A VHF Broadband Interferometer for Lightning Observation

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Abstract

A VHF broadband interferometer is a system to locate sources of the radiation events at VHF band by extracting the differences of phases at various frequency components of Fourier spectra between a pair of antennas. Lightning images are derived by sensing the electromagnetic waves radiated from lightning discharge process such as negative stepped leader. Using the system, lightning observations have been carried out firstly in Hokuriku area Japan during the onset of the winter season for rocket triggered lightning experiment, then, in Darwin Australia, and so on. Based on the successful results, the interferometer system is deployed on the GLIMS (Global Lightning and sprIte MeasurementS) mission in the International Space Station to detect and locate the VHF impulses emitted by lightning from space.

Introduction

Lightning discharges produce electromagnetic radiation over a very large frequency spectrum, from near DC field to Gamma-ray. In the VHF band, several lightning location techniques have been proposed and developed by measuring the time or phase difference of arrivals between the antennas (e.g., Rison et al., 1999; Rhodes et al., 1994; Ushio et al. 1997). Among them, broad band interferometric technique (Shao et al., 1996, Ushio et al., 1997) can reconstruct the lightning channel image by recording the sub-microsecond scale impulses emitted mainly by continuous negative breakdown process in lightning, and numerous scientific results have been obtained using this techniques (e.g., Kawasaki et al., 2000; Morimoto et al., 2005; Akita et al., 2010). Based on these scientific success, VHF broad band interferometer to locate the sources of lightning from space was proposed as a part of the GLIMS mission in the International Space Station (ISS) and is scheduled to be launched in January, 2012.

In this paper, principles of the VHF broad band interferometer is firstly described, and examples of the observation results are introduced from the early data sets which was obtained at the rocket triggered lightning experiment in 1997 and from the recently obtained data in Darwin Australia. Then, scientific objectives, system description, and current status of the GLIMS mission on ISS are presented.

Principle of the VHF broad band interferometer

The basic idea of the broad band interferometry is to estimate the phase difference at various frequency components of Fourier spectra between a pair of broad band antennas (Shao et al., 1996; Ushio et al., 1997; Mardiana et al., 2000) : (1) a discrete Fourier transform (DFT) is applied to extract phase difference of incident electromagnetic pulses at two antennas: (2) the cosines of incident angles respective to the antennas baseline are calculated: (3) the azimuth and the elevation angles of the radiation sources are derived as illustrated in Fig. 1. Since one observation site can provide only the two dimensional information which are azimuth and elevation angles of the source of event, at least two sites are needed to determine the location of the source in three dimensions.

The recording system consists chiefly of 4 broad band VHF antennas, broad band AMP, A/D converter, GPS receiver, and PC. The electromagnetic impulses from lightning channels are digitized

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at the rate of 200 MHz with 10 bit resolution. The recording time per pulse is 1.3 microsecond and total 2048 pulses can be stored for one flash.

Examples of the observation results

First observation was conducted at the rocket triggered lightning experiment in Japan about 15 years ago. Fig. 2 shows a photograph of the triggered lightning taken 50 meters away from the rocket launching site (Left panel) and the re-constructed VHF image of the events using the broad band radio interferometric technique from 3.6 km away from the rocket launching site (Right panel). In this example, the located sources are distributed around the rocket launching site, and the sources propagate straight upward from just above ground at the site which can be confirmed seeing the photograph. Since the distance from the observation site to the rocket launcher is known, a two dimensional speed of the leader progression can be estimated at $6*10^5$ m/s which is consistent with the typical speed of the negative stepped leader estimated from optical measurement.

. Fig. 3 shows a typical example of three dimensional mapping of cloud flash observed in Darwin Australia in 2007. In this example the flash begins at about 5-6 km in height and propagate upward initially at the speed of $2.1*10^4$ m/s. Then the new breakdown occurs horizontally for several km at about $7.7*10^4$ m/s. After that, interestingly the subsequent breakdown progresses through the same channel two orders of speed more $4.6*10^6$ m/s (Akita et al. 2010).

