The Panoramic Ionospheric Recorder

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Abstract

This article gives a description of a new type of recorder for ionospheric sounding. The recorder covers the frequency spectrum 1 to 20 Mc/s in 30 seconds and is for that reason of great value for investigations in the polar regions, where ionospheric conditions are very fluctuating. The use of a wide band transmitter and receiver has made the short sweep time possible. Only one variable capacitor rotating at low speed is necessary. Automatic tracking between receiver and transmitter is secured through the use of a heterodyne system. Samples of records obtained at *Kiruna* since the beginning of observations in July 1948 are shown.

Ionospheric research has been carried out by the *Research Laboratory of Electronics* since 1942 at our *Askim Observatory*, 6 miles south of *Gothenburg*. Among other projects we have been interested in sweep frequency recording and have used both automatical and manual recording apparatus (RYDBECK, 1942 a, b). A corner of the recording room is shown in fig. 1. The picture shows equipment for both fixed frequency and sweep frequency recording.

In fig. 2 is further shown an automatic mechanically tuned sweep frequency recording receiver. Although this equipment has rendered quite satisfactory service, we found already at the beginning of the last war that the development of a high speed "electronic" sweep panoramic recorder was highly desirable for the further development of ionospheric research. Due to the war situation however it was very difficult to obtain quality parts for the new equipment, the completion of which therefore was considerably delayed.

In general the usual disadvantage with ordinary sweep frequency recorders is their mechanical tuning elements. These make it comparatively difficult to construct receivers that automatically follow the transmitter through the frequency sweep. On the other hand, if the transmitter is followed manually through the frequency range on a receiver, a frequency band of say 15 Mc/s can not be covered in a shorter time than about 10 minutes. The use of tuning capacitors in the transmitter also determines an upper limit of the output pulse power of the transmitter. One method to increase this upper limit is to use oil as dielectric but this will be a complicated solution.

To avoid these difficulties, the most natural solution is to use wide band stages instead of tuned stages. The panoramic recorder employs both a wide band transmitter and an untuned receiver. The transmitter and the receiver are controlled through a heterodyne system. Thus the only rotating capacitor in the receiver is the tuning capacitor in a common oscillator. As this capacitor is on low-voltage level and consists of only a few blades there are no mechanical limits for the rotating speed. The only speed limit of the frequency sweep is the maximum permissible detuning between transmitter and receiver when the most delayed echoes arrive. Allowing a maximum permissible detuning of 8 kc/s when echoes arrive from a virtual height of 600 km

Fig. 1. A corner of the recording room at the *Askim* Observatory.

a minimum time of 10 seconds is required for each frequency sweep.

However, the single remaining rotating capacitor could also be omitted. A reactance tube could be used as a variable common oscillator. But this would probably call for the use of an intermediate frequency that would be unnecessarily high.

The panoramic system we have used was suggested already in 1939 by WILLIAM O. REED and O. E. H. RYDBECK, both at that time at *Harvard University*. The recorder covers the frequency spectrum from 1 to 20 Mc/s in 30 seconds, with an output pulse power varying from 16 kW on the lowest frequency to 6 kW on the highest frequency. The result is presented on the screen of a 12" cathode ray tube and recorded with a 16 mm ciné camera. This recording equipment has been in continuous operation at the *Kiruna Observatory* since the summer of 1948.

During the course of the development of our recording equipment information was received from the United States regarding a very similar outfit developed by P. G. SULZER and associates (1946). SULZER's work proved to be very valuable and stimulating comparison in our efforts to develop a high quality recording equipment.

The Recorder

The block diagram is shown in fig. 3. From this diagram is seen that the frequency determining part in the equipment is a common oscillator, variable from 31 Mc/s to 50 Mc/s. The output of this oscillator is mixed with the output from a fixed oscillator operating on 30 Mc/s, the result being an output voltage with a frequency continuously varying from 1 Mc/s to 20 Mc/s. This radio-frequency is amplified in an untuned wideband amplifier and fed to the transmitting aerial.

