Geodetic VLBI experiment at 22 GHz band between Japan and Italy

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Abstract

Geodetic VLBI experiments are usually conducted at S/X dual bands. Some advantages can be gained at some higher frequency band and in particular at 22 GHz band (K band). We organized a geodetic VLBI experiment on the 16th of February 1991 between Kashima 34m antenna of the Communication Research Laboratory (CRL), in Japan and Medicina 32 m telescope of the Institute of antenna(IRA), in Italy. The phase calibrator was developed using a new "up-conversion" scheme for K band. Data relative to 212 observations of 40 sources were correlated and for 152 scans we obtained correlated amplitudes, delays and delay rates. The r.m.s. residuals have been found to be 100 ps for delays, and 74 fs/s for delay rates. The coherence loss of correlation amplitude becomes large at higher frequency band than 22GHz due to the atmospheric scintillation. The estimated method of the coherence loss was presented. The correlated flux densities at K band evaluated from them were found to be smaller than the ones at X band in general.

1. Introduction

Communications Research Laboratory (CRL) has been participated in the many CDP (Crustal Dynamics Projects) experiments since 1984, IRIS experiments, and USNO's experiments. We are developing the VLBI techniques such as K4 VLBI terminal, simple ionospheric delay correction system, mobile VLBI stations for sea level monitoring, Antarctica VLBI experiment. In this paper, the 22GHz geodetic VLBI is presented. The VLBI experiments are conducted at S/X dual band presently. Higher frequency bands like the radioastronomy VLBI centered around 22 GHz, could be utilized with some advantages. The benefits of a geodetic VLBI experiment at 22 GHz band can be described as follows.

1) The observation band width more than 1 GHz is feasible easily, and the noise errors can be decreased.

2) The noise error in the delay rate becomes small.

3) The ionospheric delay contribution can be reduced at 22GHz band. Using the simple ionospheric measure system with GPS, all the capacity of the data acquisition terminal can be occupied at single band in order to improve the sensitivity. The weaker radio sources can be observed.

4) The observation data as the water vapor radiometer will be obtained by the same large antenna to be useful for the correction for the atmospheric delay of wet component.

5) The information on correlated flux, source structures and the propagation characteristics at 22GHz band will be obtained together with

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the geodetic results.

6) The positions of both H_2O masers and quasars will be observed at this band. The positions of quasars at 22GHz will be determined. Then, the relative positions of H_2O masers with respect to quasars can be measured within 10 micro arcsec. The proper motion of the maser sources could be measured.

7) The interference problems are much less severe, trouble free detection in comparison with the S band crowded man-made signals.

2. Phase calibration system

In geodetic VLBI, the bandwidth synthesis is the indispensable technique. The correlated function of all channels could be synthesized in a coherent way by the correction of phase calibration signal. In the standard Mark-III data acquisition terminal, a broadband comb generator multiplies the 5 MHz reference frequency from H-Maser up to the observation frequency band in just one step. The multiplication factor becomes more than one thousand. The comb tone signal is then arranged to give rails every 1 MHz up to X band, in order to calibrate each channel. It is tuned at a desired observation frequency. The available power becomes low at high frequency and it is questionable if it will be sufficient to operate at 22 GHz without an amplification stage. The new devices developed for this purpose are considered (R.Ambrosini, 1990).

To overcome these problems, CRL designed a phase calibration system, utilizing the "up-conversion" scheme. The comb tone signal is first generated at IF band (several hundred MHz), then it is converted up to observation frequency using frequency conversion. Since in this case the multiplication factor is less than one hundred, it is easy to achieve a good phase stability. The phase calibration signals can be made at any observation band. However, a frequency converter unit is needed for each observation band such as S, X and K band. The outline of our phase calibration is shown in figure 1.

