LIGHTNING OBSERVATIONS AND IMAGING OF CHARGE DISTRIBUTION IN THUNDERCLOUDS USING BROADBAND INTERFEROMETER

Takeshi MORIMOTO, and Zen KAWASAKI

Department of Communication Engineering, Graduate School of Engineering, Osaka University
Yamada-Oka 2-1, Suita Osaka Japan 565 0871
E-mail *morimoto@comf5.comm.eng.osaka-u.ac.jp*

ABSTRACT

Lightning Research Group of Osaka University (LRGOU) has been developing a new type of lightning location and monitoring system based on a technique of VHF broadband interferometory. It is known that VHF impulses are mainly emitted at the tip of breakdown especially in case of negative breakdown. From this aspect it is considered that the source location of negative breakdown inside the thundercloud gives the positive charge distribution. During the field observations we obtain results of two types of positive cloud-to-ground (CG) strokes. One is contributed by upper positive charges and the other is contributed by lower pocket positive charges.

INTRODUCTION

LRGOU has been developing a new type of lightning location and monitoring system based on a technique of VHF broadband interferometory[1]-[4]. The basic principle of broadband interferometry is the relative phase estimation of Fourier component of VHF impulse signals detected by several antennas, that is an antenna array. It should be noticed that the phase information of an electromagnetic (EM) signal, strictly speaking the phase difference between a pair of antennas, enables us to calculate incident direction of the EM source against the antenna array.

Since it is known that VHF impulse signals are mainly emitted at the tip of breakdown like the leader tip especially in case of a negative breakdown, the VHF impulse source location is equivalent to imaging the lightning channel development. Moreover, the source location after the occurrence of return strokes (RS) or during the continuing current in case of negative breakdown gives the positive charge distribution inside the thundercloud. In other words we are able to get images of positive charge distribution by VHF observations.

The basic system of the broadband interferometer consists of three antennas and we can define linearly independent two couples of antennas from the aspect of the phase differences. Through this procedure the broadband interferometer presents us the consecutive changing of azimuth-elevation directions of VHF sources.

The other feature of the broadband interferometer is its wide detection frequency range, and this system does not care the carrier frequency. The system observes the electric field change due to a lightning discharge in frequency range between 25MHz and 250MHz, and Fast Fourier Transform (FFT) is applied to captured waveform. Without the recent progress of electronics, such as the analog to digital (A/D) conversion with quite high sampling rate and fast data processing, the broadband interferometer cannot be realized.

This paper presents a brief explanation about the broadband interferometer system and consideration to charge distribution inside the thunderclouds using observed results.

BROADBAND INTERFEROMETER SYSTEM

The basic idea of the broadband interferometer technique is to estimate the phase differences at various frequency components of Fourier spectra between a couple of broadband antenna sensors. The phase difference is a function of incident angle of the radiation source relative to the baseline between the sensors. Using two sensors, we can locate the radiation source in one-spatial dimension. Two-dimensional location, in this case in azimuth-elevation format, can be realized by employing at least three sensors. In this system, we use three sensors, which are equipped at three apexes of an isosceles right-angled triangle, and we define linearly independent two couples of antennas from the aspect of the phase differences. Fig. 1 is a block diagram of one unit of the broadband interferometer. We use circular flat-plane antennas with a diameter of 30cm as broadband sensors whose bandwidth is between 25MHz and 250MHz, and a logarithmic amplifier is equipped below each antenna. The broadband signals received by antennas are digitized at a rate of 500MSamples/s and 8-bit resolution by a digital oscilloscope. A maximum of 2000 segments, that stores broadband pulses for 1μs each, can be recorded per lightning flash within 1second. An additional sensor to measure the electric field change antenna is equipped. This sensor is used to discriminate CG strokes and to know the polarity of lightning leader in case of CG strokes. Global positioning system (GPS) receiver is also set up to get the accurate time of the lightning occurrence.

Fig. 2 shows antennas arrangement and a schematic of the VHF impulse source location. Using three sensors, the direction of a radiation source can be detected as azimuth (α) and elevation (β) through the following equations.

$$\alpha = \arctan\ (\ \cos\phi_1\ /\ \cos\phi_2\ ) \tag{1}$$

$$\beta = \arccos\ (\ \cos\phi_1\ /\ \cos\alpha\ ) \tag{2}$$

where ϕ_1 and ϕ_2 are incident angles relative to each sensor baseline.

