THE WAVEFORM OF ATMOSPHERICS IN THE DAYTIME*

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Summary—The present paper represents the results of observations of the waveform of atmospherics in the daytime conducted at Iwatsuki Station, near Tokyo, from 1940 to 1944.

The classification of waveforms was derived and the behaviour of each variety studied in relation to the discharge mechanism of lightning flashes. They are leader stroke type, return streamer type, multiple stroke type and cloud discharge type.

It is shown that the waveforms taken in the daytime cannot be explained by the reflexion theory but interpreted with ease by the discharge mechanism.

I. Introduction

This paper gives account of an investigation of the wave form of atmospherics received mainly during the day-time in summer, and discusses the interpretation of the records obtained.

Recent studies of atmospherics, largely concerned with wave forms, may be divided into two groups: the one has been made by Lutkin[4] in England, and the other by Laby[2] in Australia as well as by Schonland[3] in Africa. The former considers that the whole of the daylight wave form arises from oscillations and multiple discharges in the parent lightning channel. The latter suggests that the structure of the high frequency portion of atmospherics, which appears as a damped wave train of gradually increasing wave length, arises from multiple ionospheric reflections of a single pulse of short duration.

The wave form of atmospherics should be studied from the mechanism of general electric discharges in the atmosphere in addition to their propagation condition, such as changes of the amplitude ratio of each wave component due to distance, the masking effect of nearer electric discharges, daily and seasonal variations of absorption and the reflection-coefficient of D- or E-layer, *etc.*

It is here shown that the forms taken by all daylight atmospherics in summer arise directly from some kinds of electric discharges in the atmosphere.

II. Method of Observation

The observations were made in Kanto-District of Japan from 1940 to 1944 at the Iwatsuki Receiving Station of the Ministry of Communications, whose environs are the open field of the Kanto-Plains, free from obstacles producing distortion of bearings, and also relieved of artificial noise origins harmful to our observations; there are no hills and mountains, no woods and forests, no electric railways, no

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high tension transmission lines, no communication lines, no factories, etc. near the station. Many technical facilities are available. We have several underground communication- and power-cables, a crystal controlled standard clock of high accuracy, and radio communications equipments controlled from the observatory. The cathode ray direction finders are installed both in this station and at Kakioka Magnetic Observatory which is situated 56 km to the north east. They were employed to find the origin of atmospherics observed.

The antenna used is an open L-type, 60 m long and 15 m high, with lead-in 25 m long, suspended at two points by wooden poles through telex-glass iusulators. In order to assist in the maintenance of adequate insulation independent of weather circumstances, careful precautions were taken. The values found by measurement for its equivalent capacity and natural wave length are $C=457$ $\mu\mu$F and $=360$ m respectively. The antenna coupling circuit consists of four different condensers which have the values 50, 100, 200, and 500 $\mu\mu$F respectively. By selecting one of the condencers mentioned above the sensitivity of the receiving system can be controlled. A resistance of 1,000 Ω in series with the antenna is sufficient to render it aperiodic, but 3,000 Ω was inserted to reduce the interference of broadcasting signals with the reception of atmospherics. The time constant of the antenna alone is 1.37 μs and for the maximum value of condenser it is 2.78 μs. To reduce the interference from Tokyo High Power Radio Broadcasting Station, situated quite near by, a trap circuit was inserted in the antenna circuit without appreciable disturbances to measurement.

The inductive action of the power lines on the aerial was compensated by means of 50 c/s electromotive force, variable in phase and in amplitude, from a circuit constructed according to one developed by O. O. Pulley.[7] This circuit worked well when power mains contained no harmonics, whereas it was often found insufficient due to distorted wave forms and we could manage to reduce those harmonics by adding amplifi-filter circuits tuned to the third or fifth harmonics.

