DEVELOPMENT OF AN ARRAY ANTENNA SYSTEM AND A MULTI–FREQUENCY INTERFEROMETER NETWORK FOR THE JOVIAN DECAMETRIC RADIATION

M. Oya*, T. Nakajo*, S. Konno*, T. Ono*, M. Iizima*, and H. Oya†

Abstract

To understand the energy source and the radiation process of Jovian Decameter Radiations (DAMs) being related to the Jovian auroras, ionosphere–magnetosphere couplings and interactions with satellite Io, it is important to obtain the information on the source location and the polarization of DAMs. The array antenna system consists of 9 antennas covering a frequency range from 20 MHz to 30 MHz. The new long baseline interferometer system employs the multi–frequency interferometer method by which ionosphere scintillation effect can be largely reduced.

1 Introduction

Jovian decametric radiations (DAMs) are understood to be generated in the Jovian polar ionosphere being associated with the electromagnetic processes in the Jovian magnetosphere. In spite of the long history of DAM studies, generation mechanisms of DAMs are still unknown. The polarization and source location are, then, fundamental information in the studies on the generation processes of DAM.

To identify the source location of DAM directly, in early phase of DAM studies in 1960's and 1970's, several experiments by using the long baseline interferometer observations had been carried out by Sydney group, Florida group and Colorado group [Carr et al., 1965; Dulk, 1970; Lynch et al., 1976; Phillips et al., 1987]. Carr et al. [1965] have carried out the interferometric observation using 55.3 km baseline at Florida at the frequency of 18 MHz. Dulk [1970] also carried out the very long baseline interferometer (VLBI) observation using baselines more than 1000 km spacing; in their works, the interferometer analyses of DAM signals have been made by using the tape recorder data. They had obtained a high correlation by using the interferometer with more than 1000 km baseline and showed that

*Geophysical Institute, Tohoku University, Sendai 980–8578, Japan
†Fukui University of Technology, Fukui, Japan

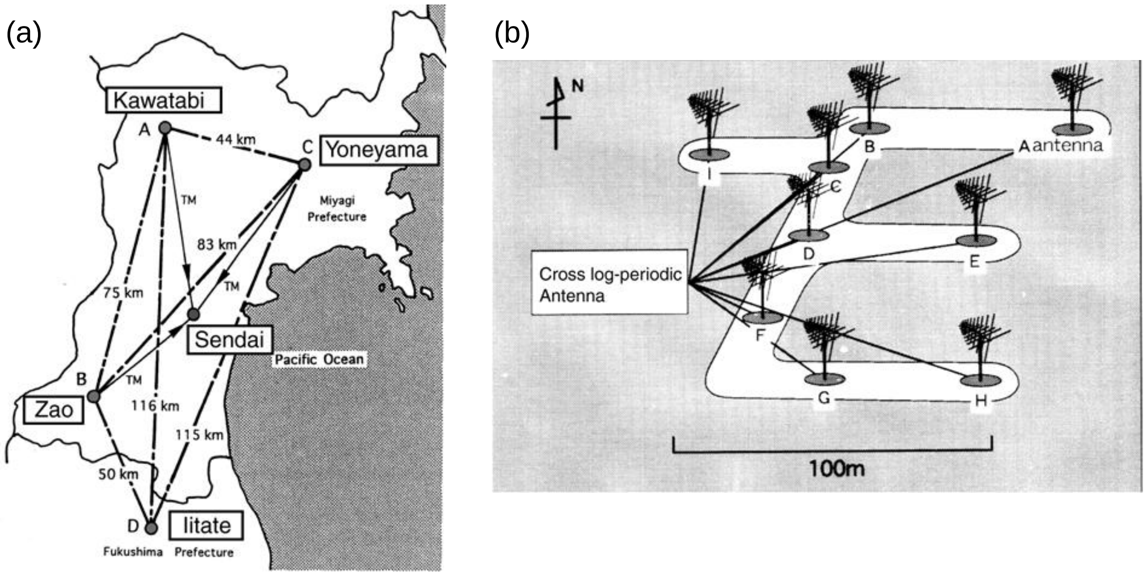

Figure 1: The long base line interferometer system (a) and the array antenna system (b) of Tohoku University. The array antenna system is located at Iitate station, which is also one of the four stations of the interferometer system.

