ON THE WAVE FORM OF ATMOSPHERICS

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1. Introduction

This paper gives an account of an investigation of the wave form of atmospherics received mainly during the daytime 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 in England, and the other by Laby in Australia as well as by Schonland 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 reflexion-coefficient of E-layer, and etc.

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

2. Method of Observation

The observations were made 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 hills and woods, and also relieved of artificial noise origins harmful to our observations: there are no electric railways, no high tension transmission lines, no factories, and etc. near the station. Technical facilities were available. We had several underground communication- and power-cables, a crystal controlled standard clock of high accuracy, and radio communications equipments. The cathode-ray direction finders were installed both here and at Kakioka Magnetic Observatory which is situated 56 km to the north east. They were employed to find the origin of atmospherics observed.

Antenna. 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 insulators. 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 were $C_0 = 457\,\mu\mu$F and $\lambda_0 = 360$ m respectively. The antenna coupling circuit is shown in Fig. 1. The

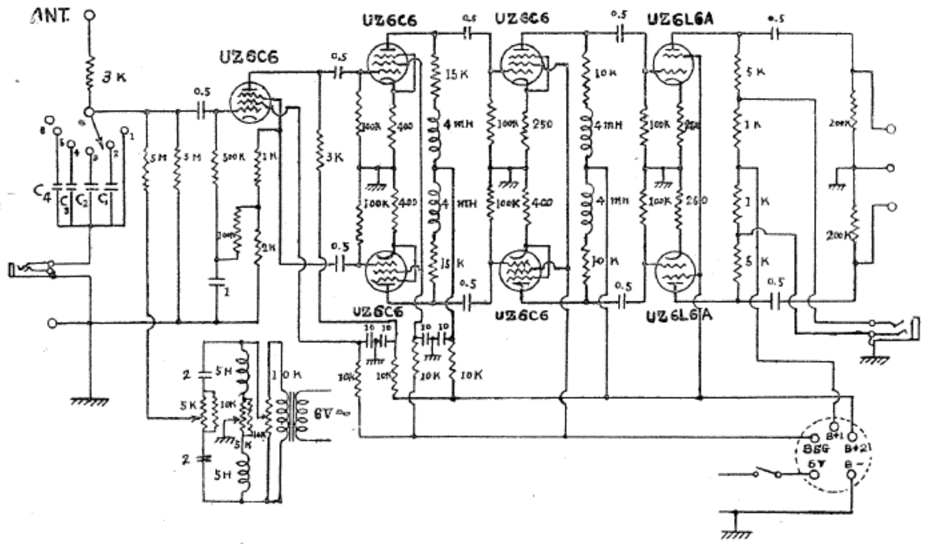

Fig. 1. Main amplifier.

condensers C_1, C_2, C_3, and C_4 have the values 50, 100, 200 and 500 $\mu\mu$F respectively. By selection of the condenser used in circuit the sensitivity of the receiving set can be controlled. A resistance of $R = 1{,}000\,\Omega$ in series with the antenna is sufficient to render it aperiodic, but $3{,}000\,\Omega$ 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 C

$$(C_0 + C_4)R = 2.78\,\mu\text{s}.$$

To reduce the interference from Tokio High Power Radio Broadcasting Station, situated quite near by, a trap circuit was inserted in the antenna circuit without appreciable disturbances to measurement.

In order to reduce the effect of electrically charged rain, and the slowly varying electric field of thunder clouds near the antenna, a condenser was inserted in series with the antenna, and it was earthed through a high resistance.

Compensation of 60 c/s Interference. The inductive action of the power mains on the aerial was undesirably large. It was compensated by means of 60 c/s emf. variable in phase and in amplitude from a circuit constructed according to one developed by 0.0. Pulley as shown in Fig. 1. 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 amplifier filter circuits tuned to the third or fifth harmonics.

