# Laser Radar Ranging and Atmospheric Lidar Techniques II

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# Laser Radar Ranging and Atmospheric Lidar Techniques II

Ulrich Schreiber
Christian Werner
*Chairs/Editors*

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# Laser Ranging I

**Invited Paper**

# TIGO – a geodetic observatory for the improvement of the global reference frame

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## ABSTRACT

The Bundesamt für Kartographie und Geodäsie (BKG) will provide a major contribution to the improvement and maintenance of the global reference frames

- ICRF (International Celestial Reference Frame),
- ITRF (International Terrestrial Reference Frame)

with the operation of

- TIGO (Transportable Integrated Geodetic Observatory).

TIGO is designed as a transportable geodetic observatory which consists of all relevant geodetic space techniques for a fundamental station (including VLBI, SLR, GPS). The transportability of the observatory enables to fill up gaps in the International Space Geodetic Network (ISGN) and to optimise the contribution to the global reference frames. TIGO should operate for a period of 2 to 3 years (at minimum) at one location. BKG is looking for a cooperation with countries willing to contribute to the ITRF and to support the operation of TIGO.

**Keywords:** reference frame, ICRF, ITRF, TIGO, geodesy, observatory, SLR, VLBI, GPS, fundamental station

## 1. OBJECTIVES OF TIGO

The global reference frames ICRF (International Celestial Reference Frame) and ITRF (International Terrestrial Reference Frame) are the basis for all geodetic reference frames applied in continental and national areas. Today the geodetic space techniques are highly efficient and cost-effective for scientific and practical applications. The geodetic space techniques such as

- VLBI (Very Long Baseline Interferometry),
- SLR (Satellite Laser Ranging),
- Microwave based observations to navigation systems,
  - GPS (Global Positioning System),
  - DORIS (Doppler Orbitography and Radiolocation Integrated by Satellite),

are realizing the global reference frame ITRF through an international network of geodetic space stations – the International Space Geodetic Network (ISGN) – consisting of

- radio telescopes for VLBI,
- laser ranging systems for SLR/LLR,

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- permanent GPS-stations,
- DORIS ground beacons.

The global distribution of the space station is so far unbalanced (IERS, Annual and Technical Reports). Concentrations of stations occure in North-America, Europe and parts of Asia (Japan), whereas gaps in the network are obviously on the Southern Hemisphere (fig. 1).

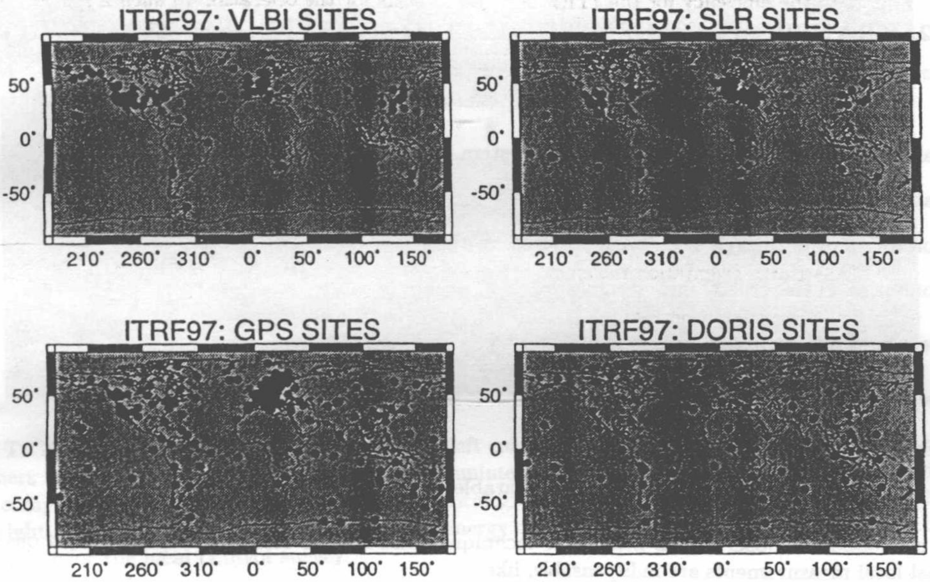

**Figure 1.** Existing sites in the ITRF97 catalog according to the individual geodetic space technique, of which some have been occupied only temporarily. The southern hemisphere has a lack of measuring sites. The purpose of TIGO is improve with additional observations in neglected regions the site distribution within the ITRF (Courtesy of Z. Altamimi, IERS).

