VHF radio observations of lightning discharges on JEM-GLIMS

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***Abstract*— Since 2012, the global lightning and sprite measurements (GLIMS) mission has been conducted on the exposed facility of Japanese experiment module (JEM-EF) of the international space station (ISS). In this mission, the VHF broadband digital interferometer (VITF) attached on JEM-EF is designed to estimate the direction of arrival of electromagnetic waves. The VITF has the bandwidth from 70 MHz to 100 MHz. The electromagnetic radiations from lightning discharges received by two antennas are digitized by the 2-channel AD converter. We introduce the outline of the mission and the VITF. The initial observational results with the VITF of the GLIMS mission are presented. The comparison of the results of arrival direction estimation of the VITF with optical observations using two methods which are an interferometry technic and the group delay characteristic of EM waves. The results agree with the position of the lightning emission captured by the LSI.**

Keywords—ligthning discharges; radio obesrvation; radio propagation;

I. INTRODUCTION

The final goal of our research is to locate the sources of impulsive VHF radiation from lightning discharges and monitor lightning activity constantly from space. In 2009, the Maido-1 satellite was launched to observe lightning discharges using VHF radio waves. We had conducted 158 sets of the observations, and more than 10,000 signals had been recorded by the Maido-1 satellite from February 12 to October 7 in 2009. We had developed the VHF sensor carried by the Maido-1 satellite and observed the lightning discharges [1]. The VHF sensor was only 1-channel sensor system. It is difficult to estimate an arrival direction of electromagnetic (EM) waves. As a next step, we have conducted the radio observation from the international space station since 2012. The outline of Global lightning and sprite measurements (GLIMS) mission is described. In order to study the generation mechanism of lightning associated transient luminous events (TLEs) and the relationship between lightning and TLEs, we carry out the lightning and TLE observation at Exposed Facility of Japanese Experiment Module (JEM-EF) of International Space Station (ISS). The observation instruments of the JEM-GLIMS mission consist of the two type optical sensors. One is two CMOS cameras at two different wavelengths (lightning and sprite imager: LSI). The other is six photometers at six different wavelengths (PHs). And also the instrument has two radio sensors, which are very high frequency interferometer (VITF) and very low frequency (VLF) receiver [2]-[4]. The objective of VITF is to capture the same lightning as TLEs event observed by the optical sensors, and then their spatial and temporal relationships are discussed.

In this paper, we estimate the arrival direction of the lightning radiation source using the VITF which consists of two VHF sensors. The comparison of an initial result of VITF with the data of the LSI is described.

II. VHF RADIO OBSERVATION PAYLOAD

VITF is developed to observe lighting discharges for the JEM-GLIMS mission as one of the observation systems including two optical sensors and VLF sensor such as Fig. 1. The objective of VITF is to estimate the arrival direction of EM waves radiated from lightning discharges [5]. Figure 2 shows the configuration diagram of VITF. VITF consists of two sets of patch-type antennas, band-pass filters and amplifiers, and 2-channel-AD-converter. The antennas are the frequency bandwidth from 70 to 100 MHz. The band-pass filters are the frequency bandwidth from 30 to 100MHz. The gain of the amplifiers is 45 dB. Table 1 shows the specification of VITF. In this paper, the 2 channel systems are termed here 'the channel A and B', respectively. The EM waveforms could be recorded by the level trigger system on the channel A. Once that level exceeded the threshold level on the channel A, a 512-sample register was stored in each onboard memory of the channel A and B at the same time, consisting of 128 samples preceding and 384 samples following the trigger. The maximum number of EM waveforms (the number of the trigger) for one event was 130 due to the size of the onboard memory of the AD converter. The two antennas are installed at the both ends of the bottom of MCE with the separation of 1.62 m.

