The First Campaign of Observations with the VLBI-Module of TIGO

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Abstract

The new 6m radiotelescope TIGO located in 60 meter distance from the 20 meter WETTZELL antenna participated in several VLBI experiments since November 1997. The purpose of this observations was to evaluate performance of the antenna and to acquire experience in short baseline phase-delay VLBI. The results of these first experiments are presented. VLBI measurements of length of the short baseline TIGOWTZL–WETTZELL show submillimeter repeatability and agree with results of local survey within its formal uncertainty.

1 Design of the TIGO-Radiotelescope

The Transportable Integrated Geodetic Observatory (TIGO) is designed as a fundamental station. Fundamental stations are the backbone for the realization of the terrestrial reference system since they are equipped with all relevant geodetic instruments. Therefore TIGO includes currently a VLBI-module, a SLR-module, GPS-receivers, super conducting gravity meter, seismometer, meteorological sensors including a water vapour radiometer.

The ideal terrestrial reference system would be based on a globally uniform distribution of observing sites. A poor representation of Earth by observing stations within the terrestrial reference frame will result in systematic errors. The reality shows wide areas without fundamental stations, especially in the southern hemisphere. Within the international efforts to improve the distribution of observing sites supporting the terrestrial reference frame, the Bundesamt für Kartographie und Geodäsie has developed and built the transportable fundamental station TIGO. The *transportability* of TIGO enables to setup a fundamental station at the *most beneficial* site for the realization of a terrestrial reference system [2].

The largest component of TIGO is the radiotelescope for VLBI which had to be designed to fit in a 12m-container. This requirement is a strong restriction for the design and the construction of the radiotelescope for geodetic VLBI. It requests

- high slewing velocity,
- reflector as large and as stiff as possible with high surface accuracy,
- high antenna efficiency,
- truly intersecting axes for the definition of the geometrical reference point as invariant point regarding source tracking,
- accessibility of the geometrical reference point for control surveys for verification of site stability.

In order to fit these criteria the concept of an offset-antenna with a receiver in the primary focus had been chosen. The asymmetrical construction allowed to tilt the receiver from the vertex axis of the primary mirror by 35.8°. The full dish is illuminated and the reflected signal is completely used. The optical scheme of the antenna is shown in figure 1.

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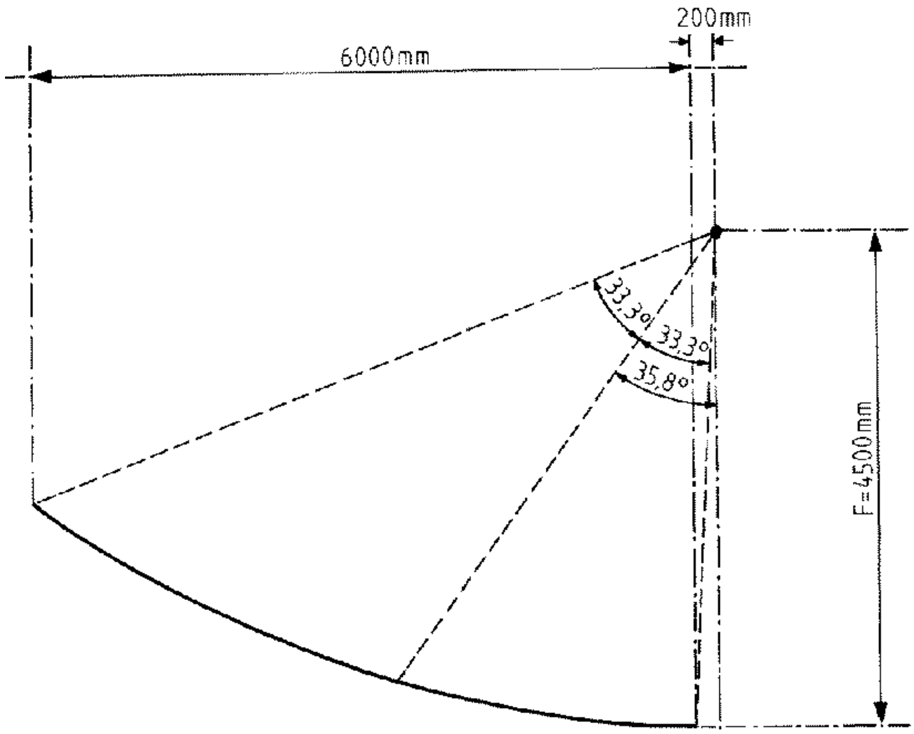

