EXPERIMENTAL STUDIES ON THE REFLECTION OF RADIO WAVES FROM THE IONIZED REGIONS

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Part I. The State of Polarization of Radio Waves reflected from Ionized Layers formed during Terrestrial Magnetic Storms and Aurorae.

1. Introduction.

According to the theory of propagation of radio waves in an ionized ionosphere first developed by Appleton[1]), a plane polarized wave penetrating in the ionized atmosphere will under the influence of the earth's magnetic field be split up into two components with different indices of refraction and different states of polarization. Each component will then penetrate the ionized atmosphere independent of the other like the bundles of rays in a double-refracting crystal.

In the radio experiments treated in the following, the transmitter and receiver were operated at a distance of 300 m from each other. The reflected waves were therefore received vertically. The inclination of the earth's magnetic field in Tromsø ($\varphi = 69°.7$ N, $\lambda = 18°.9$ E.Gr.) is about 77°. The propagation of the waves by transmission and reflection is therefore approximately along the magnetic field, i.e. longitudinal propagation. According to the theory, a plane wave entering the ionosphere and being reflected, will leave the ionized layer as two components, both circularly polarized with different indices of refraction, coefficients of absorption and opposite direction of rotation.

Appleton and Ratcliffe[2]) first showed that waves reflected from the ionosphere on medium wavelengths were circularly polarized with a lefthand sense of rotation. This is according to the theory which predicts that the righthanded polarized component on these frequencies will be strongly absorbed.

Further progress in the experimental study of the polarization phenomena could first be made after the introduction of the *Breit* and *Tuve* pulse method, which allowed a study of the different components of the reflected waves.

Principally, the state of polarization of downcoming waves is measured by using two vertical frames with their planes at right angles to each other. By measuring the amplitudes and phases of the induced e.m.f. in the two frames, the state of polarization at each moment can be determined.

The measurement and comparison of the two induced e.m.f. has been made in different ways to suit the different aims of the investigations undertaken.

The principally simplest and most complete method is to couple each of the frames to two identical receivers and the output of the receivers to the opposite plates of a cathode ray oscillograph. This method has been developed in detail by Appleton and Watson Watt[1]). The use of two separate receivers, which have to be carefully adjusted with respect to amplification and phaserelations, makes the appli-

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[1]) Appleton, I. Inst. El. Eng., *71*, 642 (1932).

[2]) Appleton and Ratcliffe, Proc. Roy. Soc. London (A) *117*, 576 (1928).

[1]) Wireless World, *17*, (1932). Watson Watt, Herd and Bainbridge Bell: The Cathode Ray Oscillograph etc. 202, London (1932).

cation of this arrangement over a greater frequency range of 3—11 Mgc/sec, which here is planned, somewhat complicated.

Ratcliffe and L. C. White[1]) have suggested an arrangement of the two frames by which only one receiver is needed. By this method the frame arrangement receives *either* the lefthanded *or* the righthanded polarized wave. Another modification of the way of coupling the outputs of the two frames to one receiver has been used by Eckersley[2]).

The antenna arrangement developed by Ratcliffe and L. C. White has been used in this investigation. The same antenna arrangement has also been used by F. W. G. White[3]) in his measurements of the absorption of the radio waves in the ionized layers.

Ratcliffe and White[1]) investigated the state of polarization of the F_2-echoes and showed that the two echo components were circularly polarized with opposite directions of rotation. On longer waves where only E-echoes could be obtained, it was stated that the echoes were sinistrally polarized (ordinary component), whereas the dextrally polarized component (extraordinary component) was strongly absorbed.

Previous investigations on the state of polarization of the echoes have only been made on echoes reflected from the ordinary E- and F-layers. In high latitudes near the auroral zone the conditions of the ionosphere are strongly influenced by terrestrial magnetic storms and aurorae. The storm effects may be summarized as follows: 1. Appearance of new reflecting layers in 100—150 km height, *i.e.*, in the niveau of the E-layer. 2. Change of the structure of the F-layer. The layer is expanded during the perturbation and the virtual heights of the echoes increase. The critical frequency of the F-layer decreases. After the perturbation the height of the layer again decreases. 3. The decrease of the amplitudes of the reflected echoes during the perturbation is due to increased absorption in heights below the E-layer. 4. During strong perturbation this increase of absorption may be so great that the reflections cannot be traced, *i.e.*, the echoes fall out over a certain frequency range.

The appearance of these new layers at 100—150 km height is explained by the corpuscular theory of the aurorae, according to which the primary cause is the intrusion of electrically charged particles in the upper atmosphere. The appearance of this increased ionization in 100—150 km height is therefore especially frequent near the auroral zone. According to our experience this increased ionization due to terrestrial magnetic activity, may be found on almost all nights, and especially during the time of maximal terrestrial magnetic activity, *i.e.*, 22^{h}—24^{h}.

In the following the results of investigations of the state of polarization of echoes reflected from these layers will be given.

2. Transmitter and Receiver Arrangements.

For the polarization tests a pulse transmitter of considerable effect was used. The effect during the pulse was more than 50 KW. (This transmitter will be described in part II of this paper giving observations of echoes corresponding to virtual distances of 500—2500 km). The receiver, which was first brought up to the highest possible gain during tests with echoes, consisted of 2 high frequency stages, 1 mixing, 3 intermediate with rectifier and 1 low frequency stage[1]).

The antenna arrangement was coupled to a high frequency amplifier in push-pull which again was coupled to the high frequency part of the amplifier (which was also built in push-pull). In this way the symmetry of the input was obtained.

The frame arrangement used is shown in Fig. 1.

The coupling of the two identical frames was arranged so that a rapid tuning on different wavelenghts could be obtained.

Circularly polarized waves coming in vertically will induce electromotive forces in the two frames which have a phasedifference of 90° relative to each other. By critical adjustment of the coil K the electromotive force of F_{II} will induce in F_{I} a voltage which either will double or extinguish the voltage originally induced in F_{I}. By means of the switch S it is possible to displace the voltage induced from F_{II} to F_{I} either $+ 90°$ or $\div 90°$. The antenna ar-

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[1]) Ratcliffe and L. C. White, Phil. Mag. *16*, 125 (1933).

[2]) See «Discussion on the Ionosphere», Proc. Roy. Soc. *141*, 709 (1933).

[3]) F. W. G. White, Proc. Phys. Soc. *46*, 91 (1934). Proc. Roy. Soc. (A) *153*, 639 (1936).

[1]) During the construction of the apparatus, as well as in preliminary tests and observations, the author was assisted by the engineer Willy Stoffregen. His technical skill in construction and persevorance during the great number of night observations have been indispensable to the success of the experiments.

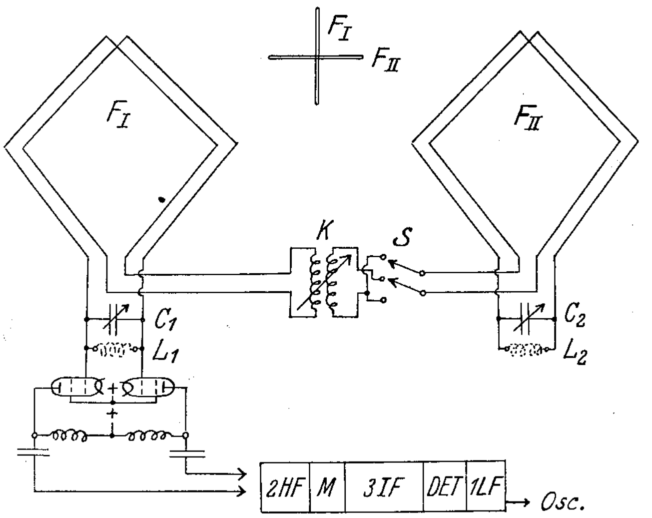

Fig. 1. Arrangement of frames and receiver during the polarisation tests.

rangement in this way is sensible *either* only for dextrally *or* only for sinistrally circularly polarized waves. The commutation of the switch S could be made rapidly by means of a relay. Linear polarized waves coming in vertically will be received with constant amplitudes for both positions of the switch.

In order to cover a greater frequency range, coils L_1 and L_2 were set over the tuning condensors C_1 and C_2. With two sets of coils it was possible to cover a frequency range of 3—11 Mgc/sec, and a complete polarization test on eleven wavelengths within this frequency range could be done within thirty minutes.

During the polarization tests the echoes on each of the frequencies selected were recorded during 10 seconds for each of the two positions of the commutator switch S. When the antenna arrangement was made sensitive for the ordinary component, a small lamp was lit before the recorder in the manner used by Ratcliffe and White[1]). The ordinary components are therefore marked out on the records by an horizontal line below the groundwave.

The receiver and the frame arrangement were set up in a small hut which lies at a distance of 200 m from the other buildings of the observatory. The transmitter was placed in another hut at a distance of 200 m.

During the polarization tests, the echoes were usually further recorded simultaneously by means of another set of pulse transmitter and receiver in the observatory building supplied with usual dipole antennas.

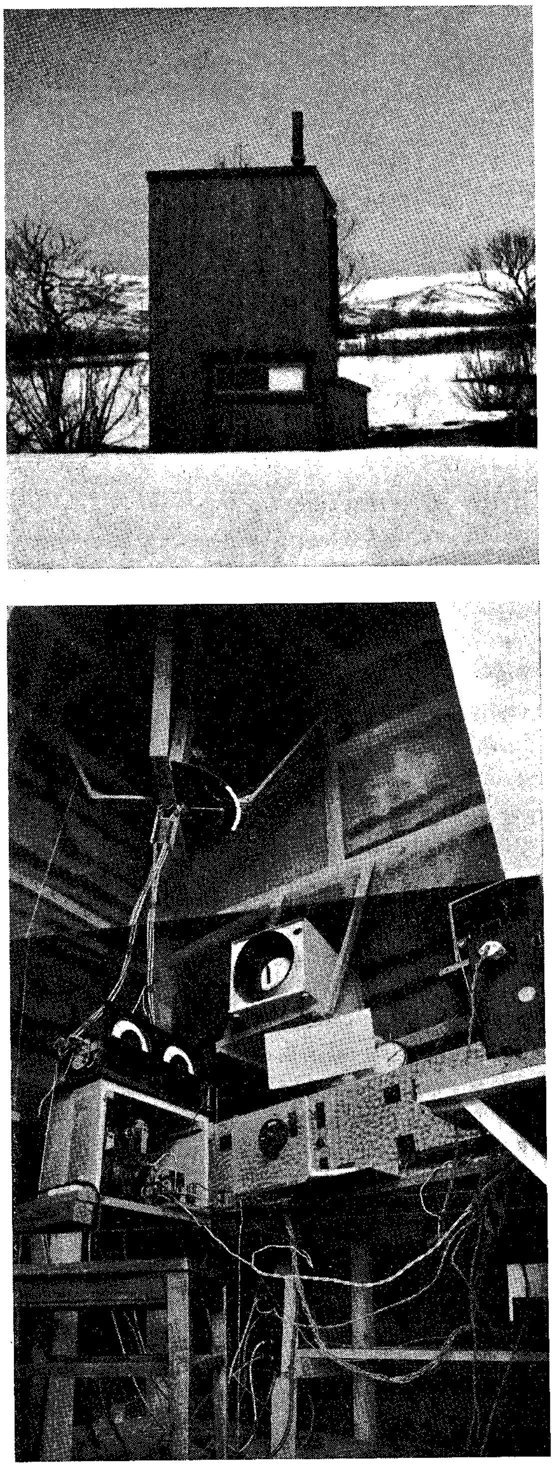

Fig. 2. The polarimeter hut. The frames, receiver and recording arrangement are seen.

3. Theory.

The propagation of the radio waves in an ionized atmosphere under the influence of the earth's magnetic field is determined by the formula for the

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[1]) Ratcliffe and L. C. White, Phil. Mag. *16*, 125 (1933).

complex index of refraction[1]) and the expression for the state of polarization, (1) and (2):

$$c^2q^2 = (\mu - ick/p)^2 = 1 + \frac{2}{2(\alpha + i\beta) - \dfrac{\gamma_T^2}{1+\alpha+i\beta} \pm \sqrt{\dfrac{\gamma_T^4}{(1+\alpha+i\beta)^2} + 4\gamma_L^2}} \quad (1)$$

$$\frac{H_y}{H_z} = \frac{i\gamma_L}{1/(c^2q^2 - 1) - (\alpha + i\beta)} \quad (2),$$

where: $\alpha = -\dfrac{mp^2}{4\pi Ne^2} - \dfrac{1}{3}$, $\beta = \dfrac{mp_\nu}{4\pi Ne^2}$,

$$\gamma_L = \frac{mp(H_L\, e/mc)}{4\pi Ne^2}, \quad \gamma_T = \frac{mp(H_T\, e/mc)}{4\pi Ne^2}.$$

Here are:

μ,	index of refraction,
k,	coefficient of absorption,
H_y, H_z	the magnetic fieldvectors of the wave in a system of coordinates where the X-axis lies in the direction of propagation of the waves,
m,	mass of the electron,
e,	charge of the electron,
N,	number of electrons pr. cm^3,
ν,	collision frequency of the electrons with the gas molecules,
p,	the angular frequency of the waves,
i,	$\sqrt{-1}$.
c,	velocity of height,
H_2,	component of the earth's magnetic field lying in the direction of the propagation of the waves,
H_T,	component of the earth's magnetic field perpendicular to the direction of the propagation of the waves.

For Tromsø, where the dip is 77°, we can very approximately regard the vertical incoming waves as longitudinal propagation. The state of polarization of the waves is determined at the moment when the waves pass out of the layer at the lower boundary. For pure longitudinal propagation we get the following simplified formulae ($H_T = 0$):

$$c^2q^2 = (\mu - ick/p)^2 = 1 + \frac{1}{\alpha + i\beta \pm \gamma_L} \quad (3),$$

$$\frac{H_y}{H_z} = \mp i \quad (4).$$

The waves leave the ionosphere as a doublet consisting of two circularly polarized components with opposite directions of rotation.

When received, the amplitudes of the two components are strongly influenced by the differential absorption in the ionosphere of the ordinary and extraordinary waves. The absorption is primarily determined by the collision frequency of the electrons, ν, and the frequency of the waves, p. For the range of wavelengths here used, one can assume $p \gg \nu$, and we get the following approximate formulae for the absorption coefficient for longitudinal propagation:

$$kc/p = \frac{(1-\mu^2)^2}{2\mu} \cdot \frac{z}{x} \quad (5).$$

Here are: $z = \dfrac{\nu}{p}$ and $x = \dfrac{4\pi Ne^2}{mp^2}$.

For a frequency in the range here used and with constant electron density, N, the refractive index will be greatest for the ordinary component, and according to formula (5), the extraordinary component will be more strongly absorbed. For the quantitative calculation of the absorption one must know the variation of the electron density and the collisional frequency along the path of the propagation. M. Taylor[1]) has made numerical calculations over the absorption and state of polarization for different electron densities and values of collisional frequencies. Further discussion of the dispersion formulae under different assumptions have been made by Booker[2]), Goubau[3]) and others.

The variation of the refractive index μ, coefficients of absorption k and state of polarization is clearly illustrated by the dispersion curves given by M. Taylor. In the following we reproduce a set for a wave-length of 80 m (3.75 Mgc/sec). The curves have been calculated for an inclination of 67° (for Southeast England), but may be applied for Tromsø without principal alterations.

On account of the greater pressure in the E-region, the collisional frequency of the free electrons is higher than in the F-layer. Numeral calculation and echo observations show that of waves in the interval 3—4 Mgc/sec, which are normally reflected from the E-layer, the extraordinary component is strongly absorbed. This is due to the fact that the extraordinary component when penetrating into the E-layer undergoes a differential absorption which is comparatively great even on depth of

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[1]) Appleton, J. Inst. El. Eng., *71*, 632 (1923).

[1]) Proc. Roy. Soc. *45*, 245 (1933) and *46*, 408 (1934).

[2]) Booker, Proc. Roy. Soc. (A), *147*, 352 (1934) and *150*, 267 (1935).

[3]) Goubau, Hochfrequentztechn. u. Elektroak. *44*, 17 and 138 (1936).