The GLIMS mission

The GLIMS is a mission to observe lightning and TLEs at the Exposure Facility (EF) of the Japanese Experiment Module (JEM) in the International Space Station. The objectives of GLIMS are to clarify the occurrence condition of TLEs, global occurrence rates and distributions of TLEs, occurrence mechanism of terrestrial gamma-ray flashes (TGFs), their relation to lightning discharges, and to locate the sources of VHF radiation emitted by lightning. The primary lightning and TLEs instruments on GLIMS are the Lightning and Sprite Imager (LSI), Photometers (PH), a VLF Receiver (VLFR), and a VHF Interferometer (VITF).

The VHF interferometer will be the first lightning location system at VHF band in space, and plays an important role in the GLIMS mission to pursue the scientific objectives. The GLIMS over view and the VITF sensor is illustrated in Fig. 4. As is well known, lightning discharge emits broad band electromagnetic radiation ranging from DC to gamma ray. Among them, the VHF band signal is intense and is believed to be radiated by the negative breakdown process such as negative stepped leader. Additionally, the strong VHF radiation event so called NBP events will be detected in the GLIMS mission. By installing the two antennas at the bottom of the platform in ISS, the direction of the electromagnetic wave at VHF band can be determined using the interferometric technique for the stepped leader and NBP events. Its key goals can be summarized as 1) providing location of VHF sources; 2) identifying the process of lightning; and 3) obtaining a new insight of TLEs and gamma-ray generation by combined use of LSI, PH, and VLFR sensor data.

