

TIGO – Transportable Integrated Geodetic Observatory

Hayo Hase, Armin Böer, Stefan Riepl, Wolfgang Schlüter, Adriano Cecioni

March 7, 2001

Abstract

The Transportable Integrated Geodetic Observatory (TIGO) is a fundamental station for geodesy built by the Bundesamt für Kartographie und Geodäsie (BKG) in Germany. Its purpose is to provide observational data for international services from a remote location in order to improve the realisation and maintenance of global reference frames. After an international invitation to bid for finding hosting countries for TIGO, the application from a consortium in Concepción was selected to host and operate TIGO jointly with BKG. The instrumentation of TIGO allows complementary observations with geodetic space techniques (VLBI, SLR, GPS) which are necessary to realise fundamental reference points in global reference systems. Some technical details about TIGO are given.

1 Reference Systems and Geodetic Observatories

Geodesy is the science of determining the size and the figure of the Earth and its external gravity field [7]. Geodesists want to map the topography of Earth which requires at least one reference system. As a matter of fact many different reference systems are existing mainly for historical and practical reasons. Geodetic reference systems can be ordered in a hierarchy in which the inertial *Celestial Reference System* (CRS) in space marks the top followed by the comoving global *Terrestrial Reference System* (TRS) with continental and national subsets until subsequent regional reference systems for land registration and cadastre at the lower end. *References systems* are based on theoretical definitions, while *reference frames* as their realisations are based on measurements or observations [6]. The measurements can be performed with different levels of precision. The measurement method determines to which extend in space the reference frame is applicable.

The reference frames are usually expressed with *coordinates* (and its *coordinate velocity*) [5]. Different reference frames are requested by users for their applications in (space) navigation, mapping, planing, land register, constructions, but also for science.

The realisation of reference systems for the Earth requires sets of materialised markers at the surface of the Earth. The number of markers must satisfy at least the degrees of freedom of the chosen reference frame. The markers are usually reference points for observations to other reference points.

The Terrestrial Reference System covers the entire Earth and

- should be linked to an inertial reference frame in the universe in order to describe Earth's position in space and
- should provide a stable frame for all subsequent continental, national, regional and local reference frames to describe any position on Earth's surface.

The Terrestrial Reference System is realised by geodetic observatories as reference points. The geodetic observatories employ modern space geodetic measurement methods at the highest precision level which allow precise coordinate determinations on a global scale. The techniques being used are:

- *Very Long Baseline Interferometry* (VLBI) with radiotelescopes providing the link to the inertial celestial reference frame of quasars,
- *Satellite Laser Ranging* (SLR) with optical laser telescopes contributing to the definition of the center of mass, determination of the external gravity field,

- *microwave based navigationsystems* such as GPS, GLONASS and DORIS contributing with global geodetic networks.

These geodetic space techniques provide a relative accuracy of $10^{-8} \dots 10^{-9}$, which corresponds e.g. to an uncertainty of 1 cm on a 10.000 km baseline.

The terrestrial reference frame is realised by geodetic observatories, which are located on a visco-elastic Earth body. The Earth's crust is deformed permanently on the level of several decimeter e.g. due to tides. Therefore only continuous observations by geodetic observatories allow a sufficient sampling of the geodynamic phenomena for a proper modelling (see fig. 1).