.The function of main amplifier is to give linear amplification over a wide range of frequency and amplitude. It was designed and constructed principally after H. C. Webster,[6] which is a resistance capacity coupled push-pull one, with some in-

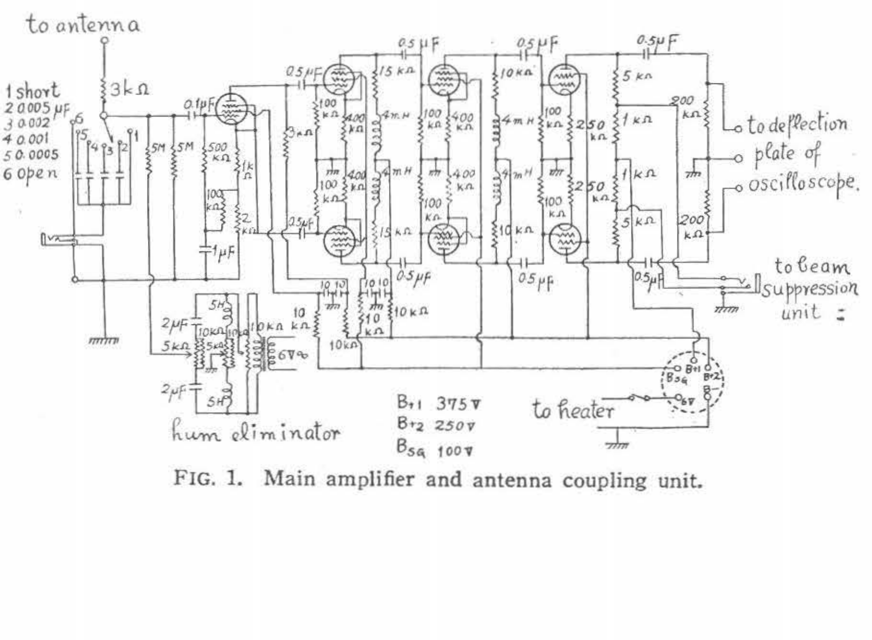
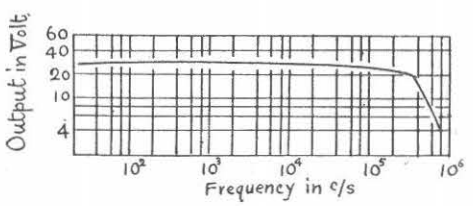


FIG. 1. Main amplifier and antenna coupling unit.

ductance after peaking principle (Fig. 1). According to the measurement, the amplification proved to be very linear over the range of frequency 25 c/s–300 kc/s where it is suddenly cut down to avoid the interference from radio broadcasting stations (Fig. 2). It has also a very linear gain characteristics of 54 db. over the range of input voltage 0.004–0.4 volts and output voltage 2–130 volts. The latter saturates slowly to 200 volts (Fig. 3).



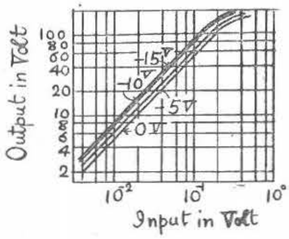


FIG. 2 (*left*). Frequency response curve of the main amplifier.
FIG. 3 (*right*). Amplification characteristics or linearity curve of the main amplifier.

The push-pull amplification is used after the first stage to suit to direct application to a pair of deflecting plates of Braun tube. An important characteristic of this arrangement is that variations in anode voltage, due to fluctuations of the power mains, affect both values of a pair equally and hence do not, except in extreme cases, produce any deflection of the cathode ray beam. For the purpose of calibrating oscilloscope, the output of the testing oscillator was injected into the amplifier and the resulting deflection of the cathode spot was photographed. It has a linear characteristic over the range of 0.1–0.9 volts input, and resulting deflections of 0.5–6.0 cm on the oscilloscope.

If the cathode ray beam impinged on the screen continuously, the latter would be damaged and the photographic film would be fogged. A unit is constructed to suppress the beam until an atmospherics is received, when the beam is restored to its full intensity. A portion of the amplifier output is applied to the input of the beam suppression unit. This causes the modulation electrode (normally held

