Earth-Space phase transfer link for the Space VLBI mission

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Abstract

The Institute of Space and Astronautical Science, ISAS, will launch the MUSES-B satellite in September, 1996, for the space VLBI mission in which accurate phase transfer is requested. A phase transfer test, a round trip phase measurement, was conducted on a 5-km two-way ground link. From the phase fluctuations we succeeded to derive the atmospheric fluctuations, the statistical property of which is similar to the former experimental results published so far. We studied the fluctuations more carefully and found that the phase fluctuations may cause a notable amount of interferometric loss of 1 percent and more.

We also made an operation of a frequency control which is requested to keep a frequency on the satellite constant. We found the control noise is the same order of magnitude as the atmospheric disturbance.

Ionospheric propagation effect is found to be small enough in the quiet ionospheric condition as compared with those of the atmospheric fluctuation and the control noise.

1 INTRODUCTION

The MUSES-B satellite [1] equipped with a large deployable 8-m antenna will be put onto an elliptical orbit of the apogee height of 20,000 km and the perigee height of 1,000 km in September, 1996. The primary mission is a space VLBI observation known as the VSOP [2], VLBI Space Observatory Program. Not only the radio astronomical mission but many other important technical tests are planned to be performed. In this paper we will present a preliminary test results of the engineering experiments by using an actual ground supporting facilities of VSOP.

In the VLBI (Very Long Baseline Interferometer) observation, the space radio telescope and other ground telescopes receive a common signal from a celestial radio source, independently. All of the ground telescope are synchronized in the same observing frequency with a highly stable frequency standard, a hydrogen maser oscillator. But the space observatory has no frequency standard on board due to weight and power limitations. To tune the space observing frequency, we need to transmit a frequency reference signal from a ground supporting station to the orbiting station by taking the doppler effect into consideration. Time and frequency in the space observatory is kept under a remote control of the transmitting frequency via the phase transfer link [3] [4].

In this paper technical aspects of the phase transfer link is described with the preliminary test results.

2 PHASE TRANSFER SYSTEM

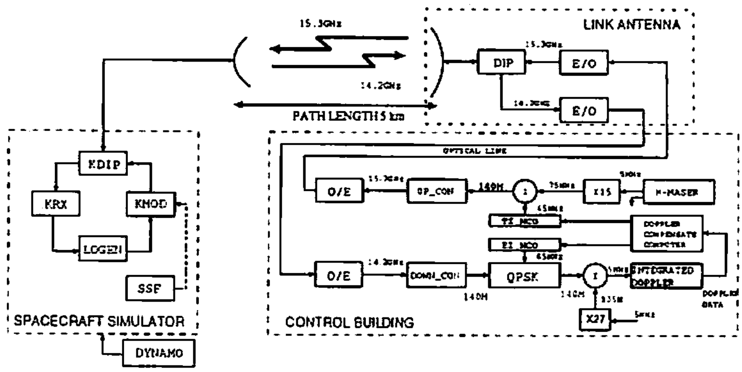

Figure 1: Block diagram of phase transfer system

A block diagram of the phase transfer system is shown in Figure.1. The uplink signal from a ground supporting station to the satellite is generated in a hydrogen maser oscillator, frequency up-converted to 15.3 GHz, and then received by a phase-locked receiver (KRX) on board. Reference signals for local oscillators and all other timing signals are generated in a LOGEN unit. A downlink carrier of a QPSK modulation for the space data refers also the frequency of 14.2 GHz to the reference signal from the LOGEN unit.

The down link carrier is retrieved in a QPSK demodulator and the phase and the frequency are measured by the IDC, Integrated Doppler Counters. If the up link frequency would be perfectly controlled so as to keep the satellite frequency constant, the down link frequency should exactly be shifted by the doppler frequency as is expected in transmitting the uplink frequency. The up-link frequency control is made by using a NCO, Numerical Controlled Oscillator.

The loop phase stability measured by the IDC is a key item to evaluate the total performance of the phase transfer system.

3 PHASE STABILITY

Accurate phase transfer is affected by atmospheric and ionospheric disturbance. To minimize the ionospheric propagation effect, a pair of Ku-band frequencies are chosen for up- and down-link transmission by carefully considering the facts that the higher frequency is better and a closer pair of frequencies gives less error on the transferred phase to the space observatory. In case that the up- and down-link frequencies are exactly same, the up-link phase is completely predictable from the loop phase by dividing the two-way phase by 2. We can compensate the ionospheric phase variation perfectly.

In Table 1, we give the ionospheric phase transfer error in some cases of up- and down-link frequencies. In the Table, we assumed the TEC, Total Electron Content, of 10^{16} electrons/m^3 and the scintillation index of 0.1. In the error calculation, we used the formula defined in [5]. Our final selection of 15.3/ 14.2 GHz is the best under restrictions of radio regulation.