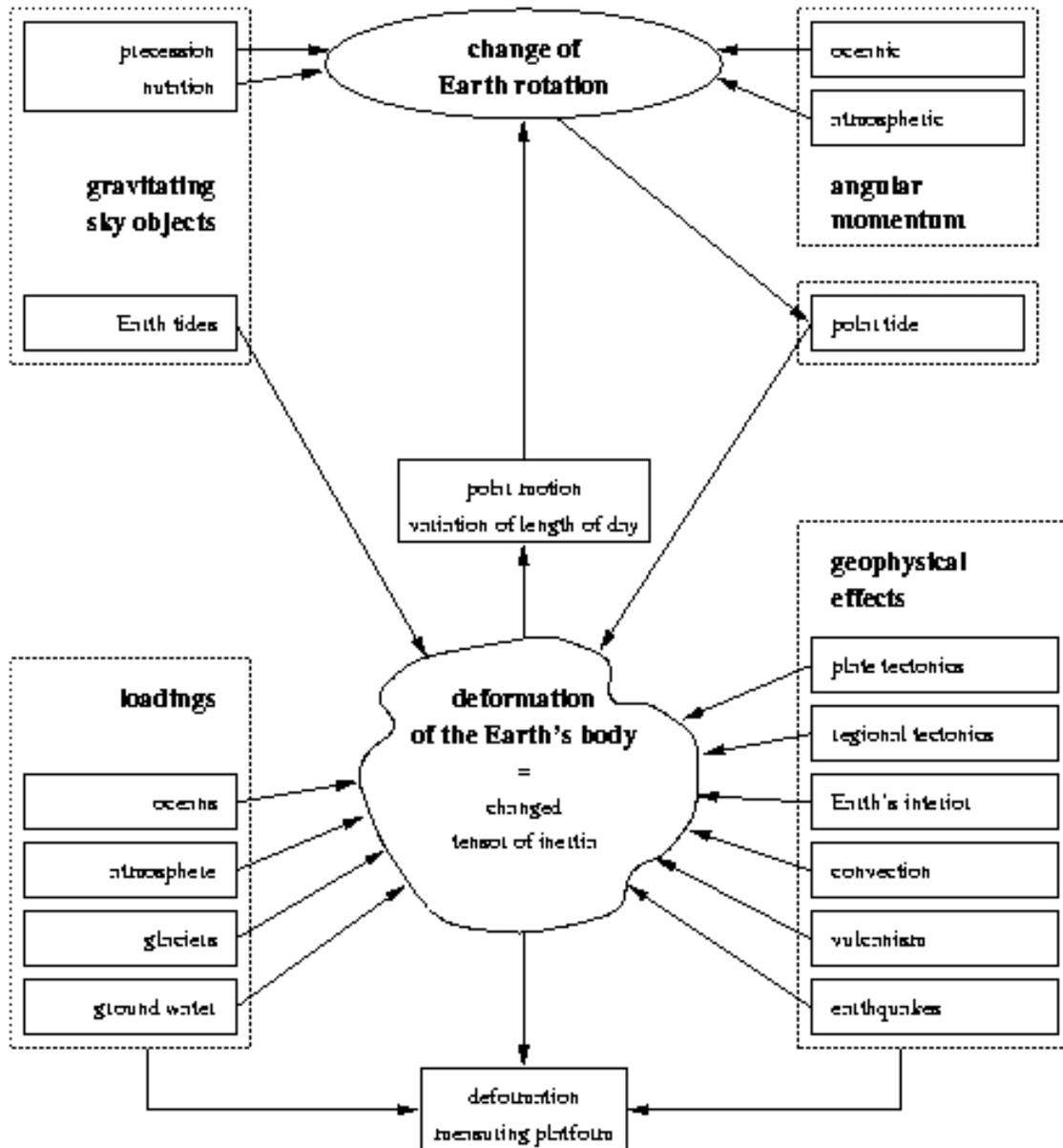


Fig. 1: Observations for the realisation of global reference systems contain signals from a variety of geodynamic phenomena. They change the geometrical relations between geodetic observatories and must be modelled properly in order to achieve precise reference frames [3].

A geodetic observatory which meets the attributes of

1. *permanency* of the observation activities,
2. *complementary* of the measuring techniques,
3. *redundancy* of the observations for quality assurance,
4. *provision of eccentricity vectors* between the reference points of the various observation methods

is called a *fundamental station for geodesy* (analogic to *fundamental stars for astronomy*). The network of fundamental stations for geodesy is the backbone for the realisation of the Terrestrial Reference System (see fig. 2, [3]).

