, daytime or nighttime, seasons and sun activity cycle. Explaining and illustrating these huge variations found on ionograms is next issue subject. So stay tuned.

-30-