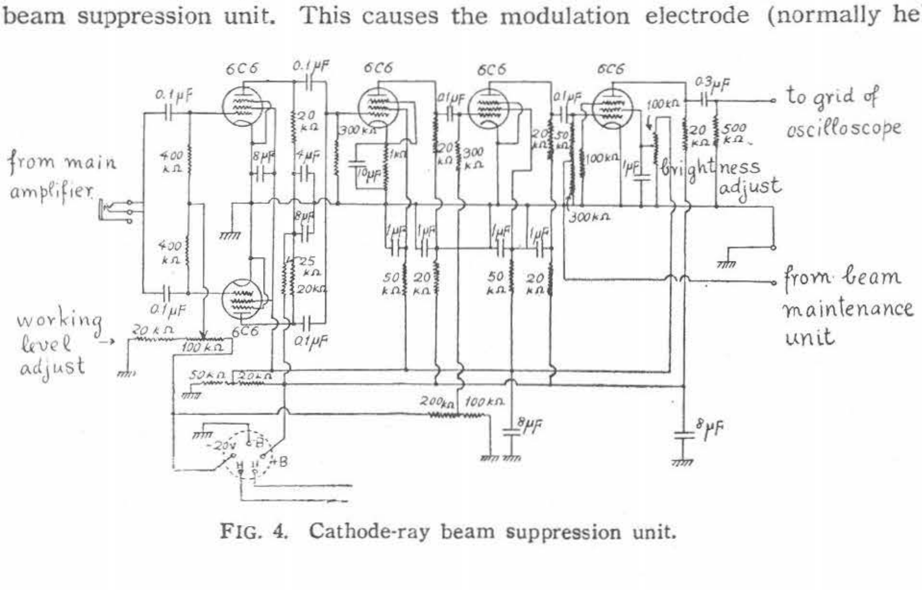


FIG. 4. Cathode-ray beam suppression unit.

at a high negative potential) to become positive whenever the amplifier output exceeds a finite value in either direction, thus allowing the cathode spot to reach full brilliance. The circuit diagram of this unit is shown in Fig. 4. The output circuit has been modified from that described elsewhere. The variable resistance 100 kΩ on the input side determines the working voltage level of this unit.

Another unit, called cathode ray beam maintenance, is used to maintain the spot at full brilliance for a specified time after the reception of an atmospherics greater than predetermined intensity. A pair of tubes are arranged in an asymmetric multivibrator circuit to discharge a condenser wherever the input voltage exceeds a specified limit. This limit is altered by varying the negative bias potential applied to the first stage in Fig. 5. The output of this unit is injected at the suppressor grid of the output valve of the beam suppression unit, causing a positive potential to be applied to the modulation electrode of the cathode ray tube for a period determined by the time constant CR.

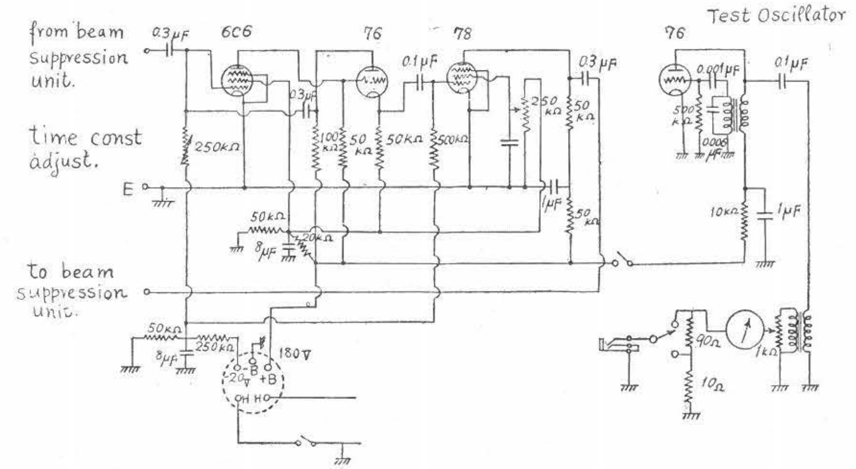
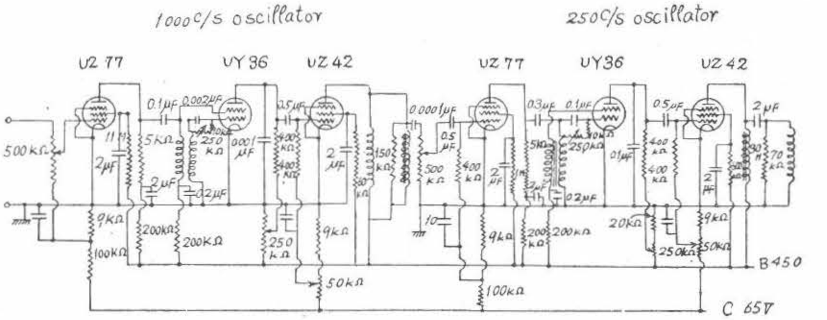


FIG. 5. Cathode-ray beam maintenance unit.