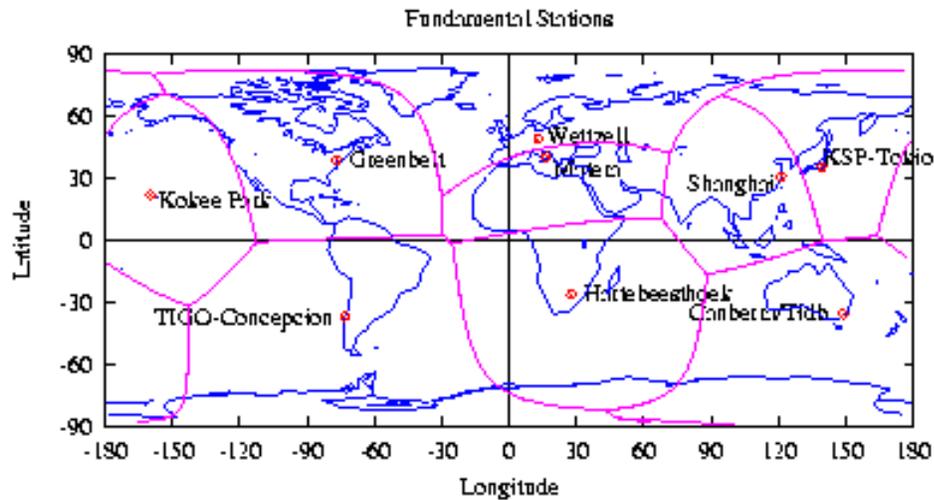


Fig. 2: Voronoi-diagram with respect to existing and future fundamental stations. The Voronoi-lines identify points of maximum distance to the two nearest observatories [2]. An additional fundamental station in Concepción realised by TIGO will represent a large region from the south-east Pacific, South-America, parts of Antarctica to the south-west Atlantic. Without this additional observatory almost a complete hemisphere would be uncovered by fundamental stations [4].

Geodetic observatories which contribute to the international task of realising global reference systems are part of the *International Space Geodetic Network* (ISGN) and have commitments to the international services within the *International Association of Geodesy* (IAG). The products of the international services

- IVS (International VLBI Service)¹,
- ILRS (International Laser Ranging Service)²,
- IGS (International GPS Service)³

like e.g. station positions and velocities, baselines, Earth orientation parameters are continuously analysed and combined for the best achievable global reference frames ITRF and ICRF by the

- IERS (International Earth Rotation Service).⁴

¹<http://ivsc.gsfc.nasa.gov/>

²http://ilrs.gsfc.nasa.gov/ilrs_home.html

³<http://igsb.jpl.nasa.gov/>

⁴<http://hpiers.obspm.fr/>

2 TIGO-Project

2.1 Milestones of the TIGO-Project

The distribution of fundamental station concentrates on the northern hemisphere and its number is low (fig. 2). *Global* geodetic networks require a *global* homogeneous distribution of reference points, otherwise undesirable systematic errors degrade the results of positioning.

Based on this background the German *Research Group for Space Geodesy* (FGS)⁵ proposed in its research program from 1989 the development of a *mobile integrated geodetic measuring platform*. The idea was to build a new transportable fundamental station which can be operated at remote locations in order to improve the distribution of fundamental stations in the global network.

In 1992 the Federal Ministry of Interior agreed to finance the development of the *Transportable Integrated Geodetic Observatory* (TIGO) for a period of five years (1993-1997) with 5 million DM each year. In May 1992 the specification of TIGO had been finished and had been used for an invitation to bid. In December 1992 the main orders for TIGO components were placed.

During June/July 1995 a platform for testing the TIGO components was built at the Fundamental Station Wettzell.

In November 1997 the first VLBI test experiment was carried out with the VLBI-module of TIGO. In January 1998 the first SLR measurements were done with the SLR-module of TIGO. Since then TIGO is continuously improved and equipped by additional sensors, measuring devices and spare parts (fig. 5, see section 2.2 for details).

On April 26, 1999, the Federal Ministry of Interior agreed to the operation of TIGO at a remote location as a German contribution to the international task of the realisation and maintenance of global reference systems.

Consequently the *Announcement of Opportunity* was published in order to find hosting countries for TIGO in July 1999 [1]. By the due date of September 30, 1999, promising proposals from Brazil, Argentine, Chile, India, Philippine and Indonesia had been sent to BKG. In November/December 11 proposed locations in the countries above had been reconitered (fig. 3). All applicants were challenged to send a *Letter of Intend* by January 15, 2000, in which the fulfillments of requests by BKG for the joint operation of TIGO had to be outlined.