Fig. 1: Optical scheme of the antenna

At the primary focus of the offset reflector a NASA standard S/X dualband cryogenic receiver is installed. Its first amplifier stages consist of HEMTs operated at about 22K resp. 60K. It is possible to observe right hand circulated polarization in the frequency spectra of 2.216 ... 2.350 GHz and of 8.108 ... 9.036 GHz. The TIGO VLBI-module is equipped with a VLBA4 terminal, which supports the Mk4 and the Mk3a standard. Recording is done on one-inch-video-thintapes with a VLBA4 tape recorder.

2 First Observations

The first fringe test was carried out on November 11, 1997.

TIGO has participated in a number of EUROPE, NEOS-A and some Wettzell–tie experiments. Table 1 shows successful experiments.

Tab. 1: Successful experiments with TIGO.

N	Date	Experiment
1	02-FEB-98	Europe-41
2	19-MAY-98	NEOS-A-264
3	22-JUN-98	Europe-43
4	20-JUL-98	Wettzell–tie–1
5	17-AUG-98	Europe-44
6	14-DEC-98	Europe-46

3 System Performance

The conducted experiments allowed to investigate the reached system performance in detail. The dependence of system temperature at X- and S-band is shown in fig. 2).

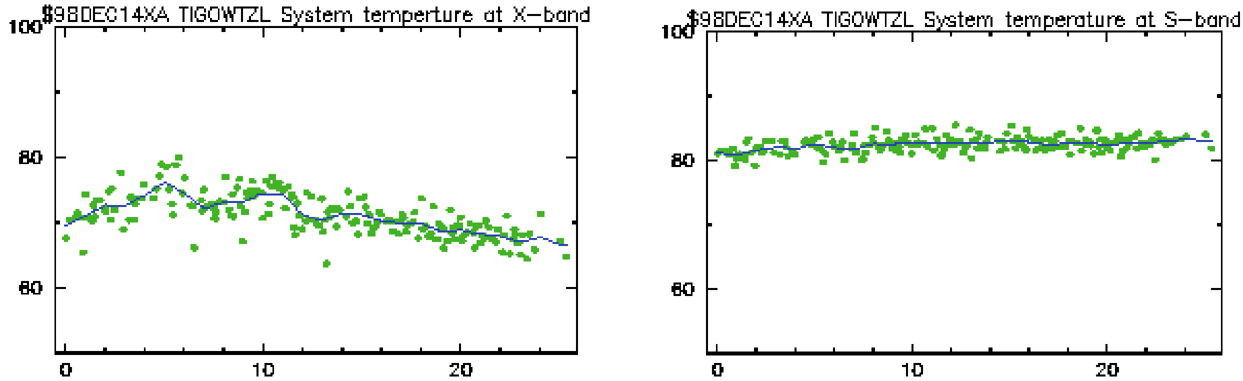

Fig. 2: System temperature in X- and S-band versus time in hours during EUROPE-46.

A number of air masses was computed on the basis of elevation angle using Chao wet mapping function [1]. It was found that the system temperature has a weak dependency on a number air mass except slight increasing in observations near zenith (fig. 3). This indicates a little spillover of ground noise due to the small dish diameter.