source size was less than 0.1 arc sec. However, no fixed source position can be identified because of the fast fringe change due to the ionospheric scintillation effects. Lynch et al. [1976] also observed Jovian S–burst using 6980 km baseline interferometer whose antenna pair was extended between the north and the south American continents, and concluded that the source size of the S–burst is as small as 0.05 arcsec. In their analyses, no fixed position could be identified on the Jovian disk. Phillips et al. [1987] have attempted new observation of DAM event at 18 MHz with 46 km cross–polarized interferometer which is consisted of two stations: one station is arranged to observe RH (right–handed) polarization, and the other is arranged to observe LH (left–handed) polarization. They thought that DAM waves are elliptically polarized and the RH and LH emissions have some coherency with each other. They concluded that in the later case two or more sources were active simultaneously. In the multiple source case, they also analyzed the scintillation index of detected power for RH and LH emissions. They pointed out that two sources for LH and RH emissions have different source sizes, and the LH sources are located in both hemispheres simultaneously, while the RH emission sources are located in the northern hemisphere.

In Tohoku University, interferometer observations using 100 km baselines have been developed [Tokumaru, 1985; Murao, 1995; Misawa, 1997]. In these works, they try to measure the source positions and motions in the Jovian disk by analyzing the interferometer data. Although there were some cases where they could detect the source movement between the north and the south hemisphere of Jupiter, they have also pointed out that terrestrial ionospheric scintillation effects are important for the interferometer observations of DAM signals [Tokumaru, 1985; Murao, 1995]. Therefore, to identify the precise source locations, it has been required to establish a method to eliminate the terrestrial ionospheric

