ELECTROMAGNETIC ENERGY RADIATED FROM LIGHTNING*

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Abstract

The purpose of this paper is to survey the study recently developed on the electromagnetic energy radiated from lightning, i. e. atmospherics, not including propagation. Characteristics of the electrostatic, induction and radiation fields of lightning are fully described, including the frequency spectrum in the neighbourhood of the source. Consequently this paper will supply a foundation to the study of propagation of atmospherics, slow tail, ELF and VLF propagations, whistlers, mechanism of lightning discharge, etc.

I. Introduction

This paper aims the survey of the general feature of the developments of observation and theory which have been made recently in the field of electromagnetic radiation from lightning.

In order to study the characteristics of the lightning discharge many kinds of measurement have been made and developed, i. e. optical, photoelectric, electrostatic and electromagnetic methods have prevailed all over the world. Here in this paper, specifically, the characteristics of electromagnetic energy, i. e. atmospherics in a broad sense, radiated from lightning, not including propagation, are described.

The atmospherics propagate through the space between the ionosphere and the earth in the wave guide transmission mode or in the ray mode reflecting between them. Some of the energy penetrate the ionosphere into exosphere along the geomagnetic line of force, and go to the other hemisphere where they are reflected back and return to the source again along almost the same geomagnetic line of force. As the exosphere is the medium of plasma with magnetic field, it is dispersive and during the journey atmospheric pulses become whistlers from which the density of electron in the exosphere is evaluated and the existence of proton in it is proved.

Frequency spectrum of atmospherics at the various distances from the source will show the propagation characteristics of LF and VLF waves. Although the intensity and phase of VLF waves are disturbed by the solar flares, the geomagnetic storms and the allied phenomena, their intensity does not change appreciably to disturb the

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radio communications on VLF waves. Generally speaking, the VLF waves propagate long distances steadily with very low attenuation in all cases, and so they are very useful in the international comparison of the frequency standards, in the radio method of navigation, and really atmospherics on VLF range emitted from meteorological disturbances such as thunderstorms, typhoons, tornadoes, fronts, troughs, etc. are indispensable to the modern weather forecasting. This is because the radio engineers and geophysicists make much of the study of atmospherics and whistlers.

Consequently the investigation of characteristics of electric fields in the neighbourhood of a lightning discharge, is very useful in the study of the mechanism of lightning discharge, the propagation of longer radio waves and the interference of atmospherics to radio communications.

For this purpose workers have made so far the waveform measurement with wide band receivers of about 50 c/s - 300 kc/s, the upper limit being taken far less than the broadcast band to avoid its interference, and the intensity measurement with narrow band receivers, in which the bandwidth is less than 1 kc/s to avoid interference in a fairly clouded higher frequency region. ELF band, 1-3000 c/s, which is recently attracting attentions of engineers and scientists, is measured with receivers of pass band 1-50 c/s for a lower frequency region and with waveform recorders for a higher frequency region, "slow tail". For HF, VHF and UHF regions observations are made with single frequency receivers of very narrow bandwidth to obtain high gain and to avoid the interference of radio communications.

Lightning discharges are divided into 2 classes, i. e. the cloud-earth discharge and the intra-cloud discharge. The cloud-earth discharge consists of the pre-preliminary discharge, the preliminary discharge (Ig, ignition stage or B, breakdown stage, I, intermediate stage and a, L, leader stage.), b, R, the return streamer stage, c, J, the junction streamer stage, S, F, the final discharge stage, etc. Corresponding to each of these optically observed stages, a characteristic change of electric field is observed with a fairy good response.[1][2][3][4][5][6]

The intra-cloud discharge also displays charateristic field changes somewhat different from those of a cloud-earth discharge. Therefore the investigation of electrostatic, induction and radiation field of these stages, and the comparison among them are very useful in investigating the details of characteristics cf lightning phenomena. This is because the electronical methods, developed remarkably in the last decade, are recommended over the optical methods for revealing the details of the phenomena quantitatively.

II. Electrostatic Field

In accordance with the observation at distances 25-250 km, Pierce[3] found, with capillary electrometers, the relation between the positive and negative slow-mean-field changes effected by distance. The field obeys the inverse cube relation and corresponds to a change of electric moment of 110 coul-km, i. e. to a field-change of 1 v/m at 100 km. It is well known that near a storm most field-discharges are positive, while as the distance of the activity increases, negative field-changes become more frequent.