The common method when making ionospheric investigations is to transmit short pulses of radio-frequency and to receive these after they have been reflected by the ionosphere. By measuring the time delay of the reflected pulses one can determine the virtual height of the reflecting layer. In this recorder the 30 Mc/s oscillator, the driver, and final stages are pulsed by a 50 microsecond pulse. The pulse repetition rate is 50, synchronized with the power line. The output from the variable common oscillator is also fed to the receiver input stage, where it is mixed with the incoming reflected signals. The difference frequency remains constant, 30 Mc/s, throughout the entire frequency band. The first intermediate frequency of the receiver is therefore chosen as 30 Mc/s, which means that the transmitter and

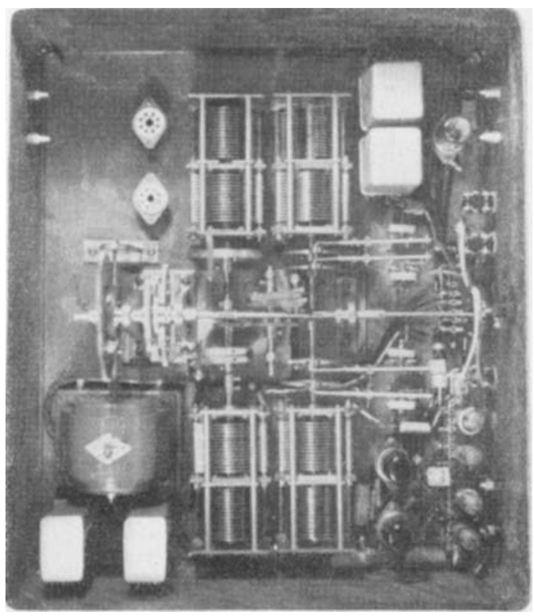

Fig. 2. An automatic mechanically tuned receiver for sweep frequency recording.

the receiver always are tuned to the same frequency.

The output voltage from the receiver, which contains both the transmitted ground wave and the echoes is fed to the indicator and applied as intensity modulation of a 12″ cathode ray tube. By chosing a suitable vertical sweep, synchronized with the pulse frequency, and a horizontal sweep, proportional to the frequency of the transmitter, the result will be presented on the screen of the indicator tube in the form that is common for sweep frequency records. The time it takes to form the image of each sweep is 30 seconds, and as the indicator tube has an afterglow time of 30 seconds each sweep can be observed visually. The various pulse and gate voltages that are needed in the recorder are generated in the time-base unit.

A short description of the different units that form the panoramic ionospheric recorder will be given below.

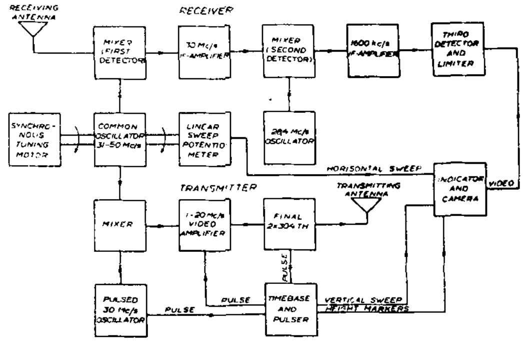

Fig. 3. Block diagram of the panoramic ionospheric recorder.

Common oscillator

The tuning capacitor in the common oscillator is made with semi-circular plates and is slowly rotated by a synchronous motor at a speed of one rpm. Thus, during one rotation of the capacitor, the frequency increases from its lowest value, 31 Mc/s, to the highest, 50 Mc/s, and then back to the lowest again. This calls for a very high degree of precision in the construction of the capacitor, the same frequency is obtained with two different settings of the capacitor, and those two settings must make the same angle with the lowest frequency setting. This is due to the fact that on the same shaft as the capacitor is mounted a precision linear potentiometer, over which is developed a dc-voltage proportional to the position of the tuning shaft. This voltage is zero when the oscillator frequency is 31 Mc/s and increases to + 50 volts on the highest frequency. The horizontal sweep of the indicator tube is driven from this source, the horizontal position of the electron beam will therefore be proportional to the frequency of the transmitter.