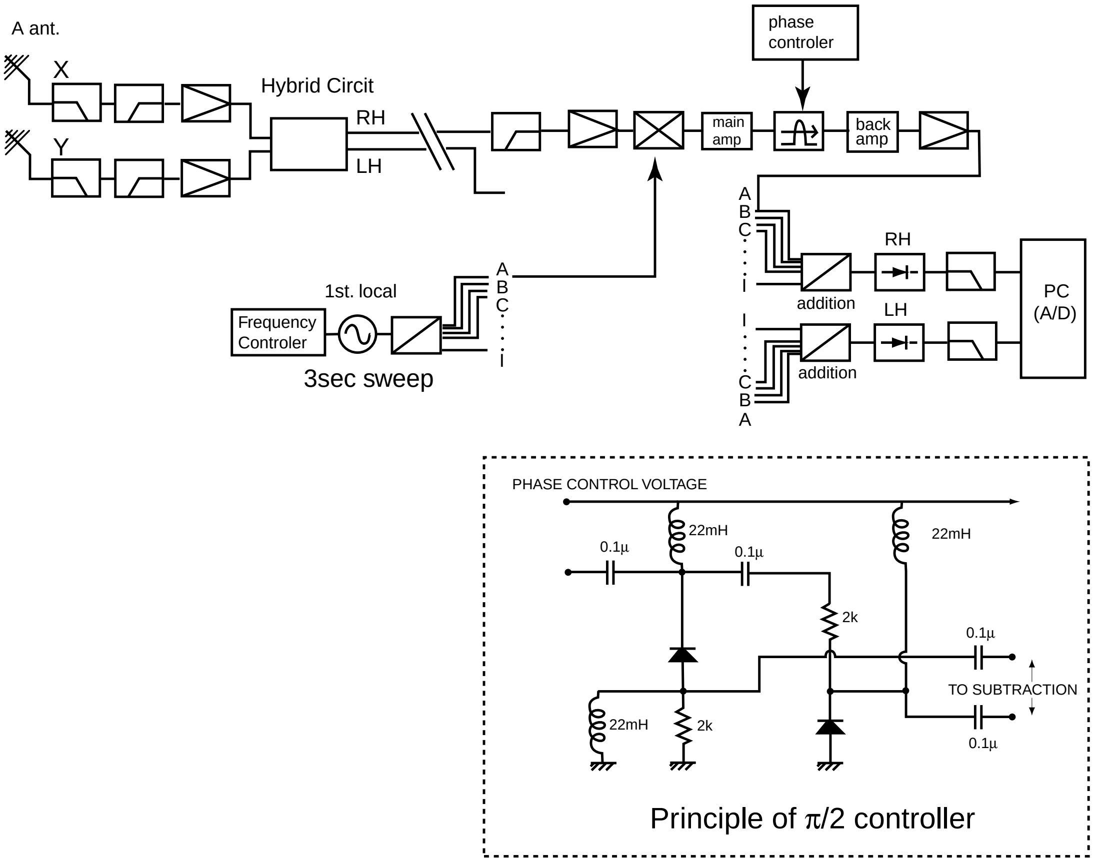

Figure 2: Block diagram and principle of the voltage controlled phase shifter applied in the interferometer.

effects.

To identify the source locations and generation processes of DAM, we have developed a new array antenna system for a sensitive polarimeter and a new long baseline interferometer system designed by using multi–frequency interferometer method by which we can largely reduce the effect of fluctuations in the terrestrial ionosphere.

2 Array antenna system

The new array antenna system is installed at Iitate observation station of Tohoku University in Fukusima prefecture, Japan. The array antenna consists of 9 log–periodic antennas with spacing from 15 m to 150 m (Figure 1(b)). Observation frequency range is set from 20 to 40 MHz for both RH and LH polarizations. The front–end of the observation system consists of orthogonal cross log–periodic antenna, a hybrid circuit for dividing received DAMs into RH and LH polarization signals, 20 MHz–40 MHz BPF (Band Pass Filter), and low noise wide–band preamplifiers with NF (Noise Figure) of 1 dB. After separation of the polarization (RH and LH), the signals are fed to 18 three–stage super heterodyne

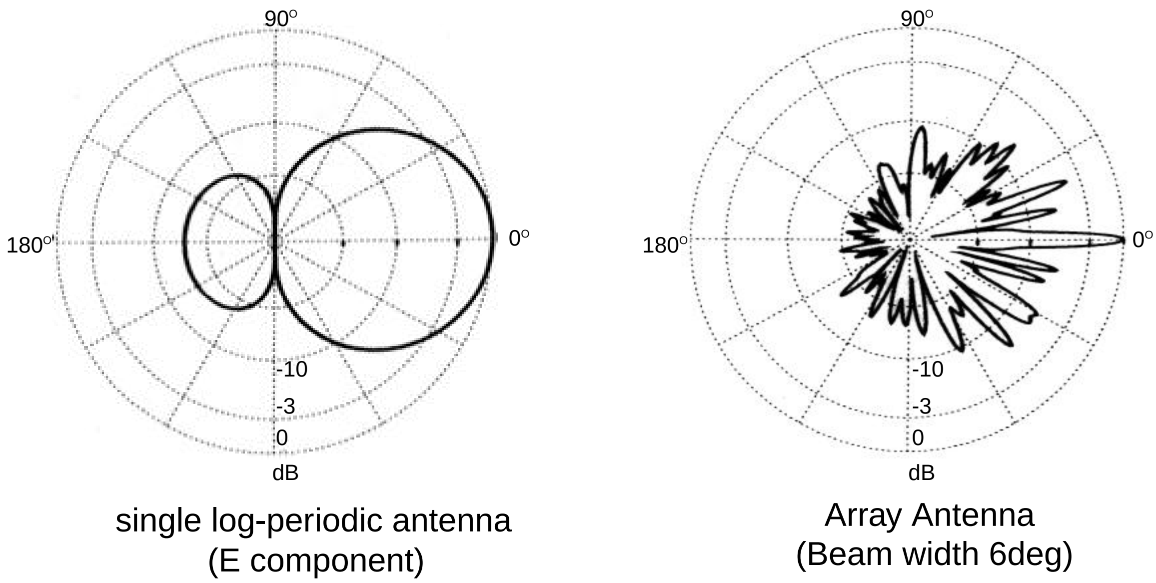

Figure 3: Beam Patterns of a single log–periodic antenna and the array antenna.