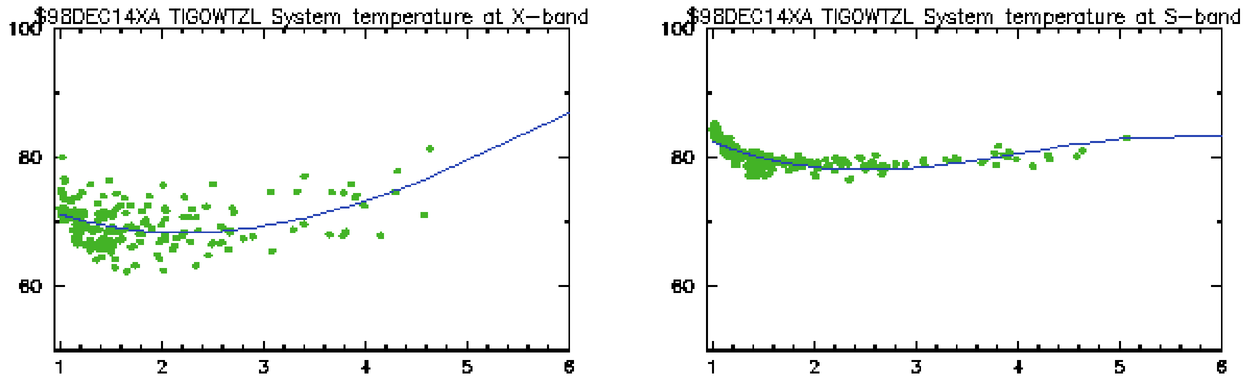

Fig. 3: System temperature in X- and S-band versus number of air masses.

TIGO and Wettzell used their own H-masers in all experiments. Therefore the clock performance could be studied. The analysis of clock performance didn't reveal any problems. Plots of the TIGO clock behaviour relative to Wettzell during the experiment 98JUL20XK as a function of time obtained from the baseline TIGOWTZL–WETTZELL (after subtraction of a linear trend) are shown in figure 4 (phase delay solution left and group delay solution right). We see only smooth variations within [-100, +100] psec interval which indicate both a good quality of hydrogen frequency standards and the lack of strong instrumental errors of clock-like nature. There is no substantial deviation between the clock function derived from phase and group delay measurements.

Under the best sky conditions (clear night) the system equivalent flux density (SEFD) is about 7000 Jy at X-band and 13000 Jy at S-band. Aperture efficiency is 70% at X-band. The S-band performance is not as good as in X-band.

One of the reasons might be that the S-band polarizer is realized by outcouplers from the feed and a coaxial combining networking. It therefore requires a piece of cable to guide the S-band signals into the dewar. This is different for the X-band which is guided through waveguides and via a waveguide polarizer directly into the dewar. Therefore the signal flow between the feed and the dewar with its first, cryogenic amplifier is different for both bands. Dual frequency feedhorns require always a compromise in their optimization. Since the wavelengths in X-band are shorter and therefore more

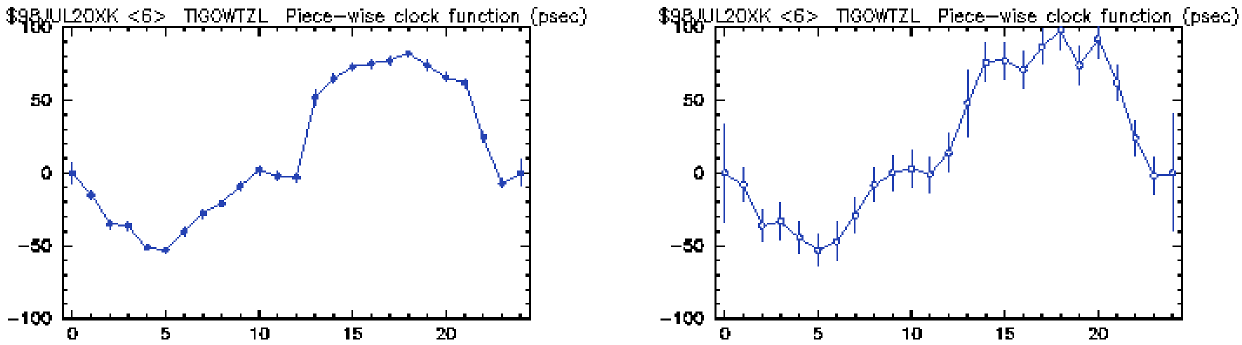

Fig. 4: Clock behavior of TIGOWTZL relative to WETTZELL in phase delay and group delay solution after removal of linear trend. Argument is time in hours.

accurate, the TIGO feedhorn was optimized for X-band reception. However the losses in the short piece of cable before the amplifier are critical for the performance in S-band and can still be optimized.

