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운방전에 의해서 방사된 자계 파형의 특징과 통계

(Features and Statistics on the Magnetic Field Waveforms Radiated by Intracloud Discharges)

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요 약

본 논문은 운방전에 의해서 방사된 전자계 펄스의 특징과 통계에 관한 것으로 LabVIEW 기반의 시변성 자계측정시스템을 구성하였다. 이 자계측정시스템의 주파수대역은 300[Hz]~1[MHz]이고, 응답감도는 2.78[mV/nT]이며, 검출된 자계 파형의 기록에는 수직해상도와 최대기록시간이 각각 12비트와 100[ms]인 데이터취득시스템이 적용하였다. 운방전에 의해서 발생한 전자계 펄스는 파두부분에 하나 또는 둘 이상의 빠른 펄스가 중첩된 양방성 파형으로 나타났다. 운방전의 평균지속시간은 약 1.05±0.32[ms]이었으며, 평균 8개의 양방성 펄스가 발생하였다.

Abstract

This paper presents some features and statistics of electromagnetic pulses radiated from intracloud lightning discharges. The LabVIEW based-measurement system of time-dependent electromagnetic fields was constructed. The frequency bandwidth of the measuring system ranged from 300[Hz] to 1[MHz], and the response sensitivity was 2.78[mV/nT]. The resolution and the maximum recording length of the data acquisition system were 12[bits] and 100[ms], respectively. In the electromagnetic pulses radiated from intracloud discharges, a pronounced bipolar pulse appeared with one or more fast pulses superimposed on the initial front part of the bipolar pulse. The mean duration of intracloud discharges was 1.05±0.32[ms], and an average of about 8 outburst pulses appeared for a period.

Key Words : Intracloud discharge, Lightning electromagnetic pulse, Surge protective device, Transient data acquisition system

1. Introduction

Electronic devices are increasingly employed in various fields of industry and business, and modern high-speed electronic equipments and systems are sensitive to lightning electromagnetic pulses. Lightning produces strong electromagnetic

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pulses and is responsible for serious disturbances and failure of electronic devices such as computers, and information and communication facilities. One of the principal research topics on electromagnetic interference/compatibility of modern microelectronic devices is the efficient and economic protection against lightning electro-magnetic pulses. Therefore, electronic circuits must be closely and effectively protected against electromagnetic field pulses caused by lightning, and so, it is important to investigate the electromagnetic fields produced during lightning discharge processes.

Also, thunderclouds have a basic dipolar charge structure consisting of negative charges at mid-levels of the thundercloud and positive charges in the upper levels. Most of intracloud lightning discharges occur between the low negative and upper positive charge regions[1]. Because intracloud lightning discharge channels are usually obscured from view by the cloud, electromagnetic field measurements have become an important means for studying intracloud lightning discharges[2].

Detailed features and mechanisms of the structure and development of intracloud lightning discharges are still not completely understood because the discharge channels are hardly visible. To provide valuable information about the protection of electronic circuits and systems from lightning transients, the electromagnetic fields radiated from intracloud lightning discharges were measured and analyzed accurately. All data presented here were measured in Incheon on the coast of the Yellow Sea in Korea during the fall of 2004. In this paper, we present statistics on the radiation field parameters such as the number of intermittent fast pulses per flash, the duration of intracloud lightning discharges, and the occurrence frequency of the stepwise fast pulses superimposed on the initial front part of the bipolar pulse Also, the implications of the electromagnetic pulse shapes and waveform parameters on intracloud lightning discharge processes will be discussed

2. Experiments

As illustrated in Fig. 1, a transient data recording system was designed to measure the electromagnetic fields radiated by intracloud lightning discharges. The magnetic field was measured by using two orthogonally crossed loop antennas (area 0.064[m²]). The H-dot sensor signal was amplified and integrated, resulting in a signal that was proportional to the magnetic field to be measured.

