

VHF Broadband Interferometer and Lightning Monitoring

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Abstract: Lightning Research Group of Osaka University (LRGOU) has been developing two- (2D) and three-dimensional (3D) VHF source mapping systems of electromagnetic (EM) waves emitted by lightning discharge progression by a unique technique based on “the broadband digital interferometry”. Through our field observations real time monitoring in terms of 2D are realized, and 3D images of lightning channels by the post processing are obtained. Since VHF impulses are radiated from mainly negative breakdowns, their source location gives the positive charge distribution. In other words, a broadband interferometer (ITF) may not only visualize negative leader progressions but also give information on positive charge distribution inside thunderclouds. In leader progression of negative cloud-to-ground (CG) flashes two categories are identified. One is characterized that negative leader begins at an altitude of around 8km agl and goes down to the ground for several tens milliseconds. The other, in contrast, has some intermittent VHF radiations at 10km agl about 1ms before continuous leader development. The ignitions at high altitudes could be powerful events and relate to transionospheric pulse pairs (TIPPs) and/or compact intracloud discharges (CIDs).

Key words: Broadband Interferometry, Lightning Discharge, Electromagnetic Radiation, Direction-of-arrival Estimation

1. Introduction

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 digital interferometry [1][2][3]. The basic principle of this technique is the relative phase estimations for various frequency components of a VHF impulse detected by a pair of antennas with a proper separation. It should be noticed that the phase information of an electromagnetic (EM) signal, strictly speaking the phase difference between two antennas,

enables us to calculate the incident angle of the EM source against the antenna array.

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

This paper presents a brief summary about a broadband interferometer (ITF), and then gives some consideration on the charge distribution inside thunderclouds using observed results. The results for negative cloud-to-ground (CG) flashes that may contribute to clarify the mechanism of lightning ignition are also shown.

2. Broadband Interferometer

A broadband ITF is a system to locate a source of VHF impulse based on the digital interferometric technique. A remarkable feature of a broadband ITF is its wide detection frequency range, and this system takes no account of a carrier frequency. The system observes the electric field change due to a lightning discharge in the ultra-wide VHF band, and Fast Fourier Transform (FFT) is applied to calculate various frequency components of the received EM pulse. Computed phase difference for each Fourier component between two antennas is a function of the incident angle of the EM pulse against the baseline. A couple of antennas as a two-element array of a broadband ITF are able to estimate the incident angle. Two pairs of antennas, and independent two baselines, enable two-dimensional (2D) mapping of sources in azimuth and elevation format.

Fig. 1 shows its antennas arrangement and the schema of the VHF impulse source location. In our

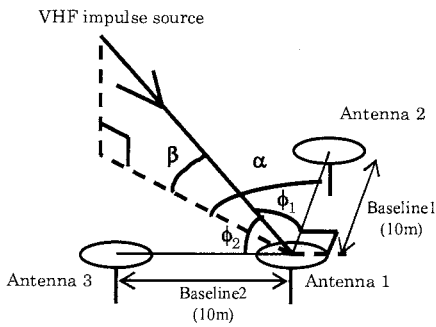


Fig. 1. Antenna arrangement of a perpendicular baseline on the ITF for two-dimensional mapping. The antennas 1 and 2 form the first baseline, and the antennas 1 and 3 form the second baseline.

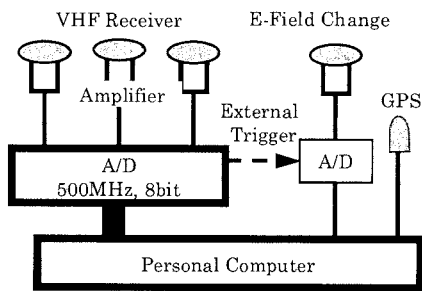


Fig. 2. The simplest radio ITF.

system, we use three sensors, which are equipped at three apexes of a level isosceles right-angled triangle, and we define orthogonal two baselines with 10m length. Fig. 2 illustrates a block diagram of one unit of the broadband ITF for 2D mapping. We use circular flat-plate antenna which has a diameter of 30cm, and its bandwidth is calibrated to be between 10MHz and 250MHz. The received broadband signals are amplified by amplifiers equipped beneath antennas, and are digitized at a sampling rate of 500MHz with 8-bit resolution. Two thousands EM pulses for 1μs with about 70μs mechanical interval between pulses can be recorded for one lightning flash within 1s. Notice that “two thousands” are the maximum and the total amount of observed EM pulse number depends on the event’s feature and distance from the observation site. Here after it is called “event triggering”. An additional sensor to measure the electric field change, called slow antenna, is equipped. This sensor is used to discriminate CG stroke and to know the polarity of lightning discharge in case of CG flash. Global positioning system (GPS) receiver is also set up to get the accurate time of the lightning occurrence.