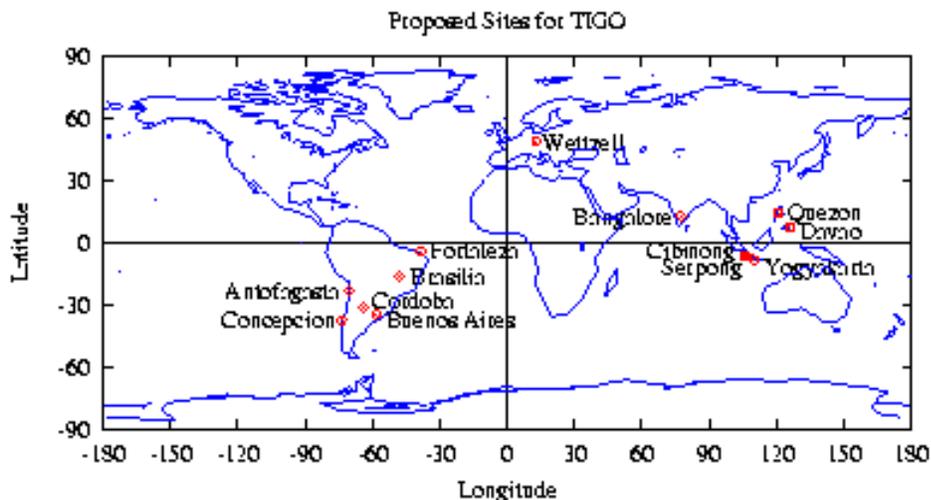


Fig. 3: Proposed sites for TIGO by institutions of the hosting countries, September 30, 1999. TIGO was developed at the fundamental station Wettzell.

⁵The *Forschungsgruppe Satellitengeodäsie* (FGS) coordinates common research activities of the Technische Universität München (TUM), the Geodätisches Institut Universität Bonn (GIUB), the Deutsches Geodätisches Forschungsinstitut München (DGFI) and the Bundesamt für Kartographie und Geodäsie (BKG) with respect to the tasks of the Fundamentalstation Wettzell.

On January 21, 2000, the jury of FGS decided to give the highest priority to the application of a consortium from Concepción, consisting of

- *Universidad de Concepción* (UdeC) as main partner for BKG,
- *Universidad del Bio Bio* (UBB),
- *Universidad Católica de la Santísima Concepción* (UCSC),
- *Instituto Geografico Militar* (IGM) in Santiago.

In March 6-16, 2000, the location for the TIGO-platform was defined at the campus area of UdeC with respect to protection of existing microwave sources in Concepción (see fig. 4). During that period an *Arrangement* between BKG and UdeC as main partner had been drafted.



Fig. 4: The selected site for TIGO in March 2000. TIGO will be installed on the left side on top of the hill. The site is still located at the campus area of Universidad de Concepción in about 2 km distance to the university institutes. It is protected against manmade electromagnetic noise by the surrounding hill chains.

The final version of the *Arrangement* was signed on behalf of the consortium by the rector of UdeC Prof. Lavanchy and the president of BKG Prof. Grünreich in Frankfurt a.M. on June 21, 2000. The minimum period of TIGO being in Concepción will be 3 years with the option of extension on a year-by-year base.

During the second half of 2000 a platform for TIGO and a way to it will be constructed in Concepción in order to receive TIGO in early 2001.

In November 2000 TIGO should be prepared at Wettzell for the transportation to Chile.

In the beginning of 2001 TIGO should start its operation with 11 Chileans from the consortium and 3 Germans from BKG.

2.2 Instrumentation of TIGO

TIGO as shown in figure 5 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 including tides.



Fig. 5: TIGO during tests at Wettzell in 1999. 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 are on the right with its radio telescope in the foreground. A sixth container (not in view) is the energy module with Diesel generators. TIGO was installed on a special prepared platform.

All relevant geodetic space techniques are employed at TIGO [3]:

- Very Long Baseline Interferometry (VLBI),
- Satellite Laser Ranging (SLR),
- Global Positioning System (GPS) and the GLONASS system.

For the performance of observations with geodetic 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 Earth tides,
- seismic measurements for monitoring earthquakes,
- meteorological measurements for monitoring the troposphere,
- local survey measurements for monitoring the site stability and excentricities between the various instrumental reference points.

TIGO has in addition own electric power generators in case of outages or instable power supply.

Figure 6 gives an overview about TIGO.

Transportability of the observatory was achieved by building the whole observatory into six 40-foot-standard containers. After installation of TIGO some of the containers serve as the operation rooms.

2.2.1 TIGO VLBI-Module

About VLBI. Very Long Baseline Interferometry (VLBI) is a geometric technique which measures the time difference between the arrival of 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 and space navigation.