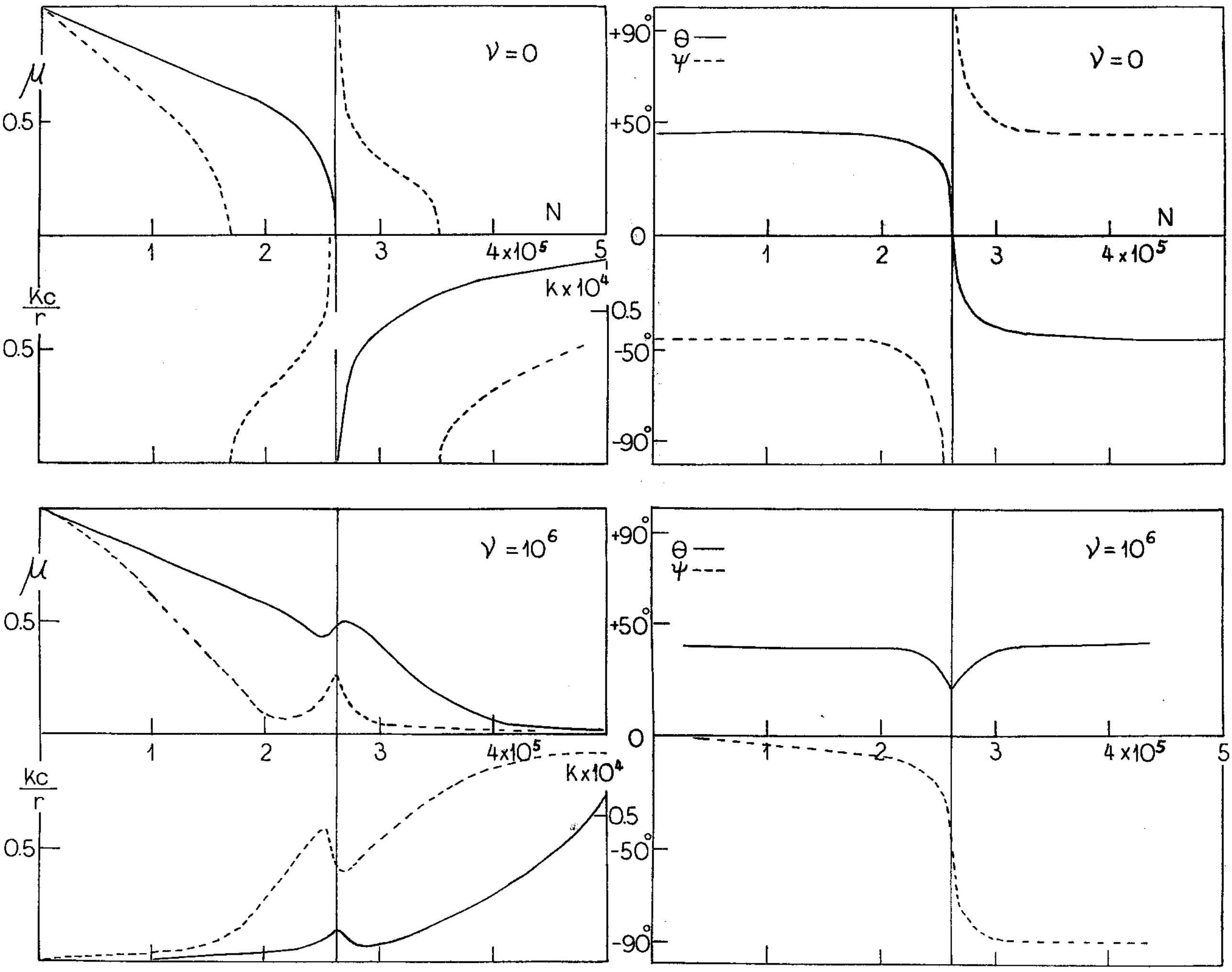


Fig. 3. Dispersion curves for a fixed wavelength of 80 m (3.75 Mgc/sec) for two values of the collisional frequency; $\nu = 0$ and $\nu = 10^6$, after *M. Taylor*. The curves to the left show the variation of the refractive index μ, and the coefficient of absorption k as a function of the electron density N for the ordinary (— —) and extraordinary (—) components. The curves to the right show the variation of the angles Θ and ψ, which determine the shape and position of the polarisation ellipse. ($\Theta = \pm 45°$ gives circular polarization.)

penetration of a few wavelengths (assuming a reasonable value of the collisional frequency). From Fig. 3 it is evident how the absorption coefficient k for the extraordinary component rapidly increases for the 80 m wave when going from a collisional frequency of $\nu = 0$ and 10^6. However, if the *E*-layer gets a very sharp lower boundary, the waves will penetrate only a short distance before conditions for reflection occur, and the differential absorption of the extraordinary component (in the frequency range here treated 3—4 Mgc/sec) will be less. As shown in the following this is actually what often happens for the echoes reflected from layers formed during small terrestrial magnetic storms and aurorae.

4. Observations.

On Plate I, No. 1 a number of snaps are reproduced which illustrate the technique of observation. By commutating the switch *S* (see Fig. 1) the antenna arrangement is made sensible either for the ordinary or extraordinary component. During the tests dealth with in the following the echoes were recorded about ten seconds in corde position of the switch for each frequency tested.

In Fig. 4 a is shown the state of polarization of the echoes in a frequency range 2.5—9 Mgc/sec during *normal* condition of the ionosphere. The P', f-curve in Fig. 4 b has been determined by recording the echoes with another set of transmitter and receiver. The values of the frequency on which polarization tests have been taken are marked by arrows. Only the *E*-echoes appear in the frequency range 2.5—3.75 Mgc/sec. The polarization tests show that these echoes consist only of the *ordinary* component, whereas the extraordinary is completely absorbed. After the critical penetrating frequency from *E* to *F*, we get the ordinary component of the *F*-echoes. On higher frequencies we see how the polarization tests confirm the identification of the two P', f-curves which cross each other, but are identified as the ordinary and the extraordinary components.

The records in Fig. 5 a were taken during a *small magnetic* perturbation on 16. 6. 1938 at 17^h MET. The perturbation was even sufficient to produce some increase of the electron density in the *E*-layer. The normal echo record in Fig. 5 b shows only *E*-echoes in the frequency range 2.5—4.0 Mgc/sec, then the *F*-echoes appear after the critical frequencies of the *E*-echoes. On the record two components of the *E*-echoes with different critical frequecies are stated and identified as the ordinary and extraordinary components of the echoes from the *E*-layer. The polarization tests confirm this identification. Further we see that on the lower frequencies 3.25—3.50 Mgc/sec, besides the ordinary component we also get the extraordinary component with appreciable intensity. This was not the case on the records taken during undisturbed conditions of the ionosphere discussed under Fig. 4.

The records in Fig. 6 were taken on 30. 5. 1938 at 18^h MET during a *smal magnetic* storm which appeared after a perturbation of considerable strength. The polarization tests show the same general development of the polarization as the previous observation. But in this case the strong reflecting *E*-layer here only reflects the ordinary component at 3.16 Mgc/sec. On higher frequencies up to 4.65 Mgc/sec both components of the *E*-echoes appear and on 5.10 Mgc/sec only the extraordinary component.

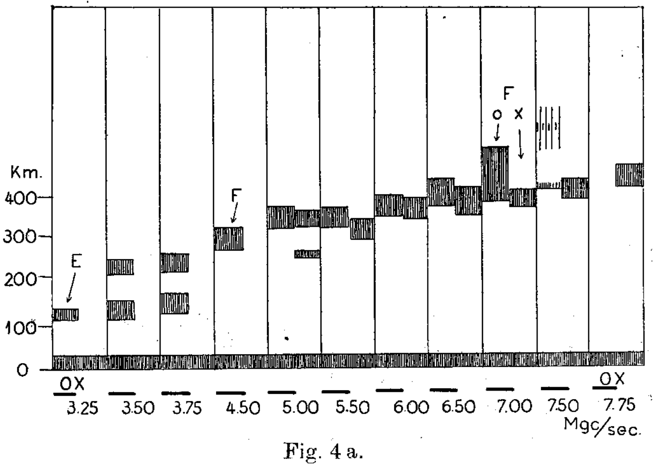


Fig. 4 a.

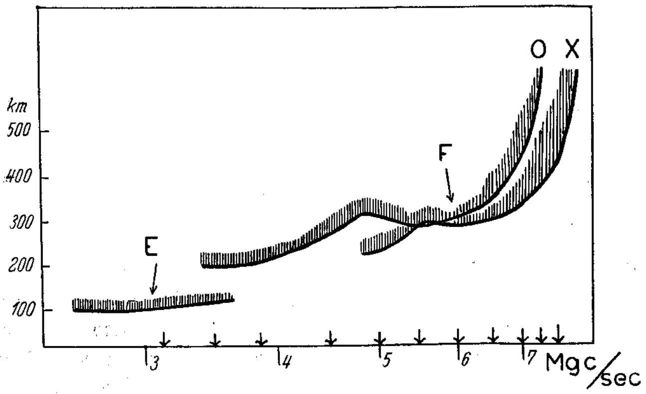


Fig. 4 b.

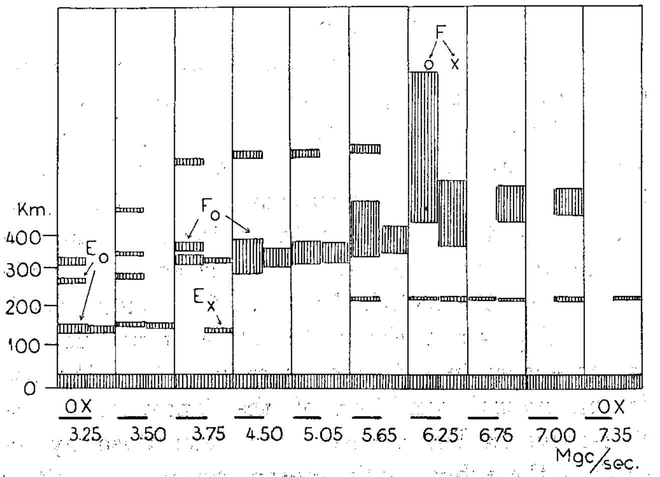


Fig. 5 a.

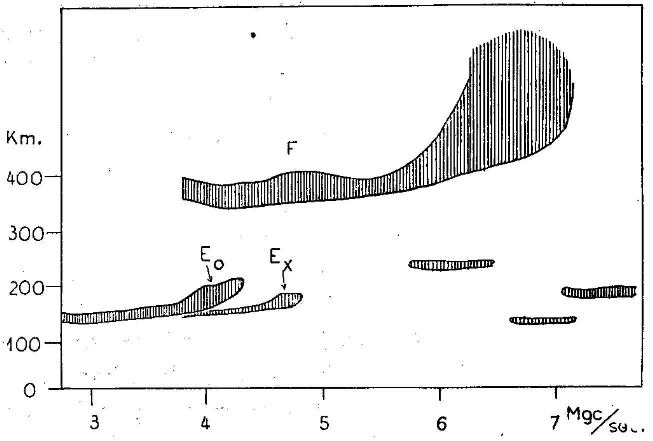


Fig. 5 b.

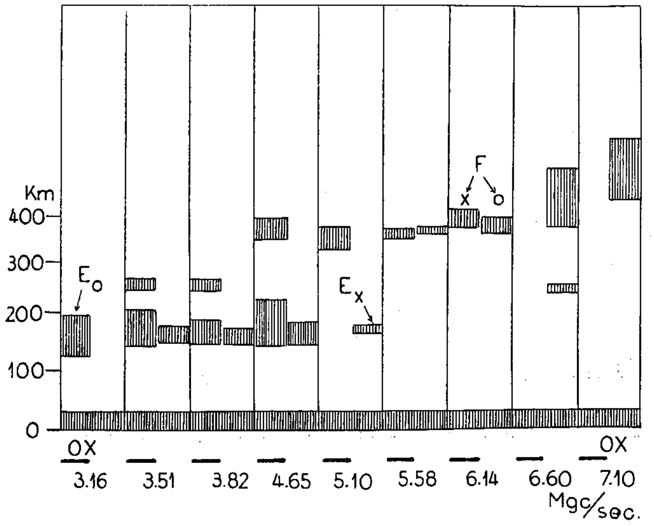
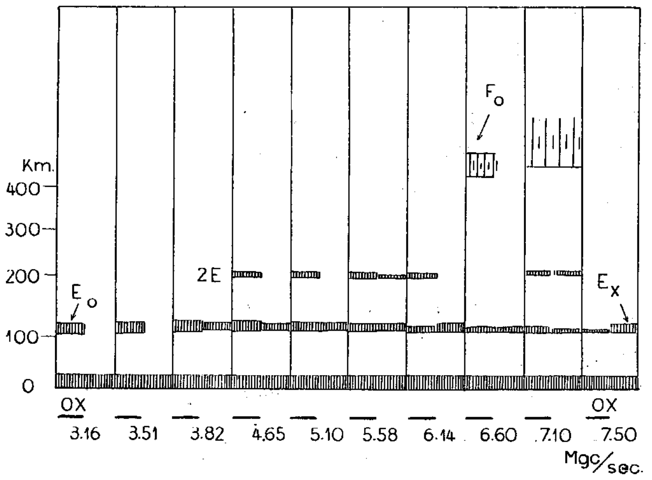


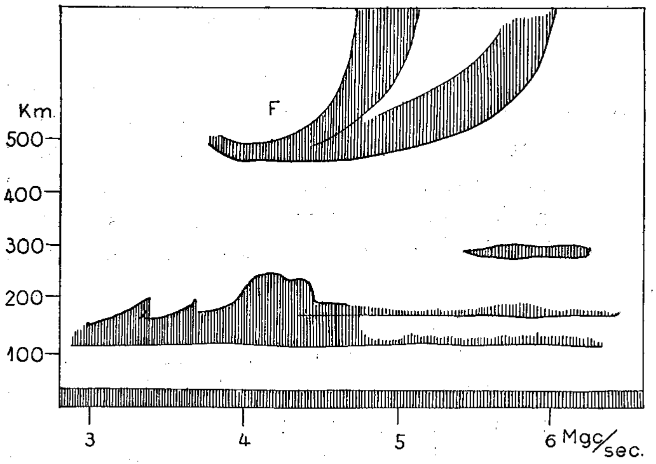
Fig. 6

The records in Fig. 7 were taken on 1. 6. 1938 at 21^h50^m MET during an *terrestrial magnetic storm* of *considerable strength.* The dense E-layer occurring during the storm screens off the waves from reaching the F-layer on frequencies up to 7.10 Mgc/sec, where some faint E-echoes are obtained. The lower edge of the E-layer has a uniform height of 110 km throughout the whole frequency range. On lower frequencies, 3.10—3.50 Mgc/sec, only the ordinary component of the E-echoes is obtained, on 4.7—6.0 Mgc/sec both components are obtained with about the same intensity, and on higher frequencies up to 7.50 Mgc/sec the extraordinary component is reflected almost exclusively. Obviously here have to do with two effects, — on lower frequencies the absorption of the extraordinary component so that only the ordinary component is received, and on higher frequencies the penetration through the layer of the ordinary component so that only the extraordinary component is received.

This polarization test indicates that when at uniform E-layer is recorded during a magnetic storm even up to frequencies of 7—8 Mgc/sec, the disappearance of the echoes must be interpreted as due to electron limitation of the layer. The highest frequency on which echoes are obtained is therefore to be regarded as the critical frequency of the layer for the *extraordinary* component. The unambiguous determination of the critical frequency with definite direction of polarization gives a quantitative determination of the increase in the electron density of the E-layer caused by the earthmagnetic storm.