Another possible cause for the high SEFD in S-band might be spillover in S-band, which has been experienced and is a known problem with primary focus antennas. In addition a parasite leakage of left hand circulated polarization is possible. These suggestions are still under investigation.

TIGO participated in too few campaigns to gather sufficient statistics for the investigation of its repeatability on long baselines. We can compare formal uncertainties of TIGO position adjustments with uncertainties of station position adjustments of the 20-meter antenna WETTZELL. A special analysis of the experiment Europe43 has been made. The data set was slightly reduced: only those scans where both TIGOWTZL and WETTZELL provided observations of good quality were left, other scans where one of the stations didn't observe or yielded observations of bad quality were not used in this analysis. Two solutions were produced: all observations of WETTZELL had been excluded in the first run and all observations of TIGOWTZL had been excluded in the second run. Formal uncertainties of the stations position obtained in these solutions are presented in the table 2.

Tab. 2: Comparison of station coordinates from two analyses of EUROPE-43 with either TIGOWTZL or WETTZELL as a network station. The network configuration is almost exactly the same.

Comp	TIGOWTZL	WETTZELL
U-comp	16.0 mm	10.7 mm
E-comp	3.8 mm	2.4 mm
N-comp	5.0 mm	3.6 mm

We modeled the situation what would occur if the 6-meters TIGO radiotelescope would replace the 20-meter WETTZELL antenna in that experiment. The geometry of the network is almost identical, the number of measurements is the same, the only factors which affect the results are differences in stations performance. The answer is: the formal uncertainties of the station position would increase by 50%.

Phase delay and group delay solutions were obtained using only observations at the short baseline TIGOWTZL–WETTZELL (see fig 5). Phase delay ambiguities can be easily resolved for a short baseline. Residual plots of the baseline length are presented in figure 6.

The values of the baseline length agree very well with the results of measurements of the baseline derived from local surveys. Up to now only two independent local surveys have been carried out. In 1996 one survey of the control network of existing Wettzell station was carried out by H. Lang with high precise theodolites, ranging instrument Mekometer 5000 and GPS receivers [3]. At that time the TIGO reference markers for the TIGO network had not been installed. In 1997 another local survey of the TIGO network and its reference markers which can be seen as an appendix to the Wettzell control network had been conducted by C. Jocham with a tachymeter Sokkia Net2B and leveling instrument Zeiss DiNi10 [4]. Both independent campaigns have been transformed using identical points of both networks and resulting in the baseline length derived from the local survey given in table 3. A new

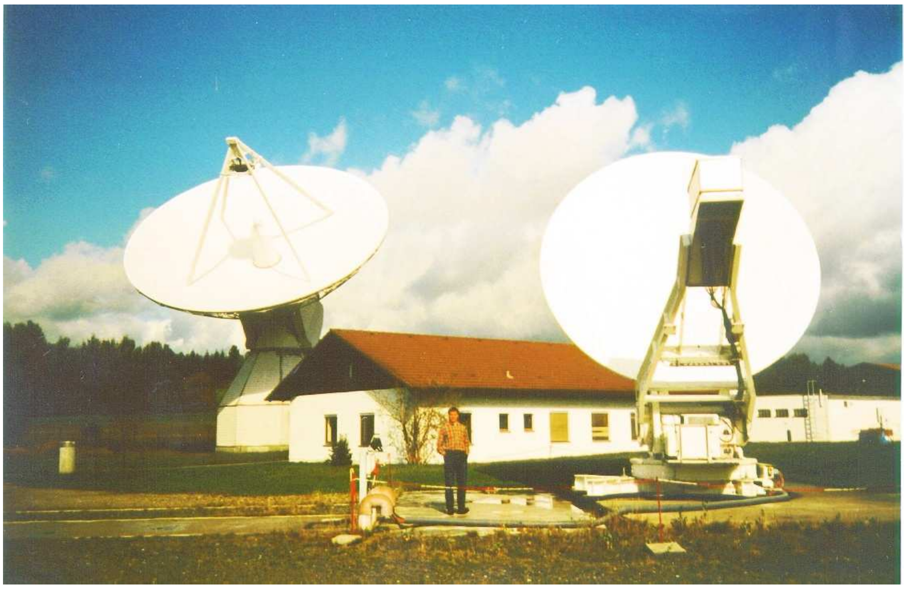

Fig. 5: 20-meter antenna WETTZELL (left) and 6-meter antenna TIGO(right)

local survey of the new extended Wettzell control network with the direct measurement of the baseline WETTZELL-TIGOWTZL is planned in 1999.