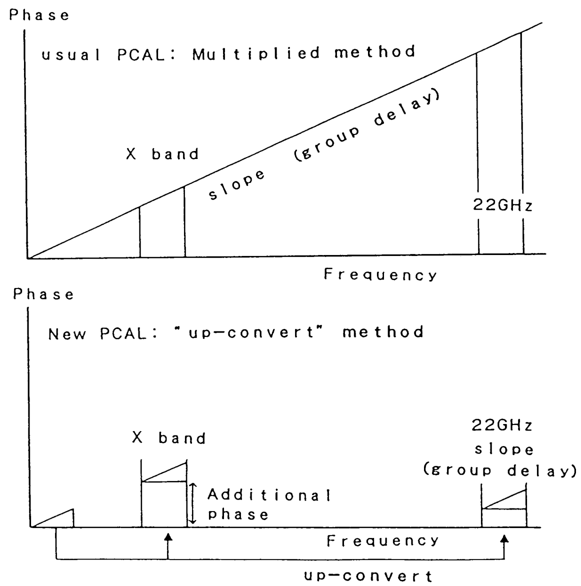

Figure 1 Scheme of phase calibration system

3. Experiment

The geodetic VLBI experiment at 22GHz band between the Kashima 34m antenna in Japan and Medicina 32m antenna in Italy, was conducted during

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27 hours since 8:57 on the 16th February 1991.

The purposes of this experiment are (1)to check of our phase calibration system; (2)to obtain the data in geodetic VLBI and the correlation flux densities of radio sources at K band; (3)to demonstrate the "K4" VLBI terminal developed by CRL (Kiuchi, 1991).

To make the experiment, we temporally transported a full "K4" VLBI data acquisition terminal and phase calibration system to the Medicina station. They arrived at the Medicina station just one day before the experiment, and we had to set them during several hours.

We had 240 scans of 40 sources. We have been able to detect fringes when SNR was greater than 8, and correlation flux greater than 0.2Jy. The lower K band receiver of Kashima is spanning from 21.9 GHz to 22.4GHz, and the fixed band of the Medicina receiver is about 22.06-22.56GHz. The observation band became 22.085-22.445 GHz with a total bandwidth of 360 MHz that was almost the same as one at X band. The number of video converters was 14 channels and its bandwidth is 2MHz. The effective frequency band width to make a synthesis was 133 MHz. The observation duration was set into 300 sec.

4. Results

The correlation processing took place at Kashima with the K-3 VLBI correlator. We made correlation processing for 212 observations. The bandwidth synthesis was successful for 152 observations.

4.1 Baseline analysis

The baseline analysis was made using the delay and delay rate. The baseline vector, the atmospheric delay of the zenith direction for every 3 hours and a few clock parameters, were estimated without applying any correction of ionospheric delay. The source positions are referred to the ICRF90 in the 1990 IERS annual report. The Earth rotation parameters are used the interpolated value of five day values of IERS-92C02, and the station positions at 1988.0 are ITRF91 from the 1991 IERS annual report. The positions at the experiment were calculated by the results of GSFC (C.MA 1992). Figure 2 shows the residual of the delay after the analysis by SOLVE. The used data were 138 observations. The residual r.m.s. was 100 ps for delay and 74 fs/s for delay rate. The adjusted X,Y,Z components of baseline were 2.7±2.7cm, -5.5±1.6cm, and -1.7±2.8cm respectively. The r.m.s.

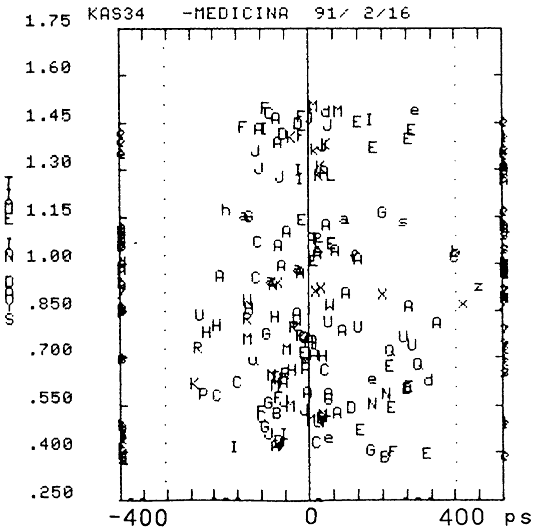

Figure 2 Residual of Delay

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without ionospheric delay correction was almost agreed with the typical value at X band. In the future, The ionospheric delay will become correct by other equipment using GPS, and the bandwidth will be widened.

