PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Trends in Early Ionospheric Research in Germany

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Trends in early ionospheric research in Germany

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[Plates 1 and 2]

If one is asked to contribute an historical account on the occasion of an anniversary, as I see it there are two possible approaches: either to give a survey of the facts as completely as possible or to base the contribution on personal recollections which is of course much more subjective and somewhat more lively. The former I have tried to do in my written contribution to the 50th Anniversary of the Discovery of the Ionosphere in *J. appl. terr. Phys.* and in this paper I should like to attempt the second approach.

When Appleton made his famous discovery, I was still a schoolboy but nevertheless already interested in radio propagation and what was then called the Heaviside layer. Having been a broadcast listener since 1924, and a real 'ham' since 1925, I had experienced the queer propagation phenomena that occurs on medium and short waves. When I entered the Technical University at Munich in 1926, I soon became confronted in Zenneck's institute with the literature on this new field of physics. By good fortune, Zenneck was editor of the periodical that was then called *Jahrbuch der drahtlosen Telegraphie*, and his abstracts of the pertinent publication in the *Proc. Inst Radio Engrs*, *Proc. R. Soc. Lond.* A and *The Electrician*, were famous for their conciseness and clarity. Having been educated at a Bavarian humanistic Gymnasium, I had learnt Latin, Greek and French, but no English, and for this reason Zenneck's abstracts were very helpful to me.

Gradually also papers by German engineers and scientists began to appear in the *Jahrbuch* and other periodicals. I was not so much impressed by the papers describing propagation conditions, since this was already well known to me from practical experience. Sometimes I even suspected that the 'commercials' knew less about propagation than amateurs. What impressed me very much was a paper by Lassen (1926) entitled: 'On the ionization of the atmosphere and its influence on the propagation of short electric waves of wireless telegraphy'. It is worth noting that he did not speak about 'the ionosphere' nor about 'radio wave propagation', since these terms were not known at that time. In 15 pages he described most aptly the formation of what was later called a Chapman layer, derived the dispersion formula of an ionized medium and calculated the transmission paths for a realistic ionospheric model. In his paper, which was initiated by Försterling, he quoted the work of Larmor (1924), Lenard & Ramsauer (1909–11), and Jeans, but of course there was no mention of Appleton since his famous paper was not to appear until the following year.

It is interesting to briefly consider what turned out to be correct and what was incorrect in Lassen's paper. According to the knowledge of the time he discussed only one layer at a height of about 100 km, which was later called the E-layer by Appleton. Although he mentioned the possibility of electrons being the active reflectors, he thought that hydrogen ions were responsible for the diminution of the refractive index. Accordingly, he came to a maximum ion density of 10^8 cm^{-3} and a recombination coefficient of 10^{-13} s^{-1}. That he thought of hydrogen ions is understandable since nobody in those days anticipated the increase in temperature with height and the preponderance of nitrogen and oxygen. In his 1926 dispersion formula, the effect of collisions was included but not the influence of the magnetic field. This was taken into account in another paper which appeared in 1927, simultaneously with Appleton's (1927) paper. Lassen's formula of 1927 and Appleton's (1932) formula, written in Lassens notation, are shown below omitting the erroneous polarization term from the former.

$$n^2 = 1 - \frac{\sigma}{p - \dfrac{\omega_T^2}{2(p-\sigma)} \pm \sqrt{\left[\left(\dfrac{\omega_T^2}{2(p-\sigma)}\right)^2 + \omega_L\right]}}, \qquad \text{Appleton (1932)}$$

$$n^2 = \frac{(p-\sigma)^2 - \omega\omega_0^2}{p(p-\sigma) - \omega\omega_0^2 - \dfrac{1}{2}\dfrac{\sigma\omega_T^2}{p-\sigma} \pm \sqrt{\left(\dfrac{\sigma}{2}\dfrac{\omega_T^2}{p-\sigma} + \sigma^2\omega_L^2\right)}}, \qquad \text{Lassen (1927)}$$

where

$$\sigma = 4\pi Ne^2/m, \quad p = \omega^2 - i\omega\nu,$$

$$\omega_0 = -eH/mc, \quad \omega_T = \omega\omega_0 \sin\alpha, \quad \omega_L = \omega\omega_0 \cos\alpha.$$

A comparison with Appleton's earlier formula would be misleading since Appleton did not take collisions into account in his earlier paper. Although the formulae look different, it is not too difficult to prove that both formulae are identical. Obviously the work of Lassen was based on earlier work of Nicols & Schelleng (1925) and Taylor & Hulburt (1926). The essential improvement achieved by Försterling & Lassen was that their dispersion formula was applicable to any angle between the propagation direction and the magnetic field, whereas in the earlier work, only parallel and perpendicular propagation was considered. From the very beginning, the so-called polarization term was omitted. As to the propagation paths, Lassen described correctly the formation of the skip distance and low and high angle radiation. Although he considered only one layer, his calculations compare favourably with the observations of Taylor & Hulburt.

Another discovery, which was made simultaneously in the U.K. and Germany, was the experimental proof of double refraction. It was Appleton & Builder (1932) who published a paper on the experimental proof of magnetoionic splitting. In the same year, Rukop & Wolf (1932) reported on their experiments with two fixed frequencies. These frequencies were chosen purposely in such a way that, on the recordings, the *o*-component of the lower frequency coincided with the *x*-component of the higher one. The difference was measured to be about 0.7 MHz which is equivalent to half the gyrofrequency of electrons in the Earth's magnetic field. The old question of whether electrons or ions are responsible for the diminution of the refractive index was solved unambiguously by this experiment.