Tab. 3: Baseline WETTZELL–TIGOWTZL determined with different methods (in mm).

Data	Average	σ	repeatability
X-band group delay	59124.8	2.5	1.6
X-band phase delay	59124.8	0.3	0.4
local survey	59125.9	0.7	—

The formal errors of the baseline length determination from phase delay VLBI are about 0.3mm and the repeatability of the adjustments over 5 experiments provides the estimates of the formal errors. They indicate due to the lack of systematics of instrumental nature the possibility to achieve an accuracy in the determination of station position at submillimeter level. This accuracy approaches the mechanical limit of 0.2 mm which is the amount of space in each of the bearings in order to allow the antenna to move.

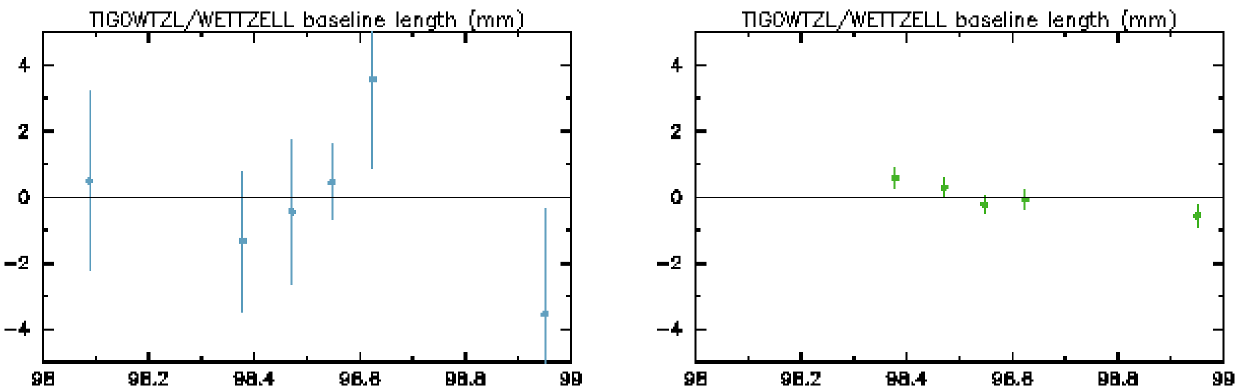

Fig. 6: Baseline length evolution after removal the average value obtained from group delay solutions (left) and from phase delay solutions (right). Argument is time in years.

4 Conclusions

The participation of 6-meter TIGO antenna in real VLBI experiments is considered as successful. Formal uncertainties of vertical position are in the range 10–20mm and formal uncertainties of determination of horizontal position are in the range 2–4mm. Accuracy of determination of the short baseline TIGOWTZL–WETTZELL shows the lack of systematic effects exceeding 1mm level. The VLBI-Module is ready for its operational use. The major remaining problem is the sensitivity at S-band which is lower than expected. Ways of increasing the sensitivity at S-band are being investigated.

Acknowledgement

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References

[1] Chao, C.C.: A model for tropospheric calibration from daily surface and radiosonde balloon measurements. Technical Memo, 391-350, Jet Propulsion Laboratory, 1972

[2] Hase, H.: TIGO and its Future Application for the ITRF, Proceedings of the GEMSTONE Meeting, Tokio-Koganei, January 25-28, 1999, *(in preparation)*

[3] Jocham, C.: Einmessung und Koordinierung eines Radio- und eines Laserteleskopes auf der Fundamentalstation Wettzell, Fachhochschule München, unpublished diploma thesis, 1998 *(in German)*

[4] Lang, H.: Das 3D-Überwachungsnetz der Fundamentalstation Wettzell als Kombination von GPS- und terrestrischen Messungen. Allgemeine Vermessungsnachrichten, S. 203-213, Karlsruhe, 1996 *(in German)*