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 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 7.

About VLBI at TIGO. The VLBI-module contains a 6 meter offset-radio telescope, which is the largest instrument of TIGO. It's 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.

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. Each 24 hours experiment consists of about 300 quasar observations about 3-5 minutes each.

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.

2.2.2 TIGO SLR-Module

About 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.

Tab. 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 (reference $\nu = 8.4$ GHz, $\lambda = 0.0357$ m)	8.1 – 8.9 GHz
T_{sys}	65 K
S_{SEFD}	7700 Jy
G/T	35.5 dB/K
η	0.824
S-band (reference $\nu = 2.3$ GHz, $\lambda = 0.1304$ m)	2.2-2.4 GHz
T_{sys}	85 K
S_{SEFD}	12000 Jy
G/T	22.3 dB/K
η	0.692

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 wavelengths dependent on clear sky and the absence of clouds during the satellite passes.

The elements of a SLR-station are shown in figure 8 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.

About SLR at TIGO. The TIGO SLR-module contains the TIGO Laser Ranging System (TLRS). It is designed to measure ranges to satellites with an accuracy better than 0.01 m simultaneously at two wavelengths $\lambda_1 = 847$ nm (near infrared) and $\lambda_2 = 423.5$ nm (violet). The TLRS is specified to track from low orbit satellites at about 300 km altitude up to geostationary satellites in about 36000 km distance.

The TIGO-SLR-Module consists of one 40ft-container in which the telescope and the necessary equipment can be stored during the transportation. The main parts of this system are

- cart-mounted 50cm-optical-telescope with its control unit,
- pulse laser,

- optical transmit/receive unit,
- single photon detectors,
- high accurate timer,
- control computer system with real-time Linux operating system.

Subsystems like aircraft detection radar and dry air compressor for the air bearing are installed as well.

At the remote site the cart-mounted 50cm-optical-telescope can be positioned precisely above the ground reference marker on a solid fundament of concrete. The components of the laser pulse generation and detectors are located indoors in a clean-room environment. The laser pulses are guided through a connecting tunnel between telescope and container. 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 includes two mirrors which are inclined 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 without a central obscuration.

The azimuth bearing is realised as an air bearing over a polished granite block as the static part. Therefore the mass of the cart with telescope is about 1700 kg. The basic tube is made of stainless steel and most of the fixations are made from titanium. Table 2 summarises the technical specifications of the optical telescope.

The laser pulses are generated in a diode pumped Cr:LiSAF oscillator with a repetition rate of 100 MHz. A regenerative Ti:Sapphire amplifier with a pockels cell assembly couples ten times per second one pulse out of the oscillator and amplifies each pulse up to 1 mJ. After that, two Ti:Sapphire multipath amplifier increase the laser pulse to its nominal output energy of about 60 mJ. The second harmonic generation divides this energy to about 30 mJ at each wavelength. Table 2 shows the technical parameter of the two-colour laser system.

The epoch event timer system measures the epochs of start events (pulse transmitted) and the epochs of the stop events (return pulse detected). It has 4 independent channels with a resolution of 1.2 ps and an accuracy of better than 5 ps rms. In addition the event timer generates the gating signal for the detectors. The interface to the host computer is performed as a standard serial port. The parameters of the event timer are listed in table 2.

Tab. 2: Technical parameters of the optical telescope, the laser system and the epoch event timing system for the TLRS.

Mass	1.700 kg
Dimensions (length, width, height)	1.3 m × 1.30 m × 2.0 m
Speed	15°/s azimuth, 6°/s elevation
Max. field of view	4 arcmin
Optical efficiency	75% 847 nm, 65 % 423.5 nm, 30% 550 nm
Aberation correction	847 nm, 423.5 nm
Wavelengths	847 nm, 423.5 nm
Pulse duration	80 ps
Pulse energy	30 mJ @ 847 nm and 423.5 nm
Pulse rate	10 Hz
Event timer channels	4
Event timer resolution	1.2 ps, 64 bit
Jitter	< 3.6 ps
Stability	< 0.3 ps/K, < ± 0.5 ps/h

The control software of the telescope control unit executes three tasks:

- computations of the orbit predictions in order to be able to track satellites,
- overall control of the measurements, which means downloading of the predictions into the mount controller and the event timer plus the permanent reading of detections of events from the event timer,
- evaluation of the measured data consists of the postprocessing of the range measurements.