For any particular year and for magnitudes less than about 100 v/m, the ratio N+/N-, where N+ and N- are the number of all positive and negative field changes, is constant. This constant value may differ from year to year, but there is no significant change with magnitude between 100 and 0.1 v/m. Above 100 v/m positive field-changes become increasingly predominant as the magnitude of the field-change rises. A field-change of 100 v/m corresponsponds to a distance of about 20 km; the constancy of N+/N- below 100 v/m, therefore, implies that discharges, producing a reversal in the sign of the associated field-change beyond 20 km, do not occur. The changes from year to year in N+/N-, for field changes $<$ 100 v/m, are, therefore, not to be regarded as characteristics of the year but rather as representing differences between particular storms.

Slow negative field-changes are due to air or cloud discharges which either lower positive charges or, more probably, raise negative charges. Slow positive field-changes are produced by flashes which do not reach the earth, and which probably involve the downward movement of negative charges. Slow positive field-changes with fast elements are produced by flashes conveying negative electricity to the ground. Usually, a gradual L rise in the field is succeeded by one or more rapid R elements separated either by quiet intervals or by slow J changes, and often there is a final S or F section.

Takagi[5] observed that in ground discharges the slow electrostatic change is negative for a near flash (within 5 km), positive to negative at distances 5-15 km, positive at 15-20 km or more, and a large ground stroke pulse almost always has a positive and very steep front.

The difference between the slow field change of a ground discharge and that of a cloud discharge is that the polarity of the dipole contributing to the slow change of a ground discharge is negative and has a reversed relation to that of a cloud discharge, because the net field change is negative in a near distance and becomes positive in a long distance. Hillebrand[4a] obtained a rather unexpected result during his observation of lightning discharges. With lightning strokes at a distance of 3-8 km from his laboratory at Uppsala, it turned out quite often that the cathode ray was disappearing for a period of 5-10 μs. The magnetic field was considerably greater than the field calculated for the return stroke with a velocity of about one-fifth to one-quarter of that of light. His interpretation would be postponed to future study and he wonders why this fact was not found in earlier observations.

1. *Pre-preliminary discharges.* Takeuti[7] observed that about 50% of the ground discharges are preceded by a pre-preliminary discharge, duration 50-800 ms with median of 177 ms, which occurs within 500 ms before the first ground stroke, and so this discharge precedes the "preliminary discharge". In some thunderclouds the greater part of the first ground stroke is preceded by a pre-preliminary discharge, while in

others the strokes are preceded only by a preliminary discharge. On the average the ground discharges preceded by a pre-preliminary discharge have fewer ground strokes than those preceded only by a preliminary discharge; the pre-preliminary discharge probably neutralizes the negative charge in the ground stroke. The relation between the pre-preliminary discharge and the preliminary discharge is not yet known at present, but the former's characteristics are almost similar to those of a cloud discharge and it seems very likely that they excite preliminary discharges.

2. *B or Ig field change.*[2][6] The B field change, duration 2-10 ms, is negative at distances up to 2 km, positive at distances in excess of 5 km and positive or negative between 2 and 5 km (Malan); negative up to 6 km, positive in excess of 10 km and positive and negative or indeterminate between 6 and 10 km (Ishikawa). Taking into account that the maximum change of electric field occurs at a distance $D=\sqrt{2}\ H$, where H is the height of charge centre, B field change is attributed either to a positive charge moving upwards from a minimum height of 1.4 km, or to a negative charge moving downwards from a maximum height of 3.6 km.[2] The fact that the calculated heights of 1.4 and 3.6 km are in close agreement with the respective heights of the base of the cloud (1.5 to 2 km) and the lower region of the negative-charge centre N (3 to 4 km), strongly suggests that the B field change is due to a discharge between N and the positive charge centre p situated near the base of the cloud to make the discharge channel between p and N conductive.

3. *I field change.*[2][6] The I field change, duration 0-400 ms, is the part to connect the B and L field changes and the rate of change of field is either fairly uniform or variable.

4. *L field change.*[1][2][6] The L field change, duration 4-30 ms, corresponds roughly to the photographed stepped leader process, but whenever a direct correlation is obtained, the L field change lasts from 1.14 to 4.5 times as long, the difference increasing with the order of the stroke in the series. This indicates that successive strokes come from progressively higher regions. The L field changes are negative and hook-shaped when near, and positive and approximately parabolic when far. The change in sign with distance shows that the leader lowers a negative charge from the cloud and distributes this charge along its channel.