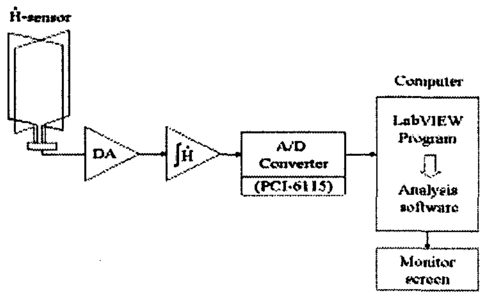


Fig. 1. Block diagram of the time-varying magnetic field measuring system

The frequency bandwidth of the magnetic field measuring system ranged from 300[Hz] to approximately 1[MHz], and the response sensitivity was 2.78[mV/nT]. The A/D converter (PCI-6115) used for the data acquisition had the resolution of 12 bits and the sampling rate of 10[MS/s]. The waveform parameter and signal analysis systems using LabVIEW program were developed. The maximum recording length of the data acquisition system was about 100[ms]. The data recording system, which can be used to investigate the structure and nature of the lightning radiation fields on a millisecond time scale, was triggered in the pretrigger mode by the signal to be measured to display the radiation field signals before and after the trigger pulse. The measuring station was located at longitude 126°39′east and latitude 37°25′north. The measuring system was installed at the high-voltage laboratory of Inha University in the Incheon area, located about 3[km] inland from the coast of the Yellow Sea in Korea. The major measurements were taken during the fall of 2004.

3. Results and Discussion

3.1 Basic features of the electromagnetic fields

The cloud lightning discharges consisted of three types of lightning: ① intracloud lightning discharge, ② intercloud lightning discharge, and ③ air discharge. It was very difficult to discriminate the three types of cloud lightning discharges by using electromagnetic fields. The majority of cloud lightning discharges were thought to be the intracloud type, although no reliable statistical data were found in the literature to confirm this thought. Often intracloud lightning discharge is used to refer to all cloud flashes[3]. In this paper, we used the term intracloud lightning discharges to all cloud lightning discharges.

Intracloud lightning discharges, which substantially take place between an upper positive thundercloud and low negative thundercloud, are the most frequent lightning discharges. Some features of the structure and development of intracloud lightning discharges have been presented in the literature[4-6]. Unfortunately, the mechanism and natures whereby cloud lightning discharges produce radiation field emissions are still not completely understood because of the lack of photographic records of cloud discharge channels. The sources of the strongest radio frequency electromagnetic radiation appear to be cloud lightning discharges, not cloud-to-ground lightning return strokes. The electromagnetic field change associated with a cloud lightning discharge is a 10~20μs duration bipolar pulse with an initial half cycle, typically followed by an overshoot in the opposite direction. The sources of strong electromagnetic radiation last for a significantly less time than the field changes. [7,8]

Figure 2 shows an example of the monitor screen of the data acquisition system displaying the radiation field waveform of intracloud lightning discharges on fast time scale. The bottom part of Fig. 2 shows the frequency spectrum of the electromagnetic radiation field, that is, the radio frequency range. The measured radiation field waveforms can be displayed on the appropriate time scale and the waveform parameters such as the rise time, the fall time, the time interval between pulses, the zero-crossing time, the full pulse width and the peak values are analyzed by using the functions of the LabVIEW program.

Also, Figure 3 shows examples of multiple-peak electromagnetic pulses due to intracloud lightning discharges. Each waveform is displayed on both a fast and a slow time scale. Electromagnetic fields produced by intracloud lightning discharges from a distance of more than 20[km] are actually the radiation component. The magnetic fields presented in this paper were the radiation component and were substantially equal to the electric fields[9]. The overall features of the radiation fields were very similar to those observed in Florida by Krider, Weidman and LeVine[10] and by Villanueva et al.[11] and in

Sweden by Cooray and Lundquist[12].

