Propagation characteristics of VHF waves recorded on the International Space Station

Hiroshi Kikuchi [1,*], Takeshi Morimoto [2], Tomoo Ushio [1], Mitsuteru Sato [3], Atsushi Yamazaki and Makoto Suzuki [4]

1. Graduate School of Engineering, Osaka University, 2-1 Yamada-Oka, Suita-shi, Osaka, Japan

2. Faculty of Science and Engineering, Department of Electric and Electronic Engineering, Kinki University, 3-4-1 Kowakae, Higashiosaka City, Osaka, Japan

3. Graduate School of Science, Hokkaido University, Kita 8, Nishi 5, Kita-ku, Sapporo, Hokkaido, Japan

4. Japan Aerospace Exploration Agency, Jindaiji Higashi-machi, Chofu-shi, Tokyo, Japan

ABSTRACT: We has been conducted the lightning observation with four type sensors at the International Space Station (ISS). One of the sensors is very high frequency interferometer: VITF. The objective of the VITF is to locate the radiation source of received signals with two very high frequency interferometer （VHF） sensors attached on the ISS. Lightning and sprite imager: LSI is also one of the optical sensor for the observation of lightning and sprite. The LSI consists of two CMOS sensors. The image captured with the LSI gives us an information of lighting position. While the VITF has the two sensors. Although the VITF is able to estimate the direction of arrival estimation using the radio interferometric technique, we cannot locate the radiation source position. The location method are used as two direction of arrival (DOA) estimation techniques, which are the interferometric technique and based on the measurement of the group delay of the received signals. The combination of the two techniques gives us the two possible position of the radiation source when an altitude of a radiation source is assumed. The initial comparison with the optical lightning position captured with LSI are reported.

INTRODUCTION

We has conducted Global lightning and sprite measurements (GLIMS) mission from November 2012. The purpose of the mission is to discuss the generation mechanism of lightning associated transient luminous events (TLEs) with the observation instruments attached at Exposed Facility of Japanese Experiment Module (JEM-EF) of International Space Station (ISS) [Ushio et al., 2011]. The sensors consist of the two type of optical sensor, which is lightning and sprite imager: LSI and photometers: PHs, and radio observation sensor, which is very high frequency interferometer: VITF and very low frequency: VLF receiver [Sato et al., 2011a, 2011b; Morimoto et al., 2011]. All sensors work synchronously for nadir

* Contact information: Hiroshi Kikuchi, Institution, Graduate School of Engineering, Osaka University, 2-1 Yamada-Oka, Suita-shi, Osaka, Japan, Email: kikuchi.hiroshi@comf5.comm.eng.osaka-u.ac.jp

observations on lighting or sprite.

The purpose of the VITF with two VHF sensors is to locate the radiation source position using the interferometry technique. The two VHF sensors only gives us a one direction, such as nadir angle. In this paper, the new location method, which is a combination of the interferometry technique and measuring the ionospheric group delay, is proposed. The method are tested using the VHF signals recorded on the International Space Station. To discuss an accuracy and limitation of this method, we compared with the approximately-synchronized optical lightning events recorded with the LSI.

OBSERVATION EQUIPMENTS

Very high frequency interferometer (VITF)

The VITF consists of the sets of patch-type antennas, band-pass filters (BPF) and amplifiers (AMP), and 2-channel-AD-converter (ADC): [Morimoto et al., 2011]. The two antennas are the frequency bandwidth from 70 to 100 MHz and installed at the both ends of the bottom of the Multi-mission Consolidated Equipment (MCE) of the ISS with the separation of 1.62 m. The two channel systems of the VITF are termed here 'the channel A and B', respectively. The VITF has 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, synchronously. The maximum number of EM waveforms (the number of the trigger) for one event was 130 due to the size of the onboard ring buffer memory.

Lightning and sprite imager (LSI)

The LSI has two Complementary Metal Oxide Semiconductor (CMOS) cameras to capture lightning and sprite images, which are termed 'the LSI-1 and the LSI-2', respectively [Sato et al., 2011a]. The LSI-1 has the wideband filtered camera, which has the centred wavelength of 797.5 nm and the full width at half maximum of 65 nm, for lightning observation. The LSI-2 aims to capture a TLE, such as a sprite. In this paper, the optical lightning data of the LSI-1 are used. The LSI-1 also has the field-of-view of 28.7 [deg] × 28.7 [deg], the total pixel number of 512 × 512. If the altitude of the ISS is 400 km, the special resolution becomes 400m per a pixel at the ground surface. The frame rate is 30 frame per second (fps).