The film is carried on the periphery of an aluminium drum, driven directly by a synchronous motor at a speed of 16 r.p.s. whose constancy is ascertained stroboscopically. The aperture ratio of its lens is $f=1.5$, and the diameter of the drum is 15 cm and consequently the film speed is 7.2 m/s. This camera is available to indicate the behaviour of groups of atmospherics, loaded with 45 cm of film, set before the oscilloscope whose horizontal deflection plates are connected to the output terminals of the main amplifier. In order to observe the fine structure of the wave form of atmospherics we used another camera of 16 mm movie. The aperture ratio of its lens is $f=0.85$ and the film speed was 20 frames per second, driven by a d.c. motor. This camera was set before an oscilloscope whose fluorescent spot is scanned horizontally and vertically by magnetic deflection coils at frequencies of 1,000 c/s and 250 c/s respectively by the output of scanning oscillators, controlled by a standard crystal clock (Fig. 6). The output of the main amplifier is connected to the vertical deflection plates and the resulting figure on the oscilloscope is like that of Fig. 7. The output of these oscillators has saw tooth wave forms (850 μs go and 150 μs return for 1,000 c/s); they were calibrated and their uniformity was asertained by imposing 20 kc/s sine wave electromotive force on the vertical deflection plates of the oscilloscope (Photo. 1). Length of the fluorescent line on the screen is 10 cm long, showing the scanning speed of 118 m/s. Focussing was carefully done by using a microscope of 20 magnification, and the wave form on the film was enlarged to 6×9 cm^2 size.



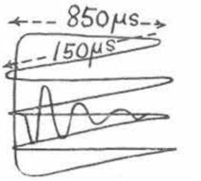


FIG. 6 (above). Cathode-ray beam scanning circuit.

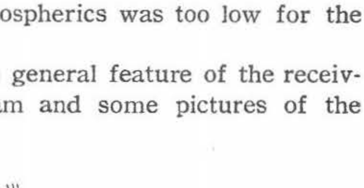
FIG. 7 (left). An example of waveform of atmospherics with scanning line on the oscilloscope.

An attempt to take a wave form and the arriving direction on the same film for obtaining the exact correlation of atmospherics with its parent weather phenomenon was made. This was found to be not so efficient as expected, because the film speed of 2 to 4 cm/s suitable for direction finding of atmospherics was too low for the wave form observation.

In order to make sure the understanding of the general feature of the receiving system we shall show an overall block diagram and some pictures of the apparata in Fig. 8, Photo. 2, 3 and 4 respectively.

FIG. 8. Block diagram of the waveform measuring equipment.

1) antenna coupling. 2) main amplifier. 3) hum balancer. 4) beam suppessor. 5) beam maintenance. 6) power supply. 7) electric timing. 8) crystal clock. 9) recording camera.



III. Results and Interpretation

An extensive study had been made on 8,500 photos of atmospherics wave forms obtained during five years and finished about half of the work, when the war was ended and some uncultured naval officers seized the occasion of the post war disturbed period in throwing the 8,500 photos in fire. However, it is fortunate that our original films were relieved of the accident and we could report some phase of the results and discuss their interpretation in the following:

(*a*) *Leader Stroke Type.* According to Schonland, average time interval of every step in the stepped leader stroke and their total duration are 31-91 μs and 1-60 ms respectively. We observed a wave form of atmospherics corresponding to these strokes. Their frequency range was 30-100 kc/s as shown in Fig. 9. These contain higher frequencies than expected from a time interval between subsequent steps, while its duration is several ms and so nearly coincides in order with those of leader strokes. These wave forms could also be found when the cumulo-nimbus were observed near the observatory. These are considered to be due to the small discharges occurring at random among small water particles in the cloud under heavy electric fields. These wave forms have some resemblance with those of snow storms found by Lutkin.

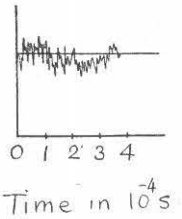


FIG. 9. Waveform of leader stroke type.