The oscillator circuit is a Hartley oscillator, and the radio frequency voltages to the transmitter and the receiver are separated by a buffer stage. This was necessary in order to avoid feed-back between the transmitter and the receiver through a common connection.

In the same unit as the common oscillator is also mounted the input mixer tube for the transmitter. This was necessary in order to decrease the frequency that had to be fed to the transmitter unit. The local oscillator for this mixer is a pulse-operated miniature triode, 6C4, working on 30 Mc/s. The output of radio frequency pulses is fed to the injector grid of a 6K8 mixer tube and the signal grid of the same tube is fed by the common oscillator. Over the plate load resistor will therefore appear a pulsed radio frequency, varying from 1 to 20 Mc/s as the tuning capacitor covers the frequency band. These pulses are then fed to the wide-band amplifier.

Transmitter and antenna system

The transmitter is a broad-band amplifier with a band-width of about 20 Mc/s, using the miniature pentode 6AK5 in the first three stages (FINK 1940). These are followed by another two stages of amplification, using a 6AG7 and a 807. The next stage is a phase-inverter stage driving a 4—250 A push-pull stage. This stage is operated with a plate voltage of 1,500 volts and a grid bias of — 200 volts. During the time when the pulsed 30 Mc/s oscillator operates, this bias is decreased to — 25 volts. Each tube draws about 0.4 A in plate pulse current. From this stage, the radio frequency is fed to the final stage, two 304TH connected in push-pull. These tubes operate with a plate supply voltage of 5,000 volts and a bias of — 1,000 volts. They are also pulsed, during the pulse the bias

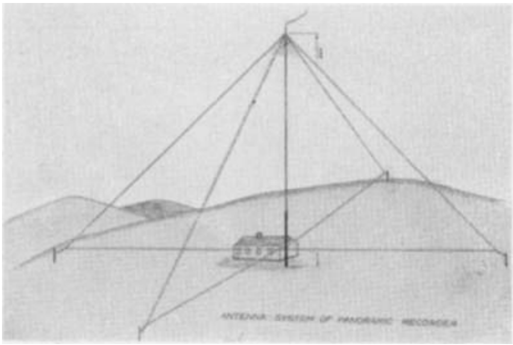

Fig. 4. The transmitting and receiving D-antenna used with the panoramic ionospheric recorder.

is reduced to — 20 volts, corresponding to a plate current of 2.5 A. Continuous operation under these conditions would of course be out of question. The maximum pulse output power is 16 kW, but a new version of this recorder is planned with an output power of 100 kW. The use of a wide-band amplifier requires more stages than an ordinary tuned amplifier, but on the other hand the problem of obtaining high output power is much more simplified.

One of the more important problems with a transmitter covering such a wide band as in this case is that of finding a suitable antenna system. The impedance of an ordinary antenna depends very much on the frequency, showing extreme values at the resonant frequencies. It is not possible to use such an antenna because the load characteristics should vary too much within the frequency band. We have therefore tried combined antennas of different kinds, and the antenna that seemed to give the best result was a construction used by the *Department of Terrestrial Magnetism, Carnegie Institution of Washington* (GEORGE 1945). This so called D-antenna has an average impedance of 600 ohms, and the impedance does not change more in amplitude than 2 : 1 within the entire frequency band. A drawing of the D-antenna is shown in fig. 4. As seen in this figure there are two antennas mounted at right angles. One of them is used for the transmitter and one for the receiver. We have not completed our tests to find an even better antenna. Further improvements are therefore to be expected.

Receiver

The input stage of the receiver is a miniature double triode, 6J6, with a 1,000 ohms resistor in the common cathode return. The radio frequency from the common oscillator is injected over this resistor and the grids are fed out of phase from the antenna. The plate circuit is tuned to the intermediate frequency, 30 Mc/s. After the mixer stage follow two transformer coupled stages of amplification. In the next stage this intermediate frequency is changed to a new intermediate frequency, 1,600 kc/s. The local oscillator is a Hartley oscillator, but in order to improve the stability this oscillator will be replaced by a crystal oscillator. After one stage of amplification the signals are rectified and passed through a limiter circuit in order to prevent the transmitted pulse and strong echoes to overload the cathode ray tube. In order still to improve this matter the receiver will be redesigned to have a logarithmic voltage response.