Whereas most of the early work on ionospheric research in Germany remained almost unnoticed abroad, the very thorough discussion of the dispersion formula by Goubau became almost an international textbook. In contrast to other workers, he omitted from the very beginning the polarization term, and took into account different collision frequencies and various mixing ratios between electrons and ions. Without going into details, I should like to show you only one set of the curves published by Goubau in 1934 (figure 1). They show the variation of the refractive index for a frequency of 3.5 MHz and for different ratios of the collision frequency to the critical collision frequency, as a function of the number density of charged particles.

Although in the initial phase, mainly radio engineers and physicists were engaged in ionospheric research, the relation with solar and geophysical phenomena soon became a field of special interest. Based on experience with long wave propagation, it was commonly believed that with increasing solar activity, the ionization also increases. This is without any doubt correct as far as long-term variations are concerned. The shift of the usable frequency range in short wave communication towards lower frequencies with decreasing sunspot number was realized as early as 1930. Then, compared with 1929, the time periods when frequencies around 20 MHz were usable in transatlantic communication had been reduced to less than 50 %. This was correctly ascribed to the decrease of solar activity by M ögel (1930), and by Plendl (1931)

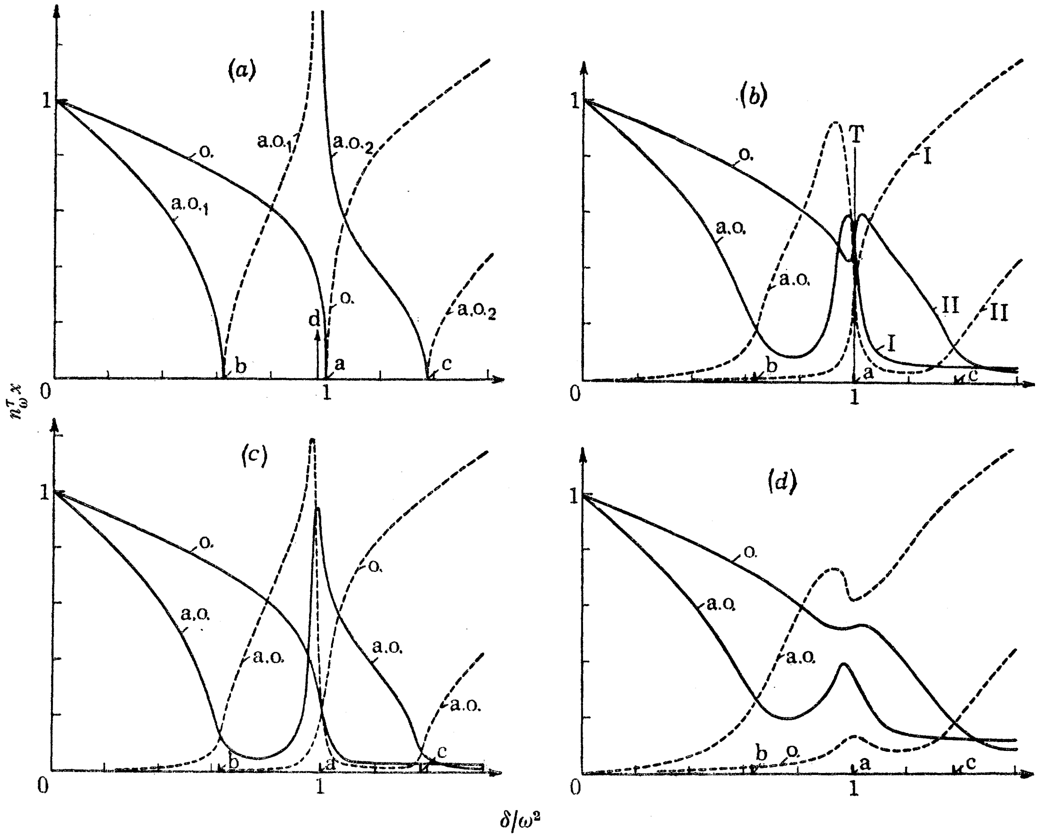


FIGURE 1. Real and imaginary part of refractive index (for $\lambda = 80$ m) against electron density for different values of collisional frequency after Goubau. (*a*) $\nu = 0$; (*b*) $\nu = \nu_0$; (*c*) $\nu = 0.5\nu$; (*d*) $\nu = 2.0\nu_0$.

independently. On the other hand, the correlation between 27 day variations of solar activity and the quality of short wave propagation was found to be statistically opposite in phase. Progress was made when magnetic disturbances were used as an indicator instead of sunspot numbers. Now it is well known that it is the ultraviolet radiation from the Sun that is responsible for the long term variation, whereas corpuscles produce what are now called ionospheric storms.