(*b*) *Return Streamer Type.* Duration of the return streamer is found to be 50-240 μs and amounts to 120-1,140 μs including those of after glow by Schonland. Stripes of light and darkness in the picture taken by high speed Boys' camera show the interval of 100-200 μs for the first one, and they increase gradually as time goes on. Atmospherics of a damped wave form originating from these phenomena have frequencies 5-10 kc/s for the first wave in which 7.5 kc/s are found most frequent as shown in Fig. 10. The subsequent amplitudes and frequencies decrease gradually as in Fig. 11 (Photo. 5). These are considered to be a characteristic phenomena of damped oscillation due to increasing resistance by the recombination of ions in the lightning discharge channel. The duration of a train of damped wave form corresponding to a return streamer, including after glow, is shown in Fig. 12, indicating the existence over the range of 100-3,000 μs as well as the maximum occurrence at 600 μs. The discharge current wave form in Fig. 13, taken by our collaborators, consists of a d.c. component and superposed high frequency components. The lightning photos taken by Boys' camera show also light and darkness stripes. The frequency of the high frequency component and the stripes coincide with those of the damped wave form in order, suggesting the intimate relation between the wave form of atmospherics and the lightning discharge mechanism. Moreover, those wave forms observed near the lightning discharge include the aperiodic component of large amplitude as well as the very high frequency component ripples of small amplitude superposed on the damped wave form mentioned above.

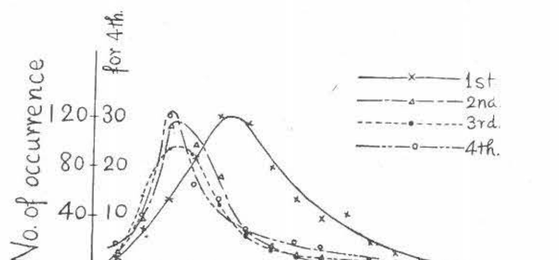


FIG. 10. Frequency distribution curve of damped waveform type of atmospherics.