For the minimisation of systematic effects and errors the ideal distribution for the ISGN would be a homogeneous network. It is obvious, that the realisation is an international task, regardless to political boarders. International and bilateral cooperations are required, which finally result in the benefit for all by the existence of a highly precise global reference frame.

The international coordination of the contributions is performed through the international services which are under the umbrella of the International Association of Geodesy (IAG), namely the

- IVS (International VLBI Service),
- ILRS (International Laser Ranging Service),
- IGS (International GPS Service).

The combination of the products is guaranteed through the

- IERS (International Earth Rotation Service).

The Bundesamt für Kartographie und Geodäsie (BKG) has developed the Transportable Integrated Geodetic Observatory (TIGO) for the support of the realisation and maintenance of the ITRF and ICRF. TIGO is currently in a test phase and is operated in collocation with the Fundamentalstation Wettzell in Germany. It is planned to start the field operations in the year 2000. Due to the transportability the contribution to the ITRF can be optimised in dependence of the location and of the duration of operation at one site. In order to fill gaps in the ISGN the area for operation is preferably on the southern hemisphere. The operation period at one site is envisaged to approximately 3 years with respect to the efficiency for the ITRF and to the costs for the operation of such a system.

## 2. TRANSPORTABLE INTEGRATED GEODETIC OBSERVATORY (TIGO)

TIGO as shown in figure 2 is a rigorous development of a fundamental station in order to provide observations for the

1. realisation of the geodetic global reference system,
2. maintenance of the global reference frame,
3. monitoring of the Earth orientation parameters,
4. monitoring of the crustal movements.

All relevant geodetic space techniques are employed at TIGO:

- Very Long Baseline Interferometry (VLBI),
- Satellite Laser Ranging (SLR),
- Global Positioning System (GPS) and comparable navigation systems.

For the conduction of observations with space techniques and for the correct interpretation of observational data additional local measurements are indispensable, like

- measurements concerning the local time and frequency keeping providing the local timescale and reference frequencies,
- gravity measurements for monitoring the Earth tides,
- seismic measurements for monitoring earthquakes,
- meteorological measurements for monitoring the troposphere,
- local survey measurements for monitoring the site stability.

TIGO has its own electric power generators in case there is no or instable power supply at the remote site.

Transportability of the observatory is achieved by building the whole observatory into six 40-feet-standard containers, which are certified for sea transportation. It is assumed, that according to its specifications TIGO can be shipped to any remote location outside arctic or antarctic environments in the world. After installation of TIGO some of the containers serve as the operation rooms. Figure 3 gives an overview about TIGO.

It is planned, that TIGO will occupy a remote site for a period of more than two years before it will be moved to another site. The un-/loading procedure of the containers from/to a truck is possible simply with muscle power (no crane needed).