4.2 Correlated amplitude

The complex correlated function obtained at the output of the correlating processor, has to be maximized with respect to delay and delay rate. The maximized absolute value is the correlated amplitude.

$F(n,\Delta t,\Delta\dot{t})$ is the summation of correlated complex function for n'th channel along the whole observation period; Δt, $\Delta\dot{t}$ are the adjusted values of delay and delay rate, and n is the channel number. The whole observation is divided into the several segments shorter than 1 minute. $f(n,\Delta t,\Delta\dot{t};k)$ is defined as the correlated complex function along the k'th segment. K is the number of segments and k represents a segment number. $F(n,\Delta t,\Delta\dot{t})$ is described as $1/K \sum_{k=1}^{K} f(n,\Delta t,\Delta\dot{t};k)$.

We calculated the following three correlated amplitudes.

$$F0 = \text{Max of } \{ \, | \, 1/N \sum_{n=1}^{N} F(n,\Delta t,\Delta\dot{t}) \, | \, \}$$
$$F1 = \text{Max of } \{ \, 1/N \sum_{n=1}^{N} | \, F(n,\Delta t,\Delta\dot{t}) \, | \, \}$$
$$F2 = \text{Max of } \{ 1/K \sum_{k=1}^{K} | \, 1/N \sum_{n=1}^{N} f(n,\Delta t,\Delta\dot{t};k) \, | \}$$

where N is the number of channels. F0 is the "true" coherent correlated amplitude, in the sense it has been obtained from an average over total observation frequency bandwidth and the whole observation period. F1 is the average of the correlated complex function over the whole observation period, but it takes the contribution of each channel separately, that is, it is averaged without the phase information between channels. So this amplitude can be considered to be "incoherent" with respect to the bandwidth synthesis process.

The deviation from 1 in the ratio F0/F1 represents the coherence loss due to the mismatch of phase calibration. In the ideal case that the phase calibration is exactly correct, the ratio F0/F1 is equal to 1. Table 1 shows the ratios for each source, and they are almost equal to 1. This means verifying the accuracy of our phase calibration system.

F2 is the average of correlated complex function for the all channels over each segment, but it takes the contribution of each segment separately, that is, it is averaged without the phase information between every segments. This amplitude can be considered to be "incoherent" with respect to the period longer than the segment period.

The deviation from 1 in the ratio F0/F2 represents the coherence loss caused by the phase variation during the whole observation. The phase variation is due to the atmospheric scintillation, the frequency standard and receiver system such as Phase Lock Oscillator. We have assumed the atmospheric scintillation and the receiver system to be the responsible for the deviation from 1 in this ratio. Almost all the values, reported in Table 2, are about 0.8, as one would expect from an atmospheric stability of 5×10^{-14} to be corrected for the elevation effect. This figure is consistent with typical VLBI measurements under good weather conditions in winter season, as it happened to be on the day of the main experiment. In conclusion we have used the F2 amplitude to evaluate the correlated flux density due to the atmosphere.