The record in Fig. 8 a and b were taken during *terrestrial magnetic perturbation* on 30. 5. 1938 at 21^h—21^h30^m MET. The polarization tests were taken about 10 minutes after the records giving the P', f-curve had been taken. As the conditions of the ionosphere were rapidly changing, the two sets of records show some differences with respect to the intensity of the reflected echoes. On both records an E-layer appears at 120 km height. Further F-echoes, with some scattering, are obtained on higher frequencies. The polarization test indicates a strong ordinary component of the E-echoes. The F-echoes show the distinct change between ordinary and extraordinary components. After the F-echoes had penetrated the layer, further observations on higher frequencies were made as scattered echoes suddenly appeared. The polarization tests show that these echoes which must be due to ionization suddenly formed, at first show no splitting up into





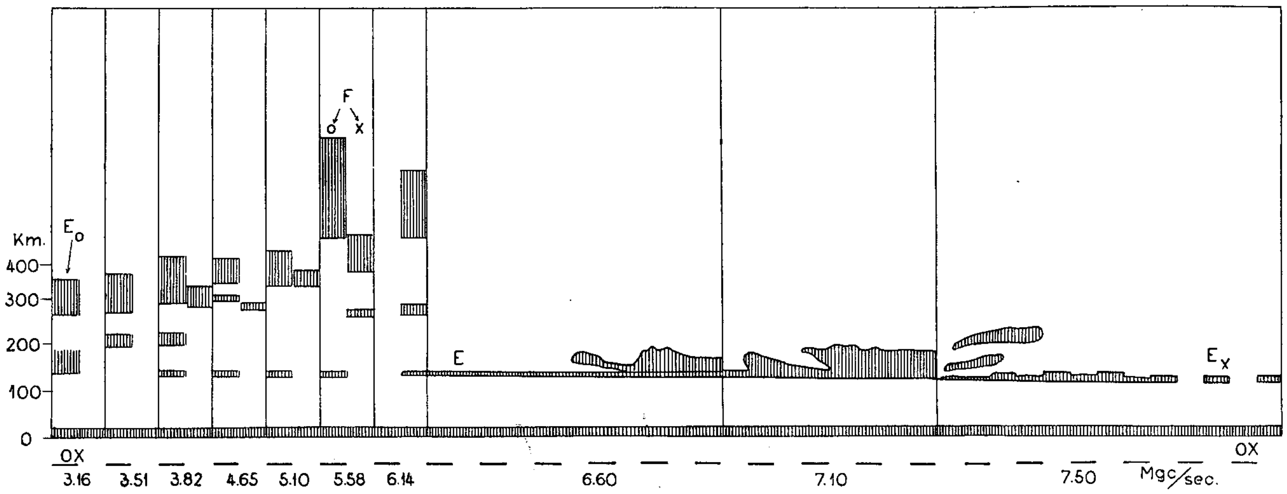


Fig. 8 b.

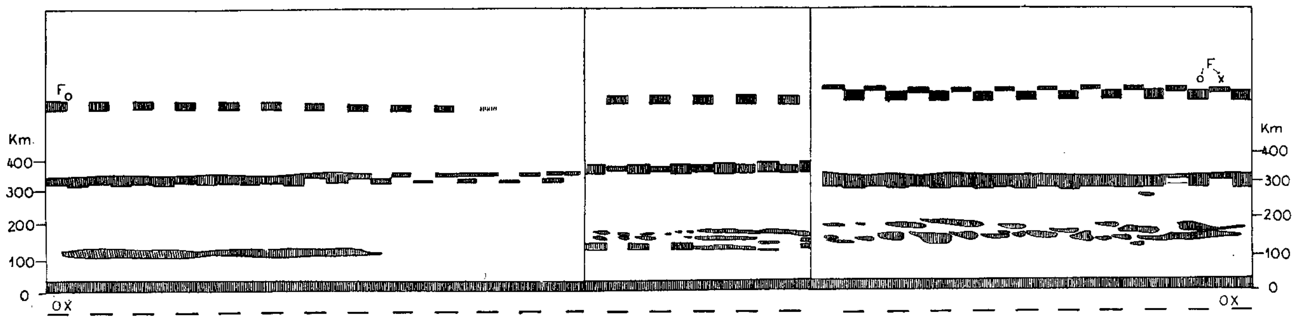


Fig. 9.

ordinary and extraordinary components. On the highest frequency of 7.50 Mgc/sec, however, we almost exclusively get the extraordinary component, which indicates the electron limitation of the layer at 120 km height. Above this layer, however, scattering centres with a very sharp lower boundary must have been formed. From the record it is evident that the «life-time» of these clouds must be very short, after 2—3 minutes they disappeared.

The state of polarization of the scattered echoes may be studies in detail on the polarization tests in Fig. 9. The records are taken on a fixed frequency of 6.1 Mgc/sec (on 7. 6. 1938 at 11^h30^m and 15^h35^m MET). The F-echoes show both components clearly. Below the F-layer, however, scattered echoes in the region of the E-layer appear. The polarization test proves that scattered echoes show no splitting up into ordinary and extraordinary components. The scattering must be due to small irregularly distributed clouds. In the middle of Fig. 9, however, we see an indication of a polarization effect, as the extraordinary component appears with some intensity. The irregularly appearing scattering centres seem at this time to flow together to a more uniform layer.

The rapid variations of the echo patterns during terrestrial magnetic storm are also recorded on the polarization tests. Fig. 10 shows the echoes recorded on a fixed frequency of 6.5 Mgc/sec, on 5. 5. 1938 at 20^h MET. A high F-layer showing scattered reflexion is present only the extraordinary component being reflected. Below this layer a new layer is formed the height of which *decreases continuously.* As in the previous examples this layer formed during the

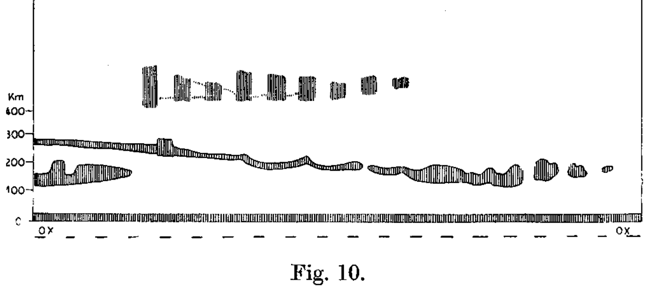


Fig. 10.

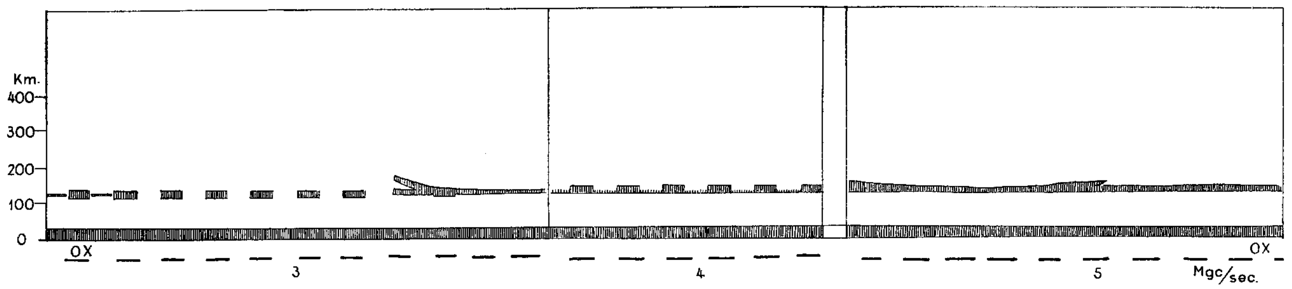


Fig. 11 a.

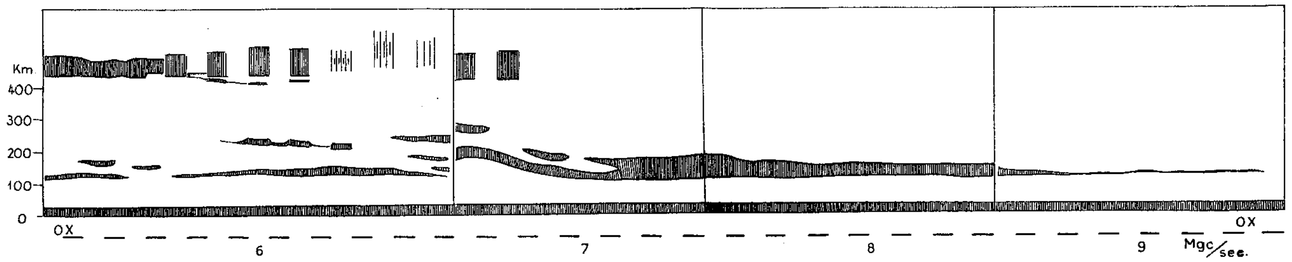


Fig. 11 b.

storm reflects both components with apparently the same intensities.

Fig. 11 shows polarization tests of the rapidly changing layers in 100—200 km height during an auroral display (on 20. 12. 1938 at 18^h—18^{h}40^m MET). Tests were taken on frequencies from 3 to 9 Mgc/sec in steps of one Mgc/sec during forty minutes. In the beginning on 3 Mgc/sec a single *E*-layer with a strong ordinary component is present. On 4 and especially on 5 Mgc/sec both components appear with approximately the same intensity. Now on 6 Mgc/sec complicated formations of layers between 100 and 250 km appear. The uniform *E*-layer is broken up into scattering clouds and the extraordinary component of an *F*-layer occurs. On 7 Mgc/sec a uniform *E*-layer is again suddenly formed, the *F*-echoes disappear and of the *E*-echoes both components appear with approximately the same intensity. This is also the case on 8 Mgc/sec.

The record in Fig. 12 taken on 28. 6. 1938 at 13^{h}50^m MET is a test which shows an *E*-layer which on the lower frequencies reflects as a normal *E*-layer

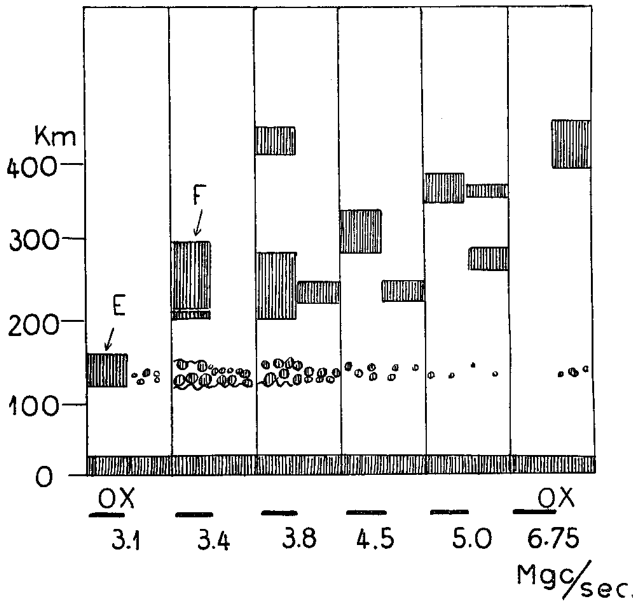


Fig. 12.

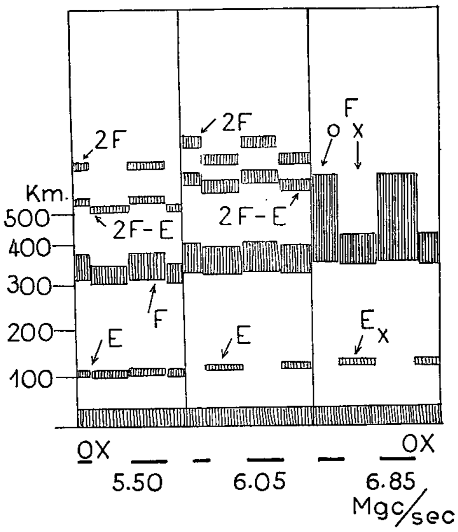


Fig. 13.

with the ordinary component predominating. On higher frequencies scattering appears and about equal intensities are obtained for both positions of the polarization switch.

The record in Fig. 13 taken on 20. 5. 1938 at 23^h40^m MET shows strong F-echoes with both components on frequencies 5.50, 6.05 and 6.85 Mgc/sec. A thin E-layer due to some terrestrial magnetic disturbance appears, which on the lower frequency reflects both components, on the two higher frequencies only the extraordinary component. Besides these also M-reflections ($2F$—E) appear, which show polarization.

5. Summary.

a. Polarization tests of the echoes reflected from the E- and F-layer have been made over a frequency range of 3—9 Mgc/sec. Under *normal* conditions of the ionosphere, the E-echoes on lower frequencies 2.5—3.7 Mgc/sec mainly consist of the ordinary component.

b. During *small magnetic storms* accompanied by an increase of the electron density in the E-layer, it frequently happens that both components are reflected with appreciable intensity even on lower frequencies. This must be due to a very steep gradient of the electron density at the lower edge of the E-layer.

c. The state of polarization of echoes reflected from the E-region over a frequency range of 3—9 Mgc/sec during *stronger* terrestrial magnetic storms has been studied. It was shown that just before the echoes disappeared on higher frequencies, only the extraordinary component was reflected. This must be due to electron limitation of the layer, and the highest frequency on which the echoes are recorded must be regarded as the critical penetrating frequency for the extraordinary component. A quantitative estimate of the maximum electron density of a layer formed during a magnetic storm is therefore possible.

d. Polarization tests have been made on scattered echoes which often appear during magnetic storms. No changes were noticed for different settings of the antenna system. When the scattering centre gradually joined to form a more uniform layer, circular polarization effects were noticed. Polarization tests have been made on the rapidly changing layers which appear during stronger terrestrial magnetic storms.

Part II. Scattering of Radio Waves from Great Virtual Distances.

1. Introduction.

Besides the usual E- and F-echoes reflected from the ionized regions, several observers have during recent years recorded reflections from different virtual distances which must be regarded as *scattered* reflection. This scattering of the waves is usually ascribed to the presence of ion clouds or other heterogeneities in the ionosphere.

Scattered echoes received from the troposphere and the region of the E-layer will be treated in parts III and IV of this paper. Scattered echoes from the F-region and above this layer are often obtained under disturbed conditions of the ionosphere during terrestrial magnetic storms and aurorae. Booker and Berkner¹) have discussed a certain type of scattered echoes with virtual reflection heights of 400 km and more, which appeared at the station Huancayo near the equator. The echoes appeared regularly during the night and were explained as due to a scattering region at 400—500 km height.

Scattered reflections corresponding to virtual distances greater than the height of the F-layer have been noticed by several observers. Appleton and Naismith¹/) report that echoes corresponding to distances of 1000—1500 km have been recorded. On the same frequency also echoes from the normal E- and F-layers were obtained. Eckersley²) using a pulse transmitter with an output up to 40 KW got reflections which corresponded to virtual distances of 1000—2500 km. Eckersley explained these echoes of longer delays as due to backward reflections over the skip-zone from distant irregularities in the E-layer, the waves being reflected downwards again by the F-layer. A more systematic investigation on the occurrence of these echoes with respect to diurnal variation and dependence on solar activity has not yet been made. In the following, observations dealing with these questions will be discussed.

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¹) Terr. Mag. *43*, 249 (1938).

¹) Nature, *143* 243 (1939).

²) Nature, *143*, 33 (1939). Gesammelte Vorträge der Hauptversammlung 1937 der Lilienthalgesellschaft für Luftfahrtforschung, 322—329.

2. Experimental Arrangements.

A pulse transmitter with considerable power was built. The scheme used is given in Fig. 14. By means of the two tuning condensors C_1 and C_2, one could with one set of coils cover the frequency range 7—13 Mgc/sec. Special emphasis was laid on the effiency of the higher frequencies, as the frequency used for observations was usually *greater* than the critical penetration frequencies of the F_2-layer. As transmitting valves two Telefunken 15 g valves were used, each rated for 1.5 KW with 4000 volts anode voltage. For pulse transmission, however, considerably greater anode voltage than rated may be used without damaging the anode. During the tests an anode voltage of 16 000—25 000 volts was applied. A $\frac{1}{2}\,\lambda$ horizontal dipole was used as antenna. The length of the dipole could be varied continuously to suit the wavelength for each frequency used within the range. The effect of the transmitter was estimated to be at least 60—80 KW during the pulse.

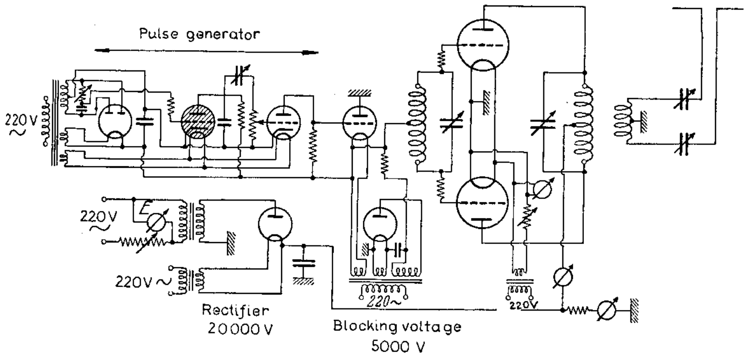

Fig. 14 a.