receivers. Figure 2 shows the block diagram of one element of this array antenna system. These receivers act as spectral analyzers by sweeping the 1st local signals with a frequency step of 100 kHz and a sweep time of 3 s. All of the local signals used in 18 receivers are generated by a signal oscillator, which is divided for all receivers. In this array antenna system, the phase control of the received signals is carried out at each frequency of the observations by calculating the phase difference of the observed signals from the source at the moment. The phase control of the receivers has been made in the intermediate frequency stage (455 kHz) by phase control bridge circuit. The phase control bridge circuit includes voltage controlled capacitances the control voltage for which is fed from the microcomputer (see Figure 2 for principle) [Oya et al., 1999]. As shown in Figure 3, the array antenna has the main beam with a size of 6 degrees, which is one tenth of the size of the main beam of a single log–periodic antenna. In Figure 4 we show one example of the first observations of DAM emissions. As shown in this figure, the array antenna system is sensitive and can observe detailed features of the dynamic spectra of DAM. However, the first observation shown in Figure 4 was carried out by using only 6 antennas, therefore, the corresponding gain of this observation is about 8 dB, compared with the observation with a single antenna.

3 Multi–frequency interferometer network

The new long base–line interferometer system consists of four stations which are located in Miyagi and Fukusima prefecture (see Figure 1(a)) where we have 6 combinations of base lines ranging from 45 km to 115 km. At each observation station, an log–periodic antenna for 20–30 MHz range and Cs (cesium) vapor frequency standard are installed.

