Observations of Bipolar Lightning Flashes Using the VHF Broadband Digital Interferometer

Manabu AKITA, Satoru YOSHIDA
Takeshi MORIMOTO, Tomoo USHIO, and Zen KAWASAKI
(Lightning Research Group of Osaka University)

2-1 Yamada-oka, Suita, Osaka, Japan 5650871
Division of Electrical, Electronic and Information Engineering
Graduate School of Engineering, Osaka University
Phone +81 6 6879 7700, Fax +81 6 6879 7774, E-mail: akita@comf5.comm.eng.osaka-u.ac.jp

***Abstract*— Lightning Research Group of Osaka University (LRG-OU) has been developing and improving the VHF broadband digital interferometer (DITF) for thunderstorm observations. It enables us to locate the impulsive VHF radiation sources caused by lightning discharges with extremely high resolutions. As a result of the VHF observations during the '07-'08 winter season in the Japan Sea coastal area, lightning flashes that neutralize both positive and negative charges inside thunderclouds. The bipolar lightning flashes are visualized by the VHF broadband DITF. The subsequent negative breakdown in bipolar flashes initiates from the proximity of the initiation point of the precedent negative breakdown some tens millisecond after the first return stroke. It is presumed that the bipolar lightning flashes have reversal of the polarity of neutralized charges. It might be caused by the unusual electrical structure of winter thunder-clouds.**

Key words: Lightning, VHF observations, bipolar flash, winter thunder-clouds

Ⅰ. INTRODUCTION

Lightning discharges during winter thunderstorm season in the Japan Sea coastal area show a number of remarkable features. The first observation results of winter thunderstorms in Japan indicated the unusual electrical behavior. (Takeuti et al. (1973, 1976) and Takeuti and Nakano (1977)). In these studies, most cloud-to-ground (CG) lightning flashes are positive, whereas negative CGs is majority in summer season. An average of one third CGs during winter thunderstorm season are positive, while the percentage of positive lightning in summer storms in Japan is only 10 percent (Suzuki 1992). A very large percentage of upward lightning discharges are observed even when the strike object is of moderate height (Miyake et al. 1990) and is located on relatively flat terrain. Other noticeable features of winter thunderstorm in Japan include a relatively high frequency of occurrence of bipolar flashes. Bipolar flashes have reversal of the polarity of charge transferred to the ground. From the bipolar lightning current waveforms, Narita et al. suggested that both polarities of currents flow through the same channel to the ground but from different oppositely charged regions in the cloud. Most bipolar flashes have the current waveforms that initially lower negative charge to the ground (Berger, 1978). It is not clear whether a polarity change from positive to negative occurs less often than from negative to positive. The occurrence of very large and slowly varying lightning currents up to tens kilo amperes is also relatively frequent. Charge transfers in excess of 1000 C have been reported (Miyake et al. 1992). Although the feature of winter lightning in Japan is gradually clarified, previously the observations of are predominated by optical observations and electric field measurements. Lightning Research Group of Osaka University (LRG-OU) has been developing the VHF broadband digital interferometer (DITF) that makes us possible to visualize the lightning channels by localizing the VHF radiation sources since 1995. The ultra-wide detection frequency brings very high accuracy to visualize lightning channels. We have operated the VHF broadband DITF in Fukui, the coastal area of the Sea of Japan during winter thunderstorm period and in Darwin, Australia during the monsoon season and so forth (Mardiana et al., 2002 Kawasaki et al., 2002; Kawasaki and Morimoto, 2003). Its time and special resolutions are improved recently. In this paper, we illustrate the developing phase of the bipolar lightning flashes by the VHF broadband DITF during the '07-'08 winter thunderstorm observation campaign in Hokuriku, Japan Sea coastal area. The reason why the polarity changes from positive to negative occurs less often than from negative to positive is also discussed.

Ⅱ. BROADBAND DIGITAL INTERFEROMETER

It is known that thousands of VHF impulses are radiated associating with lightning channel progression mainly from the tip of the breakdown. The basic principle of the DITF technique is the relative phase estimations for various frequency components of a received broadband electromagnetic (EM) wave by a pair of antennas with proper separation (Ushio et l., 1997). A VHF broadband DITF of each observation site provides the directions to the radiation sources in azimuth-elevation format. Fig.1 shows