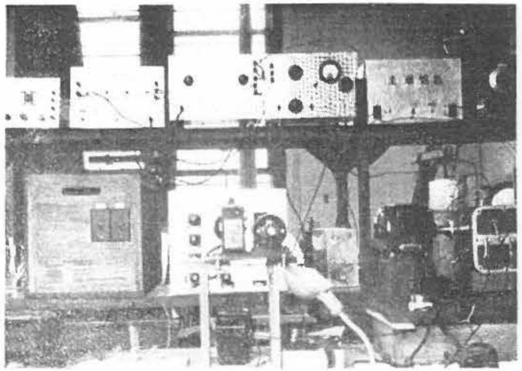


PHOTO. 2

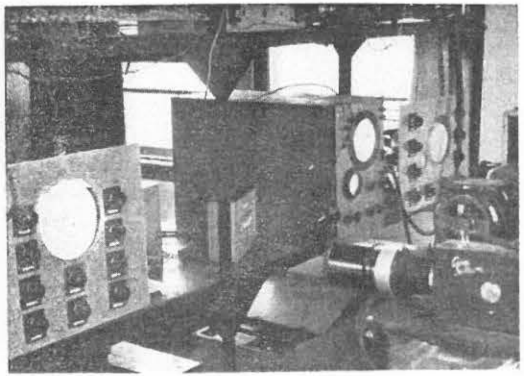


PHOTO. 3

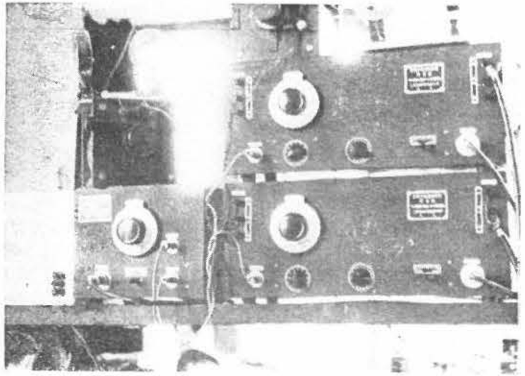


PHOTO. 4

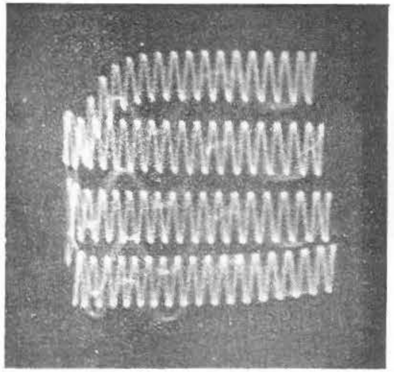


PHOTO. 1

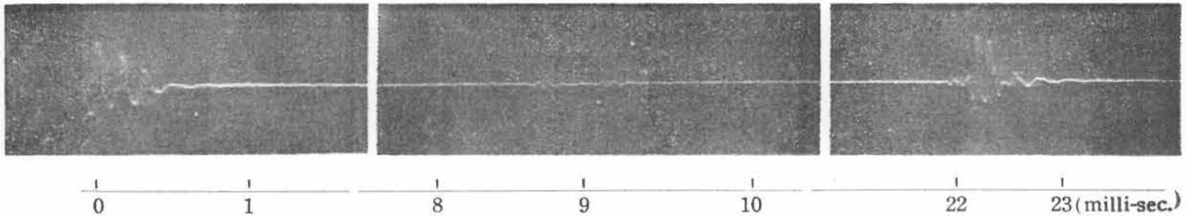


PHOTO. 5

PHOTO. 2. Main amplifier, beam suppression and beam maintenance units.
PHOTO. 3. Oscilloscopes for waveform observation and direction finding.
PHOTO. 4. Direction finder.