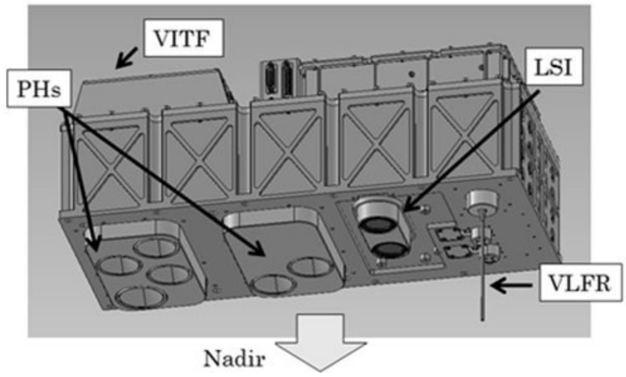

Fig. 1 GLIMS instruments. The instrument consist of the six photometers (PHs), two CMOS cameras (LSI), very high frequency interferometer (VITF) and very low frequency (VLF)

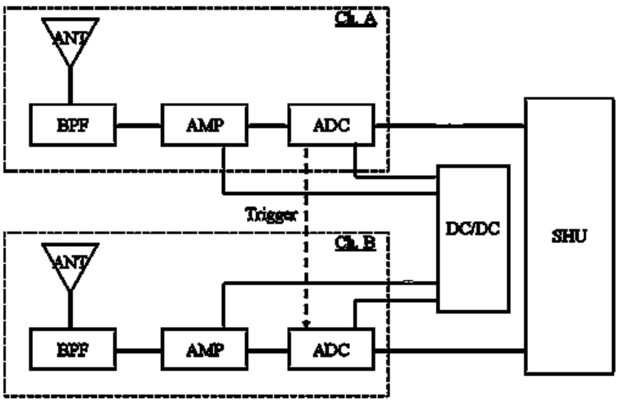

Fig. 2. Configuration of VITF

TABLE I. SPECIFICATION OF VITF

Antenna type	Patch type
Bandwidth	70-100MHz
Directionality	Omni directionality to the zenith
Input level	-85dBm～-35dBm
Input channel	2 channels
Amplifier Gain	45dB
Sampling speed	200MHz
AD resolution	8bit

III. METHODOLOGY OF DIRECTION OF ARRIVAL ESTIMATION

A. Interferometry technic

It is well known that the tips of negatively charged lightning leaders produce strong radiation in the VHF band [6]. Moreover FORTE satellite, which was launched in 1997, observed the EM waves radiated from some lighting discharge processes such as return strokes and narrow bipolar events [7], [8]. The VITF estimates the arrival direction of the EM waves using the interferometry technique. The basic idea of digital interferometry is to calculate phase differences for various frequency components of a broad band EM wave detected by a pair of antennas. The VITF is a simple interferometry. In order to calculate the direction of arrival (DOA) estimation, the following steps are used.

1. Calculate the phase component for both EM waves received by channel A and B using FFT (128 points).
2. Calculate the phase difference of two antennas.
3. Decide the incidence angle (θ) using the phase difference.
4. Assume the altitude of the radiation source is 10 km.
5. Decide the DOA estimation the hyperbolic curve of DOA estimation on the altitude at 10 km.

Figure 3 shows the illustration of the incidence wave for VITF. The result of DOA estimation depends on the position, the altitude and the pose of the ISS. To compare the VITF with LSI, the information of the position is ignored, because the relative position of both instruments is fixed.

B. Using group delay characteristics

The Earth's ionosphere introduces group delay, Faraday rotation, and refraction effects to EM waves propagating through this medium. The propagation time delay differential at each frequency is used to estimate the arrival directions of EM waves.

In order to obtain the propagation delay of the recorded EM waves, the spectrogram of the EM waveform is calculated by

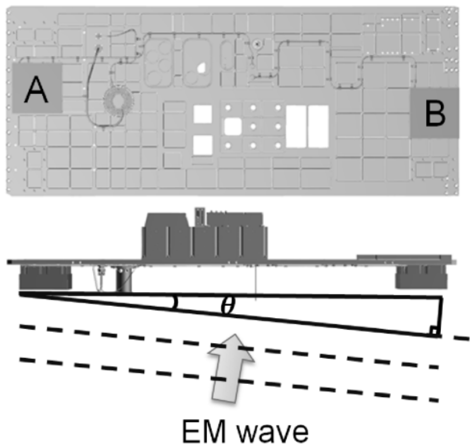

Fig. 3 Illustration of the incidence EM wave for VITF. The upper figure (a) shows the bottom of the MCE. The lower figure (b) shows the side view of the GLIMS instruments and two VHF antennas.