It was Mögel (1930) who described, based on observations at the German Overseas Receiving Centre at Geltow near Berlin, two different types of propagation disturbance. A graphical representation of what he called 'long-disturbance' is shown in figure 2. In the upper part, the horizontal component of the Earth's magnetic field as observed at Potsdam is shown. In the lower part, the field strength of different communication circuits is plotted. The terminals are shown on the left side, the respective wavelength on the right side. The envelopes correspond to average conditions, the dark areas to the individual days. Hatched areas indicate the periods with simultaneous short- and long-path propagation. Clearly, the New York–Berlin path is the worst affected whereas Java–Berlin and Siam–Berlin show little disturbance and Cairo–Berlin almost none at all. Mögel plotted the number of disturbances against what he called magnetic path density, i.e. the number of latitudinal degrees crossed per 1000 km path (figure 3). He obtained a very clear correlation. He concluded, 'that disturbances of short-wave propagation occurring in connexion with magnetic disturbances increase in amplitude and duration towards the pole, in the same way as magnetic disturbance themselves and aurorae vary with latitude and therefore a similar origin exists for these phenomena'. This was in contrast to the belief shared by many experts at that time, that all disturbances of solar origin were caused by ultraviolet radiation.

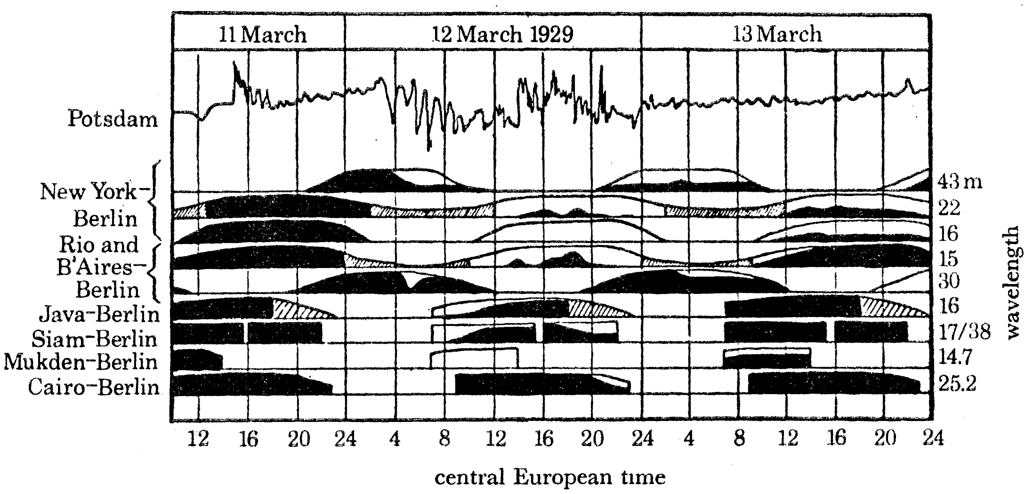


FIGURE 2. Variation of the horizontal component of the geomagnetic field at Potsdam and variation of the field strength of some long-distance circuits during a 'long-disturbance' after Mögel.

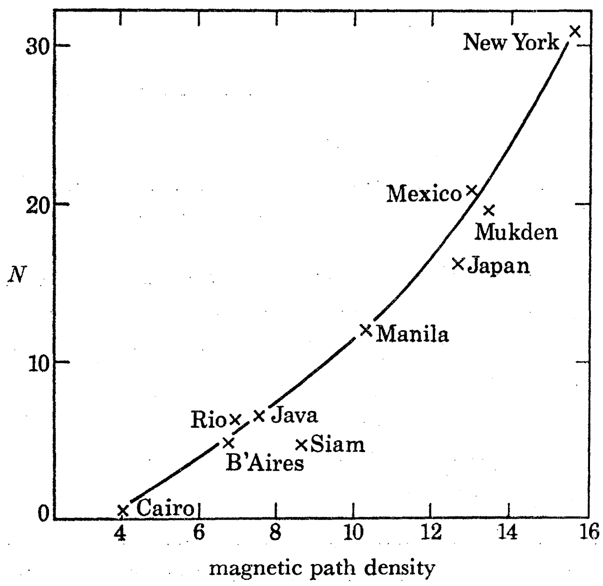


FIGURE 3. Number of disturbances (N) against 'magnetic path density' during long-disturbances after Mögel.

The other type of disturbance, called 'short-disturbance' by Mögel was, as a matter of fact, what is now called a s.i.d. or, in Germany, Mögel–Dellinger-Effect. Figure 4 which was taken from Mögels paper of 1930, shows very clearly that, coinciding with a crochet in the recordings of the horizontal component of the Earth's magnetic field at Potsdam, the field strength of all circuits in daylight collapsed, whereas the propagation on the night side was not affected at all. Mögel explained this observation as being caused by radiation that was not deflected by the Earth's magnetic field and that ionizes the lower parts of the ionosphere so that even long waves down to 25 kHz are being influenced. Obviously Dellinger did not know of Mögels work when he published his findings on s.i.ds in 1937.