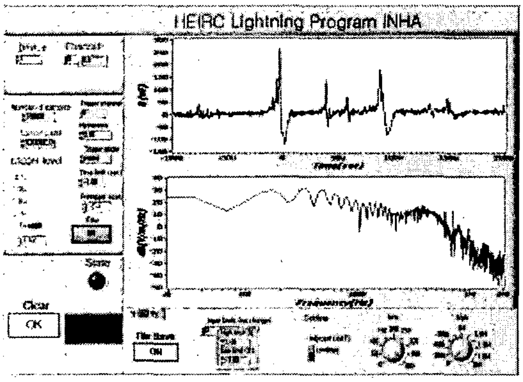
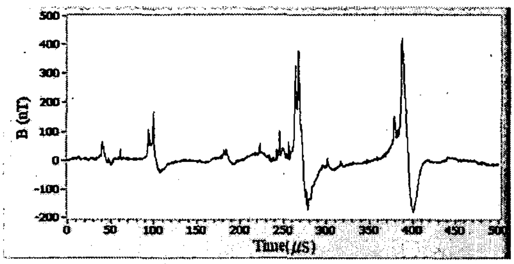
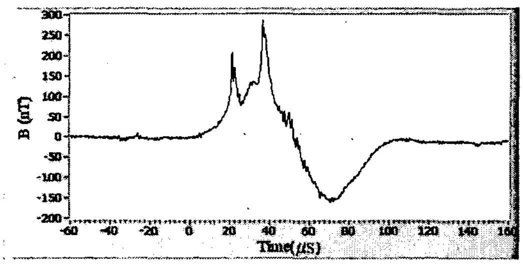


Fig. 2. Example of the monitor screen of the data acquisition system



(a) Slow time scale



(b) Fast time scale

Fig. 3. Typical waveforms of the electromagnetic fields radiated by intracloud lightning discharges

The leader field consists of pulses caused by each step streamer of the stepped leaders. The stepped leader pulses with a width of a few microseconds tend to occur early in the intracloud flashes. Most radiation field pulses, radiated by leader processes immediately preceding the main stroke, are characterized by a slow opposite overshoot following the initial fast rise to peak. The radiation fields originating from the stepped leader are closely related to the leader channel length and the leader current[13]. Two or more leader pulses prior to intracloud lightning discharge processes have been observed, and the time interval just before the main strokes is very short. In some radiation field waveforms, the leader pulse amplitude is markedly small compared to the pronounced bipolar pulses. In a few cases, only two or three leader pulses are clearly visible. The waveforms of the leader pulses are nearly similar to those produced by the stepped leaders immediately preceding the cloud-to-ground lightning return strokes.

The electromagnetic fields radiated by intracloud lightning discharges showed a pronounced bipolar shape. J. C. Willett, et al. have suggested that the pronounced bipolar pattern of radiation fields generally occurs as isolated pulses in intracloud lightning discharges[8]. The radiation field pulses revealed single or multiple-peak pulses, which occur just prior to the intracloud lightning strikes, change the field to the same polarity as the initial pulse peak, and have amplitudes equal to a small fraction of the bipolar pulse peak.

The superimposed and main peaks during the initial half cycle of the bipolar-shaped radiation fields could be produced by the initial and branched breakdown processes. Also, the spatially isolated branch channels may be an important source of the intermittent electromagnetic field pulses radiated by intracloud lightning discharges. Intracloud lightning discharge begins with the preceding leader streamers, which propagate toward the oppositely-charged center in steps. The leader streamer reaches a localized concentration of opposite polarity charge, and then the main breakdown launches. The fast pulses are probably caused by the formation of the discharge channel in several stepwise shapes. The slower current surge, which produces the pronounced bipolar component as suggested by Weidman and Krider,[13] flows either way, while the discharge channel is being established or just afterward.

3.2 Statistics on the parameters of radiation field waveforms

Most of the electromagnetic fields radiated by intracloud lightning discharges have been observed as a pulse train, as shown in Fig. 4. Because the radiation fields associated with intracloud lightning discharges are highly variable and surprisingly irregular, radiation fields can be statistically analyzed.