Acknowledgements

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Reference

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Table 3 Correlated Flux Density (Jy)

SOURCE NAME	Kashima-Medichina at 22GHz band	Kashima-Mojave at X band	Ratio 22GHz/X-band
0106+013	.4	.9	.5
0212+735	.7	1.0	.6
4C67.05	.4		
0234+285	.7	1.9	.4
0235+164	1.5	1.2	1.1
0300+470	.4		
3C84	.7		
0333+321	.6		
NRAO150	.6		
0420-014	1.4	3.2	.4
0528+134	.3	1.0	.3
0552+398	1.4	2.7	.4
0735+178	.5	1.2	.4
OJ287	.6	2.8	.2
4C39.25	.4	1.8	.2
1055+018	.6	1.7	.4
3C273B	1.3	2.0	.6
3C279	1.4	.7	1.9
1510-089	.8	3.3	.2
1546+027	.4		
1611+343	.9		
3C345	2.6	1.6	1.3
1739+522	1.5		
1741-038	.7	2.9	.3
1803+784	.8	1.5	.5
3C380	.5		
2021+614	.4		
2134+00	.3	2.2	.2
2145+067	.7	3.2	.2
CTA102	.4		
3C454.3	2.1	2.1	.9

Table-1 Coherence loss by phase calibration (F0/F1)

SOURCE	F0/F1	SOURCE	F0/F1
0106+013	1.03	0212+735	1.00
4C67.05	1.05	0234+285	0.99
0235+164	0.98	0300+470	1.00
3C84	1.01	0333+321	0.98
NRAO150	1.03	0420-014	0.98
0528+134	0.98	0552+398	0.99
0735+178	0.98	OJ287	0.97
4C39.25	0.97	1055+018	0.97
3C273B	0.98	3C279	0.97
1510-089	0.98	1546+027	1.00
1611+343	0.98	3C345	0.99
1739+522	0.98	1741-038	1.02
1803+784	1.05	3C380	1.10
2021+614	0.98	2134+00	1.00
2145+067	0.99	CTA102	0.98
3C454.3	0.98		

Table-2 Coherence loss by atmospheric scintillation (F0/F2)

SOURCE	F0/F2	SOURCE	F0/F2
0106+013	0.60	0212+735	0.86
4C67.05	0.87	0234+285	0.83
0235+164	0.87	0300+470	0.72
3C84	0.86	0333+321	0.81
NRAO150	0.80	0420-014	0.92
0528+134	0.71	0552+398	0.88
0735+178	0.76	OJ287	0.81
4C39.25	0.71	1055+018	0.70
3C273B	0.79	3C279	0.80
1510-089	0.77	1546+027	0.67
1611+343	0.88	3C345	0.92
1739+522	0.89	1741-038	0.66
1803+784	0.92	3C380	0.78
2021+614	0.63	2134+00	0.62
2145+067	0.81	CTA102	0.67
3C454.3	0.84		

4.3 correlated flux densities

We calculated the correlated flux densities. The system temperatures at K band are 120+40/Sin(El) K for Kashima and a constant value of 200 K for Medicina. The antenna efficiencies at K band are $(57-|EL-45^\circ| \times 0.7)$% for Kashima and about 37 % for Medicina.

Table 3 shows, on the first column, the correlated flux densities obtained at K band on the Kashima-Medicina baseline (8000km) during this experiment. For comparison the following column display the flux densities on the Kashima-Mojave (USA) baseline (8000km) obtained at X band from CDP (CDP) (Takahashi,1991); finally the ratio of the first to the second columns. In general the correlated flux densities at K band have second found to be half smaller than X band.

6. Conclusion

We have started the geodetic VLBI experiments at K band. We have also developed a phase calibration system utilizing the "up-converting" method. The geodetic VLBI experiment at K band has been organized between the Kashima 34m antenna in Japan and the 32 m Medicina antenna in Italy. The result of baseline analysis at K band without the ionospheric delay correction are agreed with that at S/X bands.

The good performance of the phase calibration system has been verified by comparing the coherent correlated amplitude with the incoherent correlated amplitude without a phase information of each channel. We have also presented the method to obtain the correlated amplitude without the effect of atmospheric coherence loss. The correlated flux densities at K band have been generally found smaller than the ones obtained at X band on baselines of almost same length.