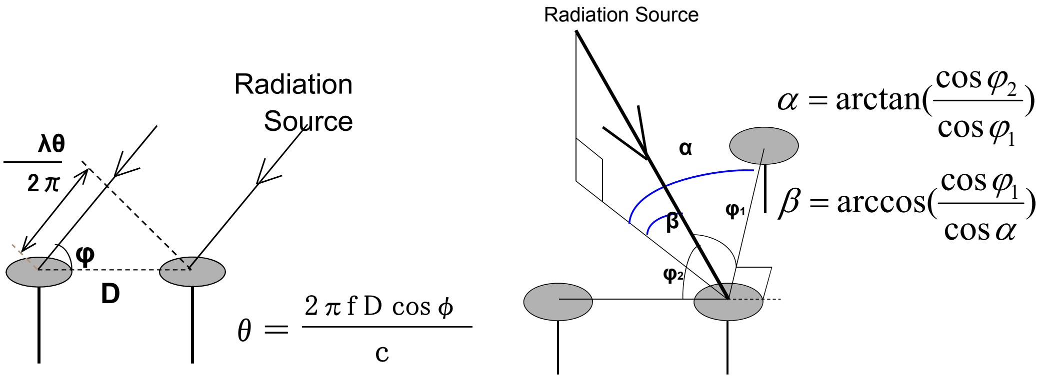

Fig. 1 Principle of the broad band interferometry

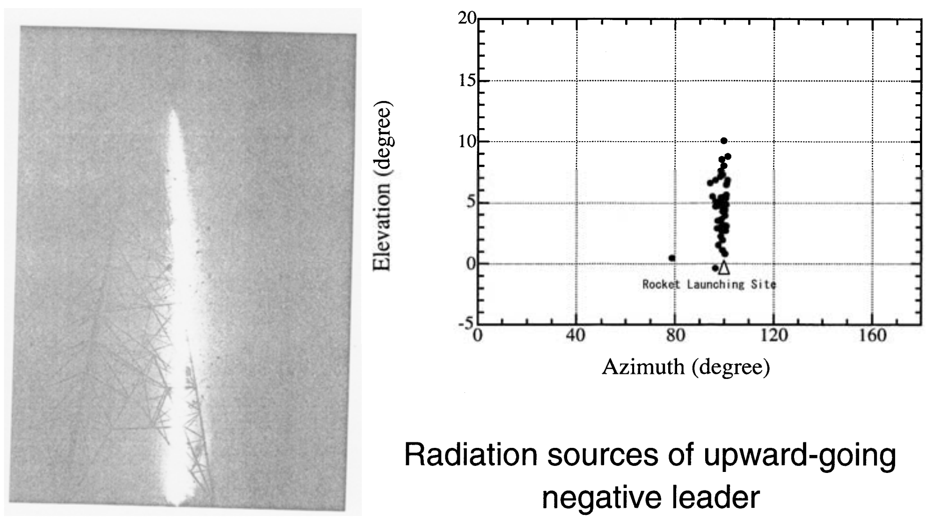

Fig. 2. Left panel shows a photograph of the rocket triggered lightning, and right panel shows the re-constructed VHF image of the event.

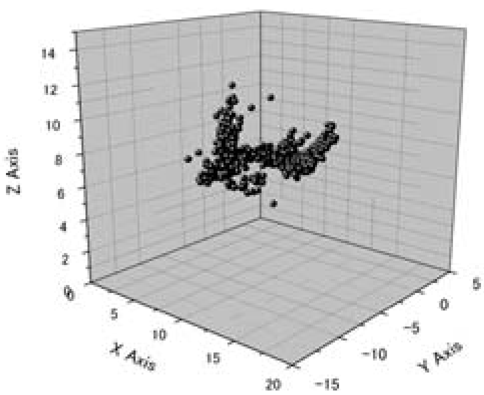

Fig. 3. One typical example of the three dimensional mapping of the cloud flash located by the broad band interferometer in Darwin Australia in 2008. The unit is kilometer.

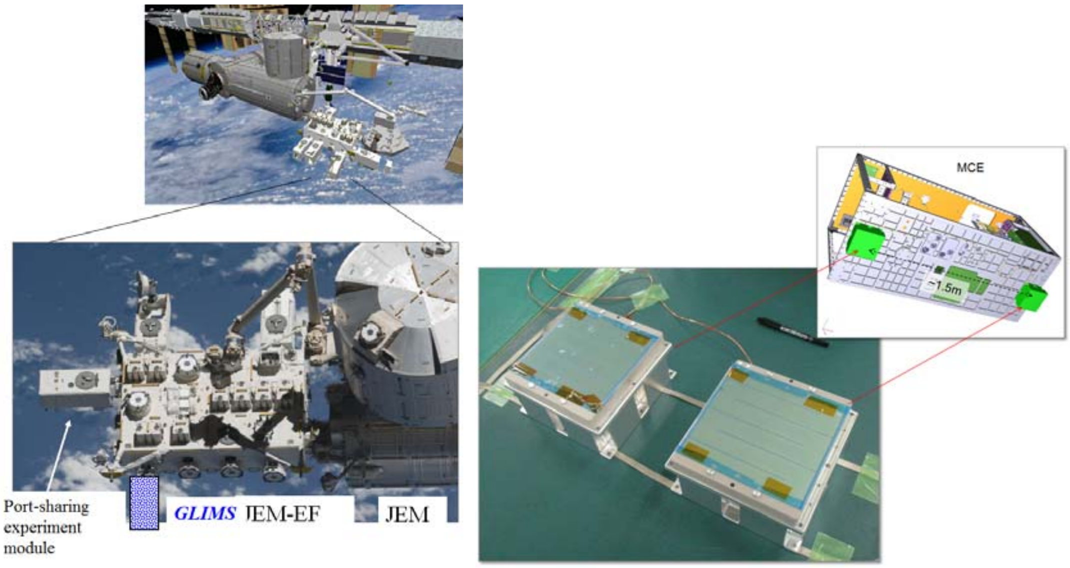

Fig. 4 Left panels shows the JEM-EF on the ISS and the location of the GLIMS. Right panels show a photograph of the antennas of the VHF broad band interferometer.

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