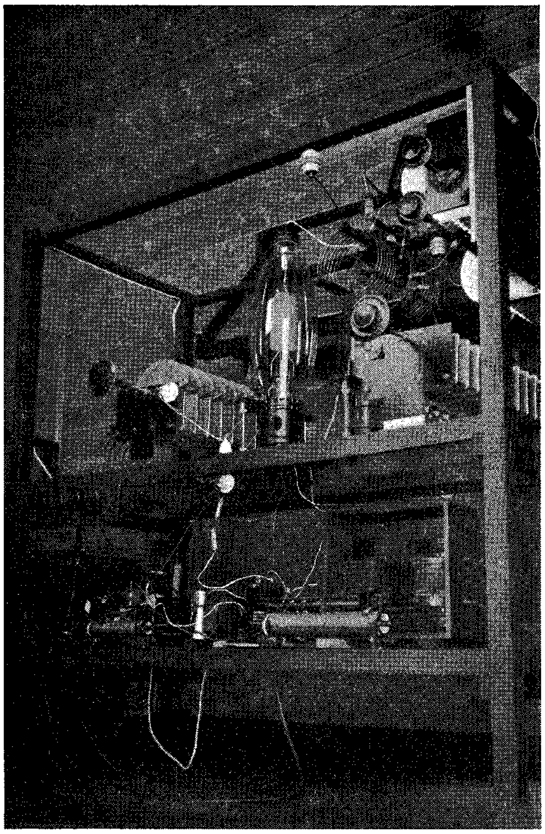

Fig. 14 b.

Fig. 14. The great pulse transmitter.

The transmitter was placed in a hut lying about 150 m from the observatory building where the receiver was placed, and could be started from the observatory by means of relays. As receiver a similar type was used as mentioned under the polarization tests.

For the recording of these echoes of longer delays a comparatively small deflection speed on the cathoderay tube was used. A coupling was devised by which the ground wave appeared as a vertical deflection at the edges to the left and right on the linear sweep. As the pulse emission of the transmitter was locked to the 50 period net, the distance between the two groundwaves on the screen corresponded to 1/50 sec., *i.e.*, to a 3000 km virtual reflection distance. The echoes appearing corresponding to reflection heights within distance could therefore be conveniently measured out.

3. Observations.

On lower frequencies, 6—8 Mgc/sec, on which reflections from the F_2-layer are recorded during autumn and spring, a great number of multiple reflections from the F-layer were obtained with the transmitter and receiver arrangement described. During daytime more than ten times multiple F-reflections were lasity obtained. A record showing a great number of F-reflections on 6.8 Mgc/sec is reproduced in Plate III, No. 1.

The critical frequencies of the E- and F-layers were controlled during the tests by a second set of apparatuses. By now using a frequency higher than the critical frequency of the F_2-layer on the high power transmitter, one regularly obtained scattered reflections which during the day corresponded to reflection distances of 600—900 km. The reflections were very faint and the amplitude was very variable. Records taken over some time, however, revealed a

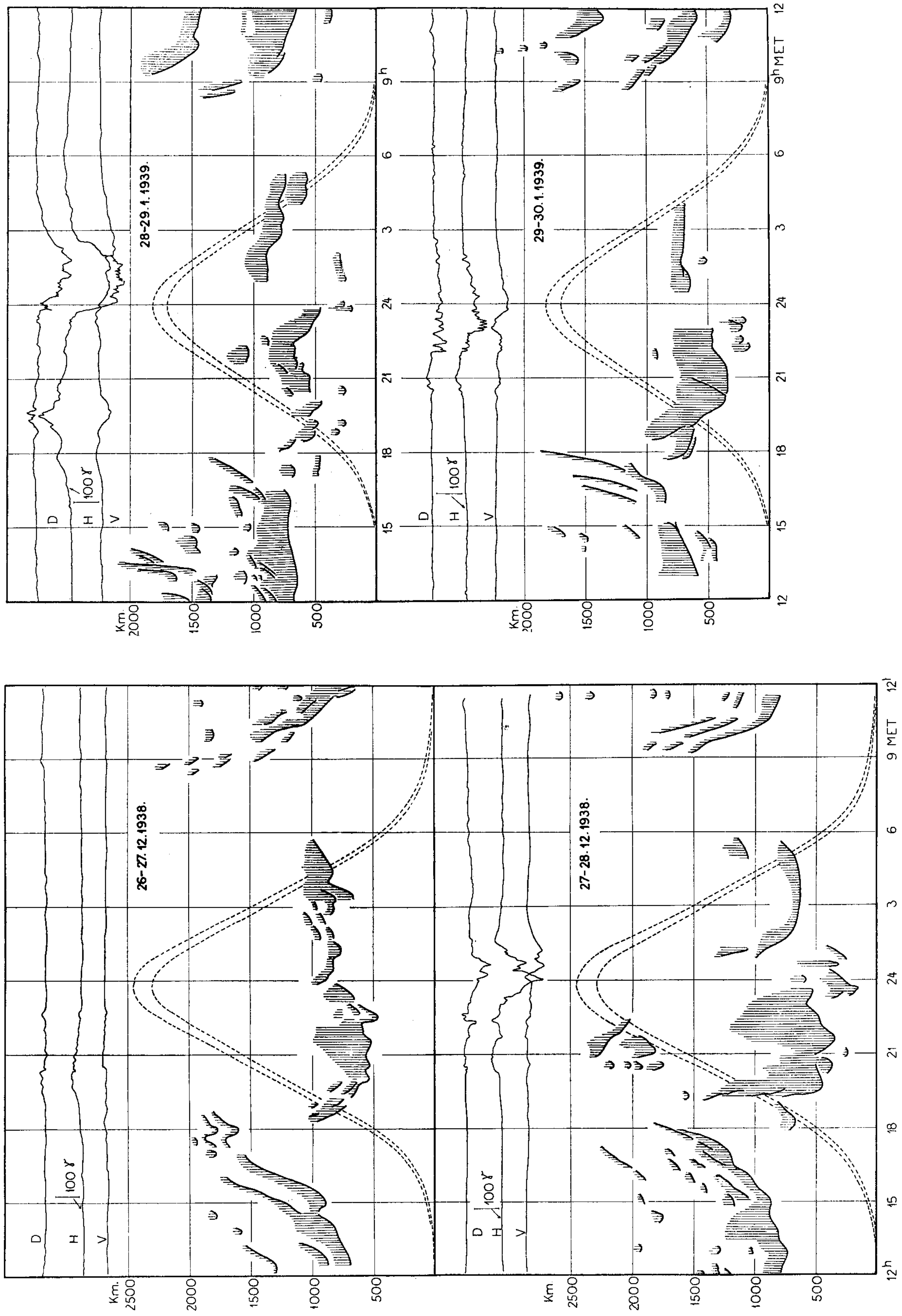

Fig. 15. Diurnal variation of the reflections from great virtual distances on four days. The broken lines indicate the height of the earth's shadow, computed with and without the effect of the atmospheric refraction.

well defined lower boundary of the reflections, with a scattering towards greater heights. In Plate III, Nos. 2, 3, 4, 5 and 6, types of echo patterns taken during *day time* conditions are reproduced. We see how the details change continuously within a few minutes in Figs. 3, 4 and 5. More complicated is the structure in Fig. 6 where a well defined lower boundary at 600—700 km appears and against greater heights a complicated system of reflecting boundaries crossing each other is seen.

Records over a whole day revealed a systematic change in the character of the echoes during the day, which was especially distinct on magnetically quiet days. During the afternoon the reflection heights increase and on the echo pattern one often sees the reflection heights as fine bundles of rays ascending from a lower boundary, see Plate IV, Nos. 1 and 2. Shortly after sunset and before sunrise the echoes are usually very weak. During the night the reflections are again stronger and more irregular in appearance. Plate IV, No. 6 shows night conditions during a magnetically quiet night.

At such a terrestrial magnetically highly disturbed place as Tromsø, terrestrial magnetic perturbations appear almost every night. During the perturbations strong reflections or scattering always occur during the moderate phase of the storm. During greater perturbations the reflections may disappear. We therefore here meet with the same storm-effects of increased absorption as have been found previously when using transmitters with lower energies and frequencies in the range 3—8 Mgc/sec. Plate IV, No. 7 shows a record taken during an terrestrial magnetic perturbation.

The diurnal variation of these reflections from great virtual distances is illustrated in Fig. 15, which shows the appearance of the echoes on the days 26.–27. 12. 1938 and 27.–28. 12. 1938 taken on a fixed frequency of 11.0 Mgc/sec, and on the days 28.–29. 1. 1939 and 29.–30. 1. 1939 taken on a fixed frequency of 10.8 Mgc/sec. The terrestrial magnetic records are copies of the magnetograms recorded at the observatory.

The four days selected are characterized by a low terrestrial magnetic activity. The first day 26.–27. 12. 1938, is almost absolutely quiet and the general developement of the heights on this day should therefore give a picture of the undisturbed conditions. The variations of the scattered reflections is more clearly illustrated by the schematic picture in Fig. 16.

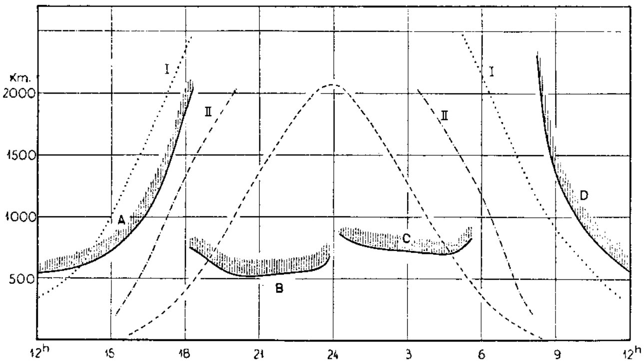

Fig. 16. General character of the diurnal variation, schematically.

- - - - - indicates the height of the earth's shadow above Tromsø,

. . . . . (curve I) indicates the distance from Tromsø to the nearest point on the earth where the sun's rays strike the earth tangentially,

- · - · - (curve II) indicates the distance to the nearest point on the earth above which the sun's rays cut through the atmosphere at 100 km height.

The diurnal variation consists of the following four phases. An evening and a morning phase *A* and *D* which cover the day from sunrise to sunset, and two night phases *B* and *C*. During the *B*-phase the heights are lower than during the *C*-phase. The disappearance and appearance of the phases on these four days are seen in Table 1.

It is most characteristic for the two day phases *A* and *D* that the heights go approximately parallel to the height of the earth's shadow. Further there is an asymmetry in the position of the *A* and *D* phase with respect to the shadow line. The *A* phase disappears at about 6 hours after noon but the *D* phase appears at about $4^1/_4$ hours before noon.

Table 1.

Date	Disappearance of *A*-phase towards great heights	Appearance of *B*-phase at 500 km height	Disappearance of *C*-phase	Appearance of *D*-phase at great heights
1938				
26.–27. 12	18^h30^m	18^h15^m	5^h40^m	8^h30^m
27.–28. 12	18 0	18 0	5 40	9 15
1939				
28.–29. 1	17 30	18 0	5 30	8 30
29.–30. 1	18 0	17 45	5 0	8 45

Concerning the two night-phases B and C, their appearance very often coincides with some terrestrial magnetic disturbance. In one case, however, on 29.-30. 1. 1939, the B-phase appeared about two hours before there had been the slightest indication of any disturbance on the magnetogram. This happened also in other cases. We are therefore not inclined to ascribe the appearance of the B-phase as due to terrestrial magnetic activity.

In Fig. 16 we see that the appearance of the B-phase coincides with the moment when the shadow line has reached a height of 500—700 km which corresponds to the heights from which the scattered echoes are reflected. In Plate IV, No. 5 is reproduced a record showing the reflections during the B-phase. We see, however, that the reflections during the B-phase are stronger and more scattered up to greater heights when terrestrial magnetic perturbations appear simultaneously.

The increase of the heights shortly after midnight to the C-phase also seems to be a general feature. We see that this increase always appears as the small or medium terrestrial magnetic perturbation is dying out.

During the most intense phase of these small or medium earthmagnetic storms on the days here treated, we see that reflections were obtained from heights even down to 150—200 km.

As previously stated these records were taken on a fixed frequency which was higher than the critical penetration frequency of the F_2-layer. The next question was therefore to see if the F-layer, when a frequency lower than the critical penetration frequency was used, would screen off the high reflections here treated. Tests on frequencier of 6—8 Mgc/sec during day time give a very complicated echo pattern of multiple reflections of F-echoes of the type reproduced in Plate III, No. 1, which completely overlap the faint high echoes. Records on a fixed frequency were therefore started just before noon on a frequency of about one Mgc/sec higher than the critical frequency of the F_2-layer at this moment. At noon the critical frequency of the F_2-layer had increased sufficiently to pass the value of the test frequency, and F_2-echoes appeared for about an hour. Plate IV, No. 3 and 4 are reproductions of such records. The record is shown schematically in Fig. 17.

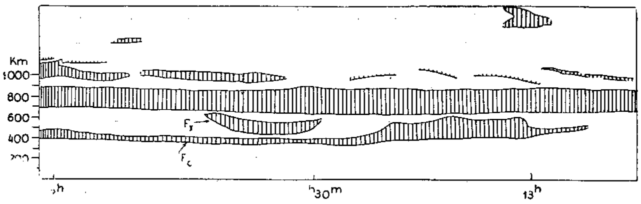

Fig. 17. Record on a fixed frequency of 11 Mgc/sec, taken on 30. 1. 1939. The ordinary and the extraordinary components of the F-echoes appear about noon. The high echoes have no connection with the F-echoes and are not screened off by the F-layer.

From Fig. 17 it is seen that the high echoes are *not* screened off by the appearing F_2-echoes. Further, there is no direct connection between the F_2-echoes and the high scattered echoes at the moment when the F_2-echoes disappear. A number of such tests have been made and the general character has been confirmed. The significance of these records concerning the explanation of the high echoes will be dealt with later. In the following, further observations of the high echoes will be given in the form of figures.

In Fig. 18 the results of registration on a fixed frequency of 11 Mgc/sec during terrestrial magnetically disturbed conditions during two days are shown. The general character of the diurnal variation is here strongly influenced by the storm effects. We see, however, that the morning phase, D, appears during the most quiet hours.

Concerning the explanation of the scattered echoes from great virtual distances we should first deal with the A and D-phases. The appearance of high echoes even when then F_2-echoes are present as demonstrated in Fig. 17, indicates that echoes during these phases most probably *can not* be due to vertical reflections. In his analysis of scattered echoes from great virtual distances Eckersley[1]) has proposed an explanation according to which the scattered echoes are due to irregularities in the E-layer. These irregularities or ionospheric clouds reflect small amounts of the energy back via the F-layer over the skip zone. The fact here pointed out, that there is an asymmetry in the diurnal variation of the heights of the high echoes of about two hours displaced towards the afternoon, indicates that the F-layer plays a rôle by the reflection of the scattered echoes, and the observations here dealt with in so far support the point of view put forward

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[1]) Nature, *143*, 33 (1939). Gesammelte Vorträge der Hauptversammlung 1937 der Lilienthalgesellschaft für Luftfahrtforschung, 322—329.

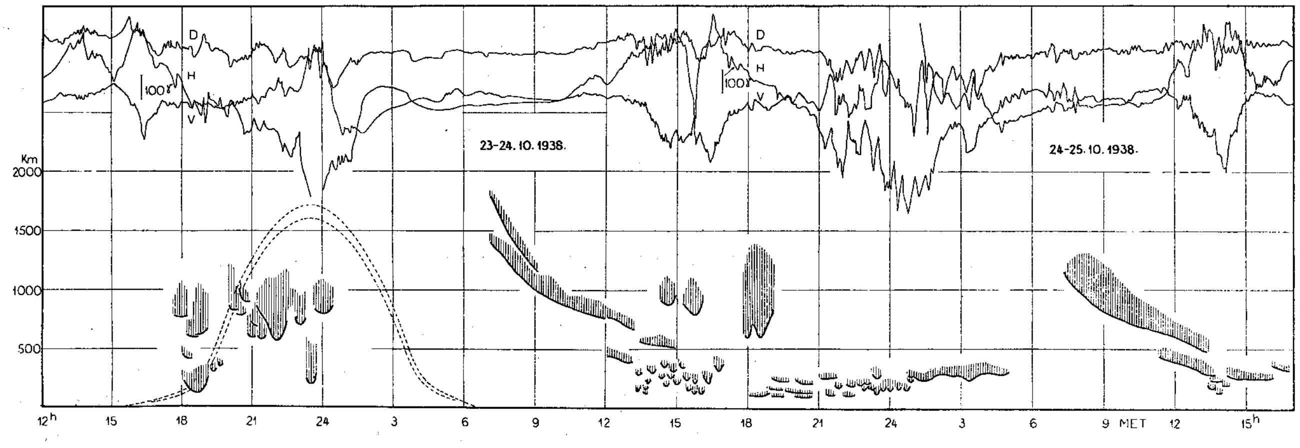

Fig. 18. Registrations on a fixed frequency of 11 Mgc/sec.

by Eckersley concerning the backward reflection of the scattered echoes via the F-layer.