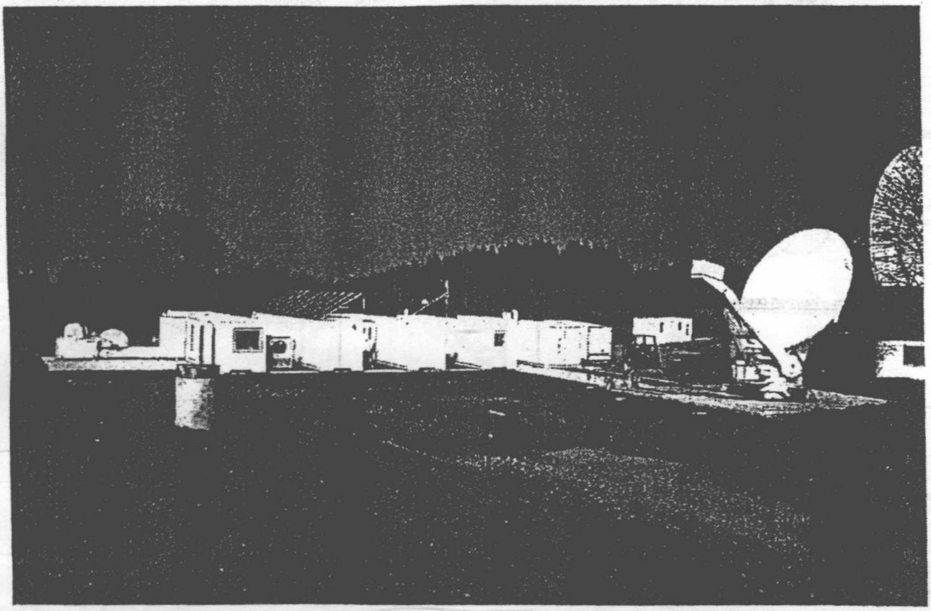

Figure 2. TIGO during tests at Wettzell in 1998. The left container is the SLR-module and its telescope. The next two containers house the solar energy power supply as uninterruptable power supply, atomic clocks and frequency standards, computer and communication facilities, meteorological sensors. The VLBI-module and its radio telescope are on the right. The sixth container in the back is the energy module with Diesel generators. The foreground shows a reference pillar for the local control survey.

## 2.1. VLBI

Very Long Baseline Interferometry (VLBI) is a geometric technique which measures the time difference between the arrival at at least two Earth based radio telescopes of a radio wavefront emitted by a distant quasar. Because the time difference measurements are precise to a few picoseconds, VLBI determines the relative positions of the cooperating radio telescopes to a few millimeter and the positions of the quasars to a few milliarcseconds. The very distant quasars provide an inertial reference frame which is two orders of magnitude more accurate than the well-known fundamental catalog of fix stars FK5. Since the radio telescopes are fixed on the rotating Earth, VLBI tracks instantaneous the orientation of the Earth in an inertial reference frame - an indispensable information for any kind of satellite orbit determinations.

VLBI observations as a microwave technique can be performed under all meteorological conditions.

The elements of a geodetic VLBI station consists in general of

- a radio telescope with a cryogenic dual band S/X-band receiver,
- a data acquisition terminal for bandwidth frequency synthesis,
- a hydrogen maser as very precise frequency standard to which all local oscillators in a VLBI-system must be phase-locked,
- a data formatting and recording device for the temporary storage of digitised quasar noise.

Usually the VLBI-data consists of digitised noise from the quasar and is recorded with a time stamp on magnetic tapes at the stations. After the completion of the observations within an experiment the magnetic tapes must be