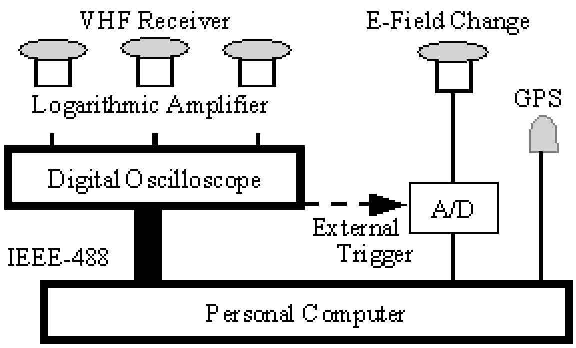

Fig. 1. Brock diagram of the broadband interferometer system

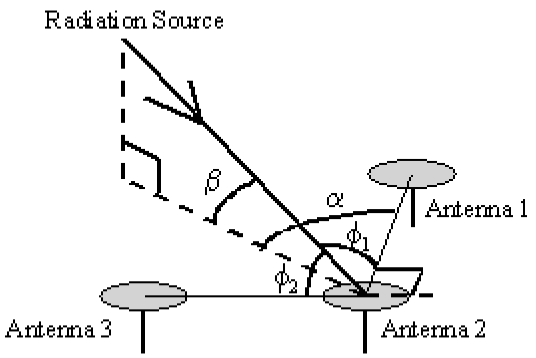

Fig. 2. Antennas arrangement and a schematic of the VHF impulse source location

OBSERVATION RESULTS

LRGOU has been conducting lightning observation campaigns at Hokuriku Coast, Japan. The main objective of these campaigns is further understanding of positive CG lightning discharges during winter thunderstorms.

Fig. 3. and Fig. 4. are two-dimensional mapping of VHF impulse sources by the broadband interferometer. These flashes occurred at January 28, 2001 17:32:08 Japan standard time (JST) and January 29, 2001 21:38:25 (JST) respectively. Each figure shows the relative electric field changes (top) and locations of the VHF impulse sources in azimuth (bottom) – elevation (middle) format, in time domain. The character "*R*" in figure indicates an abrupt electric field change denotes the occurrence of return stroke (RS). Through this paper we adopt the traditional atmospheric convention to present an electric field change, so an abrupt negative change means that positive charges are lowered from the cloud to ground. In this meaning the events of Fig. 3. and Fig. 4. are discriminated positive CG strokes. Both of figures show the activity during 200ms including the occurrence of RS. In the event of Fig. 3., VHF impulses are emitted for at most 30ms around RS. In the event of Fig. 4., on the other hand, VHF impulse sources are located for 150ms after RS and continuing current phase is noticeable in the waveform of electric field change. During '99-'00 and '00-'01 winter campaigns, we observed fifteen positive CG strokes. Two of fifteen can be classified as same type as event of Fig. 3 with short duration (type1), and the rest thirteen are classified as the other type with long continuing current (type2).

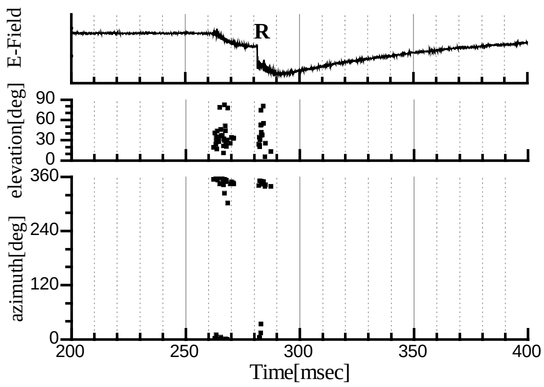

Fig. 3. Two-dimensional image of type1 positive CG stroke

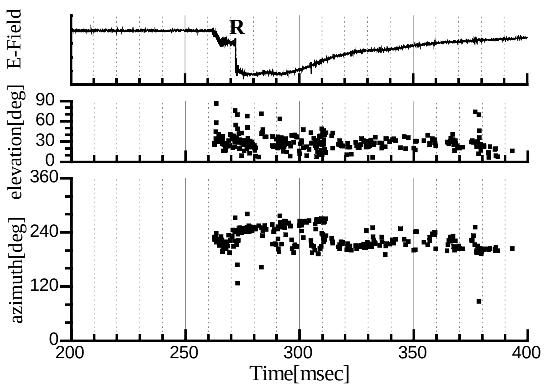

Fig. 4. Two-dimensional image of type2 positive CG stroke

This distinction may relate to charge distribution that contributes to discharges. The clouds take the dipole electrical structure at their developing stage and then tripole structure at the mature stage. Kitagawa and Michimoto[5] assume that, as to the winter thunderclouds, the period covering both dipole and tripole structures is very short, and then positive charges spread in the whole cloud at their dissipating stage, and this stage of positive monopole structure lasts much longer than the preceding two stages and occupies most of the lifetime of the clouds.
We emphasis again that the broadband interferometer makes location of the negative breakdown development, in other words, gets image of positive charge distribution. Accordingly, events classified as type1 are contributed by lower pocket positive charges during the short tripole structure period, and events classified as type2 are contributed by wide spread positive charges during dipole or monopole structure. Moreover, type2 may correlate closely with the lightning superbolts, and became a possible mother discharge for sprite occurrence in case of Hokuriku.

CONCLUSION

The broadband interferometer has been developed in order to image the lightning breakdown development and to observe positive charge distribution inside the thunderclouds. During two winter seasons lightning observation campaigns at Hokuriku Coast, two types of positive CG strokes are observed. One is positive CG for short duration, and the other is positive CG with long continuing current. It is considered that the former is mainly contributed by lower pocket positive charges (perhaps it is single flash thunderstorm), and the latter is contributed by wide spread numerous positive charges. Furthermore, type2 is a possible mother discharge for sprite occurrence in case of Hokuriku. Though to make the conclusion clearly we need more data accumulations and/or comparisons with observation data by other measurements, this paper proposes the use of the broadband interferometer to study charge distribution in thunderclouds.

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