A receiver for reception of these short pulses must have adequate band-width to pass the pulses without distortion. Special circuits have therefore been incorporated to fulfill this requirement. Another thing of importance is that the different parts of the receiver must be very well screened from each other. For example, even a small voltage leaking from the local oscillator to the input stage causes cross-modulation with strong broadcasting stations resulting in unnecessary interference lines on the recorded picture.

The sensitivity of the receiver is better than 4 microvolts over the whole band except for the lowest frequency where it decreases to 10 microvolts. The receiver assembly is shown in fig. 5.

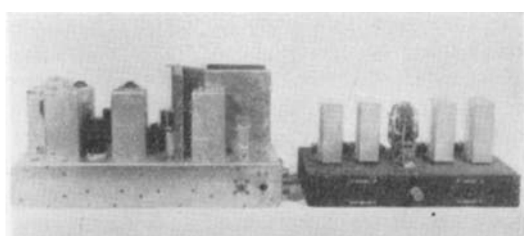

Fig. 5. The receiver and the relay assembly.

Time-base and indicator

The time-base, fig. 6, serves as a generator of the various pulse and control voltages that are required. The functions of the time-base are synchronized with the frequency of the power supply. It delivers pulse voltages for the 30 Mc/s oscillator, the driver and the power amplifier stages in the transmitter. Further it delivers a saw-tooth voltage for the vertical deflection in the indicator tube. The duration of this voltage is variable from 0 up to a time corresponding to the time it will take for the signals to travel up to a height of 1,000 km and back again. There is also delivered a negative gate pulse to the cathode of the indicator tube with a duration equal to that of the saw-tooth voltage. This voltage intensifies the spot on the screen during the sweep.

During the vertical sweep there are also delivered short positive pulses to the grid of the indicator tube. These pulses occur with a frequency of 3,000 cps. They will therefore serve as markers for each 50 km in virtual height. If there is no deflecting voltage on the horizontal plates of the indicator tube these pulses and the pulses from the receiver will appear as dots on a vertical line on the screen. But during the frequency sweep the voltage from the linear potentiometer in the common oscillator will make the beam move horizontally over the screen. Then the markers and the echoes will appear as horizontal lines on the screen. The broadcasting bands will appear as vertical lines.

In front of the screen of the indicator tube is placed a 16 mm *Paillard-Bolex* motion-picture camera. This can be seen in fig. 7, which shows some units of the recorder. The shutter of this camera remains open during each frequency sweep. After the sweep is completed the shutter closes for a moment to allow the camera to advance a new frame of film. The record will therefore be a time exposure. The operation of the camera is made by means of a mechanical device driven by a solenoid, which is energized through a micro switch in the common oscillator. In addition to the frequency sweep a small watch showing local time is photographed on the same picture. This identification system will in the near future be completed with another marking showing the date of the day.

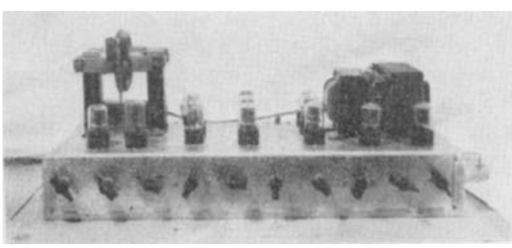

Fig. 6. The time-base used for generating the various control voltages in the recorder.

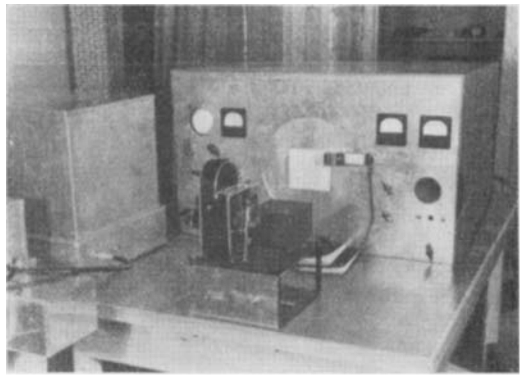

Fig. 7. This picture shows the indicator with its associated camera, the transmitter and the common oscillator.