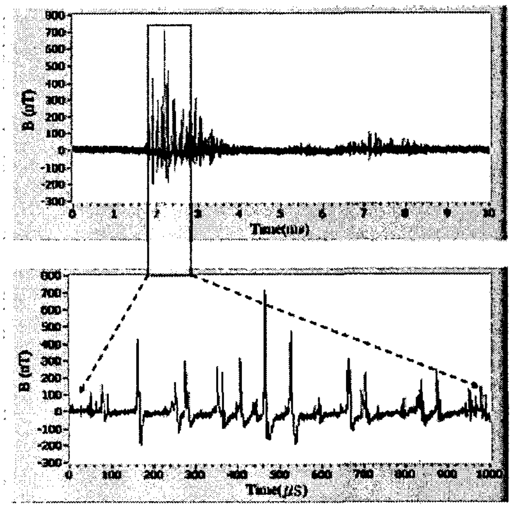


Fig. 4. Examples of lightning electromagnetic pulse trains. Upper: slow trace, low: enlarged waveform at the maximum pulse

To analyze the accurate amplitude statistics of the electromagnetic fields radiated by intracloud lightning discharges, we must have precise information about the lightning strike point such as the direction and distance from the lightning stroke to the loop antennas. Information on the position of intracloud lightning flashes is difficult to find. Unfortunately, we did not measure the distance between the lightning point and the observation site. Thus, in this work, the statistics were mainly focused on the number of occurrences and the duration of the electromagnetic field pulses radiated by intracloud lightning discharges. The duration of intracloud lightning discharges were distributed in the wide range of 0.5[ms] to 1.8[ms]. Figure 5 shows the distribution of the duration of intracloud lightning discharges. The data were prepared from 20 sample radiation field waveforms, and the number of the data used in this statistics does not represent the total occurrence frequency of intracloud lightning discharges. Data having severe noise or illegibility were excluded in this statistics. The mean of the duration of intracloud lightning discharges was 1.05[ms] with a standard deviation of 0.32[ms]. Sometimes, single-blow intracolud lightning discharges with the duration of less than 100[μs] or long-sustained intracloud lightning discharges with the duration of greater than 5[ms] occurred, but extremely irregular events of infinitesimal number were excluded in this statistics.

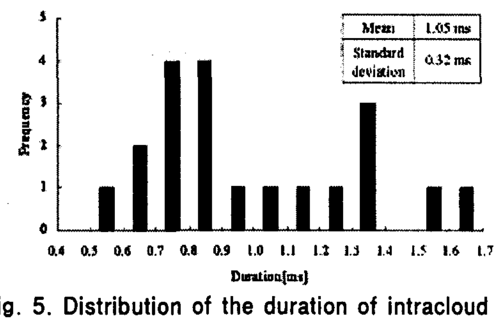


Fig. 5. Distribution of the duration of intracloud lightning discharges

The number of electromagnetic pulse trains relative to the nature and characteristics of the development process of intracloud lightning discharges was examined. Electromagnetic pulses have different amplitudes and origins. Large peaks of electromagnetic pulses radiated by intracloud lightning discharges are directly associated with the charge change and the motion of branch channels. The number of the electromagnetic pulses with a large peak is related to the number of branch channels of intracloud lightning discharges. Figure6 shows the distribution of the number of electromagnetic pulses in an intracloud lightning flash. Here, only the data having the amplitude of greater than 25% of the maximum peak in a pulse train were adopted, in order to exclude the leader pulses and noises. The number of the intracloud lightning radiation fields with large peak is distributed over the wide range 2 to 16 with a mean and standard deviation of 8.05 and 3.15, respectively.

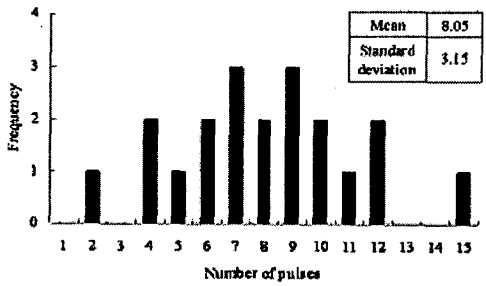


Fig. 6. Histogram of the number of electromagnetic pulses radiated by intracloud lightning discharges

One of the basic features of the electromagnetic fields radiated by intracloud lightning discharges is the narrow stepwise pulse superimposed on the initial half-cycle of the large bipolar pulses as described in Sec. 3.1. The narrow stepwise pulses are caused by the extension of the channel in a stepped process. The regular sequences of primarily unipolar electromagnetic pulses are produced in the final stage of intracloud lightning discharges[14].