Trigger system on GLIMS instrument

The PHs work as a triggering instrument of all GLIMS instrument. If the sampled data by any of the six photometers exceeds the threshold, a trigger flag will be announced to all other instruments. The science instruments handling unit (SHU) will execute such a process of the real-time data sampling and the threshold comparison of all six channel photometers simultaneously [Kikuchi. et al., 2011]. The SHU will judge as a transient optical flash was occurred [Sato et al., 2011b]. On the other hand, the SHU will execute to stop to record the data of the VITF after 100 ms from the triggering time of PHs. The stored data will be saved in the onboard memory.

METHODOLOGY OF DIRECTION OF ARRIVAL ESTIMATION

Interferometric technique

The VITF estimates the arrival direction of the EM waves using the interferometry technique. The

VITF is a simple interferometry. To calculate the direction of arrival (DOA) estimation, we calculate the phase difference of a pair of antenna. The phase difference of each frequency component depends on the incident angle of EM waves, which are calculated by the Fast Fourier Transform. The window width of 128 points is used, which means 0.64 μs. The incident angle for based line of a pair of antenna is defined as the θ_{itf}. If an altitude of the radiation source is assumed, the radiation source position is estimated on a line, which is represented by the hyperbolic curve, at an altitude.

Group delay characteristics

When EM waves propagate in the ionosphere, EM waves are affected by the ionospheric group delay. To calculate the group delay of the EM waves recorded by the VITF, the spectrogram is calculated by the short-term Fourier transform (STFT) with a 128-point Hanning windows and a moving step of 1 sample (5 ns). This gives a spectral resolution of 1.56 MHz. The VHF propagation time delay due to the total electron content along a path is theoretically given by the following Eq. (1) [Levis et al., 2010].

$$\Delta t = 1.345 \times 10^{-7}/f^2 \times sTEC(\theta_{nadir}) \quad (1)$$

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 nadir direction of the ISS. In this paper, the value of the electron density in the ionosphere refer to the International Reference Ionosphere (IRI) 2012 [Bilitza et al., 1993; Bilitza and Reinisch, 2008]. We assume that the altitude distribution of the electron density along the propagation path has the same distribution when the slant TEC are calculated in each incidence angle (θ_{nadir}). The following procedures are conducted to estimate the incidence angle (θ_{nadir}) for an EM waveform recorded by the VITF. (1) We calculate the theoretical group delay curve of a nadir angle using the Eq. (1). (2) The spectrogram of a received EM wave are calculated by STFT. (3) The local maximum values at each frequency is found in the spectrogram. (4) We carry out the curve fitting between the theoretical curve and the local maximum values using the least square method. (5) The step from (1) to (5) is repeated in every nadir angle, and the most likelihood incidence angle (the estimated nadir angle) is defined. In a previous study, we tested the DOA method using this method for the VHF observation data recorded by a VHF sensor onboard the small satellite 'Maido-1' [Kikuchi et al., 2013].

Combination of the two DOA method

The new location technique using the two DOA methods is proposed. The calculated θ_{itf} and θ_{nadir} draw the hyperbolic curve and the circular curve at the altitude of 10 km. We can locate the radiation source point as the two intersection points between the two lines. One of the two intersection points is associated with the radiation source, but the other point is not.

CASE STUDY

In May 28, 2013 at 03:11:15.38639 UTC, the PHs triggered and VITF stored the VHF observational data. Figure 1 shows the waveform data of A and B system recorded by the VITF. The proposed DOA method is used for this case. In this figure, we use the waveform data between two dashed lines for the DOA estimation using the interferometric technique. The blue triangle indicates the position of the maximum