Two types of L variation preceding the first rapid R element are distinguished upon the field records.[3] In the first, the increase in field is uninterrupted up to the R portion, while in the second, the initial slow field-change is succeeded by a quiet part usually lasting until the rapid section, although there is sometimes a fairly short slow rise in field immediately preceding the R element. Somewhat similar effects have been noted by Schonland and given the titles α and β; this nomenclature is retainded here, the two kinds of initial field-change being denoted by L (α) and L (β). The average duration for the L (α) change is 50 ms, while the corresponding figure for the L (β) variety is 175 ms. The proportion of the total change of field, due to the whole discharge, occuring during the L section, is found to be significantly higher for L (β) than for L (α) variations; the appropriate percentages are 55% and 40% in

Europe[3] and 75% and 9% in Japan.[6]

5. *R or Main discharge field change.*[1] The R field change is made up of 2 parts. The rapid portion Rb has a duration of 50 to 250 μs (most frequent value 165 μs), and evidently corresponds to the rapid upward movement of the return streamer, its duration between 1.5 and 2.0 times as great as the time taken for the return streamer to reach the cloud base. Rb is followed by a slow field change Rc which lasts from 70 to 900 μs, corresponding roughly to the duration of continuing luminosity in the return streamer channel. Both Rb and Rc are of positive sign at all distances as would be expected if they were due to the removal to the earth of negative charges from the leader channel and the cloud. But at the distance of more than 15 km, Rb indicates a superposed pulse which deflects at first on the positive side and then on the negative.[1][5][6] Rc from a near flash to the ground frequetly shows small hook-shaped field changes which occur for a period of up to 6 ms after Rb. Its duration is between 200 and 800 μs and its amplitude is 0.2 to 0.01 times of Rb. It seems that these hook-shaped changes can be directly related to the M components of luminosity in the return streamer channel. At a distance they show only minor radiation pulses.

6. *J field change.* This field change[8] in the interval between the separate strokes of a multiple discharge to the groud is found to be negative for a near flash (within 5 km), negative to positive at a distance 5-12 km, Malan[8] found 23% positive, 37% zero and 40% negative, while Wormell and Pierce[9] found 25% positive and 75% zero. It is believed that during this process there occurs a discharge between the positive charge brought to the top of the discharge channel by the return streamer and the negative charge in the cloud. This discharge makes conductive the part of a colum in the cloud, which has abundant negative charges, to excite the next dart leader. Taking into account the change of sign of J field change with distance, Malan[8] considered that the discharge proceeds upward in the cloud and at the same time the effect of positive charge, which is high above the cloud and discharges upwards, does not come out at a short distance due to the masking effect of the J field change and appears progressively with increasing distances. According to the observation at Soccoro Mountain (alt. 7,200 ft or 2,200 m) by Brook[10] the J process, in which a streamer moves slowly upward in the intervals between the return strokes was clearly visible as it penetrated the remote regions of the cloud. The uppermost region from which the return stroke originated was observed to move (in steps reminiscent of darts) upward and outward, illuminating new regions of the cloud, before a new section was added to the channel of the previous return stroke and a new stroke occurred. Some discharges to the ground appeared to originate from a vertical column, but by far the greater number were seen to progress horizontally or inclined about 30° to the horizontal. The horizontally progressing junction streamer occurred about 3 times as often as the vertical streamer. These observations are consistent with the field measurement of Wormell and Pierce.[9]

Hewitt[11] employed a radar equipment at a frequency of 600 Mc/s for the study of streamer movement within thundersiouds in the intervals between strokes to the ground. The observations show that ascending echoes occur at increasing ranges and angles of elevation in the interstroke intervals, the heights increasing with the order of the intervals in the series. This is in accord with what would be expected if the echoes came from J streamers and the observed vertical velocity agrees with that found for the J streamer. A futher observation shows that echoes at lower heights less than 4 km persist throughout the series of ascending streamers and often show a considerably horizontal movement.