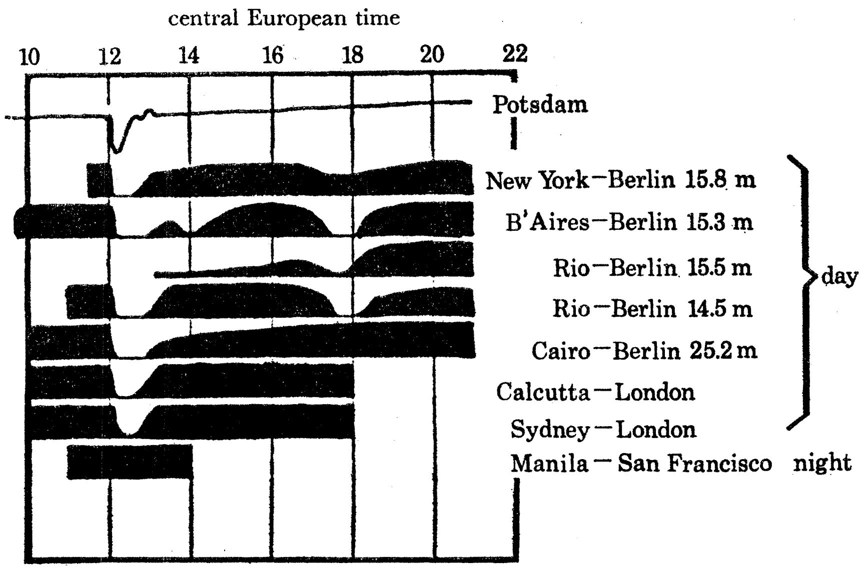


FIGURE 4. Variation of the horizontal component of the geomagnetic field at Potsdam and variation of the field strength of some long-distance circuits during a 'short-disturbance' after Mögel.

A feature which was overestimated by Mögel was the direct influence of the variations of the magnetic field on the double refraction of radio waves. He presumed that the changes in phase velocity might cause interference fading directly. Later on it was realized that other mechanisms producing fading, are by orders of magnitude more effective and would obscure this type of fading, if there were any.

The first ionospheric sounding station in Germany (Goubau & Zenneck 1931) was set into operation in 1929 at Mount Herzogstand in the Bavarian Alps. This station had a peculiar site, and history. Initially it was planned to build there a long wave transmitter with a Poulsen arc generator for long distance communication. Accordingly a large antennae system was built consisting of three wire ropes of silver-steel, clad by aluminium, 2.4 km in length, which were secured at the summit of Mount Herzogstand, at a height of 1800 m, and to another rock about 1100 m in height, at the appropriate distance.

The transmitter building was situated in a valley approximately in the middle of the antenna, at a height of about 900 m. The station was accessible only by a very rough road that in places had an incline of 33 %. Because of the advent of short waves, the transmitter was never installed rather, the station was used by the German Post Office and the Bavarian Broadcasting System for test purposes. A 1.5 kW transmitter was set up, operating on a frequency of 563 kHz, allocated to the broadcasting station of Munich. This very transmitter was used for the first pulse transmissions carried out by Goubau (1930) under the auspices of Zenneck, who was Professor of Physics at the Technical University of Munich, at that time. The pulses were produced at a rate of 450 s^{-1} by an oversaturated transformer. They controlled the grid of the 1.5 kW transmitting tube. The signals were received at distances of from 5 to 150 km and recorded by taking snapshots of the screen of a cathode ray tube, which incidentally, was invented by Ferdinand Braun and is therefore called Braun's Tube in Germany. Synchronization was achieved by the ground wave which was strong enough on this frequency over distances up to 150 km. Operation was possible only when the Munich broadcasting station was not on the air, that is to say, between midnight and 6 o'clock in the morning. Daylight operation was possible only on Good Friday when the Bavarian broadcasting system was off the air, except for a broadcast of the opera Parcival by Richard Wagner which lasted about 3 h. But only very weak echoes were observed on that occasion, for obvious reasons.

When I took over the operation of the Herzogstand station from Goubau in 1931, a new transmitter was finished (Goubau & Zenneck 1932). The power was increased to 6 kW by using four tubes in parallel, instead of one. The circuits could be switched quickly to six fixed wavelengths namely 40, 80, 150, 250, 500 and 1000 m. The transmitter was an exact replica of the German broadcasting transmitters of that time, rated for continuous operation at peak power. Hence the equipment was rather large as may be seen in figure 5, plate 1. Nevertheless, it looked rather small in the still larger transmitter building which was planned originally for a transmitter of many hundreds of kilowatts. Because of the remoteness of the site and the poor accessibility, the operation of the transmitting side was rather awkward to say the least. Everything had to be carried on a man's back to the station. There was a huge vehicle on tracks left over from the time of building the station, but the operation would have been much too expensive for our means. On the other hand, it was very romantic and even exciting when, for example, in Autumn, the roaring stags came quite close by.