The operation of the recorder is wholly automatical, a system of relays is incorporated to make the recorder start and stop at predetermined times. A precision clock controls the starting pulses for this system of relays. The relay panel is shown in fig. 5.

Usually the recorder starts every hour and records six pictures, but it is also possible to let the recorder run continuously day and night. Normally the ionosphere does not change so very much from picture to picture. Therefore it is possible to play the recording in an ordinary movie projector and study the gradual changes in the ionosphere. Especially during magnetic disturbances when ionospheric conditions are changing very rapidly, these films are of very great importance for investigations of the character of the disturbance.

Records

In fig. 8 and fig. 9 two typical records are shown obtained with the panoramic recorder at *Kiruna* during the spring 1949.

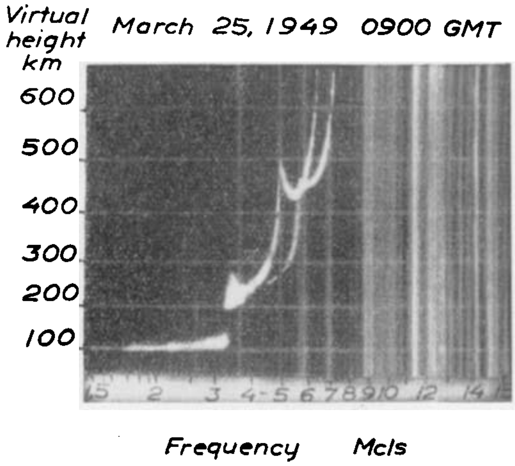

Fig. 8. Record made on an undisturbed day, April 25, 1949, at 0900 GMT.

Fig. 8 shows a typical record made on an undisturbed day. The echoes start at the lower frequency limit of the recorder, appearing at a height of 100 km which is the normal height of the E-layer. At 2.1 Mc/s the virtual height seems to increase, and at 3.45 Mc/s the critical frequency of the E-layer is reached. At 3.3 Mc/s echoes also arrive from the F1-layer at a height of 200 km. The echoes are split into two components from 4.4 Mc/s. These are the ordinary and the extraordinary components of the wave due to the magneto-ionic effect of the terrestrial magnetic field. The critical frequency of the ordinary wave is 5.0 Mc/s.

Echoes from the F2-layer appear at 5.7 Mc/s and these are also split in two components. The ordinary wave has a critical frequency of 6.4 Mc/s and the extraordinary disappears at about 7.1 Mc/s. The vertical lines seen on the picture are broadcasting stations within the frequency band.

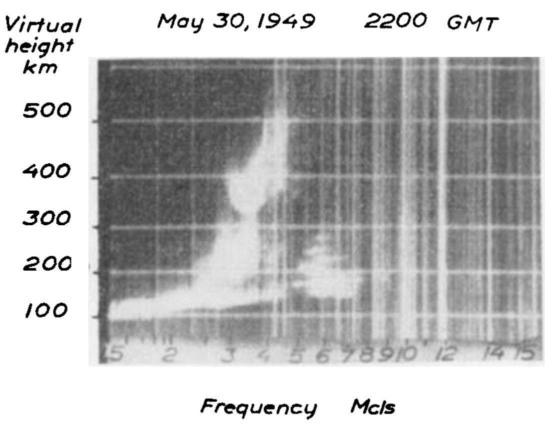

Fig. 9. Record made on a disturbed day. May 30, 1949, at 2200 GMT.