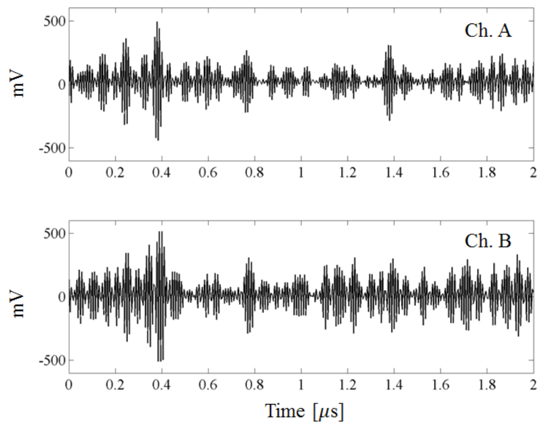

Figure 1 EM waveform recorded by the VITF in May 28, 2013 at 03:11:15.38639 UTC

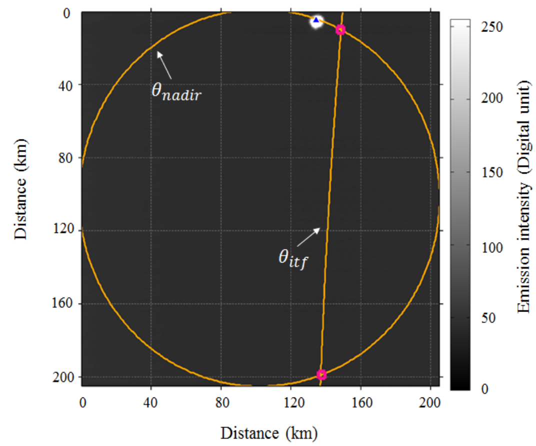

Figure 2 Estimated RF source position with proposed method

emission captured with the LSI-1. The yellow lines are the two results of the two types of DOA estimation method. The red square signs indicate the two intersection points between the two yellow lines. The result of the DOA estimation (θ_{itf}) is 84 degrees. The DOA estimation using the group delay characteristics (θ_{nadir}) is 15 degrees. The lower square sign has little relevance to the lightning emission of the LSI-1, while the upper square sign agrees with the position of the lightning emission. The estimated radiation position were temporally and spatially, close agreement with the optical lightning position captured with LSI-1. The spatial difference was less than dozen kilometers.

CONCLUSION

The new method for radio source location using the two DOA estimation technique were tested using the lightning data observed at the ISS. One of the DOA technique is the interferometric technique using the phase difference of the received VHF signals. Another is based on the measurement of the group delay of the signals. The combination of the two techniques gives us the two possible position of the radiation source when an altitude of a radiation source is assumed. The comparison between the estimated radiation position and the optical lightning position captured with LSI-1 are reported. The estimated radiation position were temporally and spatially, close agreement with the optical lightning position captured with LSI-1. The spatial difference was less than dozen kilometers. To discuss the estimation accuracy, we will apply the many more cases of optical and radio observation on lighting in JEM-GLIMS mission.

REFERENCES

Bilitza, D., K. Rawer, L. Bossy, and T. Gulyaeva, “International Reference Ionosphere -Past, Present, Future”, Advances in Space Research, Volume 13 (3), Pages 3-23, 1993.

Bilitza, D., and B. Reinisch, International Reference Ionosphere 2007: Improvements and new parameters, J. Adv. Space Res., 42, (4), 599-609., 2008

Kikuchi, H., S. Yoshida, T. Morimoto, T. Ushio, and Z-I. Kawasaki, VHF Radio Wave Observations by

Maido-1 Satellite and Evaluation of Its Relationship with Lightning Discharges, IEICE TRANSACTIONS on Communications Vol.E96-B No.3 pp.880-886, 2013

Kikuchi, M., M. Sato, A. Yamazaki, M. Suzuki, and T. Ushio, Development of Science Data Handling Unit (SHU) for Global Lightning and Sprite Measurements (GLIMS) onboard Japanese Experiment Module (JEM) of ISS, IEEJ, Vol. 131, No. 12, pp. 989-993, 2011.

Levis, C.A., J.T. Johnson, and F.L. Teixeira, Radio wave propagation: physics and applications, Imprint: Hoboken, NJ : Wiley, 2010

Morimoto, T., H. Kikuchi, M. Sato, M. Suzuki, A. Yamazaki, and T. Ushio, VHF Lightning Observations on JEM-GLIMS Mission -Gradual Approach to Realize Space-borne VHF Broadband Digital Interferometer-, IEEJ, Vol. 131, No. 12, pp. 977-982, 2011.

Sato, M., Y. Takahashi, M. Kikuchi, M. Suzuki, A. Yamazaki, and T. Ushio, Lightning and Sprite Imager (LSI) onboard JEM-GLIMS, IEEJ, Vol. 131, No. 12, pp. 994-999, 2011a.

Sato, M., Y. Takahashi, M. Suzuki A. Yamazaki, and T. Ushio, Six-Channel Spectrophotometer (PH) Onboard JEM-GLIMS, IEEJ, Vol. 131, No. 12, pp. 1000-1005, 2011b.

Ushio, T., M. Sato, T. Morimoto, M. Suzuki, H. Kikuchi, A. Yamazaki, Y. Takahashi, Y. Hobara, U. Inan, I. Linscott, Y. Sakamoto, R. Ishida, M. Kikuchi, K. Yoshida, and Z-I. Kawasaki, The Global Lightning and Sprite Measurement (GLIMS) Mission of the International Space Station - Concept and Overview -, IEEJ, Vol. 131, No. 12, pp. 971-976, 2011.