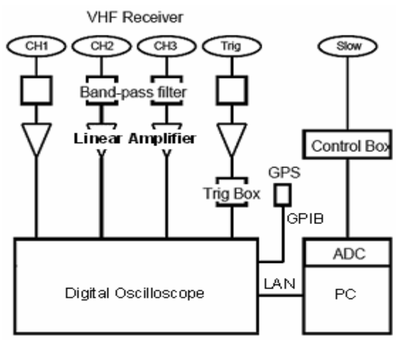

Fig.1 The formation of the one unit of the VHF broadband DITF for 2D mapping.

the block diagram of the VHF broadband DITF. It consists of three antennas equipped at the apexes of a right triangle with two 10m sides. The DITF system used in this paper adopts a commercially available high-speed digital oscilloscope with a sampling rate of 250MHz and an 8-bit resolution. There are about 4μs mechanical time interval between data acquisitions for each pulse. An additional antenna is installed to reduce fault-triggering by narrowband EM signal like broadcast wave. The triggering signal is generated by Trigger Box and transmitted to the oscilloscope only for broadband signals. A slow antenna with a 10s decay time constant is also equipped to measure the E-field change. The output signal of the slow antenna is digitized by an analog-to-digital converter (ADC) with a sampling rate of 1MS/s and 12-bit resolution for 1s.

Ⅲ. RESU LTS

Fig.2 shows the two-dimensional (2D) mapping of a lightning flash (Flash A) by the VHF broadband DITF in time domain, and the E-field change in atmospheric electricity sign convention. Since it is known that the average intensity of VHF radiation with a positive breakdown is at least 15dB weaker than that with a negative breakdown (Onuki et al., 1997; Shao et al., 1999; Kawasaki et al., 2002), VHF observations mainly visualize the developments of negative breakdowns. This event, which was recorded at 0758:36 h on 20 December 2007(JST), is recognized as a CG flash, because an abrupt change associated with return stroke is noticeable in the E-field change at the time of 400μs. The time 0 corresponds to the time when the first VHF pulse is received. The azimuth increases anticlockwise from the north. Fig.3 is the enlarged view of 2Dmapping and E-field change from the time of -2ms to 2ms in Fig. 2. The negative breakdown is visualized in the VHF 2D mapping before the abrupt E-field change corresponding to the return stroke. The E-field change associating with the negative breakdown (A) is also noticeable. The return stroke follows 400μs after the first VHF pulse. Another breakdown (B) initiates from the proximity of the initiation point of the first negative breakdown at the time of 30ms. The negative breakdown remains at the same place intermittently to the time of 90ms. The negative breakdown

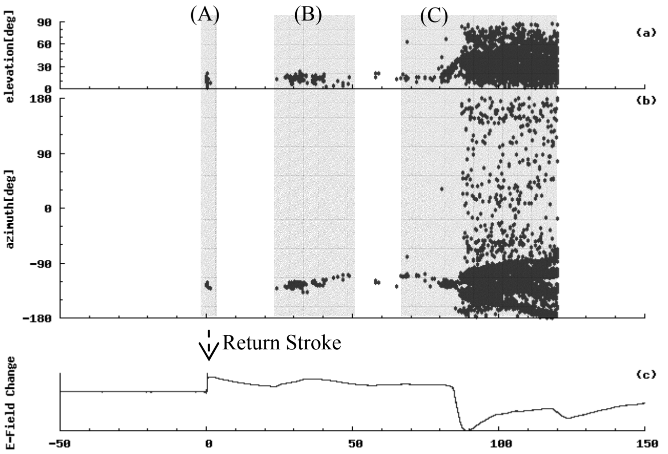

Fig.2. The 2-D mapping and the E-field change for the Flash A recorded at07:58:36 h on 20 December 2007(JST). (a) elevation ,(b) azimuth and (c) E-filed change.

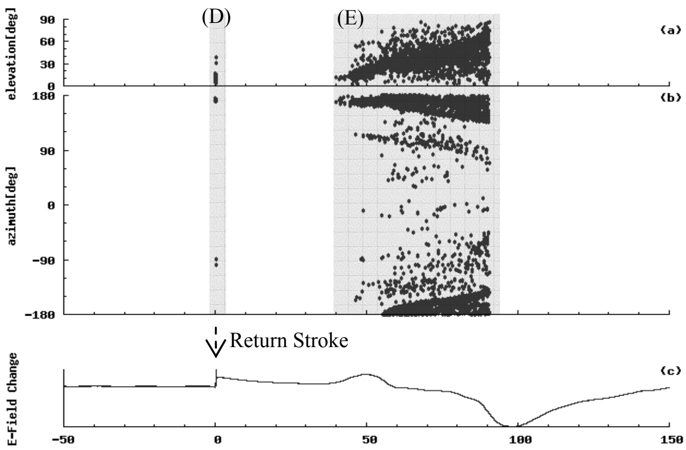

Fig.4. The 2-D mapping and the E-field change for the Flash B 22:33:59 h on 30 December 2007(JST). (a) elevation ,(b) azimuth and (c) E-filed change.