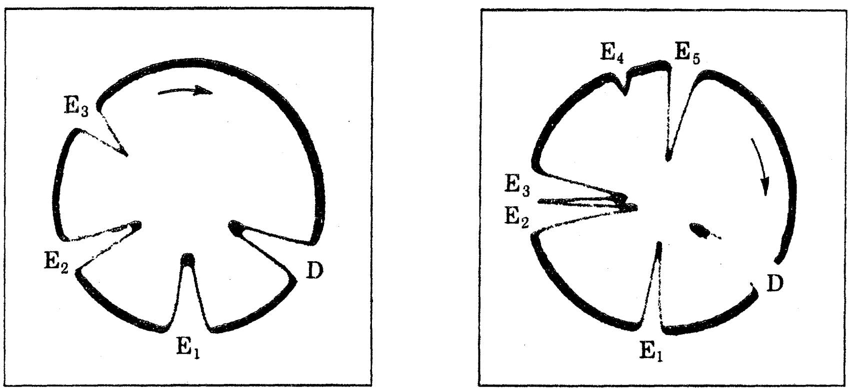
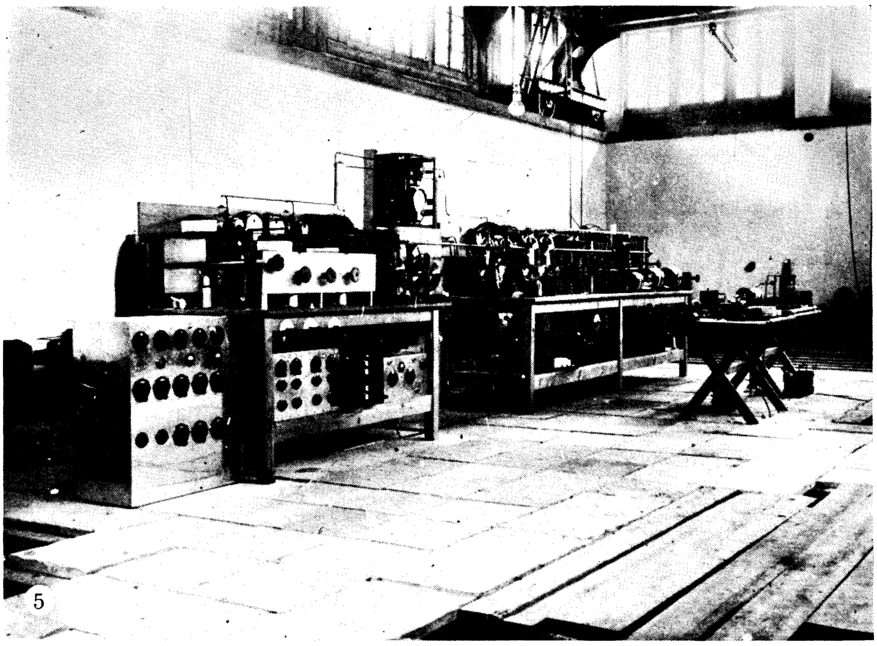


FIGURE 6. Echo pattern with circular time base and radial deflexion (Goubau 1932). D, direct wave; E_1–E_5, echoes.

The receiving side was set up in a building belonging to the German Post Office 5 km away at an altitude of some 600 m, in the part of the country where it flattens out towards the north. I do not want to go into details of the equipment, but I may mention that a circular time base with a radial deflexion of the echoes was originally used (figure 6). The repetition frequency was 450, 225 or 150 Hz initially. Synchronization was achieved via a telephone line which was also used



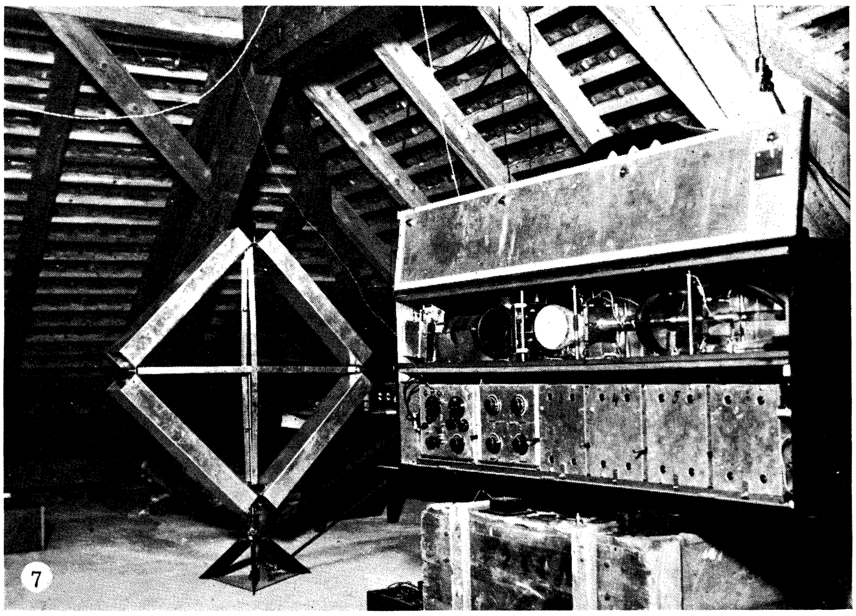


FIGURE 5. Pulse transmitter of Herzogstand station for 6 fixed frequencies, 6 kW (Goubau & Zenneck 1933).
FIGURE 7. Receiver and recorder for 6 fixed frequencies (Goubau & Zenneck 1933).

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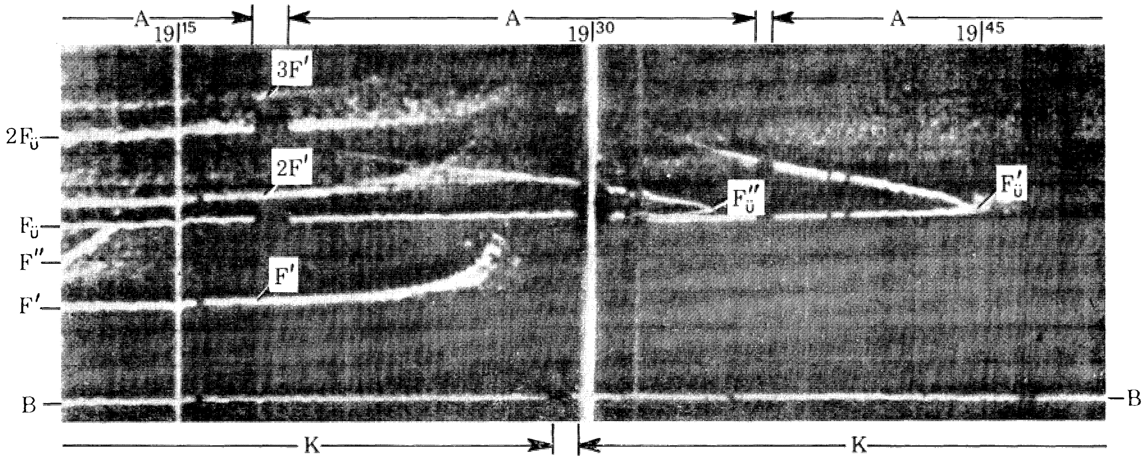

FIGURE 8. Simultaneous vertical and oblique incidence record on fixed frequency (Crone *et al*. 1936). K, periods of vertical incidence sounding; A, periods of oblique incidence transmission; B, ground way; F′, F″ 2F, 3F, vertical incidence traces; $F_{ü}$, $2F_{ü}$ oblique incidence traces.