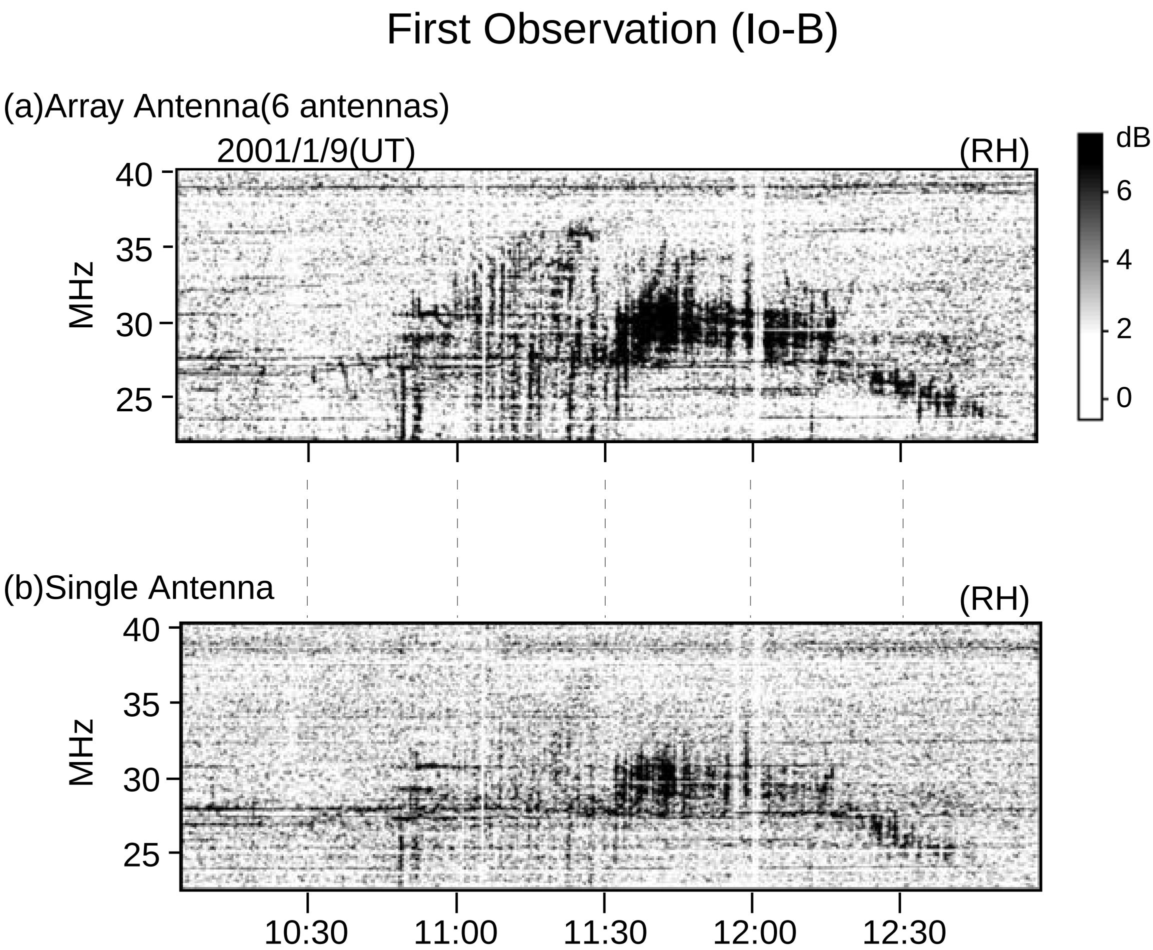

Figure 4: Comparison between observations of the array antenna (a) and the single antenna (b). This observation of the array antenna was carried out by using only 6 antennas.

The signals from four stations are transmitted directly to the central station at Sendai through the telemetry channels.

For a long base–line interferometer, the effect of fluctuations in the terrestrial ionosphere becomes important for the decameter wave length range. Observed phase difference between two stations (see Figure 5(a)) are given by

$$\Delta\phi = \frac{2\pi f}{c} L \cos\theta - \frac{K}{f} \Delta N_{TEC} \tag{1}$$

$$K = const.,$$

where $\Delta\phi$ and L represent observed phase data difference at frequency f and a base line distance, respectively. ΔN_{TEC} is a total electron content along the ray path of the DAM signals. The first term and the second term of Eq. (1) represent the direction of the source location and the effect of fluctuations in the terrestrial ionosphere, respectively. To reduce

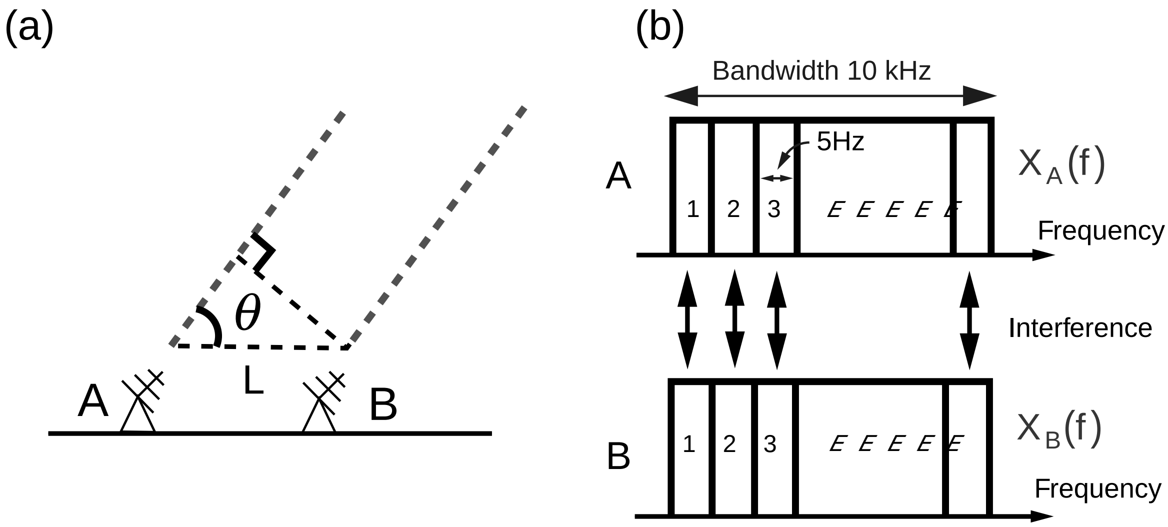

Figure 5: Methods of the new long–base line interferometer system.