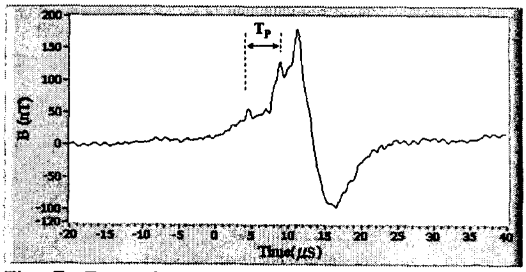


Fig. 7. Example of the fine structure of bipolar pulse radiated by intracloud lightning discharges

Figure 7 shows a typical radiation field waveform of a large bipolar pulse and superimposed stepwise pulses on the initial half-cycle of the bipolar pulse and illustrates the definition of the time interval between the superimposed stepwise narrow pulses (Tp). The distribution of the number of stepwise narrow pulses superimposed on the initial half-cycle of large bipolar pulses is shown in Fig. 8. The occurrence number of the stepwise narrow pulses ranged from 1 to 3 and was 1.66±0.74 on the average for 58 bipolar pulses. Also, Fig. 9 shows the distributions of the time intervals between the narrow pulses superimposed on the initial half-cycle of the radiation field waveforms reported in the literature[9].

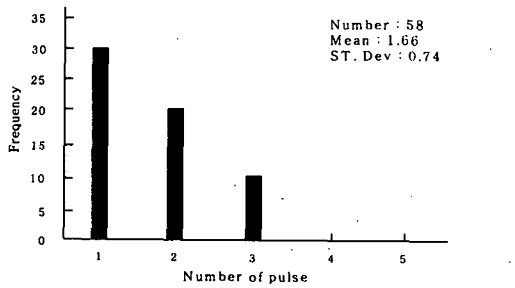


Fig. 8. Histogram of the number of leader pulses superimposed on the initial half cycle of bipolar pulses

When the bipolar pulse width is large, the occurrence number and the interval between the superimposed stepwise pulses increased. The time intervals between the superimposed stepwise pulses were distributed within the range of less than 12μs. The mean time interval was 4.43μs with a standard deviation of 2.76μs for the 145 bipolar pulses.

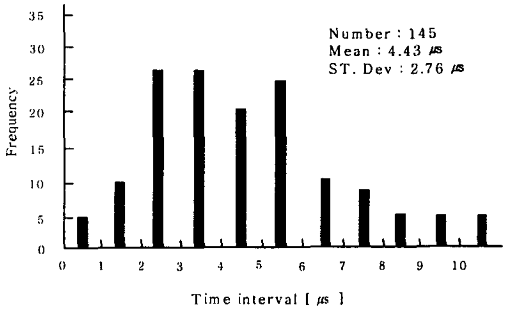


Fig. 9. Histogram of the time intervals between the stepwise pulses superimposed on the initial half-cycle of the large bipolar pulses

The time intervals between the narrow stepwise pulses superimposed on the initial half-cycle of the large bipolar radiation fields were much less those between the stepped leader pulses preceding the bipolar pulses. It is considered that the origin of the narrow stepwise pulses superimposed on the initial half-cycle of the bipolar component is different from the propagation mechanism of the stepped leader pulses.

4. Conclusion

Basic features and statistics with the electromagnetic fields radiated by intracloud lightning discharges were experimentally investigated near the west coast of Korea. The electromagnetic fields radiated by intracloud lightning discharges consisted of intermittent fast pulses and showed bipolar shape and the superimposed stepwise pulses on the half-cycle of the bipolar pulses. The duration of intracloud lightning discharges were normally distributed over the range from 0.5[ms] to 1.8[ms]. The occurrence frequency of narrow stepwise pulses superimposed on the half-cycle of the bipolar component was 1.66 with a standard deviation of 0.74. The present results are useful for better understanding of the physical properties associated with intracloud lightning discharges to develop an efficient device for protecting electronic systems against lightning electromagnetic pulses.

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