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for ordering the wanted wavelength and repetition frequency. Recordings initially were made by taking snapshots but later automatic recording of the echo delay was introduced (Goubau & Zenneck 1933) and the repetition frequency set at 75 Hz, since it was not possible to synchronize to the mains frequency as the transmitting station was fed by a separate generator, from the nearby Walchensee power station, which was not synchronized to the general power system. Since 75 Hz is not transmitted by a telephone line a carrier tone of 225 Hz was used, which was divided by 3 in order to obtain 75 Hz. The equipment was operated normally over a period of 24 h,twice a week. Since the receiver and recorder were located immediately under the roof of the building (figure 7, plate 1), it became rather cold in wintertime and I wore a rather thick coat and felt boots. Later, I built a cardboard hut around the equipment which was kept somewhat warm by the heat radiated by the equipment. In 1938 when I had already left the station, a swept frequency sounder of Goubau's design was installed and operated successfully by a series of Zenneck's students, some of whom became well known in ionospheric research.

The end of the famous Herzogstand station is a rather sad story. After the war, operation was resumed under the supervision of the occupation forces. Soon after the resumption of soundings a telegram was received from the U.S. asking for the delivery of a typical German ionospheric recorder. The equipment was dismantled and sent to Ft Belvoir where it slowly decayed in the open air. Later on it turned out that the station had fallen the victim of a transmittal error: The text of the telegram which had asked for 'a typical German record', was garbled to, 'a typical German recorder'.

After this chapter, which has had a highly personal flavour, but which gives I hope some insight into the working conditions of ionospheric research in the early thirties, I should like to deal briefly with the development of oblique incidence soundings in Germany. This I feel is justified because German researchers took a major role in that technique. As a matter of fact, the very first soundings at the Herzogstand station were made at oblique, rather than vertical incidence. Even up to 1938, the receiving station was 5 km from the transmitter, so that special means had to be used to synchronize the pulse recurrence frequency with the time base of the recorder. Since the use of the ground wave for synchronization proved not very reliable, synchronization by telephone line was introduced as early as 1931. This technique was used also over rather long distances. In 1938, a series of oblique incidence transmissions on fixed frequencies was carried out between Herzogstand and Berlin, a distance of 560 km. The quality of the records was remarkable (figure 8, plate 2). The occurrence of low and high angle rays, of loops and similar phenomena were studied in detail. Among other findings it was concluded that the F-layer is, under normal conditions, rather uniform and hence predictable whereas sporadic E is localized and therefore not appropriate for a conversion of vertical to oblique incidence. The main operational problem of the technique was to induce the girl operators at the intervening switchboards to abstain from disconnecting the line when they heard no voice, but only the continuous pilot tone.

Synchronization with the mains frequency was used successfully by a group working at the test centre of the German Air Force at Rechlin. An experimental circuit was operated for many months between a site in the Alps and another one in Northern Germany over a distance of some 600 km. Both sites happened to be very close to the overhead power line connecting the hydropower stations in the Alps to the Rhein–Ruhr area. The phase was sufficiently stable along the line to achieve good records most of the time. Synchronization by power line was also used in an experiment aimed at studying the movement of sporadic E-patches, by a network of three transmitters and one receiver. The publication of these results was inhibited by the outbreak of the war. In passing, I may mention that this experiment created some concern here in the U.K., because it was conjectured that it might be a navigational system similar to LORAN, but this in fact was not the case. As a matter of fact, a hyperbolic navigational system using pulses was discussed somewhat later, at a rather high level, but the possibility of using E-reflexions which are characterized by a rather constant travel time, was discounted by some so-called experts.

Since the synchronization by power line becomes more and more unreliable with increasing distance, another system, which is completely independent of any connexion on the ground, was introduced: synchronization by a pair of crystal clocks. This was used successfully by all the field stations of the Central Advisory Board for Radiocommunication. Besides the swept frequency sounder of the station, fixed frequency transmitters controlled by a crystal clock were operated, which could be recorded by any other station in the network. At the end of the war, even swept frequency equipment was available where the frequency variation was identical to such a degree, that oblique ionograms could be recorded over any distance. Because of the events of the war, this system did not become operational. The experience gained however was used later to establish the well-known oblique incidence experiments between Lindau and Finland (Möller 1963) and between Lindau and Southwest Africa (Röttger 1973). A major result of the former was the early discovery of a strong north–south gradient in electron density producing by way of asymmetrical paths, very substantial increases in the operational maximum usable frequency. An interesting result from the latter was the discovery of field alined irregularities which appear after sunset in the equatorial belt, producing great circle deviations of up to 50° and rapid flutter fading.