The control software allows adjustments to the telescope tracking, the optical unit and the range gate generator. The complete software runs on a Linux-based PC.

2.2.3 TIGO Basic-Module

The basic-module of TIGO comprises devices for

- microwave techniques such as GPS-receivers,
- time and frequency keeping,
- gravity measurements,
- seismic measurements,
- meteorological measurements,
- the local survey of TIGO,
- data administration and communication,
- local energy generation,
- maintenance of the TIGO devices, and
- a social room

described in the following paragraphs.

GPS. TIGO includes four permanent GPS Ashtech Z12 receivers with choke ring antennas. One receiver will be collocated at the TIGO platform next to the VLBI- and SLR-telescopes. Three receivers will be used in the region around the TIGO platform in order to monitor the site stability.

The data of all four GPS receivers will be administrated and made available through the central data server of the basic module of TIGO.

Time and Frequency. TIGO contains two hydrogen masers, two cesium standards and two GPS time receivers (fig. 10). These oscillators are referenced to one cesium standard as master clock of TIGO by using 1 pps signals which are derived from phase locked clock modules. A control computer registers each 3 hours the clock offsets. Occasionally the clock rates must be readjusted. The offset of TIGO master clock versus GPS can be reported to the BIPM⁶ in Paris since the requested hardware for the international timing service is available.

The TIGO time and frequency standards are powered by batteries, which are charged by solar energy and station power.

Gravity. A superconducting gravity meter is part of TIGO (fig. 11). The measurement principle of this instrument consists of a hollow sphere suspended by a magnetic field which is produced by currents in superconducting coils. Owing to the missing resistance the currents in the coils are nearly constant, therefore this gravity meter has a long-term stability. Forces acting by accelerations on the probing body are compensated by regulating the current in an additional coil, which serves as the signal.

Due to the small instrumental drift and the high resolution of the signal (relative sensitivity of 10^{-11}) it is possible to cover the spectral range of the acceleration variation from seismic eigenmodes over the Earth main tides up to the variation in the centrifugal force due to the Chandler period of about 435 days in the polar motion.

A superconducting gravity meter requires a silent pillar indoors. The cryogenic cooling is achieved with a helium compressor.

⁶<http://www.bipm.fr>

Seismicity. The TIGO broad spectrum seismometer is a Güralp Systems CMG-3T instrument. It consists of 3 orthogonal sensors with a sensor mass of 0.180 kg each. The positions of the masses are monitored by capacitive sensor. The processed signal outputs are position and velocity of the sensor masses in vertical, north-south and east-west direction.

The TIGO seismometer is designed to be located at a silent place near the TIGO platform. It has a solar panel for its local energy supply and is controlled remotely via 200 m long optical fibres from the basic-module of TIGO. The time reference is taken from an own GPS-time receiver at the seismometer site.

Meteorology. TIGO contains a complete meteorological station with sensors for dry temperature, relative humidity, air pressure, wind direction, wind velocity and a rain counter. In addition a water vapour radiometer (WVR) is used for the determination of the water content in the atmosphere which is used for the derivation of the zenith wet path delay of microwave propagation in the atmosphere.

The weather samples are recorded each 15 minutes by a computer and are made available via database to the users. Actual weather data samples for the refraction correction during trackings are also available.

The WVR measures continuously profiles at different directions. One profiling takes about 15 minutes and results in one zenith wet path delay value.

Local Survey. The local survey at a fundamental station with various geodetic space techniques ties the reference points of the telescopes and phase centers into a local geodetic network. The space vectors between the reference points enable the tie among the geodetic space techniques. Since geodetic space techniques are accurate to a few millimeter in a global scale, the local survey should aim to be one magnitude better in accuracy. Therefore only geodetic precision instruments can be used for this task.

A periodically repetition of the local network measurement verifies the stability of the TIGO platform with respect to its local surroundings. For this purpose special monuments must be available at the TIGO platform. The regional stability is monitored with the TIGO-GPS-array (see above).

The local survey equipment of TIGO consists of a tachymeter Geotronics Bergstrand, a digital levelling instrument Zeiss DiNi11 and accessories. A processing software called GeoGenius is also included.