Main Amplifier. The function of this amplifier is to give linear amplification over a wide range of frequency and amplitude. It was designed and constructed principally after H. C. Webster, which is a resistance capacity coupled, push-pull one, with some inductance after peaking principle (Fig. 1). When tested, 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

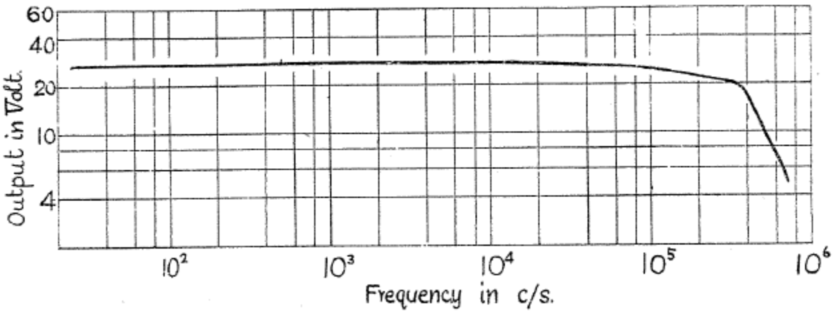

Fig. 2. Frequency responce curve of the main amplifier.

voltage 0.004-0.4 volts and output voltage 2-130 volts. The latter saturates slowly to 200 volts (Fig. 3).

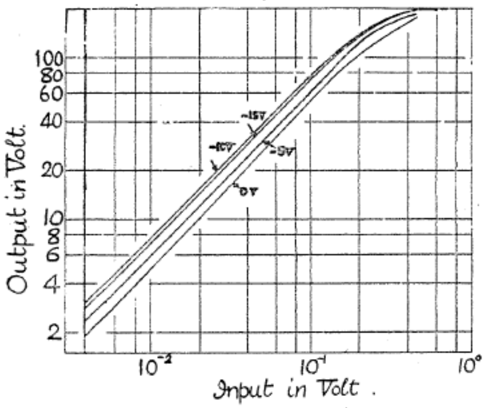

Fig. 3. Amplification characteristics or linearity of the main amplifier.

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 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 main 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.

Cathode-Ray Beam Suppression Unit. If the cathode ray beam impinged on the screen continuously, the latter would be damaged and the photographic film would be fogged. A unit was constructed to suppress the beam until an atmospherics was received, when the beam was restored to its full intensity.

A portion of the amplifier output voltage is applied to the input of the beam suppression unit. This causes the modulation electrode (normally held 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. Variable resistance $R = 100\,\mathrm{k\Omega}$ determines the working voltage level of this unit.

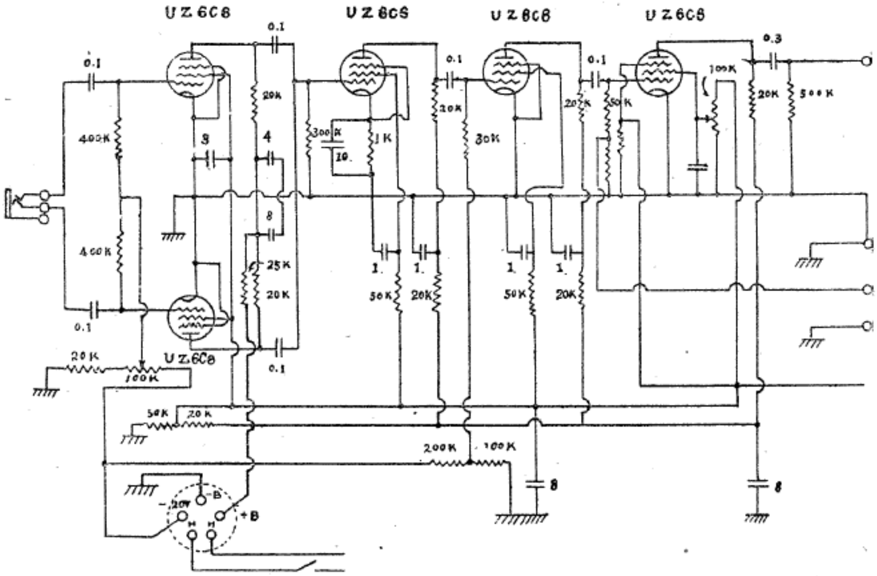

Fig. 4. Cathode-ray beam suppression unit.

Cathode-Ray Beam Maintenance Unit. This unit maintains the spot at full brilliance for a specified time after the reception of an atmospherics greater than a predetermined intensity.

A pair of tubes are arranged in an asymmetric multivibrator circuit to discharge a condenser whenever 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.