Concerning the primary origin of the scattering, Eckersley considers this due to clouds in the E-layer, without dealing further with the point. It has now been shown by Eckersley[1] and Appleton and Piddington[2] that scattered reflections from the region of the E-layer occur regularly. Observations of such reflections in Tromsø will be dealt with in part III of this paper. According to our estimates, however, the irregularly scattered reflections from the E-layer received directly, are weaker and have another character than the scattered reflections from great virtual distances.

In Fig. 16 we have drawn two curves, curve I indicating the distance from the place of observation to the nearest point on the earth where the sun's rays strike the earth tangentially. Curve II simulilarly determines the distance to the nearest point on the earth above which the sun's rays cut through the atmosphere at 100 km height. We see that the diurnal variation of these distances goes approximately parallel to the reflection distances recorded. It is probable that in the border region between the dark and sunlit atmosphere, heterogeneities in the electron density appear which increase the scattering power of the E-layer in this border region and we may put forward as a tentative assumption that the scattering clouds which are responsible for the reflections of great virtual distances during the A and D phase are mainly formed in the border region between the dark and the sunlit atmosphere.

As to the B and C-phases, the reflections during these night hours are most probably due to scattering areas lying in or near the zenith. The fact that the B-phase appears at the moment when the shadow line passes the zenith at 500—600 km height, which coincides with the virtual distances of the reflections during the B-phase, should support the point of view that irregularities in the ionosphere due to the sudden appearance or disappearance of the ionizing agency, are formed and are responsible for the scattering which starts during this phase at these moments. During the greater part of the B and C-phases some terrestrial magnetic disturbances always appear, and the scattering here must partly be ascribed to the sudden formation of ion clouds due to ionization by the impact of electrically charged particles. The different character of the scattering during a quiet or only a slightly disturbed night is illustrated in Plate IV, Nos. 5 and 6 and during a disturbed night in No. 7.

4. Summary.

Using a pulse transmitter of high power, scattered reflections corresponding to virtual reflection distances of 500—2500 km have been obtained.

The test frequencies used were usually greater than the critical penetration frequencies of the F_2-layer. Records on a fixed frequency over a number of days have been taken in order to study the diurnal variation and dependance on terrestrial magnetic activity and aurorae. Four different phases in the diurnal variation have been recorded.

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[1] Nature, *143*, 33 (1939). Gesammle Vorträge der Hauptversammlung 1937 der Lilienthalgesellschaft für Luftfahrtforschung, 322—329.

[2] Proc. Roy. Soc. (A) *162*, 451 (1937).

During the two day phases it has been shown that the scattered reflections can not come in vertically as they are not cut off by the F-layer.

During the two night phases the echoes are reflected from scattering areas lying in or near the zenith at 500—800 km height. Small terrestrial magnetic disturbances increased the scattering at these heights. Stronger perturbations were accompanied by scattering from heights down to 150—200 km.

Part III. Scattered Reflections from the Niveau of the E-Layer.

1. Experimental Arrangements.

The great pulse transmitter has been used to investigate if scattered reflections may occur normally at lower heights than the reflection distances dealth with in part II of this paper. For these observations a test frequency had to be used which was greater than the critical penetrating frequency of the E-layer. During the observations here dealt with, a frequency lying in the range 6—8 Mgc/sec was used.

More or less scattered reflections are usually obtained during terrestrial magnetic perturbations from a region ranging from the E-layer and upwards. The observations here to be dealt with were therefore taken on terrestrial magnetically quiet days. A comparatively high deflection velocity of the electron bundle in the cathode ray tube was used. On the screen 100 km reflection height corresponded to 18 mm.

2. Observations.

The first preliminary tests showed that when watching the screen one observed from time to time echoes appearing and disappearing with reflection heights corresponding to that of the region of the E-layer. For the recording of these echoes, snaps were taken by an observer who was watching the oscillograph screen and operating the shutter, when an echo suddenly appeared. On plate V, No. 2 are shown series of snaps of the scatterings.

The scattered echoes from the E-region were obtained during the whole day and also during the night. During the evening and the night the scattering increased, which we assume must be due to the formation of scattering areas produced by the impact of electrically charged particles. In the following we shall therefore only deal with observations taken during the day and on absolutely quiet days.

Observing the echoes on the screen the following features were noticed concerning their appearance: 1. The echo amplitude normally increased steadily until a maximum value was attained and then decreased steadily. The greater part of the echoes showed nox fadings during their «life-time». 2. There was apparently no shift towards greater or lower heights during their «life-time». 3. The duration of the echoes varied, from ½ second to 2—3 seconds. It is especially remarkable that the echoes seem to have a certain minimum value of «life-time». Echoes having a «life-time» of 0.1 sec. or less and which would occur on the oscillograph screen like an atmospheric or artificial disturbance, were not observed.

The number of echoes appearing varied from one day to the next. In Table 2 are given, as an example, the number of snaps taken on four short series of observation.

Table 2.

	Time of observation in minutes	Total number of echoes	Echoes per minute
1938			
29.4 at ca. 18^h	39	81	2.1
30.4 » 9^h	25	104	4.1
» » 13^h	25	82	3.3
2.5 » 12^h	35	179	5.1

From Plate V, No. 2 it is seen that the heights were different for the echoes. In Fig. 19 a typical frequency curve of the heights is given, measured out from a number of snaps.

Previous observations of these echoes have been made in southeast England by Appleton and Piddington¹) and Eckersley²) who used pulse transmitters of considerable output. It is of interest to notice that the frequency curve given by Appleton and Piddington coincides almost exactly with the curve found in Tromsø. Both have a maximum at about 118 km with rapidly decreasing numbers towards lesser heights and more slowly decreasing

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¹) Proc. Roy. Soc. (A), *162,* 451 (1937).

²) Nature, *143,* 33 (1939). Gesammelte Vorträge der Hauptversammlung 1937 der Lilienthalgesellschaf für Luftfahrtforschung, 322—329.

against greater heights. Appleton draws attention to the fact that the frequency curve of these echoes lies within the same height interval at the lower boundaries of the aurorae.

It would be of interest to state whether echoes of the same type occurred at greater heights. Careful observations were therefore made in the height interval 200—400 km on days when the scattered echoes from the E-region were most frequent, but no scattered echoes from these greater heights were observed.

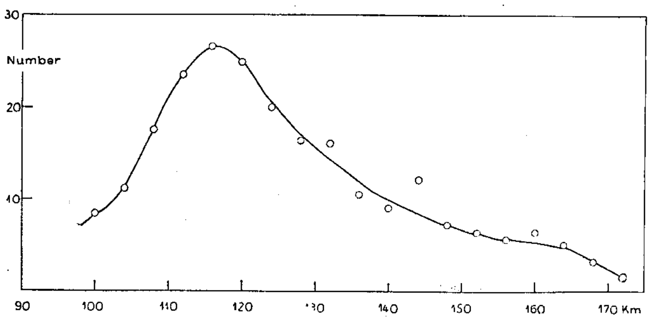

Fig. 19. Frequency curve of the scattered reflections from the E-region on 6.4 Mgc/sec.

Part IV. Reflection of Ultrashort Waves from the Ionized Regions.

1. Introduction.

The maximum value of the frequency of radio waves which can be reflected by the ionized regions is determined by the critical frequencies of the layers. At vertical incidence of the waves the maximum value of the critical frequency of the F_2-layer may be 12—14 Mgc/sec at noon, and such high values only occur during the spring and autumn maximum and also only during years of maximum solar activity. Concerning the layers in the niveau of the E-layer which are formed during terrestrial magnetic storms and aurorae, reflections may according to our experience be followed up to 10—12 Mgc/sec.

During strong terrestrial magnetic storms and aurorae the echoes disappear on all frequencies and do not occur again until after the maximum phase of the perturbation. This disappearance of the echoes is due to increased absorption. If we assume that an intense ionization is formed at the lower border or below the E-layer, the pressure here is comparatively great. On account of the increased pressure the collision frequency of the electrons, ν, is high and an increased absorption of the radio waves occurs.

To simplify the case we will not take the influence of the terrestrial magnetic field into account. The absorption coefficient, k, is then given by the following formula:

$$k = \frac{\nu}{2\mu c} \cdot \frac{4\pi N e^2}{m(p^2 + \nu^2)},$$

where:

$$\mu^2 = 1 - \frac{4\pi N e^2}{m(p^2 + \nu^2)}.$$

For the propagation of short waves in the ionosphere we may usually assume $p \gg \nu$, and we get the following approximate formula:

$$k = \frac{\nu}{2\mu c} \cdot \frac{4\pi N e^2}{m p^2}.$$

An increase of the collision frequency will increase the absorption. If we, however, use waves of increasing frequencies, the increase in the absorption may be even more than compensated.

The basic idea of the echo tests to be dealt with in the following was to find out if it was possible by using pulses on ultrashort waves to obtain reflections from the somewhat hypothetical, strongly ionized and absorbing layer which is formed at the lower border of the E-layer during strong terrestrial magnetic storms and aurorae.

As explained above, one should expect that the absorption on these high frequencies would not be very high, and accordingly it should be possible to obtain regular reflections if the maximum ionization is sufficiently high, or scattered reflections if heterogeneities in the layer occur.

The frequency used for the echo tests dealt with in the following was 41 Mgc/sec ($\lambda = 7.3$ m). This is far outside the band on which vertical reflections are obtained from the E- and F-layers.

2. Transmitter and Receiver Arrangements.

A tune-grid tuned-anode oscillator of the same type as given in the coupling scheme in Fig. 1 was used as transmitter. Two RCA 905 ultrashort wave valves were used as oscillator valves. The blocking voltage was 1500—3000 volts and the anode

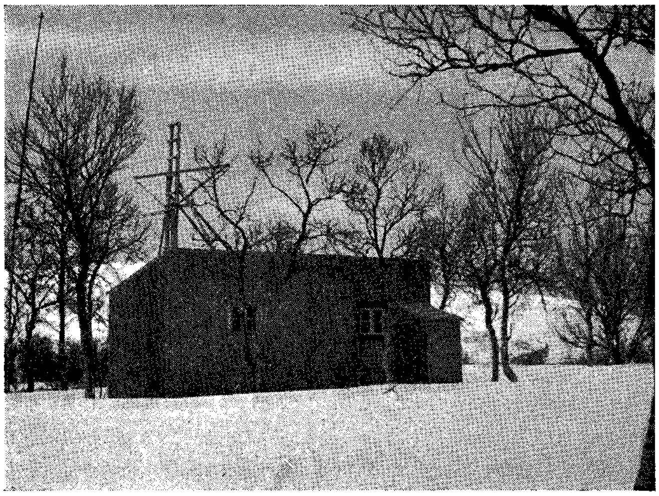

Fig. 20. Transmitter hut with antenna arrangement.

voltage used was 5000 volts. The length of the pulse produced by the pulse generator used was 1/100 000—2/100 000 sec. The use of a blocking voltage is here essential to prevent undesired oscillations after the pulse. The transmitter worked on a ½ λ horizontal dipole which was supplied by a reflector. The transmitter hut with the antenna arrangement is seen in Fig. 20. The dipole could be placed either in a horizontal or vertical position. The energy in the antenna on 7.3 m was about 4 KW.

Fig. 21 shows the scheme for the receiver. The receiver consisted of two HF stages with mixer, the IF section consisted of eight stages on 4 Mgc/sec, then came a rectifier and two LF stages. In the IF stages the grid circuits were strongly damped by introducing 5000 ohm resistances over the condensors. In this way a sufficiently broad band-pass was obtained, which was necessary for the short pulses here used. In the HF and IF sections the valves EF 8 were used, which are especially well suited on account of the low internal noise. The width of the groundwave corresponded to 8 km when the transmitter and the receiver were 150 m apart. When the distance was greater, the width of the groundwave corresponded to 4 km reflection height.

3. Observation of Echoes during Great Terrestrial Magnetic Disturbances and Aurorae.

For several months the signals received from ultrashortwave transmitter and television transmitters from Central Europe were followed. Signals from such stations were received with considerable strength during October—November 1938 between 10^h and 16^h MET. In several cases it was possible to identify the signals from the Berlin television transmitter. We notice that these signals on 7 to 9 m were only received about noon and during October—November when the critical frequencies of the F_2-layer had the greatest values. In December—January the signals disappeared, or were very weak, simultaneous with the midwinter minimum in the critical frequencies of the F_2-layer. In February 1939 the signals again appeared with great intensities as the critical frequencies of the F_2-layer again increased. During the summer it was impossible to get the signals from the ultrashort wave stations in Central Europe. The observations here mentioned prove that the propagation of the ultrashort waves was conducted via the ionosphere as the usual short waves.

Regular watches during quiet and disturbed conditions on evenings and nights were mainteined during the winter 1938—39. On December 16, 1938, echoes were for the first time observed on 7.3 m between 19^h and 21^h MET during a violent terrestrial magnetic storm accompanied by strong aurorae in the zenith. During the most intense displays the aurorae showed red colours.

The echoes appeared as irregular scatterings from the height interval 400—800 km. The amplitudes were low and showed rapid fadings. We noticed that the echoes with regard to fadings and displacements towards greater and lower heights showed a far greater variation than the scattered reflections from the niveau of the E-layer dealt with in part III of this paper. On plate V, No. 1 a reproduction is given of the echoes recorded, the echoes appearing are shown schematically in Fig. 22.

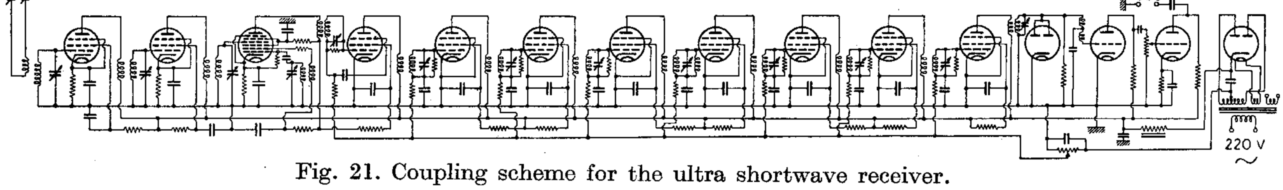

Fig. 21. Coupling scheme for the ultra shortwave receiver.

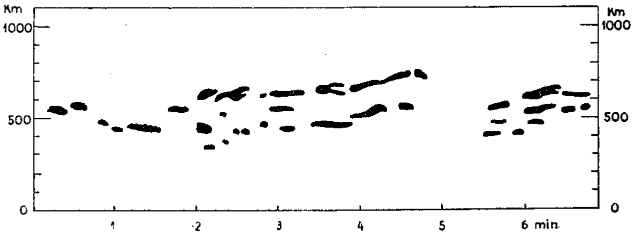

Fig. 22. Scattered reflections on 7.3 m wavelength recorded during a great terrestrial magnetic storm.

During the test on ultra-shortwaves the conditions of the reflecting power of the ionosphere were controlled by the second set of apparatus in the frequency range 1—15 Mgc/sec. No echoes were observed here and we may conclude that the absorbing layer at the lower border of the E-layer must have been present.

The fact that the ultrashort waves were scattered from heights between 400 and 800 km shows that the ultrashort waves must have penetrated the absorbing layer at lower heights, and that the maximum electron density here present had not been sufficient to produce refraction or reflection. This gives a measure for a possible upper limit of the maximum value of the electron density in the layers which are formed during terrestrial magnetic storms and aurorae.

The echoes on ultrashort waves from 400—800 km height must be regarded as scattered reflections due to irregularities or clouds formed suddenly during the terrestrial magnetic storm. These clouds are most probably formed by the ionizing power of the electrically charged particles penetrating into the atmosphere during the aurorae.