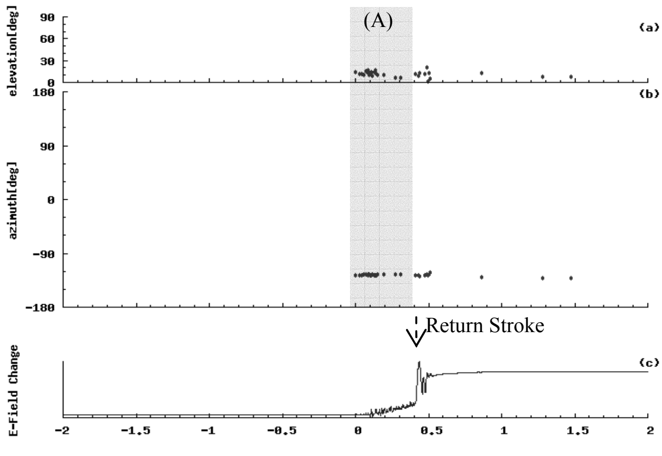

Fig.3. The enlarged view of 2Dmapping and E-field change of the Flash A from the time of -2ms to 2ms

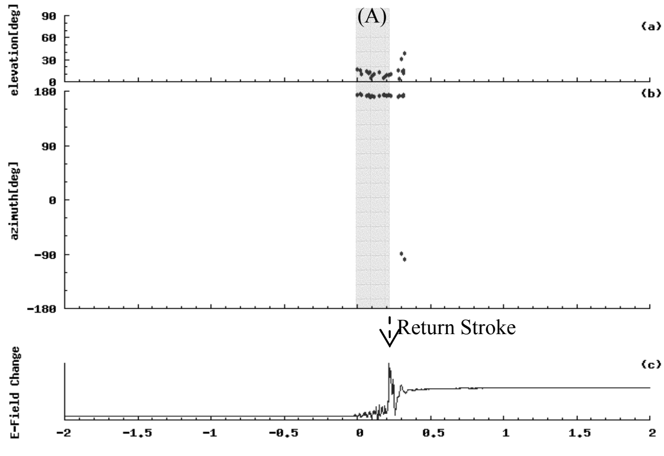

Fig.5. The enlarged view of 2Dmapping and E-field change of the Flash B from the time of -2ms to 2ms

(C) progresses from the elevation of 20° to 50° from the time of 90ms to 100ms.

Fig.4 shows the 2D mapping of a flash (Flash B) drawn in time domain and the E-field change, which is recorded at 2233:59 h on 30 December 2007(JST). It is recognized as a CG flash, because an abrupt change associated with return stroke is noticeable in the E-field change at the time of 200μs. Fig.5 is the enlarged view of the 2D mapping and E-field change from the time of -2ms to 2ms. The abrupt E-field change corresponding to the return stroke of a negative CG is noticeable at the time of 200μs. The E-field change associating with the negative breakdown (D) is also noticeable from the time of 0ms to 200μs. Another breakdown (E) initiates from the proximity of the initiation point of the first negative breakdown at the time of 40ms. The negative breakdown progresses from the elevation of 10° to 80° from the time of 40ms to 90ms as same as the negative breakdown (C) in the case of the Flash A.