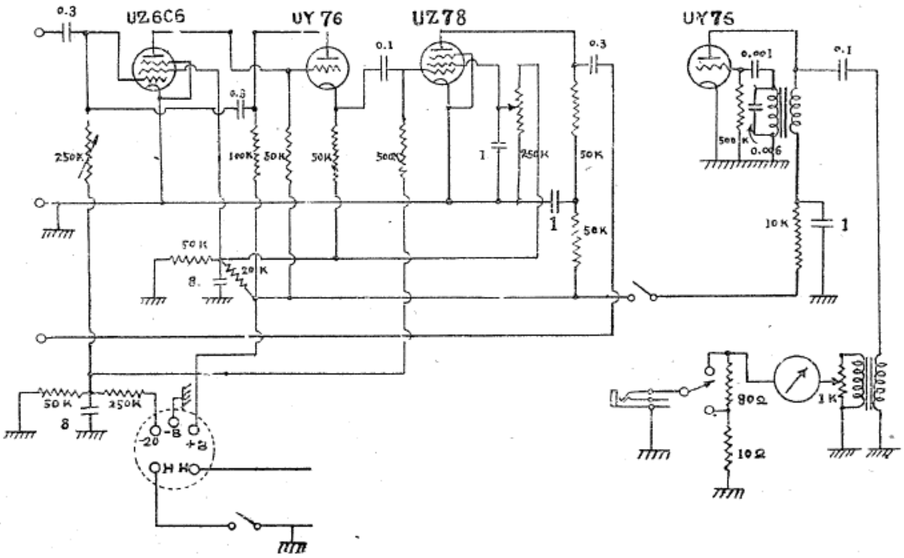

Fig. 5. Cathode-ray beam maintenance unit.

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.

Camera and Oscilloscope. 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 radio 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 radio 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

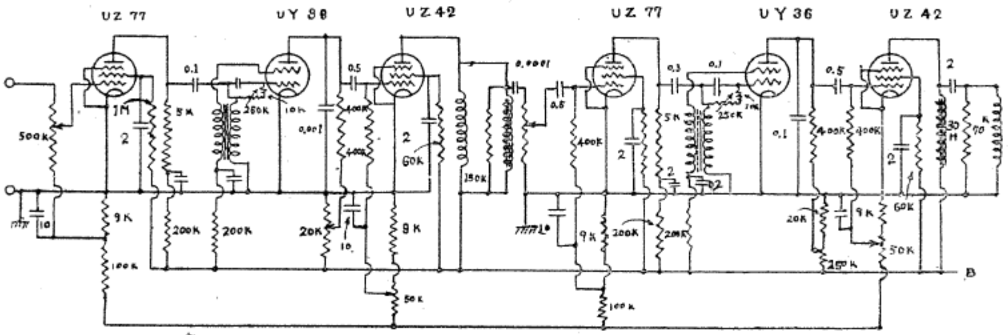

Fig. 6. Cathode-ray beam scanning circuit.

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 amplifiers has saw tooth wave forms (850 μs go and 150 μs return for 1,000 c/s): they were calibrated and their uniformity was ascertained by imposing 20 kc/s sine wave emf. on the vertical deflection plates of the oscilloscope. 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.

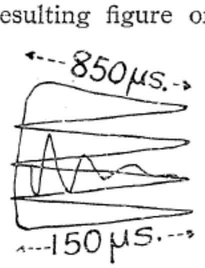

Fig. 7.
An example of wave form of atmospherics with scanning line on the oscilloscope.

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 2-4 cm/s suitable for direction finding of atmospherics was too low for the wave form observation.

3. 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. 8. 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 abruptly 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.

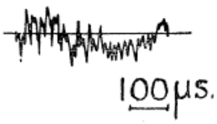

Fig. 8.
Wave form of leader stroke type.

(*b*) *Return Streamer Type.* Duration of the return streamer is found to be 50-240 μs and amounts to 120-1140 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. 9. The subsequent amplitudes and frequencies decrease gradually as in Fig. 10. These are considered to be a characteristic phenomena of damped oscillation due to 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. 11, indicating the existence over the range of 100-3,000 μs as well as the maximum occurrence at 600 μs. The

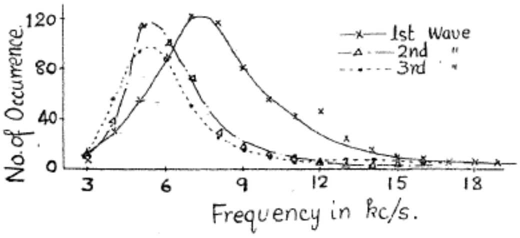

Fig. 9. Frequency distribution curve of damped wave form type of atmospherics.