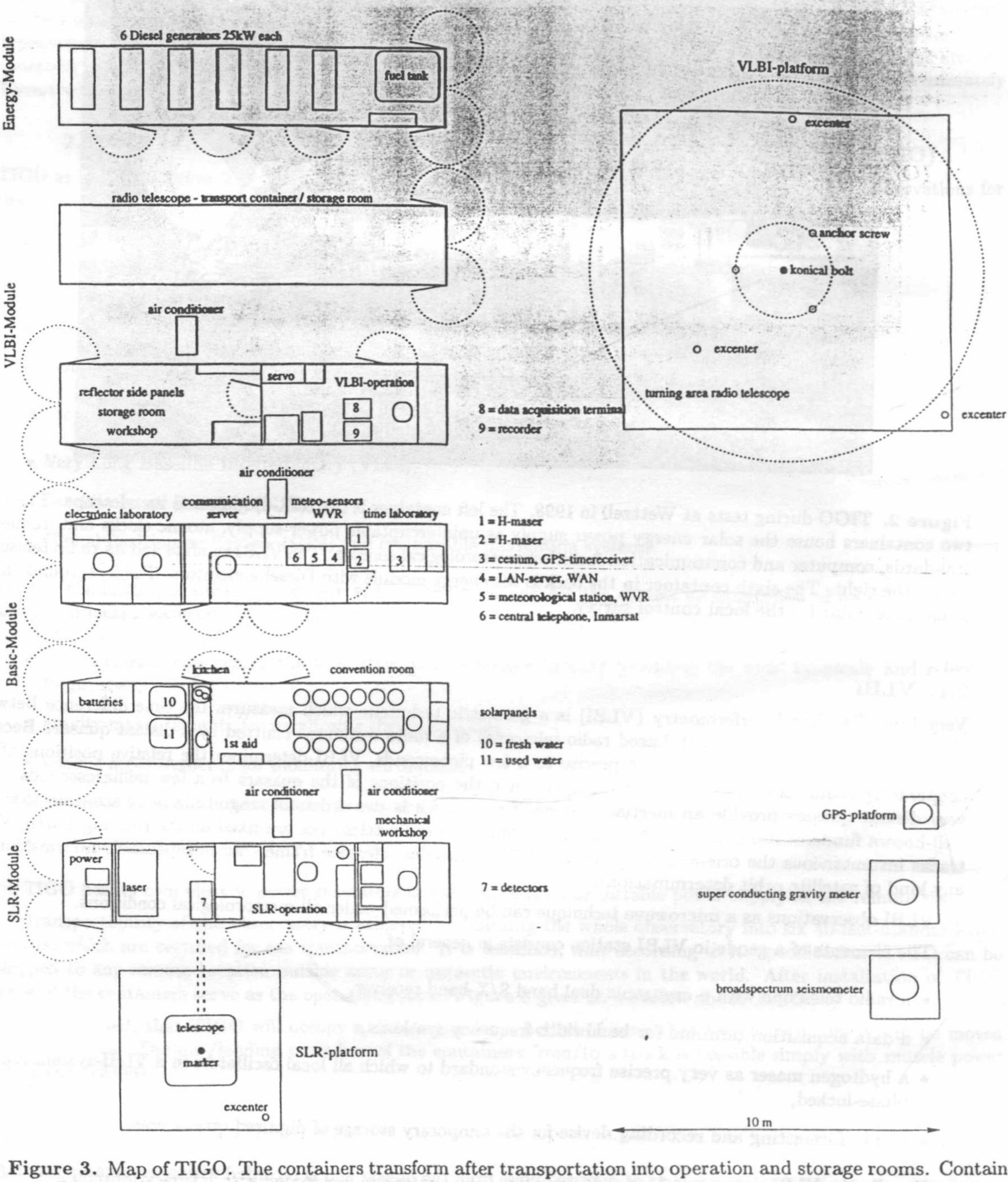

**Figure 3.** Map of TIGO. The containers transform after transportation into operation and storage rooms. Containers and the telescope platforms are linked by underground cable channels. The mount of the radio telescope requires a special prepared platform.