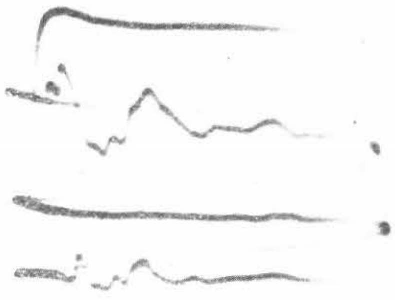


PHOTO. 6*a*

PHOTO. 6*b*

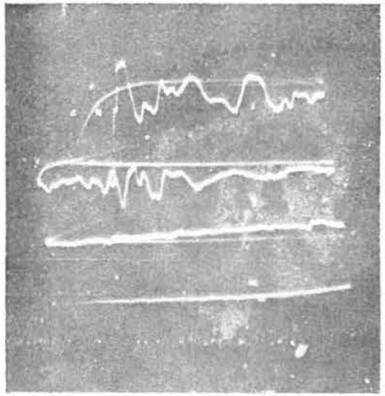


PHOTO. 7

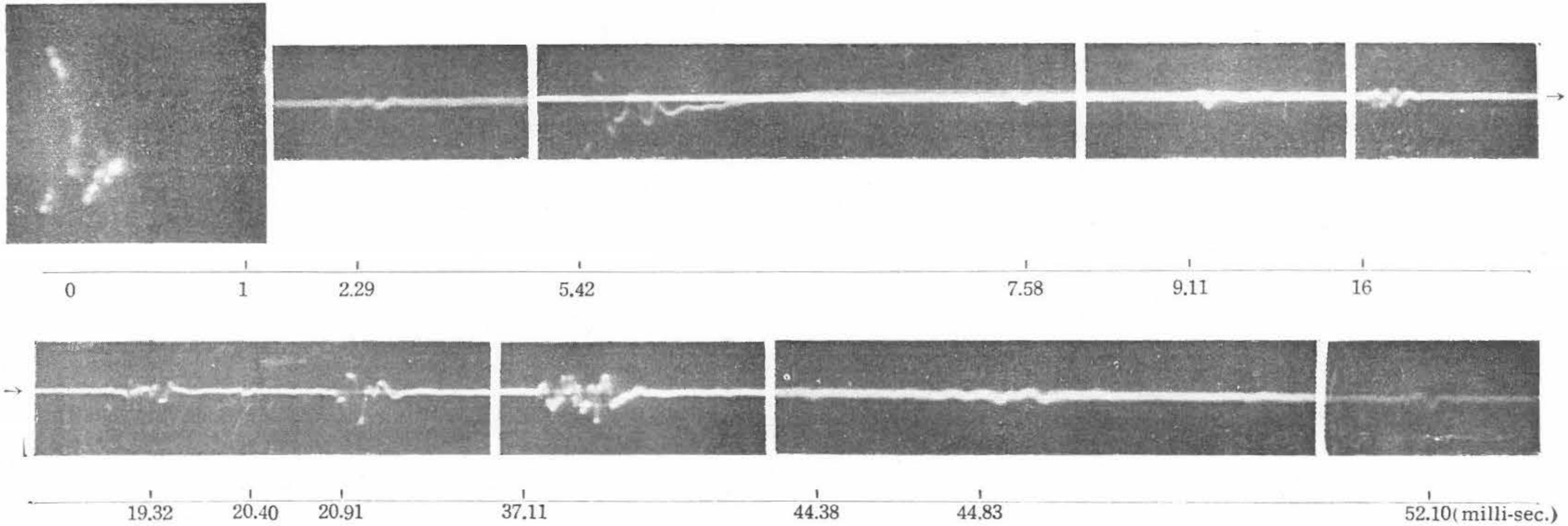
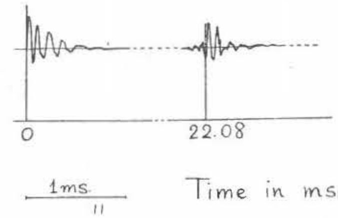
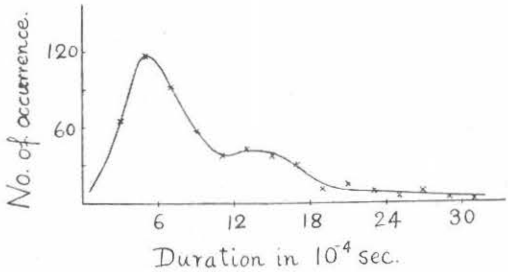


PHOTO. 6*c*





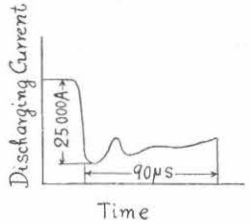


FIG. 11 (*left-above*). Waveform of return streamer type.
FIG. 12 (*right-above*). Distribution of durationof damped waveform type of atmospherics.
FIG. 13 (*left*). Waveform of discharge current through lightning arrester.

Generally speaking, we should of course investigate the wave form of atmospherics from the view point of propagation, especially the reflection between the ionosphere and the earth, in addition to the mechanism of the parent lightning discharge. Moreover, it is well known that the lower part of the E- and the D-layers in the ionosphere concerns specifically to the reflection of the long wave, and further the reflection-coefficient at night is much larger than that in the day-time. In fact, as the long wave is nearly absorbed in the ionosphere by day, it is mainly the surface wave that we receive in the day-time. Therefore, in summer days we can reasonably conclude that in the propagation of atmospherics over the earth shorter ones attenuate more quickly than longer ones; consequently we assume that the damped wave forms of atmospherics originate directly from discharge phenomena and lose their aperiodic component due to the inverse cubic distance law and the high frequency ripples due to their quicker attenuation on the way to receiving station from the parent lightning discharge. Observing atmospherics mainly in winter nights in Africa, Schonland attributed the wave form of atmospherics to the multiple reflections of a single pulse of short duration originating from electric discharges in the atmosphere. We studied the results of our observation mainly in summer days for five years after his method of evaluation, and found the culculated heights of ionosphere very irregular even in the same wave train and hence unreliable. Investigating these differences carefully, we arrived finally at the conclusion that it is due to the difference of the reflection-coefficient of the ionosphere in winter nights and in summer days as mentioned above. In the former the reflecting power of the ionosphere is so large that pulses reflected many times on the reflecting layer can be observed, while in the latter the absorption in the ionosphere is too large to reflect pulses many times. Therefore the observed waveform is mainly due to the mechanism of the parent electric discharge and the attenuation on the way to receiving station, not so much influenced by the reflected wave as in the former.

(*c*) *Multiple Stroke Type.* Multiple stroke, the repeated electric discharge in the same channel in the atmosphere, was observed by our collaborators through

Boys' cameras to have intervals 1.2-253 ms, maximum total durations 542 ms for discharges between clouds and 462 ms for discharges between clouds and earth. The wave form in Photo. 6 and in Fig. 14, where we see nearly the same type of wave trains repeated at the interval of several ms. In Fig. 14 *c* about four kinds of wave trains are observable and in some places more than two types continue or superpose, resulting complex wave forms.