7. *F field change.* Malan[12] found that the F field change is a large final slow positive field change most frequently occuring after flashes having fewer than 4 strokes in the multiple stroke process. It is shown that this field change is due to a continuous discharge to the ground of part of the negatively charged column higher than that reached by the last stroke. The mechanism of progress of upward discharge in the column is similar to the J process. The discharge to the ground changes from intermittent to continuous when the charge density becomes too low. It is believed that during this process there occurs a more active discharge between the positive charge at the top of the cloud and the negative charge above it, and the effect of this discharge is not clear at short distances due to the masking effect of F process in the negatively charged column, but it appears markedly with increasing distances.

8. *Intra-clond discharge field change.* Cloud discharges show large slow continuous electrostatic field changes which are positive when the discharge is near and become negative when the distance increases.[5][13] Small rapid step-like or pulse-form changes which are responsible for sudden bursts of bright luminosity are usually superimposed in sporadic fashion on the slow field change.

Takagi[5] found that in cloud discharges the slow electrostatic change is positive for a near flash (within 5-10 km), negative at 10-20 km or more. It suggests that the cloud discharge generally dissipates a positive dipole in a cloud. The observed and estimated field intensities of the electrostatic field changes due to cloud discharges are shown in Table 1, where the estimated value is obtained by assuming that the charges +25 and −25 coul, are located at the height of 8 and 4 km respectively on the ground discharge.

Table 1. The observed and the estimated field intensities of the electrostatic field changes due to cloud discharges.

Distance (km)	Observed		Estimated
	Rapid process (v/m)	Slow process (kv/m)	absolute value* (kv/m)
0 — 5	50 — 300	1 — 30	2.6 — 21
5 — 10	10 — 100	.1 — 5	0 — 2.6
10 — 15	2 — 20	.1 — 1	.25 — .31
15 — 25	5 — 10	.05 — .5	.09 — .25

* It is assumed that +25 and −25 coul of electricity are located at the altitudes 8 and 4 km respectively on a vertical line.

III. Induction Field

1. *B or Ig pulsations.* According to Ishikawa,[6] Clarence and Malan,[2] at a distance more than 15 km the B or Ig field change starts with a train of large and predominantly positive pulses of varying and gradually decreasing amplitude. The interval between the pulses is irregular and varies from 80 to 230 μs. The most frequent duration of the pulse train is between 2 and 4 ms, the longest train observed lasting for 12 ms, the durations corresponding with those of the electrostatic B field changes. Small amplitude pulsations of which time separations are between 5 and 10 μs are often superimposed on the large low frequency B pulses. They usually continue with varying amplitude up to the incidence or the return stroke.

2. *I pulsations.*[2][3] The pulsations in the interval between the B and L stages are high frequency pulsations of very small amplitude. Periodic spurts of isolated pulses, of amplitudes comparable with those of the B pulses, often occur during the I phase. These pulses are positive when the rate of change of electrostatic field increases and negative when the rate of change of field decreases. When a return stroke follows a large B pulse train in less than 30 or 40 ms, the whole intermediate interval is occupied by the characteristic high frequency L pulsations described in the next paragraph, which suggests that in these cases the I stage is short or absent.

3. *L pulsations.*[2] The field changes immediately preceding a return stroke consist of a train of steep and predominantly positive pulses following one another at 5 to 10 μs intervals. Some of the pulses are of larger amplitude than those intervening. The larger pulses follow one another at intervals between 30 and 80 μs, which is the same as the pause time between the bright steps of stepped leaders. The observation, however, that strokes subsequent to the first are often preceded by similar pulse trains, indicates that they cannot wholly be due to the stepped process in the downward leader. Since the effects in the intervals between the strokes of a flash must be due to J streamers, it is reasonable to conclude that the similar field changes immediately preceding the first stroke are also mainly caused by streamer discharges inside the cloud, which supply charge to the advancing leader. The pulses during the L part of the discharge are smaller in amplitude than the B pulses. The amplitude ratio of B to L pulses varies from 3 : 1 to 20 : 1, the higher the rate of change of the electrostatic field during the B stage, the larger this ratio.

IV. The Radiation Field[2][13][14]

1. *Preliminary discharge process.* The radiation field of a preliminary discharge process in the ground discharge is remarkable in every frequency. It is observed even when the static field change is not clearly approved. The B, I and L stages always show some indication of high frequency radiation. Usually the amplitude of L is largest, and then that of B and I the smallest; the radiation fields of B and I stages are negligibly small in the frequency range between 200 c/s and 20 kc/s. The radiation

field of subsequent dart leaders is not essentially distinguished from that of J process filling up in interstroke period especially at higher frequencies.