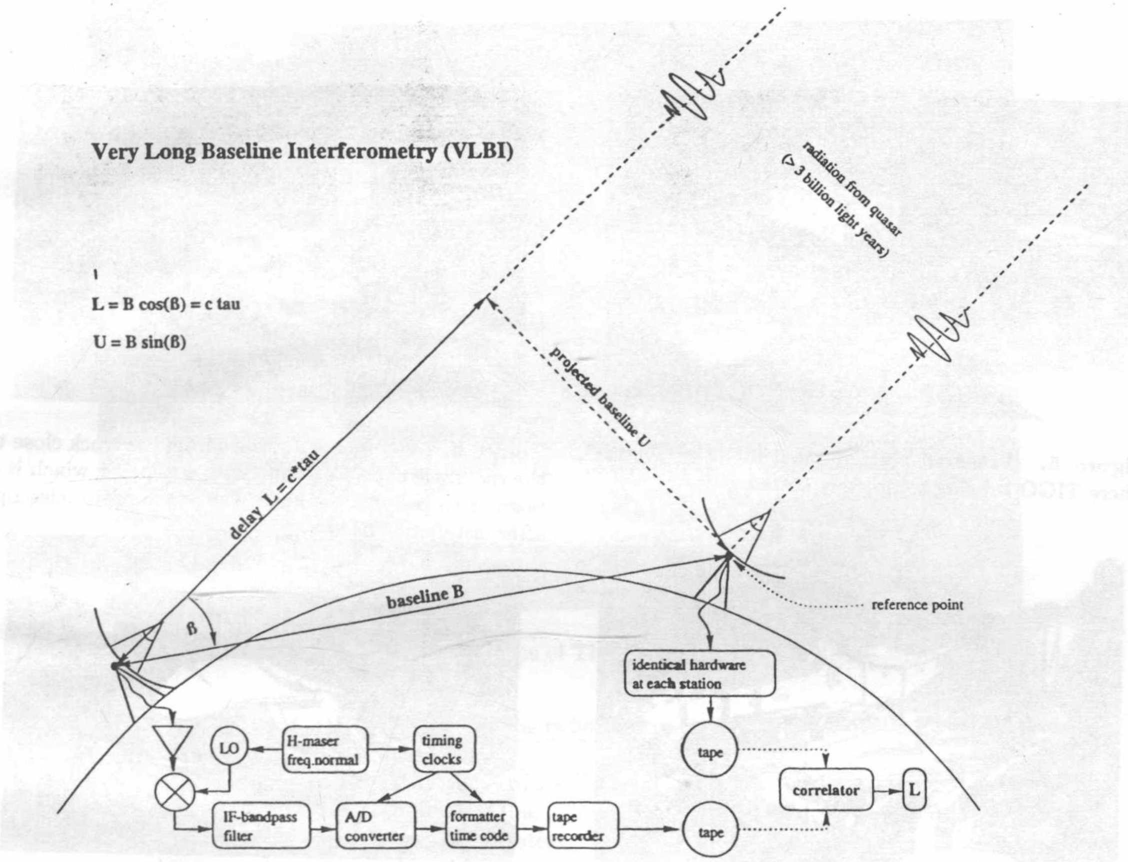

Figure 4. Principle of Very Long Baseline Interferometry shown in a tape recorder correlation interferometer.

shipped from all co-observing stations to a VLBI-correlator. After the arrival of these tapes the interferometer is setup at the correlator. The correlation process plays back the recorded data from all the station simultaneously and the processor searches for the maximum of the cross-correlation-function. The correlator output are the fringe phase and the fringe amplitude from which the delay and delay rate of the wavefront can be derived. The delay is the primary observable in geodetic VLBI and shown in figure 4.

### 2.1.1. TIGO VLBI-Module

The VLBI-module contains a 6 meter offset-radio telescope, which is the largest instrument of TIGO. Its mass is about 23 tons. The radio telescope can be transported in two containers. The design allows that two persons are able to setup the whole VLBI-module within a week without any crane (fig. 5 - 10).

The technical parameters of the TIGO radio telescope are summarised in table 1.

The data acquisition terminal is a Mark IV compatible so called VLBA4 terminal. It is controlled by the NASA PC Field System running on PC under the Linux operating system. The data are recorded on one-inch magnetic thin tapes at the VLBA4 recorder.

Usually the VLBI operation is scheduled within the International VLBI Service (IVS). The main program is the continuous observation of the rotation of Earth (CORE) in which a VLBI station observes in different global VLBI networks one to three times a week for 24 hours. For a 24 hours experiment with about 300 source observations the

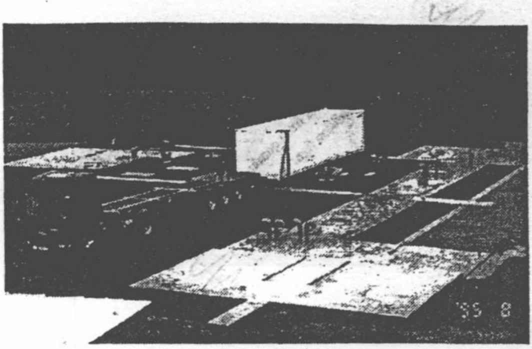

**Figure 5.** Prepared platform for TIGO at Wettzell, where TIGO is being completely tested.

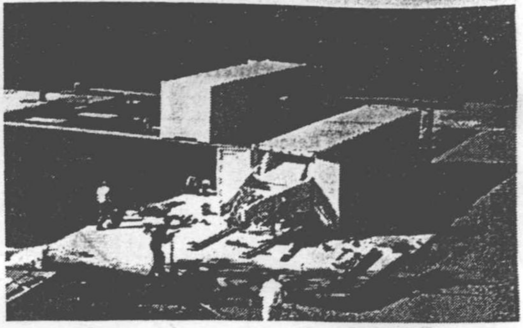

**Figure 6.** Container is unloaded from the truck close to the radio telescope platform. With a gripping winch it is possible to pull out the main part of the radio telescope after installation of two rails.