the Short Term Fourier Transform (STFT) with a Gaussian window of a length of 0.64 μs. The VHF propagation time delay due to the total electron content along a path is given by the following Eq. (1) [9].

$$\Delta t = \frac{1.34\times10^{-7}}{f^2} \times sTEC(\theta_{nadir}) \quad (1)$$

Where, Δt is the propagation time delay in second, f is the radio frequency in Hz, and sTEC (θ_{nadir}) is the slant TEC on the propagation path for the incidence angle (θ_{nadir}). The incidence angle is defined as the angle between the arrival directions of EM waves and the nadir direction of the satellite. sTEC(θ_{nadir}) is the following Eq. (2).

$$sTEC(\theta_{nadir}) = \int_{l(\theta_{nadir})} n\, ds \quad (2)$$

Where, n is the electron density in the ionosphere and $l(\theta_{nadir})$ is the propagation path length for the incidence angle. The electron density profiles in the ionosphere are obtained from the International Reference Ionosphere (IRI) 2007 [10]. For given location, time, and date, the IRI provides monthly averages of the electron density, electron temperature, ion temperature, and ion composition in the altitude ranging from 50 km to 2000 km.

The simple ionosphere model is used to estimate the incidence angle of EM waves. In this model, the radius of the Earth is 6370 km and the lowest altitude of the ionosphere is a height of 80 km. In a very general sense, for the VHF propagation characteristics in the nighttime ionosphere, we can ignore the effect of the wave refraction under moderate ionospheric conditions. The IRI provides the data set of the electron density every 10 km in the ionosphere and the vertical TEC above the subsatellite point. We assume that the altitude distribution of the electron density along the propagation path is the same altitude distribution along the nadir direction and determine the slant TEC in each incidence angle. The theoretical curve of the propagation time delay is calculated by Eq. (1). The following procedures are conducted to estimate the incidence angle for one EM waveform recorded by the VHF sensor.

1. We find the local maximum values of the spectrogram at each frequency.
2. The theoretical curve is calculated by Eq. (1) in an incidence angle.
3. Compared between the local maximum values and the theoretical curve, a fitted curve is calculated by the least squares method.
4. Repeating the steps 2 and 3 in every incidence angle (θ_{nadir}), the most likelihood incidence angle (the estimated incidence angle) is calculated.

IV. INITIAL OBSERVATION RESULTS AND DISCUSSION

The GLIMS mission has started for steady observation on lightning and LTEs in November 2012. The lightning event is triggered by PHs at 6:28:36.34502, February 14, 2013 (UTC). The event was not TLEs event according to the results of six photometers. Figure 4 shows an example of the waveform data recorded by VITF. There are some pulses in 2.5 μs time duration. Figure 5 shows the comparison of the direction of arrival estimation result of the VITF with LSI data. The LSI data are recorded at the triggered time. The field of view of the LSI is 28.7 × 28.7 degrees from nadir, that means the special resolution is 390 m per a pixel. We assume that the altitudes of the ISS and the lightning emission are 410 km and 10 km, respectively. The LSI captured the lightning emission in the left below of the figure. The waveform data of channel A and B in Fig. 3 are used to estimate the arrival direction of EM waves. In this case, the estimated incidence angle (θ) of EM wave is 100 degrees. The red line means the result of arrival direction of EM waves by VITF. We found that the direction-of-arrival estimation of VITF agrees with the observation results by LSI. Figure 6 shows the typical spectrograms and the arrival direction estimation. The spectrogram is calculated by short-time Fourier transform (STFT). The window size of STFT is