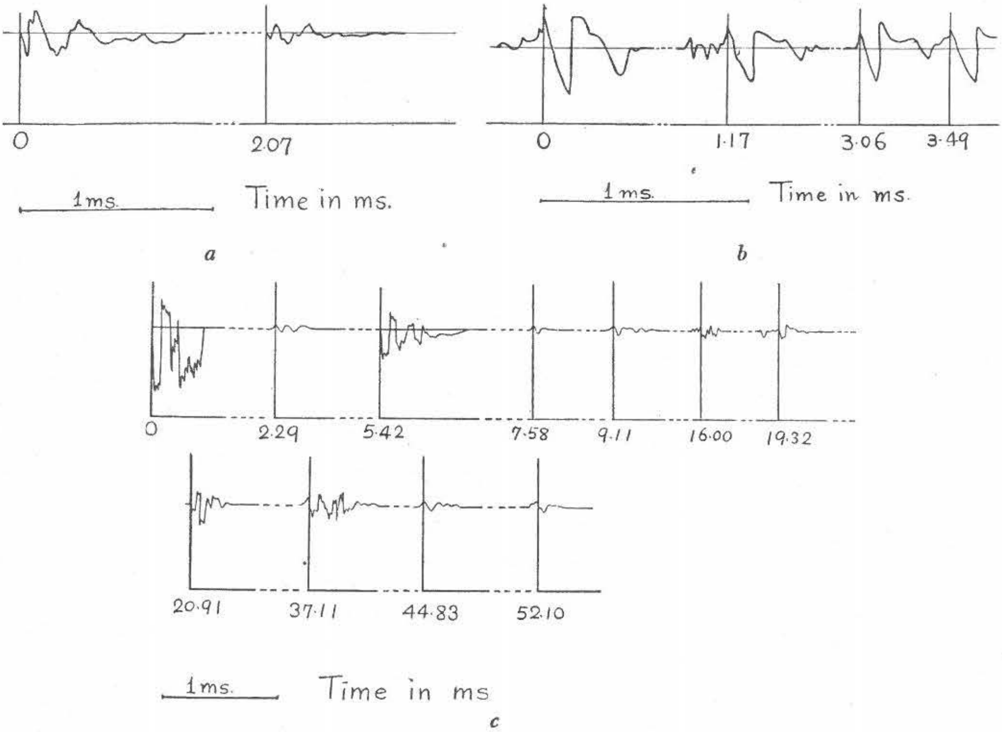


FIG. 14 *a*, *b*, and *c*. Waveform of multiple stroke type.

(*d*) *Cloud Discharge Type.* In summer we see often a flash of lightning in considerable length without accompanying any appreciable roaring. It is, as discovered by one of our colleagues, attributed to a kind of creaping discharges, through charged clouds scattered between clouds in high potentials, breaking the insulation of the air from one end to another successively. Wave forms of atmospherics originating from this type of discharge have characteristics of some kinds of damped wave train in succession (Fig. 15 and Photo. 7), each of which begins at the end or middle of the preceeding one, and the total duration amounts to several ms. Lutkin in England indicated similar wave forms originating from a discontinuous surface.

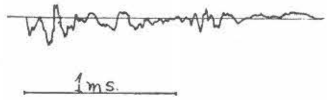


FIG. 15. Waveform of cloud discharge type.

(*e*) *Reflexion Type by Schonland.* In the middle of autumn we observed the wave form like that of Schonland at night, as shown in Fig. 16, from which we could evaluate the reasonable value for the height of reflexion layer.

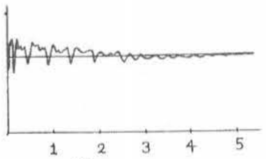


FIG. 16. Waveform multiple reflexion type.

IV. Acknowledgement

This work has been done under the direction of the Lightning Research Committee in Japan whose president was the Late Dr. S. Fujiwara. The author wishes to acknowledge his indebtness to Dr. M. Shibuzawa and Dr. T. Otani for their kind support and useful suggestions, and also to Messrs. Fujita, Amano, Kondo and Inagaki for their heartful assistance.

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