The records obtained during the daytime illustrate three common types of L field radiations. (i) The α type (duration 2-25 ms) having a small, almost uniform train of pulsations whose amplitudes are often less than 1/100 of that of the return stroke. (ii) The slow β type (duration 3-19 ms) whose initial pulsations are slightly larger than the later ones, which resemble those of the α type. (iii) The large-amplitude fast β type (duration 1-7 ms) whose initial pulsations may have amplitudes up to half as large as the first return stroke pulsation. Intermediate types are also obtained. The time intervals between the L pulsations vary from 30 to 100 μs, which indicates that they originate from stepped leaders. Night time atmospherics show the same three types of leader, but the apparent time interval between the steps is smaller owing to successive ionospheric reflections.

2. *The return streamer process.* The salient points regarding the radiation field of ground discharge is as follows. At 3 kc/s the radiation is confined to the return strokes. This remains true up to about 20 kc/s except that the preliminary and interstroke pulses occasionally appear with amplitudes of 1% to 2% of those of the return strokes. With increasing frequency up to about 1-2 Mc/s, return strokes still have the largest amplitude, but radiations from other parts of the discharge increase progressively. At 4-12 Mc/s, especially when higher than 10 Mc/s, the latter surpasses the return strokes in amplitude. An interesting phenomenon is observed at these higher frequencies. The radiation is intense and continuous during the course of the first few strokes of a flash, except for pauses varying from 2 to 20 ms immediately following a return stroke.[5][13] After the initial burst of activity the pulses become more and more spaced in time. With increasing frequencies, the intermittent impulsive radiations change gradually into continuous radiations, but at frequencies higher than 100 Mc/s they occur very often associated with electrostatic pulses.

3. *The cloud discharge process.* In the intra-cloud discharges small rapid steps like field changes responsible for sudden bursts of bright luminosity are usually superimposed in sporadic fashion on the slow field change. At frequencies from 3 to 10 kc/s there are usually only one to three very small radiation pulses which are associated with rapid but not necessarily the largest K field changes. As the frequency increases to 2 Mc/s, more and more radiation pulses appear, those associated with K field changes remaining the largest. At 4-12 Mc/s the radiation becomes practically continuous and the K pulses can no longer be distinguished from the rest of the radiation. The cloud discharge has high frequency characteristics somewhat similar to the J process in the ground discharge and it is generally composed of slow J-like streamers and many rapid local streamers. At higher frequencies over 100 Mc/s, continuos and intermittent radiations independent of any process like stepped leaders are observed. Lightning flashes within 5 km very often show a continuous radiation, which has a duration larger than 100 ms, accompanied by an electric field of complicated variation.

The following figures give the ratios of the amplitudes of the return stroke radiation of ground discharges to the amplitudes of the most intense radiation components of cloud discharges at different frequencies:

Frequency	Amplitude ratios
3 kc/s	20/1-40/1
6 〃	10/1-20/1
10 〃	10/1
20 〃	5/1
30 〃	2/1-3/1
50-100 〃	1/1-1.5/1
1.5-12 Mc/s	1/1

V. Frequency Spectrum

The frequency spectrum of atmospherics is very important in the study of wave propagation, propagation of atmospherics, and the mechanism of lightning discharge, but it is also very difficult to obtain a frequency spectrum at various distances from the source, at various stages of lightning discharges, at various geographical features, at various meteorological and seasonal conditions. Although the data avaiable at present are very few, the following are the main results of observation from ELF to UHF all over the world.

Taylor and Jeans[15] recorded the intensity of atmospherics at 1-40 kc/s emitted from the ground discharge at distances between 150 and 600 km. Watt and Maxwell[16] made similar observations at 1-100 kc/s at distances between 30 and 50 km. Horner[17] measured at 11 Mc/s and 6 kc/s at distances between 1.5 and 6.5 km. Takagi[14] measured at 100 kc/s-500 Mc/s at 15-20 km. Schafer[17] measured at 150 Mc/s at 1-32 km. Summarizing these data and normalizing at a distance of 10 km for the receiver bandwidth of 1 kc/s, we obtain a frequency spectrum as shown in Fig. 1. But as the methods of measurements and characteristics of each apparatus are different, the curve in the figure is not fully reliable; it only shows the general tendency. The waveform of atmospherics in the neighbourhood of a lightning discharge depends on the geographical feature (sea, mountain, plain, city, town, tower, etc.), geographical position and the kind of discharge (ground discharge, cloud discharge, etc.), and changes from time to time during the discharge process.