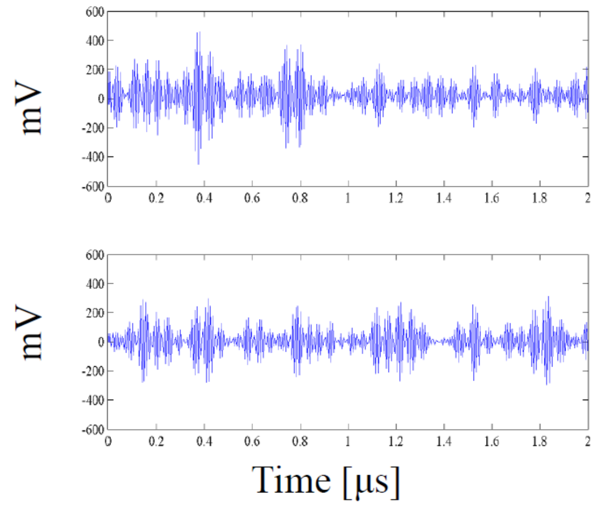

Fig. 4 Initial observation results of the waveform recorded by the VITF

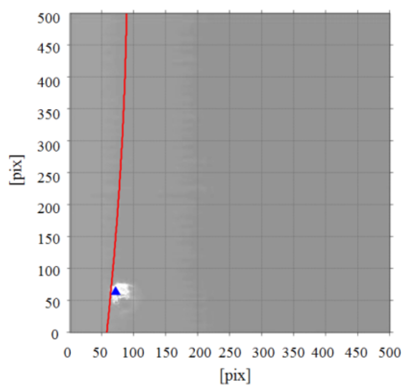

Fig. 5 Comparison the direction of arrival estimation result of VITF with LSI data. The blue triangle sign is the position of the maximum value of the optical emission. The red line means the result of arrival direction of EM waves by VITF. The estimated incidence angle (θ) is 100 [deg].

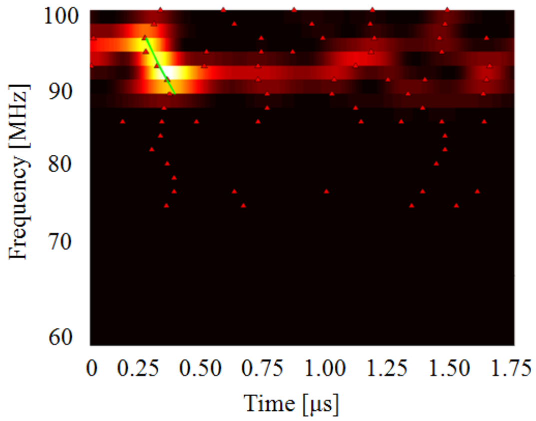

Fig. 6. The typical spectrograms and the arrival direction estimation. The green line indicates the most likelihood curve. The red triangle signs are the local maximum values at each frequency.

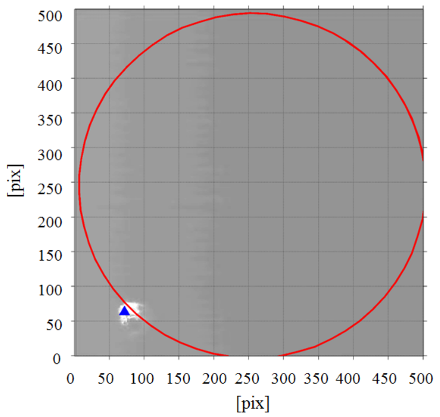

Fig. 7. The result of the arrival direction of EM waves estimated by the group delay characteristic (red line). The blue triangle sign is the position of the maximum value of the optical emission.

0.64μs. The intensity of EM wave is larger in the frequency band more than 90 MHz. We thought that it depends on the antenna characteristics of VITF. The green line indicates the most likelihood curve. The red triangle signs are the local maximum values at each frequency. In this case, the estimated nadir angle (θ_{nadir}) is 14 degrees. Figure 7 shows the result of the arrival direction of EM waves estimated by the group delay characteristic. From the figure, the arrival direction of EM waves estimated by the group delay characteristic agrees the lighting position captured by the LSI.

V. SUMMARY

In this paper, the initial observation results of the VITF of the JEM-GLIMS mission were described. As a case study, the lightning event captured by the two optical sensors (PHs and LSI) was analyzed. In this event, the wave form data of VITF were used to estimate the arrival direction of EM waves. There are two methodologies which are the interferometry technic and the group delay characteristic of EM wave. We compared the results of direction of arrival estimation with LSI data. The results agreed with the position of the lightning emission captured by the LSI.

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