4. Observations of Echoes from Heights of 9 to 22 km.

It has been reported by several observers that echoes on the usual short waves have been obtained from different heights even down to 9 km. (Colwell and Friend¹) in U. S. A., Watson Watt and colloborators in England²) and Mitra and Syam³) in India). Especially convincing are the records reproduced by Watson Watt and collaborators according to which scattered reflections are obtained from a number of heights from 9 km and up to the E-layer. According to Appleton and Piddington⁴) these echoes, which were recorded on 6 Mgc/sec, must be regarded as scattered reflections with very low amplitudes. According to Appleton and Piddington the reflection coefficient must be of the order 0.00007.

For observations of these very faint scatterings a pulse transmitter of considerable power and a receiver of broad band-pass of the type used by the ultrashort wave experiments must be used.

By careful adjustment of the transmitter and the receiver it was possible to press down the «width» of the groundwave on 41 Mgc/sec to 8 km equivalent height when the transmitter and the receiver were 150 m apart.

The observations showed a number of reflections from the height interval 8—20 km. Tests showed that these echoes were real and not produced by instrumental errors. The echo amplitudes were constant and showed no fadings.

Experiments were now made with the transmitter and the receiver placed at 150, 900 and

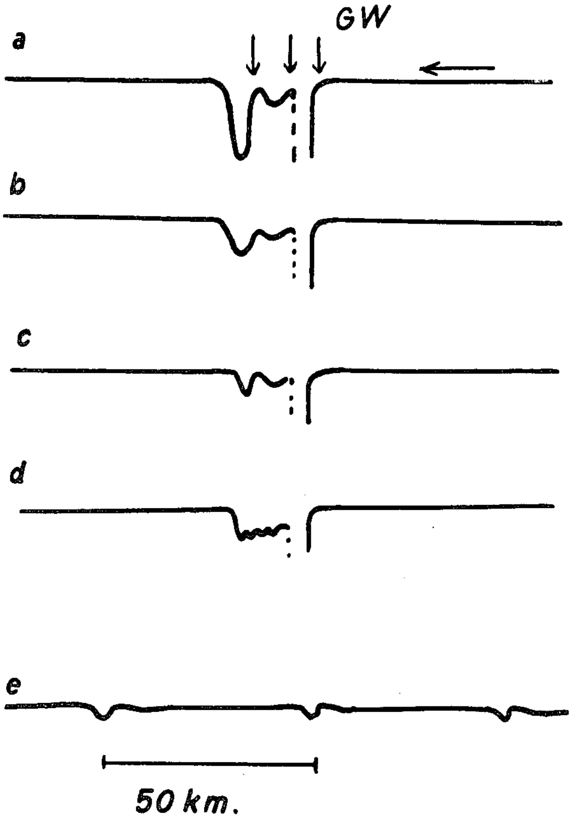

Fig. 23. Snaps of echoes on 7.3 m reflected from short distances.

a. transmitter dipole E—W, with reflector.
b. » » E—W, without »
c. » » N—S, » »
d. » » vertical, » »
e. calibration frequency 3000 cycles/sec.

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¹) Nature, *137*, 782 (1936).

²) Proc. Roy. Soc. London (A) *161*, 181 (1937).

³) Nature, *135*, 953 (1935).

⁴) Proc. Roy. Soc. (A), *162*, 451 (1937).

2000 m from each other. The groundwave showed a rapid decrease, but the character of the echoes remained unchanged. A change in the radiating character of the antenna of the transmitter, however, showed a change of the character of the echoes. In Fig. 23 the echoes received are shown schematically with the transmitter antenna in *E—W*, *N—S* and vertical direction. With the dipole in *E—W* two echoes appeared at the heights 8 and 14.5 km. With the dipole in *N—S* only one echo appeared corresponding to a distance of 15.6 km. With the antenna in vertical direction a number of reflections occurred covering the whole range between 8 and 15 km.

These tests indicate that the echoes received most probably are not due to vertical reflections, but must be interpreted as lateral deflections. Special weight must be laid upon the fact that the echoes showed no fadings. The place of observation, Tromsø, is surrounded by mountains in all directions rising from the level of the sea to 800—1600 m in height. It is therefore probable that scatterings of ultrashort waves by the landscape and the mountain hills appear, and that the echoes received are to be explained in this way.

5. Observations of Low Reflections on 11.5 Mgc/sec.

In addition to the low reflections observed on ultrashort waves, experiments were also made with the great pulse transmitter described on p. on 11.5 Mgc/sec, to see if low reflections occurred on this frequency. The receiver used had a band-pass which gave a «width» of the groundwave corresponding to 10 km when the transmitter and the receiver were 2 km apart. The observations were strongly disturbed by the incoming signals from shortwave stations which were received on account of the low selectivity of the receiver. Nevertheless, a faint echo with *constant* amplitude was received which corresponded to a reflection distance of 17 km. Further control tests of this echo have not been made.

6. Summary.

a. Echo tests on ultra-shortwaves of a wavelength of 7.3 m have been made. The intention was to determine whether the absorbing layer formed during strong terrestrial magnetic storms and aurorae would reflect ultrashort waves. The observations showed that no reflections from the expected heights of the lower border of the *E*-layer appeared during a strong terrestrial magnetic storm. Scattered reflections, however, were obtained from a region at 400—600 km height during the most intense phase of the storm.

b. Reflections on ultrashort waves were obtained from reflection distances of 8—20 km. It was shown that the echoes most probably were lateral reflections and it was assumed that these were due to scattering or reflections by the landscape.

c. Using the high power transmitter on 11.5 Mgc/sec a faint echo with constant amplitude was obtained corresponding to a reflection distance of 17 km.

Acknowledgments.

For the construction of the apparatus and the carrying out of the observations, financial grants have been received from Norsk Rikskringkasting who also most kindly have placed valves and components of transmitters at our disposal.

In the construction of the transmitter and receiver we have been most ably assisted by the engineer W. Stoffregen whose technical skill and perseverance during the observations have been indispensable for the work carried out. On account of unforseen circumstances he has not had the opportunity to join the authorship of this manuscript.

Explanation to Plate I.

1. Snaps showing the technique of observation.
2. Polarization tests over the frequency range 3—8 Mgc/sec during *undisturbed* conditions of the ionosphere. The E-echoes on the lower frequencies only consist of the ordinary component, the F-echoes on higher frequencies of both.

3a. Polarization test during a faint terrestrial magnetic storm taken on 16. 6. 1938 at 17^h MET (see Fig. 5 in the text). The storm was sufficient to produce a slight increase of the ionization in the E-layer. The E-echoes here on the higher frequency 3.75 Mgc/sec only show the extraordinary component.

3b. P', f-curve recorded during the polarization test.

4. Polarization test during a small magnetic storm taken on 30. 5. 1938 at 18^h MET (see Fig. 6 in the text). On the higher frequency 5.1 Mgc/sec, only the extraordinary component appears.
5. Polarization test during a terrestrial magnetic storm of considerable strength taken on 1. 6. 1938 at 21^h50^m MET (see Fig. 7 in the text). The dense E-layer screens off the reflections from the F-layer. On the highest frequncy 7.50 Mgc/sec almost only the extraordinary component of the E-echoes is reflected.
6. Polarization test taken on 28. 6. 1938 at 13^h50^m MET, on which the E-echoes on the lowest frequency 3.1 Mgc/sec mainly consist of the ordinary component. On the higher frequencies scattering appears (see Fig. 12 in the text).
7. Polarization test taken on 20. 5. 1938 at 23^h40^m MET, on which M-reflections are recorded.

Plate II.

1. Polarization test over the frequency range 3.1—7.5 Mgc/sec taken on 30. 5. 1938 at 21^h—21^h30^m MET during a terrestrial magnetic perturbation (see Fig. 8 in the text). The layer formed in the niveau of the E-layer changes rapidly during the storm. On the highest frequency almost only the extraordinary component is recorded.
2. P', f-record taken during the polarization test with the second set of apparatuses.
3. Polarization test on a fixed frequency of 6.1 Mgc/sec taken on 7. 6. 1938 at 11^h30^m and 15^h35^m MET (see Fig. 9 in the text). The record demonstrates the difference in the state of polarization of the normal F-echoes and the scattered reflections from the E-region.
4. Echoes recorded on a fixed frequency of 6.5 Mgc/sec taken on 5. 5. 1938 at 20^h MET (see Fig. 10 in the text).
5. Polarization tests taken on 20. 12. 1938 at 18^h—18^h40^m MET in the frequency range 3—9 Mgc/sec during an auroral display. (See Fig. 11 in the text). The structure of the E-layer changed rapidly during the display. On 6 and 7 Mgc/sec we see how an E-layer suddenly screens off the F-echoes during the test.

Plate III.

1. Multiple F-reflections on 6.8 Mgc/sec recorded with the great pulse transmitter and the receiver with reduced sensitivity.
2. Scattered reflections from 700—100 km virtual distances, taken on 22. 10. 1938 on 10.8 Mgc/sec. Day conditions.
3. Scattered reflections from 600—1000 and 1400—1900 km virtual distances, taken on 22. 10. 1938 on 10.8 Mgc/sec. Noon conditions.
4. Scattered reflections from different virtual distances up to 2000—2300 km, taken on 1. 11. 1938 on 11.8 Mgc/sec.
5. Scattered reflections from different virtual distances, taken on 22. 10. 1938 on 10.8 Mgc/sec. The lower reflections correspond to 550—700 km distances, above these reflections a number of scatterings from continously varying distances appear, the greatest distances correspond to 2300 km.
6. Complicated system of scatterings and reflections taken on 28. 1. 1939 on 10.8 Mgc/sec. The lower reflections correspond to 650—1000 km virtual distances.

Plate IV.

1. Record on 11 Mgc/sec taken on 27. 12. 1938 during the afternoon. The reflection distances increase during 17^h—18^h from 1250 to 1800 km.
2. Afternoon record of the same type as No. 1, taken on 29. 1. 1939 on 10.8 Mgc/sec. Notice the «rays» which ascend towards great heights.
3. Simultaneous appearance of reflections of great virtual distances and F_2-echoes at noon, taken on 16. 1. 1939 on 9.6 Mgc/sec.
4. Simultaneaous appearance of reflections of great virtual distances and the extraordinary component of the F_2-echoes, recorded on 30. 1. 1939 on 11 Mgc/sec.
5. Night conditions of the high reflections, recorded on 27. 12. 1938 on 11 Mgc/sec. The reflecting and scattering heights go down to 450 km.
6. Night conditions of the height reflections, recorded on 20. 10. 1938 on 10.8 Mgc/sec. The reflecting and scattering areas lie at 700—1200 km heights.
7. Reflections and scatterings during a terrestrial magnetic storm of considerable strength accompanied by aurorae, taken on 14. 1. 1939 on 8.1 Mgc/sec. The reflecting and scattering areas during the phase of most intense perturbation go down to 150—200 km height.

Plate V.

1. Scattered reflections on ultrashort waves of 7.3 m during a great terrestrial magnetic perturbation accompanied by aurorae.
2. Scattered reflections from the niveau of the *E*-layer on 6.4 Mgc/sec.
3. Reflections from distances of 8—20 km on ultrashort waves of 7.3 m.
    - a. transmitter dipole in *E—W*, with reflector.
    - b. » » » *E—W*, without »
    - c. » » » *N—S*, » »
    - d. » » vertical, » »
    - e. calibration frequency of 3000 cycles/sec.

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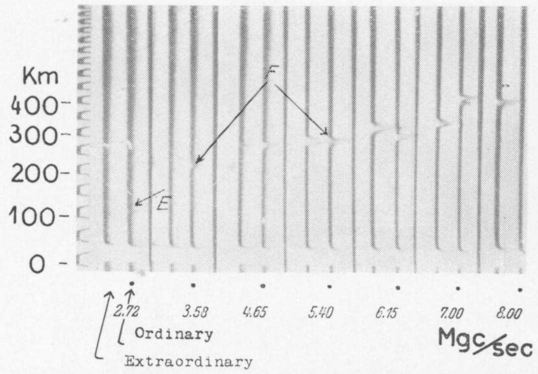

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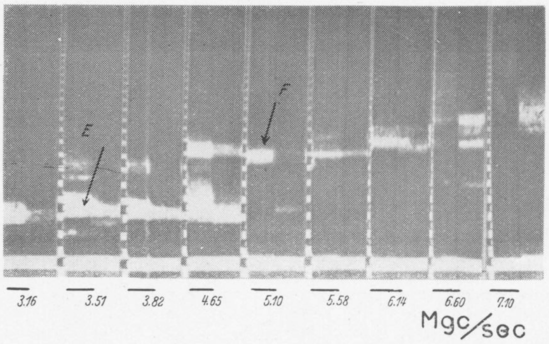

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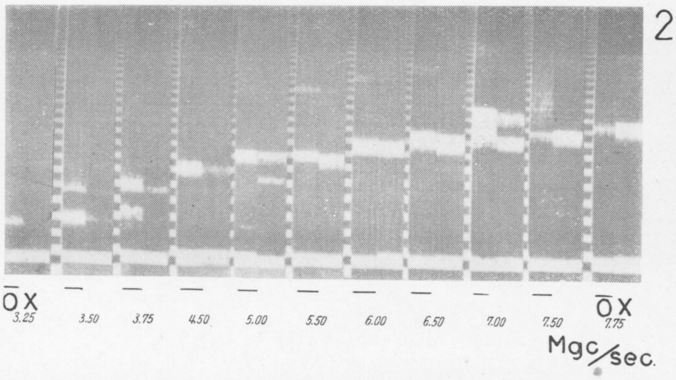

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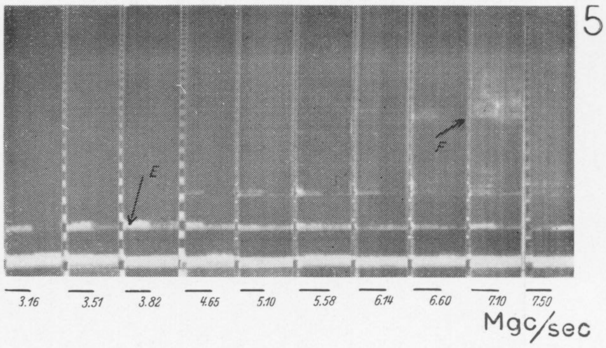

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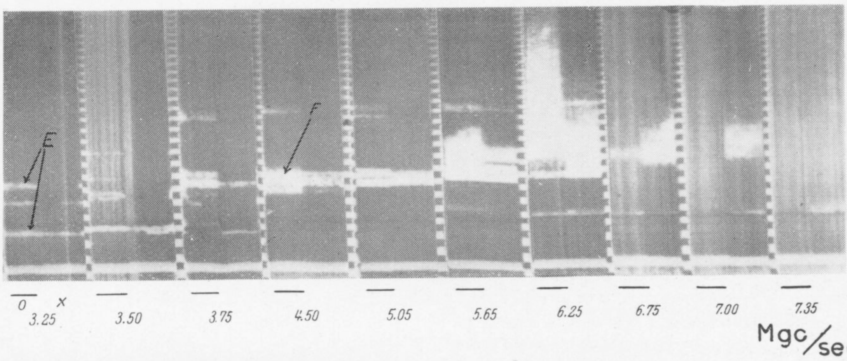

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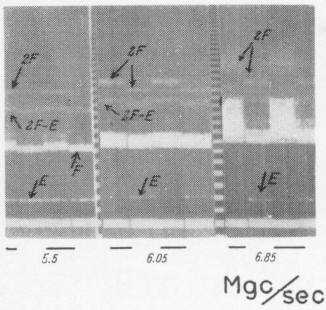

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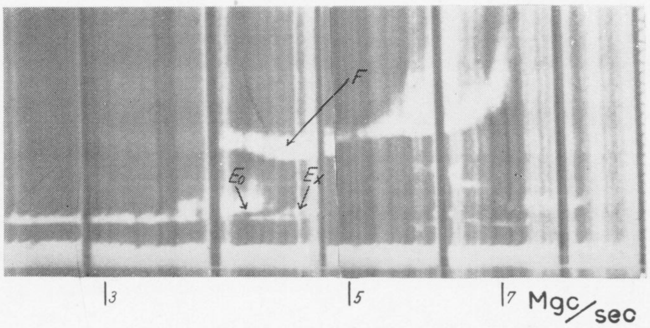

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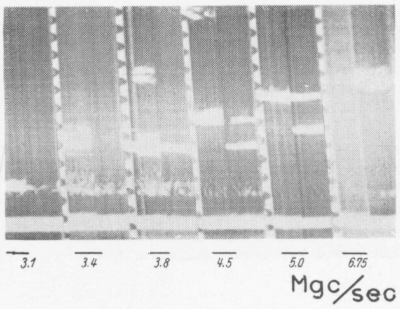
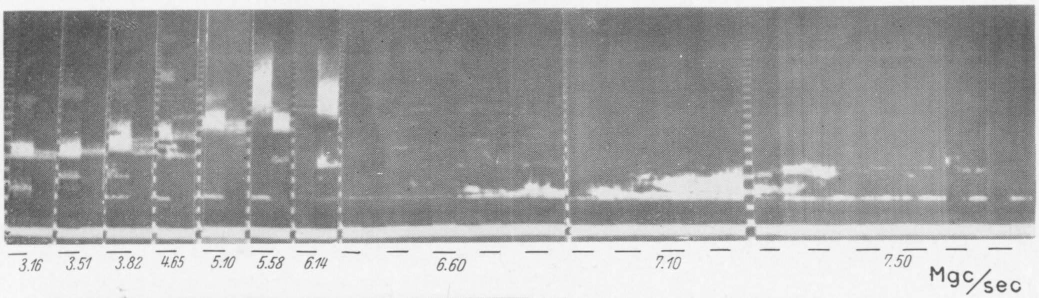


6

Plate I.