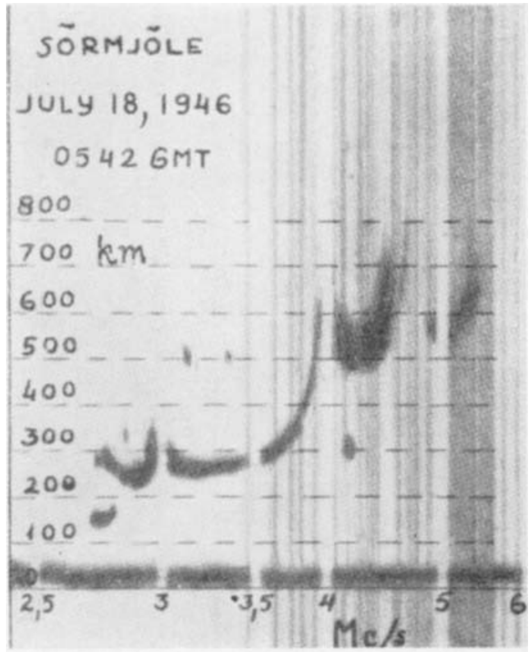

Fig. 10. A sweep frequency Kerr-cell recording, July 18, 1945.

Fig. 9 on the other hand shows a record made on a magnetically disturbed day. There are no distinct layers present. The reflections from 1.5 Mc/s up to 9.1 Mc/s in the height interval 90 km to 320 km are all probably due to ionizations caused by corpuscular bombardment. The F2-layer also shows a very diffuse character with a critical frequency of approximately 4.6 Mc/s.

In fig. 10 is shown an example of a Kerr-cell recording (RYDBECK 1945, 1946), obtained on July 18, 1945 by the *Chalmers' Solar Eclipse Ionospheric Expedition*. This record is obtained by a manual sweep frequency recorder. The time required for this frequency sweep was six minutes, the corresponding time for the panoramic recorder is 15 seconds. However, the example shows a very good proof of the quality of the Kerr-recorder.

Finally in figs. 11 and 12 are shown two records obtained on May 5, 1949, fig. 11 at

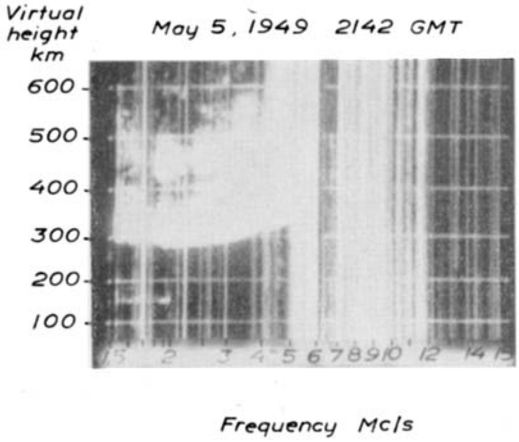

Fig. 11. Record made on May 5, 1949 at 2142 GMT.

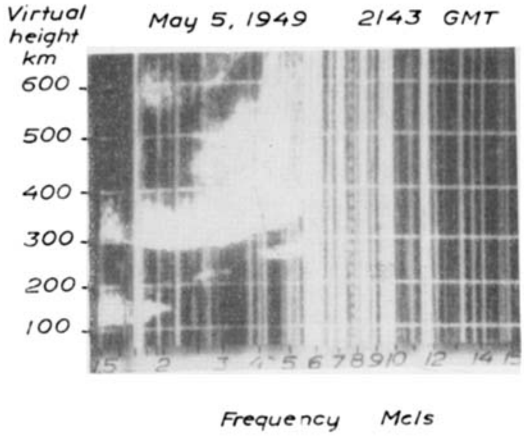

Fig. 12. Record made on May 5, 1949 at 2143 GMT.

2142 GMT and fig. 12 at 2143 GMT. The time elapsed from the end of the first record to the start of the second is one minute.

These two records give a very good example of how rapidly the conditions in the ionosphere often vary north of the arctic circle.

The scattered reflections at 2142 GMT within the height interval 400—550 km have disappeared at 2143. What remains in that interval is a multiple reflection of the F2-layer. Instead there appears several new echo patterns in the height interval 100—300 km. It is also interesting to note how the recorded signal strengths of the various traffic bands vary.

These records are shown only as examples of the performance of the panoramic ionospheric recorder, especially for investigations of rapidly changing ionospheric phenomena. Detailed analysis and discussions of the many records obtained at the observatory will appear shortly in special reports from the *Research Laboratory of Electronics.*

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