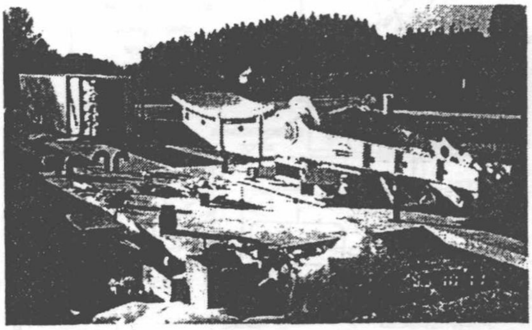

**Figure 7.** The empty transport container is pulled away, hence the radio telescope part rests on the platform.

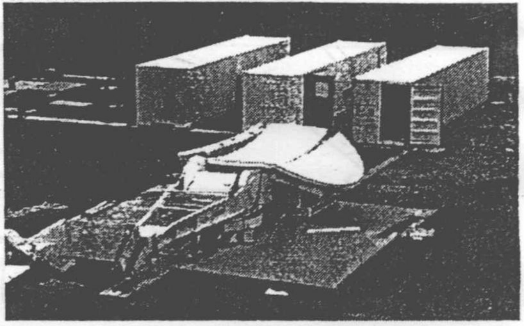

**Figure 8.** Fixation of the two side panels which are transported in the back of the VLBI-operations container.

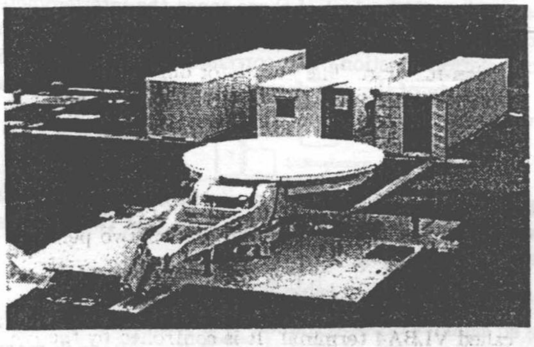

**Figure 9.** Side panels are fixed with braces and precision screws.

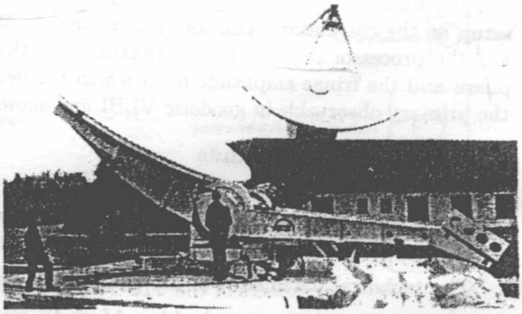

**Figure 10.** Reflector is moved up by motor force, that the receiver comes into the focus.

qualified operator needs about 2 hours of checking out the equipment prior the experiment and about 1 hour for administrative tasks after the experiment. The presence of an operator during the 24 hour of observations to control the overall performance of the automated execution of the observations is a necessity.