1



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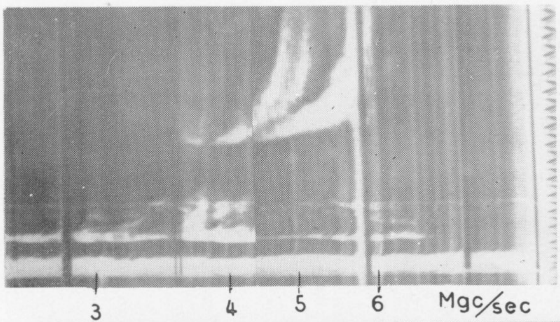

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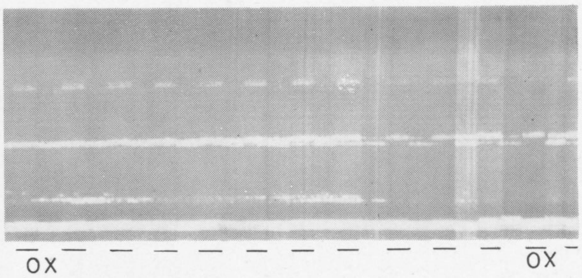

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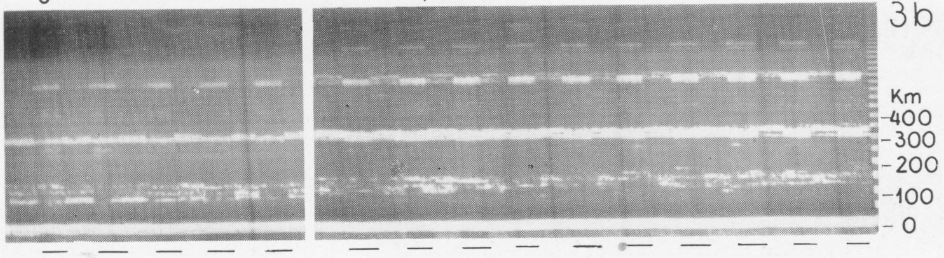

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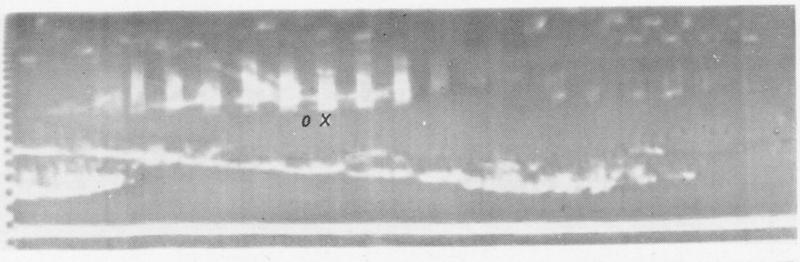

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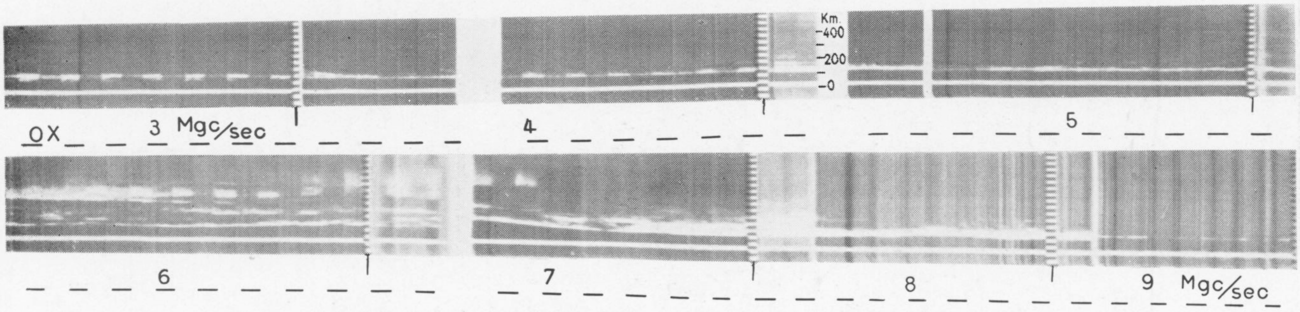

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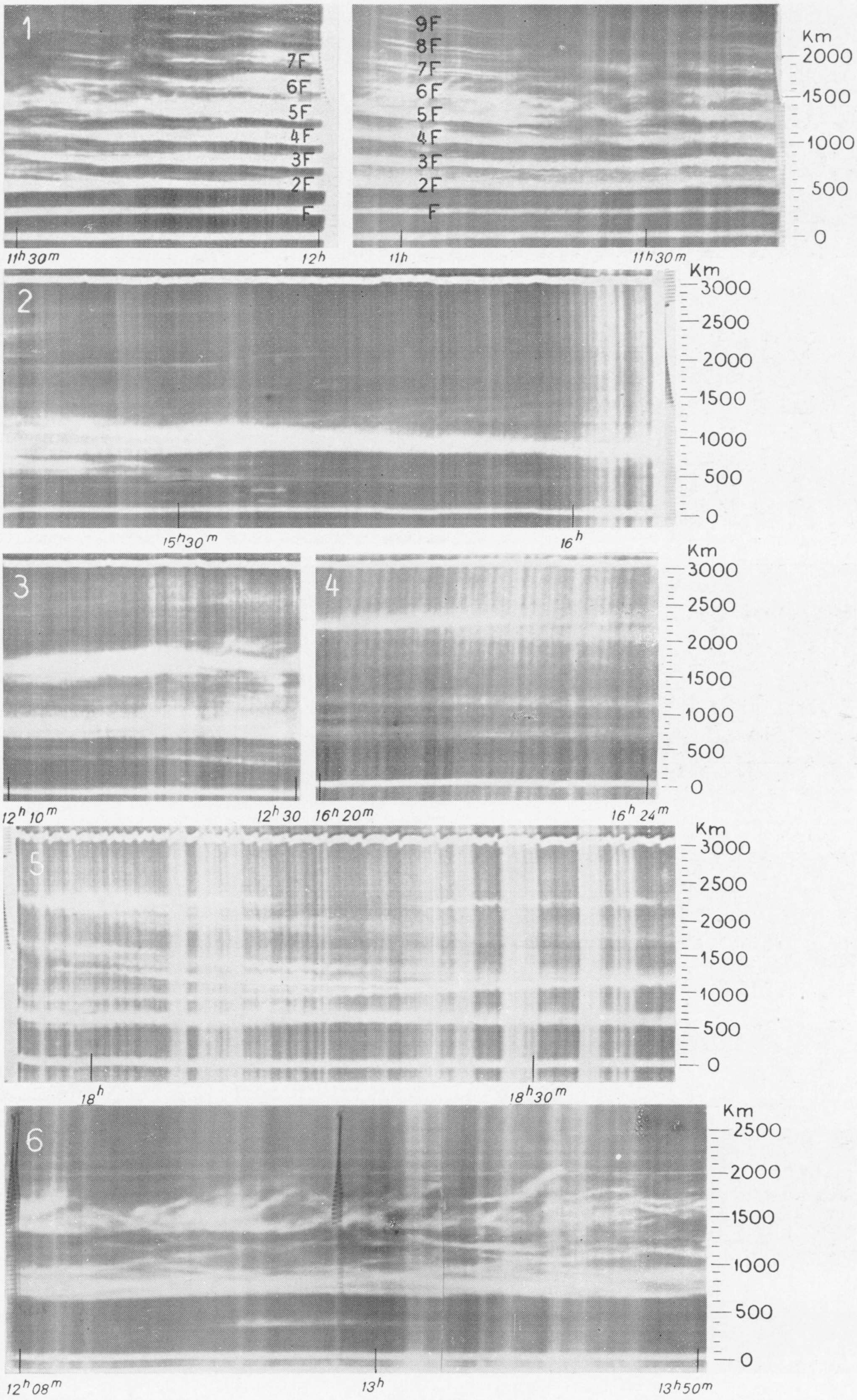

1
7F
6F
5F
4F
3F
2F
F
9F
8F
7F
6F
5F
4F
3F
2F
F
Km
2000
1500
1000
500
0
11h 30m
12h
11h
11h 30m
2
Km
3000
2500
2000
1500
1000
500
0
15h 30m
16h
3
4
Km
3000
2500
2000
1500
1000
500
0
12h 10m
12h 30
16h 20m
16h 24m
5
Km
3000
2500
2000
1500
1000
500
0
18h
18h 30m
6
Km
2500
2000
1500
1000
500
0
12h 08m
13h
13h 50m

Plate III.

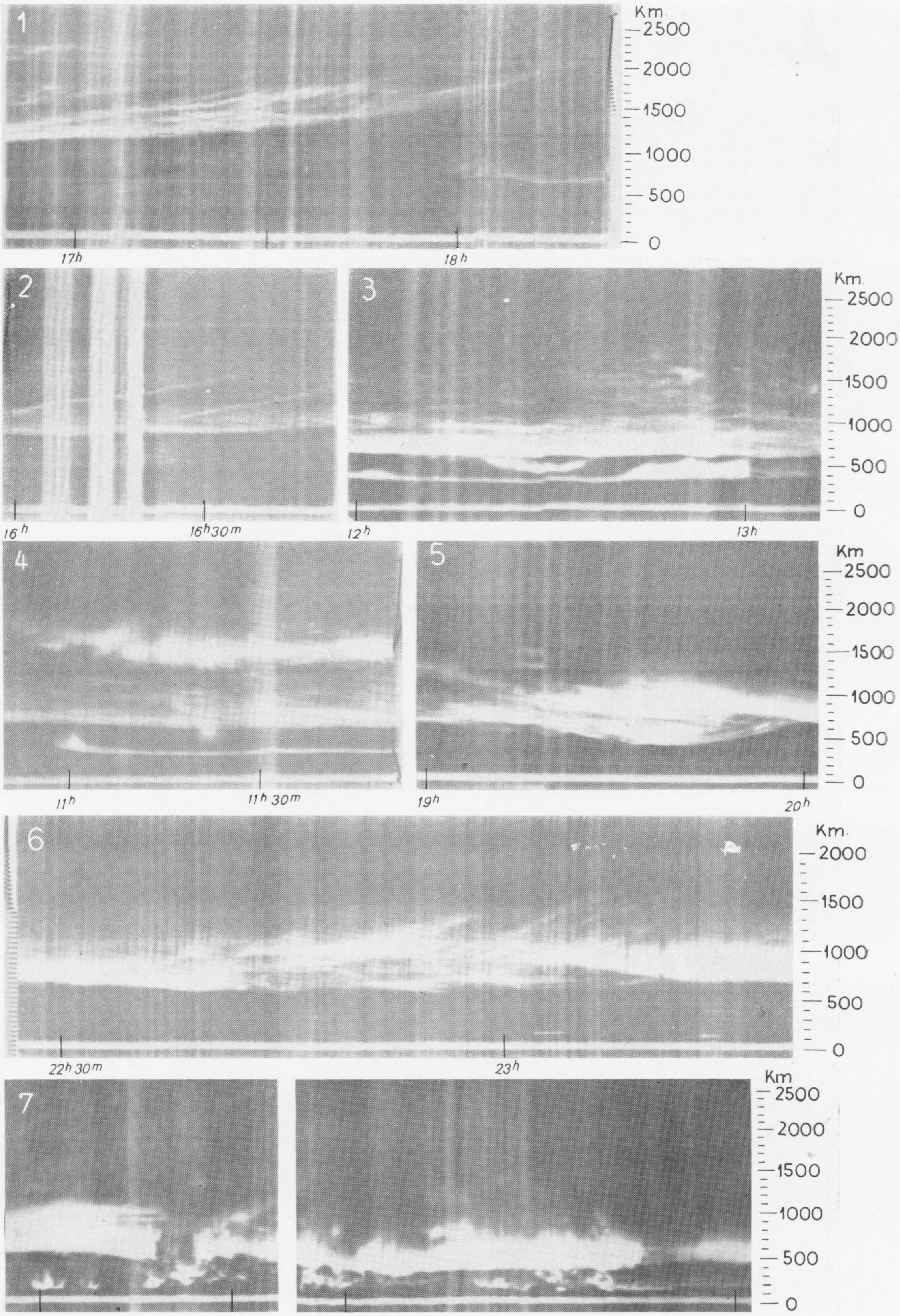
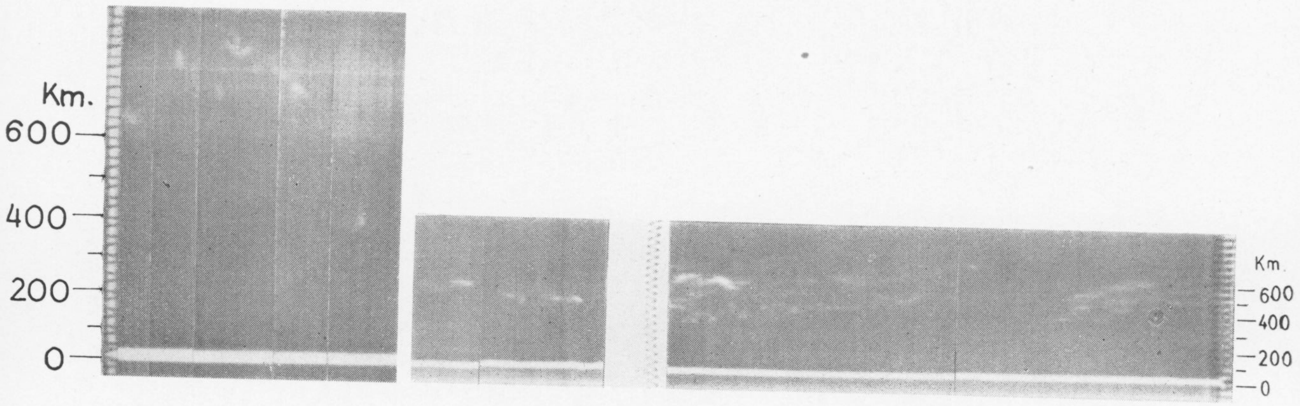

1
Km.
2500
2000
1500
1000
500
0
17h
18h
2
16h
16h30m
3
12h
13h
Km.
2500
2000
1500
1000
500
0
4
11h
11h 30m
5
19h
20h
Km
2500
2000
1500
1000
500
0
6
22h 30m
23h
Km.
2000
1500
1000
500
0
7
23h 15m
23h 45m
0h
1h
Km
2500
2000
1500
1000
500
0

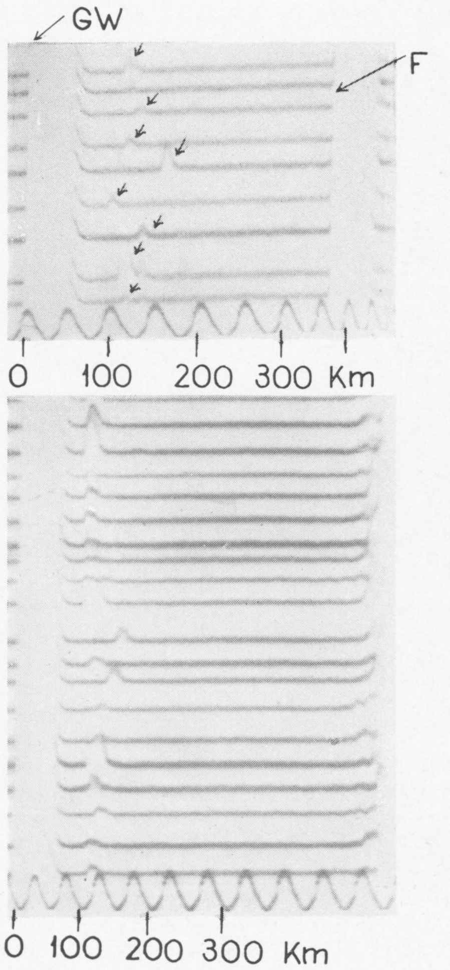
Plate IV.