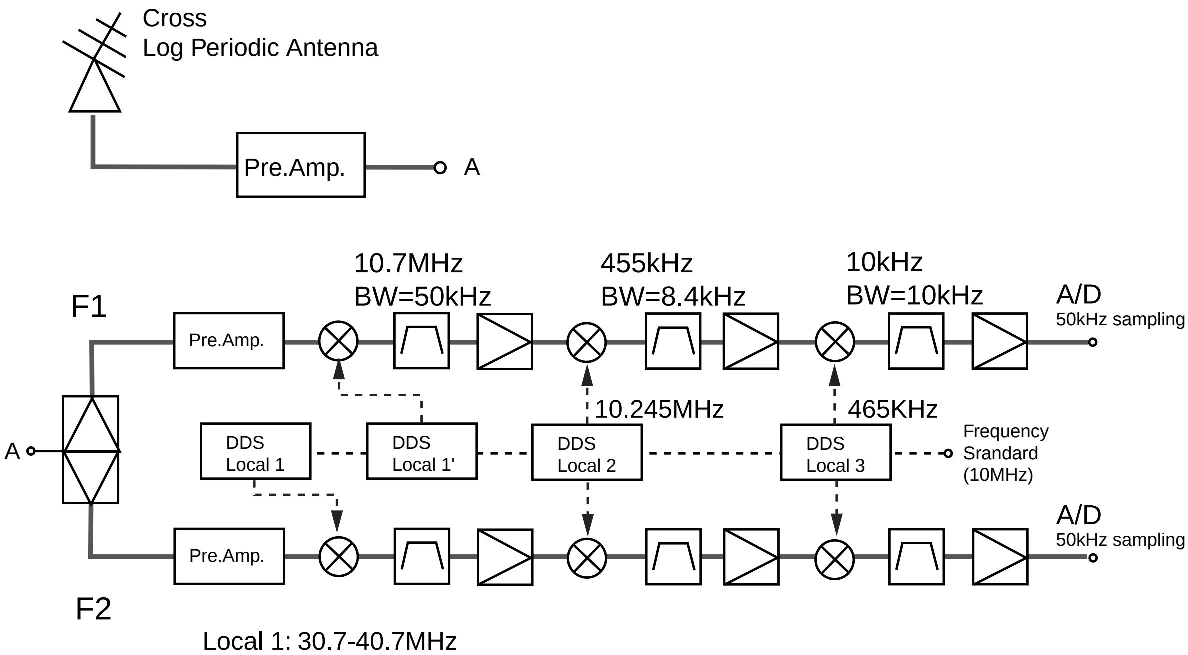

Figure 6: Block Diagram of the new long–base line interferometer system.

the effect of fluctuations in the terrestrial ionosphere, the double frequency interferometry with multi sub–band method is introduced to the new long base line interferometer system.

3.1 Double frequency interferometry

To reduce the effect of fluctuations in the terrestrial ionosphere, we apply double frequency interferometry which is used in VLBI to our long base line interferometer system. Observed phase differences between two stations by using double frequency interferometry are given by

$$\begin{aligned} \Delta\phi_1 &= \tfrac{2\pi f_1}{c} L\cos\theta - \tfrac{K}{f_1}\Delta N_{TEC} \\ \Delta\phi_2 &= \tfrac{2\pi f_2}{c} L\cos\theta - \tfrac{K}{f_2}\Delta N_{TEC} \\ K &= const., \end{aligned} \tag{2}$$

where $\Delta\phi_1$ and $\Delta\phi_2$ are observed phase data difference at frequencies f_1 and f_2, respectively. We assume that the difference of these two ray paths at f_1 and f_2 can be neglected. Then, we can determine the effect of ΔN_{TEC} and θ in Equation (2).