The phase transfer test was made by using an actual ground support facilities equipped in the Usuda satellite tracking station and a spacecraft simulator. The simulator has the almost same coherent transponder as is shown in the Figure 1. Figure 2 indicates the Allan standard deviation of the link phase stability. The instrumental noise was measured by setting the simulator just on the link antenna. The atmospheric instability was measured by setting the

Table 1: Ionospheric phase transfer error

Link Frequencies		Unmodeled Ionospheric Error	Link Path Fluctuation
F_{up}	F_{down}	$\frac{F_{down}}{F_{up}+F_{down}}\left(\tau_i(F_{up}) - \tau_i(F_{down})\right)$	σ_{res}
(GHz)	(GHz)	(picoseconds)	(picoseconds)
13.401	15.05	0.82	0.50
13.9	15.05	0.53	0.47
15.3	14.2	-0.44	0.42

simulator at the remote site, about 5-km away from the link antenna. The statistical property of the atmospheric instability is very similar to the test results published so far [6]. A broken line in the Figure 2 is a goal to be reached in our phase transfer system, which may cause an interferometric coherence loss of 1 %, the coherence loss factor of 0.99.

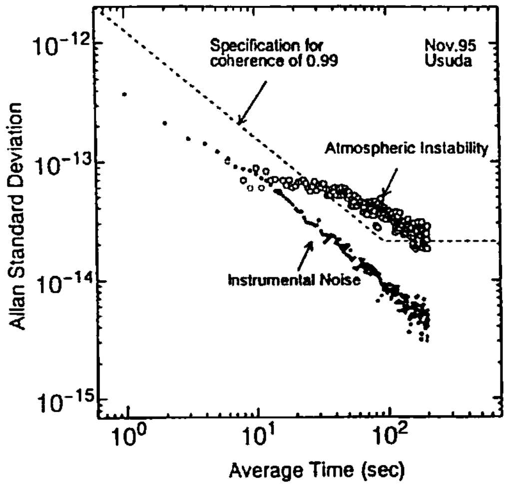

Figure 2: The link phase stability

4 FREQUENCY CONTROL NOISE

In order to keep the frequency of the space observatory constant and the same to other ground observatories, we need to do the up-link frequency control. A phase noise inevitably caused by the frequency control has to be studied carefully. The goal of this study is to establish the best strategy of the frequency control which makes the control noise on the link phase minimum.

In the first attempt, we made the preliminary test of the frequency control by changing the frequency of two independent maser oscillators in time assuming an actual satellite orbital motion. Figure 3 shows the results.

Four typical cases were examined, frequency changing rate is the maximum in Case-1, a large changing rate is assumed in the Case-2, a medium and the minimum rates are given in Case-3 and -4. A control interval of all four cases is fixed to 1 second.

As clearly seen in the figure, even in the minimum changing rate, a large phase noise is generated. In all cases except the Case-1 the noise exceeds the specified goal line. This experimental result implies the necessity of a better way in the frequency control. We changed the control interval from 10 seconds to 1 second and observed the improvement of the phase noise in the shorter control interval. We concluded from these fact that the frequency control of 0.1 seconds or shorter interval is requested to reduce the noise much smaller than the

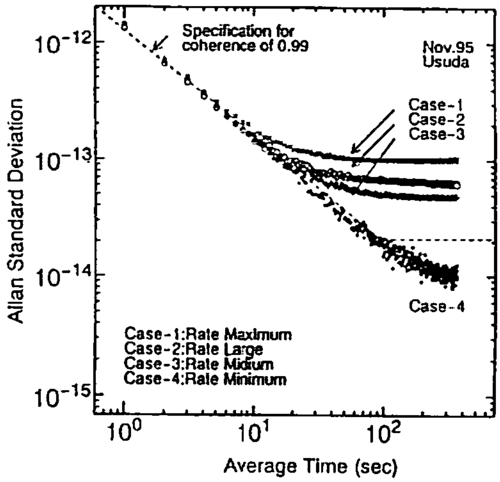

Figure 3: Frequency control stability

atmospheric phase noise indicated in Figure 2.

5 CONCLUSION

We have made a preliminary test of a link operation for the MUSES-B phase transfer system to achieve the minimum loss of coherence in the space VLBI observation. In the test we found the atmospheric phase noise is larger than the goal we have been expecting for the coherence factor better than 0.99. The ionospheric noise is small enough to keep the interferometric coherence within the goal. The frequency control at the interval of 1 second causes a larger noise than the goal we expect. We need to do the much faster control of 0.1-second interval or shorter.

All other noises except for the atmospheric fluctuations we can reduce them within the goal. If a loop phase only reflects the atmospheric disturbance, we can use it as an indicator of atmospheric fluctuations and compensate the phase noise to keep the coherence factor within the expected value.

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