1



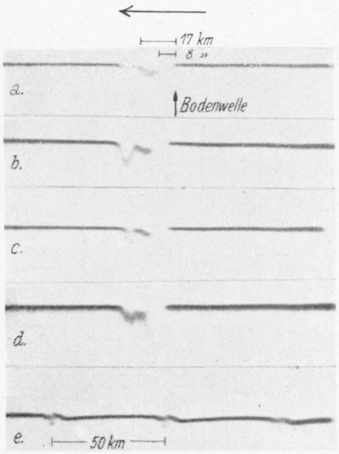
Km.
600
400
200
0
Km.
600
400
200
0

2



GW
F
0
100
200
300
Km
0
100
200
300
Km

3



17 km
8 »
a.
Bodenwelle
b.
c.
d.
e.
50 km

Plate V.

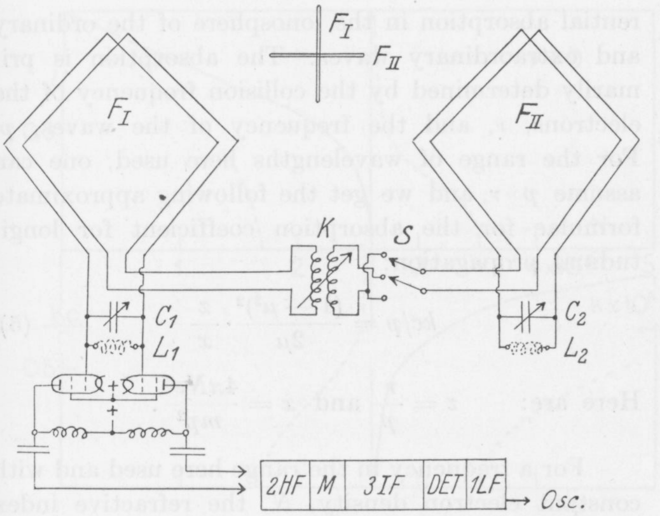


Fig. 1. Arrangement of frames and receiver during the polarisation tests.

rangement in this way is sensible *either* only for dextrally *or* only for sinistrally circularly polarized waves. The commutation of the switch S could be made rapidly by means of a relay. Linear polarized waves coming in vertically will be received with constant amplitudes for both positions of the switch.

In order to cover a greater frequency range, coils L_1 and L_2 were set over the tuning condensors C_1 and C_2. With two sets of coils it was possible to cover a frequency range of 3—11 Mgc/sec, and a complete polarization test on eleven wavelengths within this frequency range could be done within thirty minutes.

During the polarization tests the echoes on each of the frequencies selected were recorded during 10 seconds for each of the two positions of the commutator switch S. When the antenna arrangement was made sensitive for the ordinary component, a small lamp was lit before the recorder in the manner used by Ratcliffe and White¹). The ordinary components are therefore marked out on the records by an horizontal line below the groundwave.

The receiver and the frame arrangement were set up in a small hut which lies at a distance of 200 m from the other buildings of the observatory. The transmitter was placed in another hut at a distance of 200 m.

During the polarization tests, the echoes were usually further recorded simultaneously by means of another set of pulse transmitter and receiver in the observatory building supplied with usual dipole antennas.

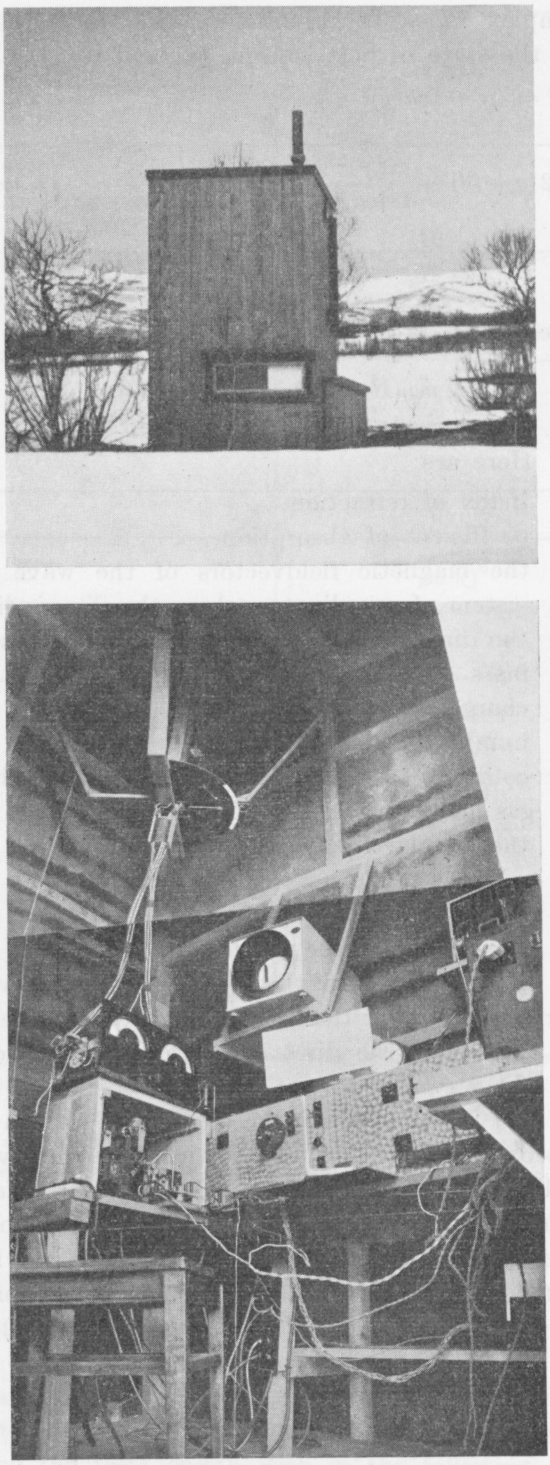


Fig. 2. The polarimeter hut. The frames, receiver and recording arrangement are seen.

3. Theory.

The propagation of the radio waves in an ionized atmosphere under the influence of the earth's magnetic field is determined by the formula for the

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¹) Ratcliffe and L. C. White, Phil. Mag. *16*, 125 (1933).

2. Experimental Arrangements.

A pulse transmitter with considerable power was built. The scheme used is given in Fig. 14. By means of the two tuning condensors C_1 and C_2, one could with one set of coils cover the frequency range 7—13 Mgc/sec. Special emphasis was laid on the effiency of the higher frequencies, as the frequency used for observations was usually *greater* than the critical penetration frequencies of the F_2-layer. As transmitting valves two Telefunken 15 g valves were used, each rated for 1.5 KW with 4000 volts anode voltage. For pulse transmission, however, considerably greater anode voltage than rated may be used without damaging the anode. During the tests an anode voltage of 16 000—25 000 volts was applied. A ½ λ horizontal dipole was used as antenna. The length of the dipole could be varied continuously to suit the wavelength for each frequency used within the range. The effect of the transmitter was estimated to be at least 60—80 KW during the pulse.

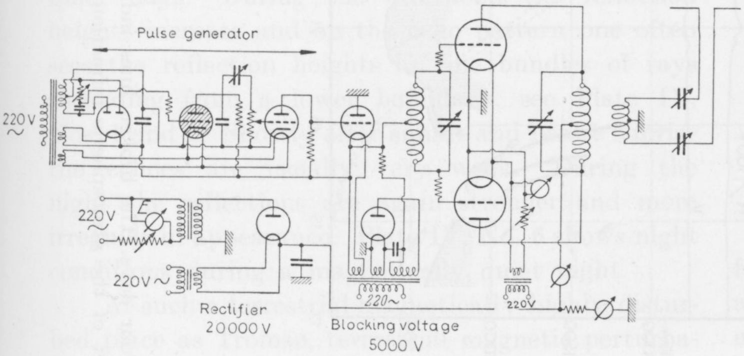

Fig. 14 a.

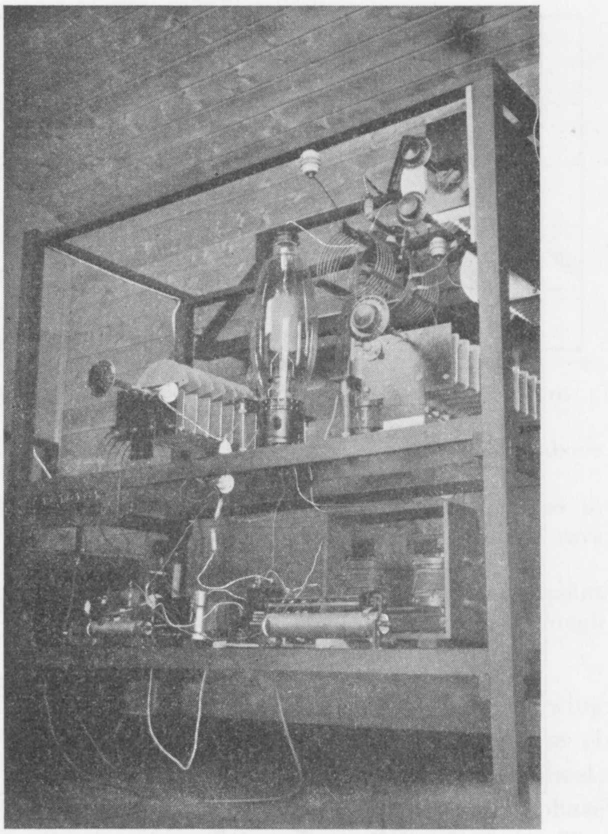

Fig. 14 b.

Fig. 14. The great pulse transmitter.

The transmitter was placed in a hut lying about 150 m from the observatory building where the receiver was placed, and could be started from the observatory by means of relays. As receiver a similar type was used as mentioned under the polarization tests.

For the recording of these echoes of longer delays a comparatively small deflection speed on the cathoderay tube was used. A coupling was devised by which the ground wave appeared as a vertical deflection at the edges to the left and right on the linear sweep. As the pulse emission of the transmitter was locked to the 50 period net, the distance between the two groundwaves on the screen corresponded to 1/50 sec., *i.e.*, to a 3000 km virtual reflection distance. The echoes appearing corresponding to reflection heights within distance could therefore be conveniently measured out.

3. Observations.

On lower frequencies, 6—8 Mgc/sec, on which reflections from the F_2-layer are recorded during autumn and spring, a great number of multiple reflections from the F-layer were obtained with the transmitter and receiver arrangement described. During daytime more than ten times multiple F-reflections were lasity obtained. A record showing a great number of F-reflections on 6.8 Mgc/sec is reproduced in Plate III, No. 1.

The critical frequencies of the E- and F-layers were controlled during the tests by a second set of apparatuses. By now using a frequency higher than the critical frequency of the F_2-layer on the high power transmitter, one regularly obtained scattered reflections which during the day corresponded to reflection distances of 600—900 km. The reflections were very faint and the amplitude was very variable. Records taken over some time, however, revealed a

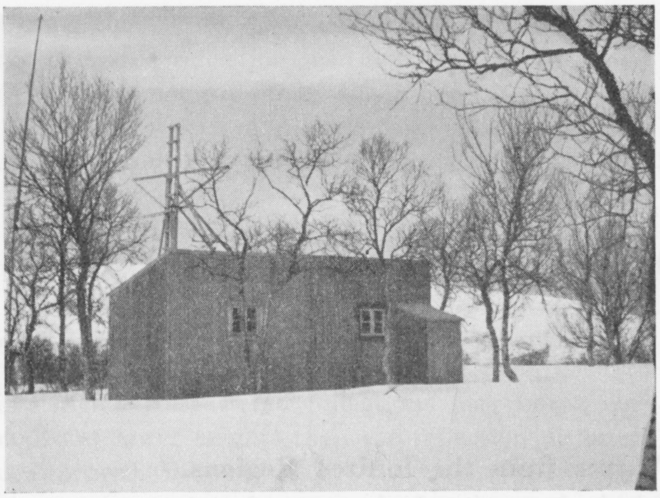

Fig. 20. Transmitter hut with antenna arrangement.

voltage used was 5000 volts. The length of the pulse produced by the pulse generator used was 1/100 000—2/100 000 sec. The use of a blocking voltage is here essential to prevent undesired oscillations after the pulse. The transmitter worked on a ½ λ horizontal dipole which was supplied by a reflector. The transmitter hut with the antenna arrangement is seen in Fig. 20. The dipole could be placed either in a horizontal or vertical position. The energy in the antenna on 7.3 m was about 4 KW.

Fig. 21 shows the scheme for the receiver. The receiver consisted of two HF stages with mixer, the IF section consisted of eight stages on 4 Mgc/sec, then came a rectifier and two LF stages. In the IF stages the grid circuits were strongly damped by introducing 5000 ohm resistances over the condensors. In this way a sufficiently broad band-pass was obtained, which was necessary for the short pulses here used. In the HF and IF sections the valves EF 8 were used, which are especially well suited on account of the low internal noise. The width of the groundwave corresponded to 8 km when the transmitter and the receiver were 150 m apart. When the distance was greater, the width of the groundwave corresponded to 4 km reflection height.

3. Observation of Echoes during Great Terrestrial Magnetic Disturbances and Aurorae.

For several months the signals received from ultrashortwave transmitter and television transmitters from Central Europe were followed. Signals from such stations were received with considerable strength during October—November 1938 between 10^h and 16^h MET. In several cases it was possible to identify the signals from the Berlin television transmitter. We notice that these signals on 7 to 9 m were only received about noon and during October—November when the critical frequencies of the F_2-layer had the greatest values. In December—January the signals disappeared, or were very weak, simultaneous with the midwinter minimum in the critical frequencies of the F_2-layer. In February 1939 the signals again appeared with great intensities as the critical frequencies of the F_2-layer again increased. During the summer it was impossible to get the signals from the ultrashort wave stations in Central Europe. The observations here mentioned prove that the propagation of the ultrashort waves was conducted via the ionosphere as the usual short waves.

Regular watches during quiet and disturbed conditions on evenings and nights were mainteined during the winter 1938—39. On December 16, 1938, echoes were for the first time observed on 7.3 m between 19^h and 21^h MET during a violent terrestrial magnetic storm accompanied by strong aurorae in the zenith. During the most intense displays the aurorae showed red colours.

The echoes appeared as irregular scatterings from the height interval 400—800 km. The amplitudes were low and showed rapid fadings. We noticed that the echoes with regard to fadings and displacements towards greater and lower heights showed a far greater variation than the scattered reflections from the niveau of the E-layer dealt with in part III of this paper. On plate V, No. 1 a reproduction is given of the echoes recorded, the echoes appearing are shown schematically in Fig. 22.

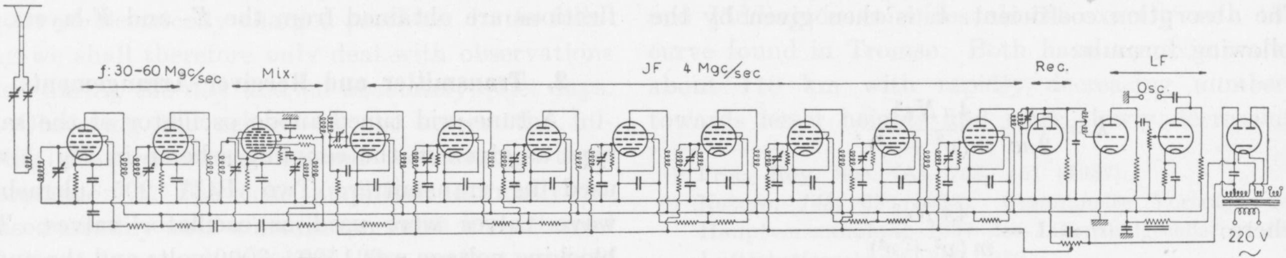

Fig. 21. Coupling scheme for the ultra shortwave receiver.