Two widely quoted expressions have been given for the current surge during the return-stroke of a lightning flash to the earth. Both[18] have the same double exponential form $i_t = i_0 \, (e^{-\alpha t} - e^{-\beta t})$, where t is the time in sec. and i_t the current at time t, the origin of time being taken at the start of the return-stroke. Bruce and Golde[19] gave the following figures for the parameters, namely. $i_0 = 28{,}000$ A, $\alpha = 4.4 \times 10^4$, $\beta = 4.6 \times 10^5$, while Norinder[20] suggested the values $i_0 = 20{,}000$ A, $\alpha = 7 \times 10^3$, $\beta = 4 \times 10^4$.

It is well known,[18] for instance, that individual lightning flashes differ considerably in their spectral characteristics, the excitation of which may be anticipated to be related to conditions, and therefore currents, in the return-stroke channel. Perhaps the most striking evidence, however, for the existance of at least two main types of current surge is that derived from the study of atmospherics. The frequency spectra of the electromagnetic fields radiated respectively by return-strokes carrying the Norinder and Bruce-Golde forms of current surge, with the current assumed to be uniform along the channel, can easily be calculated.

Hill[21] calculated the radiation energy of lightning in the VLF range, considering only the return stroke, and found that the spectral energy distribution is centred at about 11 kc, with a total width at half-maximum of 12 kc/s.

In 1952 it was suggested by Shumann[22] that the earth and ionosphere may together act as a cavity resonator for electromagnetic wave and that the first resonance should occur at 10.6 c/s. Refinement of the theory indicated that losses due to absorption by the ionosphere or radiation through the ionosphere should reduce the resonant frequency by at least 1.5 c/s. Experimental evidence for the existence of the first resonant mode was reported first by Schumann and König[23] and, in considerably more detail by König.

The theory of ELF resonances was more recently discussed by Wait, and experimental evidence for the existence of the first and higher resonant modes, based upon measurements of electric fields, was presented by Balser and Wagner.[24] Their results were also applied by Raemer to the calculation of an ionospheric loss parameter which is a function of the height and the conductivity of the sharply bounded ionosphere assumed in the first order theory. Additional experimantal results were published recently by König, by Maple, by Lokken, Shand and Wright, by Polk and Fitchen, and by Sao, Jindo and Kumagai; König[25] reported that almost the same types of ELF were observed at Bonn and Munich, classified into 5 types correlating with weather phenomena, and on the occasion of solar eclipse, similar changes were observed with the sunrise and sunset phenomena; Polk[26] confirmed the existence of comparatively strong natural oscillations in the 7 to 10 c/s frequency range, but the resonant frequency exhibits short time variations and at night they are considerably weaker than during daylight hours and stronger than usual during periods of geomagnetic activity; Sao[27] suggested that only 25% of lightning discharges emit ELF and 81% of ELF come from sources which radiate VLF around the observatory and not from sources all over the world.

VI. The Study Programme for the Future

1. According to the observation for a long time it seems that the characteristics of atmospherics, which define its frequency spectrum, depend on the configuration and development of thundercloud. They show variations in accordance with the seasonal and meteorological conditions as well as geographical features such as the plateau, plain, mountain, sea, lake, town, city, tall tower, etc. Therefore it is recommended that the frequency sepectrum from ELF to UHF be measured at various distances from the source, at every meteorological and seasonal conditions as well as at every geographical feature. It will contribute to the study of wave propagation, mechanism of lightning discharge, properties of whistlers, etc. Indeed some authors have shown that the occurrence of whistlers depends on the frequency spectrum of mother

atmospherics and on the propagation conditions, and those atmospherics which have a peak near 5 kc/s, in place of ordinary 10 kc/s, excite whistlers very often.

2. At present many scientists observe the production, development and destruction of thunderclouds at many points on the ground with electronical instruments, and evaluate the electrical configuration of thunderclouds. But this is after all an indirect method and it is complicated; it requires a large area, much man-power, etc. Therefore it is recommended to determine the specification of a radiosondé and a Radar with PPI and RHI scopes suitable for observing horizontal and vertical configurations of thunderclouds.