Using three sensors, the direction of an impulse

source can be estimated as azimuth (α) and elevation (β) by the following equations (see Fig. 1).

$$\alpha = \tan^{-1} \frac{\cos \phi_1}{\cos \phi_2} \dots \dots \dots (1)$$

$$\beta = \cos^{-1} \frac{\cos \phi_1}{\cos \alpha} \dots \dots \dots (2)$$

Where ϕ_1 and ϕ_2 are the angles of incidence relative to each baseline.

Three-dimensional (3D) imaging of VHF impulse sources are accomplished by a synchronized operation of two units of the ITFs with a proper distance separation.

3. Results and Discussions

3.1 Consideration to Charge Distribution Inside Thunderclouds

Figs. 3 and 4 show azimuth-and-elevation mappings of VHF impulse sources by the broadband ITF. These are recorded '00-'01 winter thunderstorm observation campaigns in Fukui. Each figure shows the relative electric field change (top) and estimated VHF impulse sources in azimuth (bottom) – elevation (middle) format in time domain. The character “R” in these figures indicates an abrupt electric field change, which denotes the occurrence of RS. Through this paper we adopt the traditional atmospheric sign convection to present an electric field change. So an abrupt negative change means that positive charges are lowered from the cloud to the ground. In this meaning the events in Figs. 3 and 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, in which we operate one-unit broadband ITF that is 2D observation, we observed 15 positive CG strokes. 2 of 15 can be classified as the same type as the event in Fig. 3 with short duration (type1), and the rest 13 are classified as the other type with long continuing current (type2).

LRGOU discovered that the UHF radiation intensity due to negative breakdown is about 20dB stronger than that of the positive breakdown by observed upward initiated lightning from a 200m-stuck that is uni-directional and singular polarity leader [4]. Shao et al., [5] reported the VHF radiation intensity due to negative leader is at least 25dB stronger than that of the positive leader and predicted that only VHF/UHF

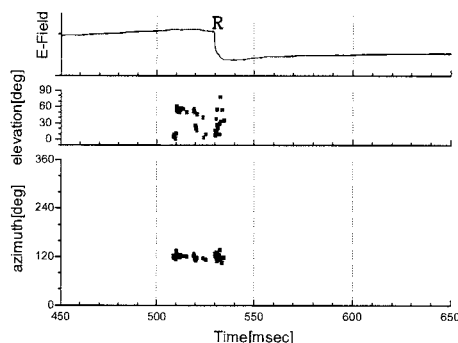


Fig. 3. Azimuth-and-elevation mapping of VHF radiation sources for positive CG type1. The character "R" indicates an abrupt electric field change, which denotes the occurrence of RS.

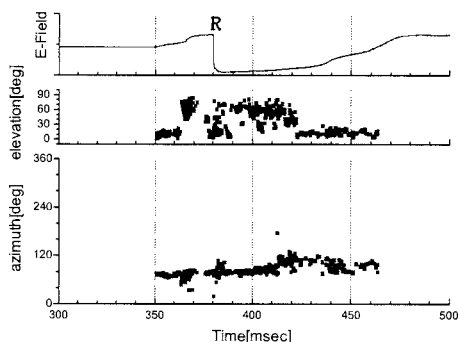


Fig. 4. Similar to Fig.3 but for positive CG type2.

radiation due associated with the negative leader can be detectable because of the masking effect. Summarizing these, VHF radiation sources located by a broadband ITF are mainly related to the negative breakdown, and negative breakdown, which follows a positive RS in case of CG, propagates into positive charge region. A visualization of lightning progression inside a thundercloud by a broadband ITF could give us information on positive charge distribution. This argument is supported by the comparison between VHF 3D lightning imaging and cloud charge structure inferred from balloon soundings of electric field [6] or aircraft observations [7].