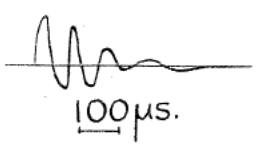

Fig. 10 a.

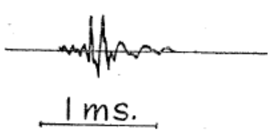

Fig. 10 b.

Wave form of return streamer type.

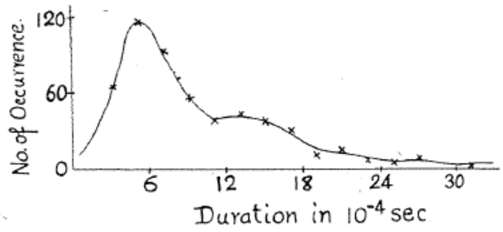

Fig. 11. Duration of damped wave form type of atmospherics.

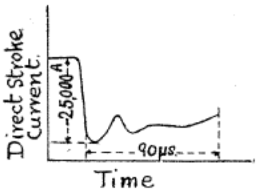

Fig. 12. Wave form of discharge current through lightning arrester.

discharge current wave form in Fig. 12, 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 h.f. 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 apperiodic component of large amplitude as well as the very high frequency component ripples of small amplitude superposed on the damped wave form mentioned above.

In the propagation of radio waves over the earth surface, shorter ones attenuate much quicker than longer ones. Therefore we assume the damped wave forms of atmospherics originate directly from discharge phenomena and lose their apperiodic 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 reflexions of a single pulse of short duration originated from electric discharges in the atmosphere. We checked 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 and unreliable. Investigating these differences carefully, we arrived finally at the conclusion that it is due to the difference of the reflexion coefficient of the ionosphere in winter nights and in summer days. 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 wave form 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 of atmospherics corresponding to multiple stroke were also observed as shown in Fig. 13, where we see nearly the same type of wave trains repeated at the interval of several ms. In Fig. 13 c about four kinds of wave trains are observable and in some places more than two types continue or superpose, resulting complex wave forms.

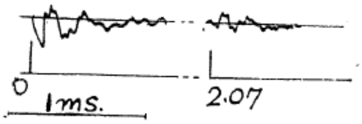

Fig. 13 a.

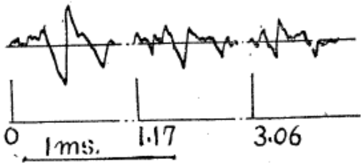

Fig. 13 b.

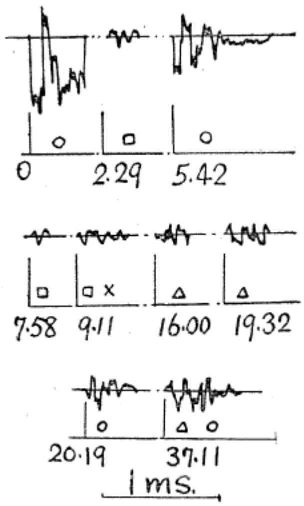

Fig. 13 c.

a–c. Wave form 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 collaborators, attributed to a kind of creaping discharge, 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 originated from this type of discharge have characteristics of some kinds of damped wave train in succession (Fig. 14), 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 originated from a discontinuous surface.

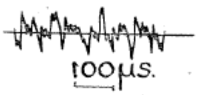

Fig. 14. Wave form of cloud discharge type.

(*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. 15, from which we could evaluate the reasonable value for the height of reflexion layer.

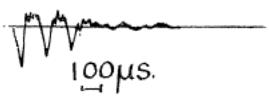

Fig. 15. Wave form of multiple reflexion type due to Schonland.

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References.

1) M. R. Bureau: Les foyers d'atmosphériques, 1936.
2) T. H. Laby: Proc. Roy. Soc. A, Vol. 174, No. 957, p. 145, 1940.
3) B. F. J. Schonland: Proc. Roy. Soc. A, Vol. 176, p. 180, 1940.
4) F. E. Lutkin: Proc. Roy. Soc. A, Vol. 171, p. 285, 1939.
5) B. F. J. Schonland: Proc. Roy. Soc. A, Vol. 166, p. 56, 1938.
6) H. C. Webster: Bulletin No. 127, Report No. 14, Radio Research Board, Melbourne, Australia.