In this method, however, it is required that the DAM events are observed with large signal–to–noise (S/N) ratio, because the difference between two observation frequencies should small for the assumption of the same ray path in the ionosphere. Therefore, to improve the S/N ratio, we further employ the multi sub–band method.

3.2 Multi sub–band method

To achieve enough of S/N ratios for observed DAM signals, the bandwidth of the observation system needs to be wide. However, when the bandwidth become wide, interferometry becomes difficult. To solve this problem, we use multi sub–band method, shown in Figure 5(b), where the observed data with a wide bandwidth is divided into multi sub band, and the observed interferometer data is analyzed in each sub band. This interferometry processing is given by the following equation

$$C = \int X_A(f)X_B^*(f)\exp[-i\frac{2\pi f}{c}L\cos\theta_{JC}]df, \tag{3}$$

where $X_A(f)$ and $X_B(f)$ are observed data at station A and B, respectively (see Figure 5(b)), and θ_{JC} is the direction of Jovian center. The subtraction of fringe phase of Jovian center ($-i\frac{2\pi f}{c}L\cos\theta_{JC}$) enables the interferometry of wide bandwidth. The real data processing is carried out each sub band of 5 Hz (see Figure 5(b)).

Figure 6 shows the block diagram of the new long–base line interferometer system employing the double frequency interferometer method and the multi sub–band method.

4 Conclusion

We have developed two new observation systems for DAM, i.e., the array antenna system and the long base line interferometer, to understand the energy source and the radiation process of DAMs. The new array antenna system consists of 9 log–periodic antennas with spacing from 15 m to 150 m, which can observe RH and LH polarizations with high sensitivity. The corresponding gain of the array antenna is designed to be about 10 dB when we use the full set of 9 antennas. The new long base line interferometer system consists of 4 stations with spacing from 44 km to 116 km by using double frequency interferometry and multi sub–band method by which we can largely reduce the effect of fluctuations in the terrestrial ionosphere. We have estimated that it is possible to determine the source position (North or South) for the condition when the fluctuation of ΔN_{TEC} is less than 5.0×10^{15} $[el/m^2]$ by using a simulation study considering the ray paths of DAMs. In addition, we are now developing a new monitoring method of ΔN_{TEC} for the cases of larger amplitude disturbances by using TEC data from the GPS observation network in Japan.

References

Carr, T. D., S. Gulkis, A. G. Smith, H. Bollhagen, N. F. Six, Jr., and N. E. Chatterton, Recent decameter–wavelength observations of Jupiter, *Radio, Sci.*, **69**, 1530–1536, 1965.

Dulk, G. A., Characteristics of Jupiter's decametric radio source measured with arcsecond resolution, *Astrophys. J.*, **150**, 117, 1970.

Lynch, M. A., T. D. Carr, and J. May, VLBI measurements of Jovian S–bursts, *Astrophys. J.*, **207**, 325, 1976.

Misawa, H., Studies on the origin of Io–related Jovian decametric radiations, Ph. D. thesis Tohoku University, 1997.

Murao, H., Identification of the Jovian decameter wave radiation sources using two–frequency interferometer network system, Ph. D. thesis Tohoku University, 1995.

Oya, H., and M. Iizima, Cluster of super massive black holes in the central region of our galaxy observed by decameter radio wave pulses: - Discovery of 24 super massive black holes and their motions, Sci. Rep. Tohoku Univ., Ser. 5, 32, 1–78, 1999.

Phillips, J. A., T. D. Carr, W. B. Greenman, and J. Levy, Cross–polarized interferometry of a Jovian decametric radio storm, *J. Geophys. Res.*, **92**, 9971–9977, 1987.

Tokumaru, T., Studies on the source location of Jovian decametric radiation using 1 km and 75 km interferometer, Ph. D. thesis Tohoku University, 1985.