Taking into account the above, we speculate that the distinction of VHF radiation between Figs. 3 and 4 might relate to charge distribution that contributes to discharges. The thunderclouds take a di-pole electrical structure at their developing stage and then tri-pole structure at the mature stage. Kitagawa and Michimoto

[8] assume that, as to the winter thunderclouds, the period covering both di- and tri-pole structures is very short, and then positive charges spread in the whole cloud at their dissipating stage, and this stage of positive mono-pole structure lasts much longer than the preceding two stages and occupies most of the lifetime of the clouds. We emphasize again that a broadband ITF makes locations of the negative breakdown developments, in other words gets image of positive charge distribution. Accordingly, events classified as type1 are contributed by lower pocket positive charges during the short tri-pole structure period, while events classified as type2 are by wide spread positive charges during di- or mono-pole structure. Moreover, type2 might correlate closely with the lightning superbolts, and become a possible mother discharge for sprite occurrence around the coastal area of the Sea of Japan in winter thunderstorm seasons.

3.2 A Distinct Class of Negative CG Flashes

In Figs. 5 and 6, altitudes of VHF radiation sources located by a broadband ITF are drawn in time domain. Both are correspond to leader propagation phases of negative CG flashes recorded during '02 summer thunderstorm observation campaign in Darwin. The character "R" in these figures indicates the occurrence of RS. When we pay our attention to leader propagation channel of negative CG flashes especially their initiation, two categories as shown in Figs. 5 and 6 are identified. In the former, negative leader begins at an altitude of around 8km agl and goes down to the ground for several tens milliseconds. The latter, in contrast, has some intermittent VHF radiations at 10km agl about 1ms, which circled in Fig. 6, before continuous leader development. From the fact that narrow bipolar pulses (NBPs) are clearly noticed in the electrical field changes in synchronization with VHF radiations at high altitude, it is clear evident that these two categories are classified phenomenally. The results of cross-polarized radar observations show that the main precipitation particles are wet graupel at an altitude of 8km and the dry snow is dominant above 10km high. Assuming the tri-pole electric charge structure based on the riming electrification mechanism [9], it is considered that the former is triggered at lower positively charged region or between lower positive and dominant negative charge region, and the latter is triggered at higher positively charged region or between higher positive and dominant negative charge region. Additionally, the ignitions at high altitude might relate to transionospheric pulse pairs (TIPPs) [10] and/or compact intracloud discharges (CIDs) [11].

4. Conclusion

A broadband ITF has been developed in order to image the lightning channel and to identify the positive

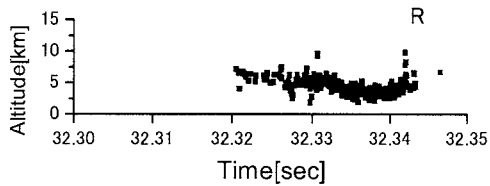


Fig. 5. Altitudes of VHF radiation sources located by the broadband ITF in time domain.

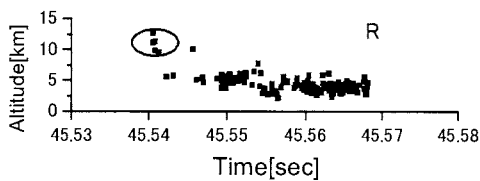


Fig. 6. Similar to Fig.5.

charge distribution inside the thunderclouds.

Through our lightning observations, 3D imaging of lightning channel is realized. Since the VHF radiation sources detected by a broadband ITF are mainly related to negative breakdown, they can be the positive charge location in case of continuing currents and recoil streamers. In VHF radiations correspond to positive CG in winter thunderstorm seasons, two types of positive CG strokes were observed. It is considered that one is mainly contributed by lower pocket positive charges (perhaps it is the single flash thunderstorm), and the other is by wide spread numerous positive charges. Furthermore, the latter is a possible mother discharge for sprite occurrence.

In leader progression of negative CG flashes two categories are identified. One is characterized that negative leaders begin at an altitude of around 8km agl and go down to the ground for several tens milliseconds. The other, in contrast, has some intermittent VHF radiations at 10km agl about 1ms before continuous leader development. The ignitions at high altitude could be energetic events and relate to TIPPs and/or CIDs.

Though to make the conclusion clearly we need more data accumulations, these results contribute to clarify the ignitions of lightning discharges. An advanced broadband ITF with higher spatial and temporal resolution is preparing.

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