3. Although we could not succeed due to disturbance by a typhoon, we made a measurement of characteristics of a ground discharge with a large paper balloon, connected with a grounded conducter, at 200 m high on the plateau of Mt. Haruna (1448 m), around which many equipments for measurements were arranged. It is, therefore, highly recommended that studies and discussions be carried out to determine the most useful method of this kind, so that a similar but more elaborate method may come out.

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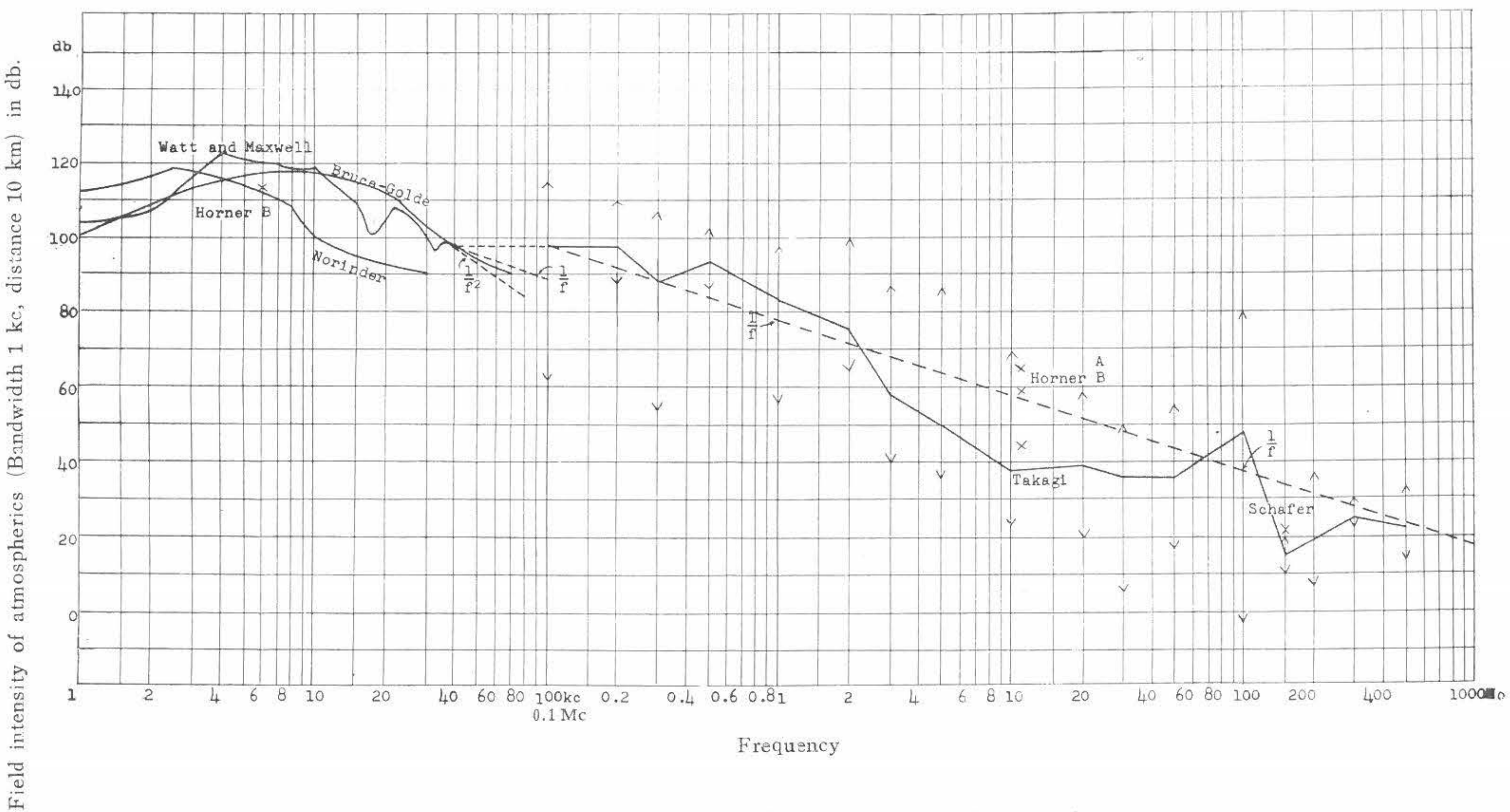

Fig. 1. Frequency spectrum of atmospherics in the neighbourhood of the source.