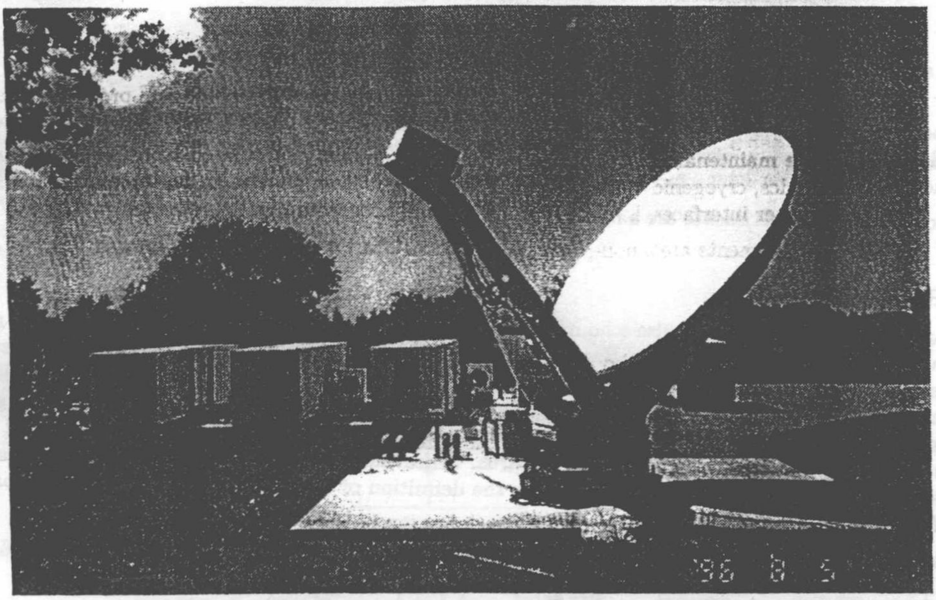

**Figure 11.** Radio telescope of TIGO is operational for VLBI.

**Table 1.** Technical parameters of the radio telescope of TIGO for geodetic VLBI.

| Parameter | TIGO-VLBI |
|---|---|
| owner and operating agency | BKG |
| year of construction | 1995 |
| radio telescope system | offset |
| receiving feed | primary focus |
| diameter of main reflector $d$ | 6 m |
| focal length $f$ | 2.18 m |
| $f/d$ | 0.3629 |
| surface contour of reflector | ± 0.2 mm |
| X-band<br>($\nu_{ref}$ = 8.4 GHz, $\lambda$ = 0.0357 m) | 8.1 – 8.9 GHz |
| $T_{sys}$ | 65 K |
| $S_{SEFD}$ | 7700 Jy |
| $G/T$ | 35.5 dB/K |
| $\eta$ | 0.824 |
| S-band<br>($\nu_{ref}$ = 2.3 GHz, $\lambda$ = 0.1304 m) | 2.2-2.4 GHz |
| $T_{sys}$ | 85 K |
| $S_{SEFD}$ | 12000 Jy |
| $G/T$ | 22.3 dB/K |
| $\eta$ | 0.692 |

The TIGO VLBI-module is equipped with measuring tools like spectrum analyser, frequency and time counters, power meter, digital oscilloscopes, signal generator, chart recorder and the necessary mechanical tools. For the maintenance of the cryogenic cooling system a vacuum pump and helium bottles are available. Many of the most important spare parts are also available in order to minimise the downtime due to technical problems at the remote site.

The operation and the maintenance of the VLBI equipment requires expertise in high frequency technologies, analog and digital electronics, cryogenic cooling, vacuum technology, atom physics for the atomic clocks, mechanics, celestial mechanics, computer interfaces, Linux operating system, programming.

The geodetic VLBI experiments are a non-profit international effort organised by the International VLBI Service (IVS) *.

## 2.2. SLR

Satellite Laser Ranging (SLR) is a pulse-echo measuring technique, which uses lasers to measure ranges from ground stations to satellite borne retro-reflectors. Because the events of sending and receiving a pulse can be registered within a few picoseconds, SLR determines the position of the ground station and of the satellite within a few millimeter. SLR is a dynamical measuring technique since the target at the satellite is moving in an orbit through the gravitational field of Earth. Hence the satellite is a sensor for the lower frequency parts of Earth's gravitational field, which allows the determination of the center of mass of Earth. Since the very compact and passive SLR-satellites have a very stable orbit, SLR plays an indispensable role in the definition of the origin and the scale of a global geocentric reference frame.

SLR is due to the use of optical wavelength dependent on clear sky and the absence of clouds during the satellite passes.

The elements of a SLR-station are shown in figure 12 and consists in general of

- an optical telescope for high-energy laser pulses,
- a laser pulse generator,
- a time measurement system with event timers,
- a control computer for the computation of orbit predictions, controlling the telescope and processing the returns.

Predicted orbits are available for each satellite in order to compute the pointing angles for the telescope tracking. Operators adjust three offsets: time bias, along-track and across-track in order to find return signals. The registered returns are processed at the SLR-station after the observation has been made. Several hundreds of returns are summarised to a few so called normal points. The tracking report after a successful observation contains information about the offsets to the predicted orbit elements and the normal-points.

### 2.2.1. TIGO SLR-Module

The TIGO SLR-module consists of one container in which the telescope and the necessary equipment can be stored during the transportation. At the remote site the cart mounted 50cm-optical-telescope can be positioned precisely above the reference marker. The components of the laser pulse generation and detectors are indoors in a clean-room environment. The laser pulses are guided through a connecting tunnel between telescope and container. The SLR-system is specified to track from low orbit satellites at about 300 km altitude up to geostationary satellites at about 36000 km altitude. If the telescope is moved out of the container, the gained space is transformed into the operators room from which the laser ranging is performed.

The Gallilean type laser telescope contains a system of two mirrors which are inclinated with respect to the telescope main axis. Therefore the folded beam enables a very compact design of the telescope and the use of the full aperture of 50 cm avoiding any front lens mirror (fig. 13).

The azimuth bearing is realized as an air bearing over a polished granite block. Therefore the mass of the cart with telescope is about 1700 kg.

The laser system provides two colours based on Titan-Sapphire crystal which is tuned to wavelengths of 847 nm and 423.5 nm. The Titan-Sapphire laser amplifiers are pumped with Nd:YAG laser as shown in figure 14. The SLR-module contains for the use at a remote location without prohibited zone for aircrafts a Doppler radar for aircraft detection. The technical parameters are summarised in table 2.

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*`http://ivscc.gsfc.nasa.gov`