Ⅳ. DISCUSSION

Flash A shown in Figs.2 and 3 is considered phenomenologically as follows. The abrupt E-field change corresponding to the return stroke of a negative CG follows the first negative breakdown (A). Taking into account the E-field change before the return stroke, the first negative breakdown (A) before the return stroke is considered to progress for 400μs. Since the abrupt E-field change has the shape of negative CGs, the first negative breakdown is considered to progress downward from the inside of thundercloud to the ground. If the progression velocity of a negative breakdown is assumed as 10^5m/s, which is an average velocity of negative stepped leaders, the negative breakdown progresses as few as 40m. The negative charge region in early or late stages of winter thundercloud is reported to be about 2-4km altitude (Kitagawa and Michimoto, 1994). Although the negative charge region may sometimes be lower than 2km, the 40m altitude is too low. Therefore the negative breakdown (A) can be considered to progresses at the speed of 10^6 m/s, which is average velocity of negative dart leaders. Thus it may suggest that the negative breakdown (A) follows the preceding positive upward leader in the upward negative lightning. Although considering progressing time of the first negative breakdown (A) and the low elevation, the negative charge region is assumed to be very low altitude, lower than 2km. The second negative breakdown (B) that initiates from the proximity of the initiation point of the first negative breakdown (A) at the time of 30ms remains near the initiation point for about 30ms. The third negative breakdow n (C) initiates from near the initiation point of the first and second negative breakdown (B) and progresses from the elevation of 20° to 50° from the time of 90ms to 100ms. In this process, negative breakdown initiates from the way of lightning channel of the first stroke or the end of the channel, and the negative breakdown progresses toward the upper positive charge region. In other words, the Flash A is a bipolar lightning that neutralize both negative and positive charge in a flash. The Flash A is considered to neutralize positive charge after neutralizing negative charge. The lightning channel of the first stroke considered to keep electrically conductive for a few tens of milliseconds. Therefore the lightning channel of the first stroke may be considered to play a role of tall object in the upward lightning. Fig.6 shows the diagram illustrating the bipolar lightning described above.

Flash B, shown in Figs.4 and 5 is also considered phenomenologically as follows. The abrupt E-field change corresponding to the return stroke of a negative CG follows the first negative breakdown. Taking into account the E-field change before the return stroke, the first negative breakdown (D) might progress for 200μs. From the direction of the abrupt E-field change the first negative breakdown is consider to progress downward to the ground as same as the Flash A. The negative breakdown (E) also progresses with the speed of 10^6 m/s for the same reason in the case of the Flash A. The second negative breakdown (E) that initiates from the proximity of the initiation point of the first negative breakdown at the time of 40ms, and progresses from the elevation of 10° to 80°. As is in the case of the Flash A, the negative breakdown (E) seems to initiate from the way of or the end of the channel of the first stroke, and to progress toward the upper positive charge region. Thus the Flash B is also a bipolar lightning. The lightning channel of the first stroke considered to maintain electrically conductive for a few tens of milliseconds. Therefore the lightning channel of the first stroke may be considered to play a tall object in the upward lightning as in the case of the Flash A.

In the cases of the Flashes A and B, the first negative leader progresses downward to the ground at a velocity of 10^6m/s. They create a conductive path between negative charge region inside thundercloud and the ground, and deposit negative charge along the path. It may follow the preceding positive upward leader. When the negative leader reaches a ground object, the return stroke traverses the path and neutralizes the negative charge deposited along the path. The second negative breakdown initiates from the proximity of the initiation point of the first negative breakdown with tens milliseconds interval. The second negative breakdown progresses upward to neutralize the positive charge existing in the upper region of the thunderclouds. It is presumed that the bipolar lightning flashes having reversal of the polarity of neutralized charge are caused by the unusual electrical structure of winter thunder clouds. Since there are negative charge regions at very low altitude, the lightning flashes lower the negative first. The lightning channel to the ground that maintain conductive play a role of a tall object in the upward lightning to neutralize the positive charge. That might be the reason why a polarity change from positive to negative occurs less often than from negative to positive in bipolar lightning flashes.

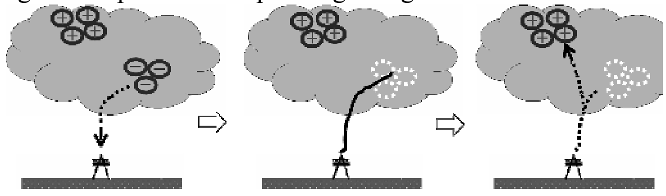

Fig6. Diagram illustrating a bipolar lightning visualized by the VHF broadband DITF.

V. CONCLUSION

Lightning discharges during winter thunderstorm season in the Japan Sea coastal area show a number of remarkable features. Although the feature of winter lightning in Japan is gradually clarified, the previous observations are predominated by optical observations and electric field measurements. From the observations using VHF broadband DITFs during the '07-'08 winter season in Japan Sea coastal area, bipolar lightning flashes are visualized. As a result, it is found as follows. The first negative leader progresses downward to the ground at a velocity of 10^6m/s. When the negative leader reaches ground object, the return stroke traverses the path and neutralizes the negative charge deposited along the path. The subsequent negative breakdown initiates from the proximity of the initiation point of the first negative breakdown with tens milliseconds interval. The subsequent negative breakdown progresses upward to neutralize the positive charge existing in the upper region of the thunderclouds. Since there are negative charge regions at very low altitude, the lightning flashes lower the negative charge firstly. The lightning channel to the ground that maintain conductive play a tall object in the upward lightning to neutralize the positive charge.

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