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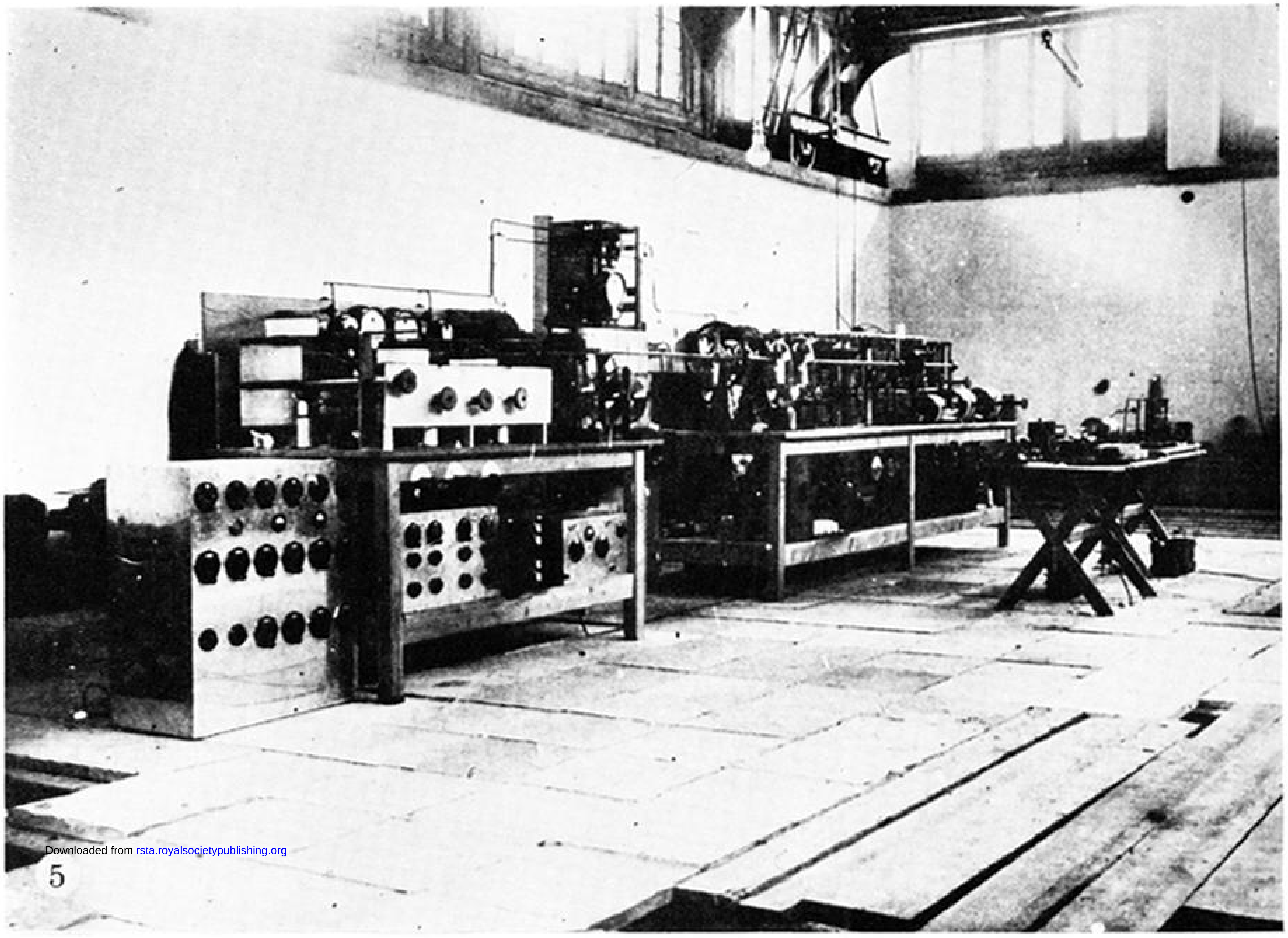

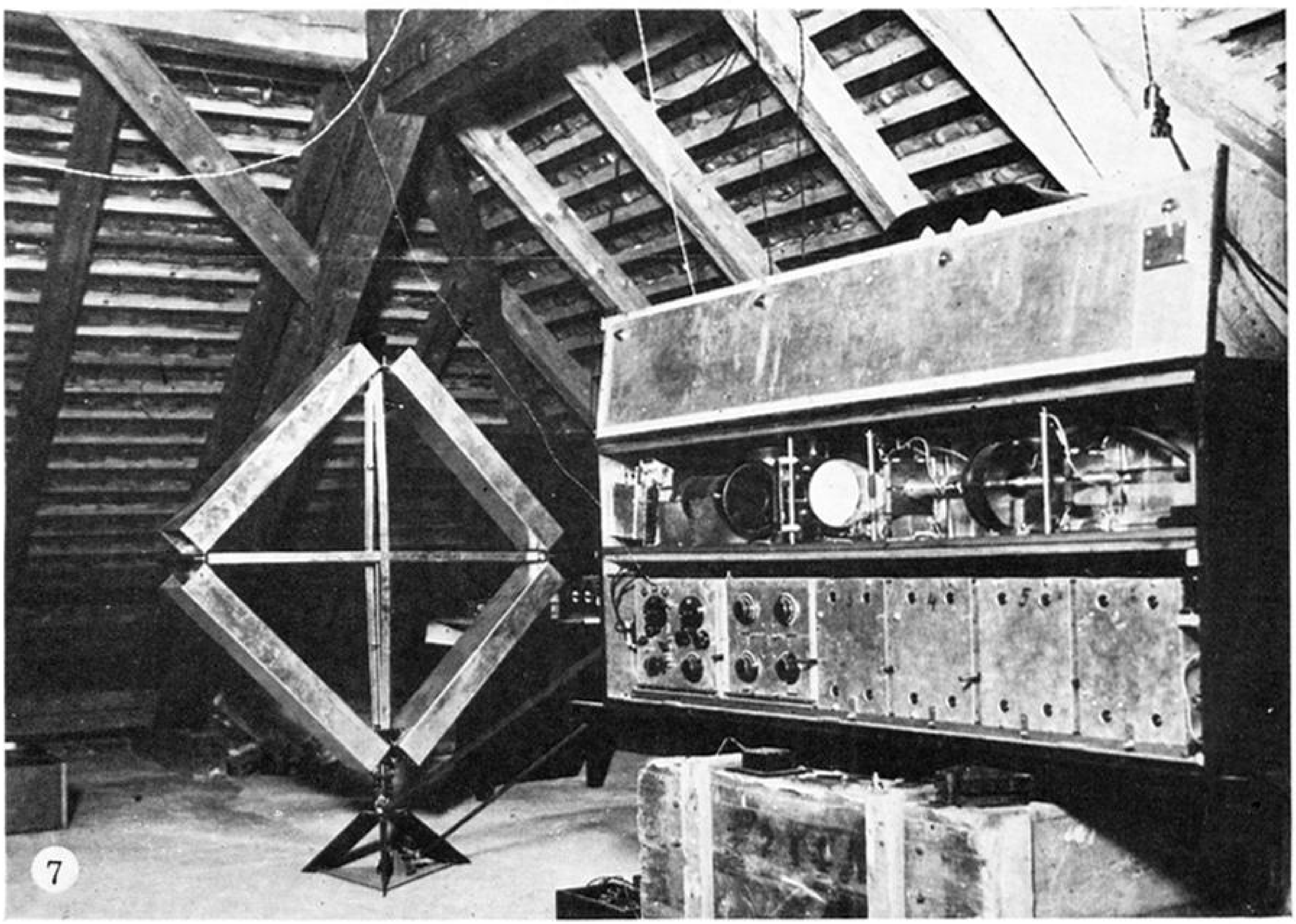

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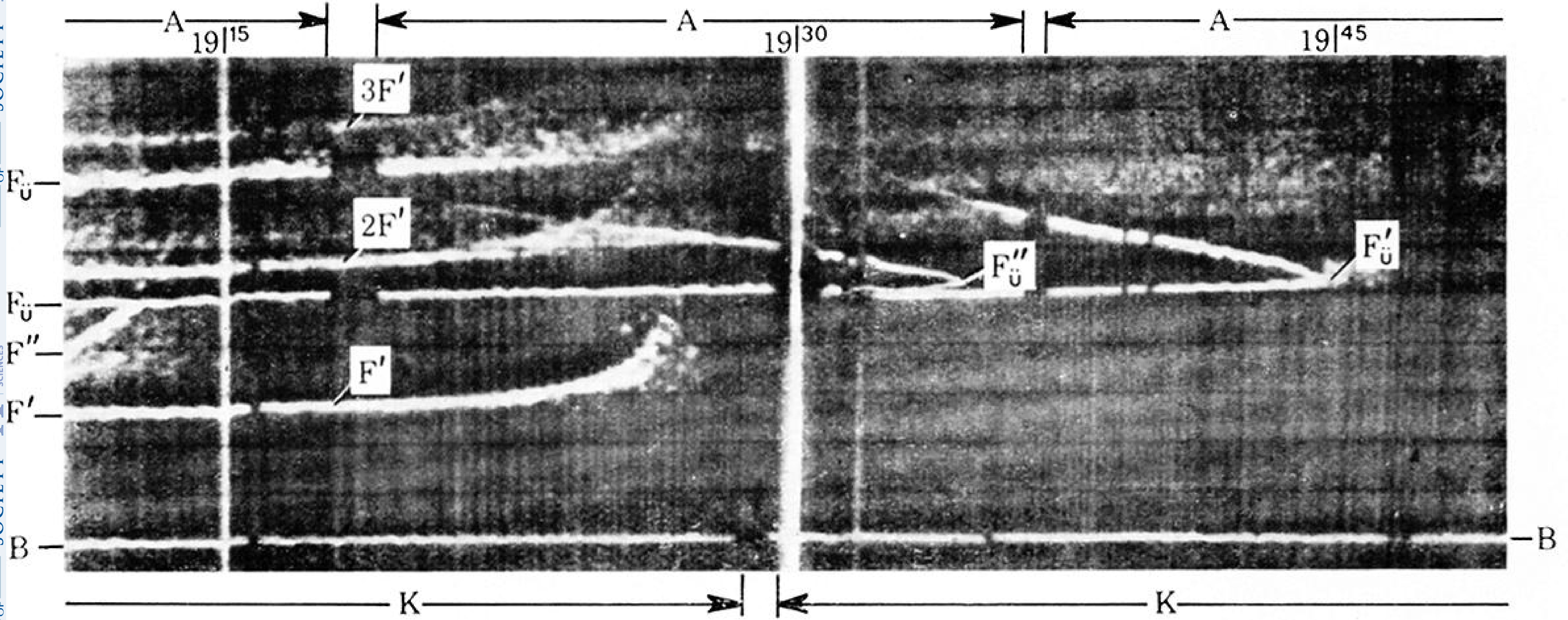

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