Data Administration and Communications. Observation schedules and logfiles as well as acquired data needs to be temporarily stored or archived, administrated and send to or received from the user communities. These are tasks for the central computer server which is the interface to the wide area network.

A Linux based PC-server with a RAID fix-disk mass storage system, a backup system and a CD-writer is available. The TIGO-LAN is based on optical fibres between the server and hubs inside the containers. The backup systems are part of the server. The server is powered by an uninterruptable power supply. All TIGO printers are connected to the LAN. The database of TIGO is based on PostgreSQL.

For communications TIGO owns a telephone system based on ISDN technology and an Inmarsat telephone (for emergency calls).

Several spare parts for the LAN and tools are available.

Maintenance. Technical devices function properly if they are maintained regularly. Therefore workshops are indispensable in which repairs and maintenance procedures can be performed.

TIGO is equipped with a 2 workspaces electronic laboratory and a 1 workspace fine mechanical workshop. Necessary tools and materials for TIGO are present.

For several tasks heavy goods needs to be lifted. TIGO owns a Toyota forklift of the 2 tons class.

Social Room. TIGO has one convention room for 14 persons in order to organise working shifts at staff meetings.

The convention room contains also the first-aid equipment.

A small kitchen offers for operators during night shifts the possibility to warm up meals. TIGO has a fresh water tank for about 500 liters and another one as sewage collector. TIGO is designed to treat the environment friendly.

2.2.4 TIGO Energy-Module

Any activity requires energy. Moving telescopes, air-conditioning, running computers and atomic clocks require stable and continuous power supply. If the remote site cannot provide electricity according to north European standards, TIGO can be powered autonomously by its Diesel generators. Six 25 kW generators are available and can be used according to the necessary load. The maximum load is expected to be about 120kW, that means that always one generator can be maintained without interruption of the operation.

Atomic clocks and some computers have to be powered continuously. Therefore an additional solar energy supply, consisting of 4 kW solar panels mounted on top of one of the containers and the necessary batteries, realises the uninterruptable power supply. The batteries can be charged by the generators as well.

3 Conclusions and Outlook

TIGO is a geodetic observatory. Its purpose is to produce observational data to the international services with the highest possible precision. The first location for TIGO in a hosting country was selected with a lot of consideration for the success of TIGO. TIGO is the largest project of BKG and is unique in the world.

Observational data production requires manpower to operate such an observatory 7 days a week, 24 hours a day. Eleven specialists from the Chilean partner consortium and three experts from BKG will be responsible for the successful operation of TIGO.

TIGO offers a lot of possibilities for science and research work: While engineers may improve the existing measuring systems, researchers may analyse the with TIGO locally acquired data and interpret it in a global context.

TIGO will link Concepción not only to the most remote objects in the universe and to Earth orbiting satellites but also to many scientists and engineers around the world.

References

- [1] Announcement of Opportunity on Hosting TIGO, <http://www.wettzell.ifag.de/tigo>
- [2] Hase, H.: New Method for the Selection of Additional Sites for the Homogenisation of an Inhomogeneous Cospherical Point Distribution, in: Int. Ass. of Geodesy Proceedings, Towards an Integrated Global Geodetic Observing System (IGGOS), Munich, October 5-9, 1998, edited by R. Rummel, H. Drewes, W. Bosch, H. Hornik
- [3] Hase, H.: Theorie und Praxis globaler Bezugssysteme, Mitteilungen des BKG, Band 13, Frankfurt a.M., 1999
- [4] Hase, H., Böer, A., Riepl, S., Schlüter, W.: Transportable Integrated Geodetic Observatory (TIGO), in: IVS 2000 General Meeting Proceedings, Ed. Vandenberg, N., Baver K.D., NASA/CP-2000-209893, 2000 <http://ivscc.gsfc.nasa.gov/publications/gm2000/hase>
- [5] Heitz, S.: Coordinates in Geodesy, Springer, Berlin Heidelberg New York, 1988
- [6] Kovalevsky, J., Mueller, I.I.: Comments on Conventional Terrestrial and Quasi-Inertial Reference Systems, in: Reference Coordinate Systems for Earth Dynamics, Ed. Gaposchkin, E.M., Kolazcek, B., Kluwer Academic Publ., Dordrecht, 1981
- [7] Torge, W.: Geodesy, 2nd edition, Walter de Gruyter, Berlin-New York, 1991

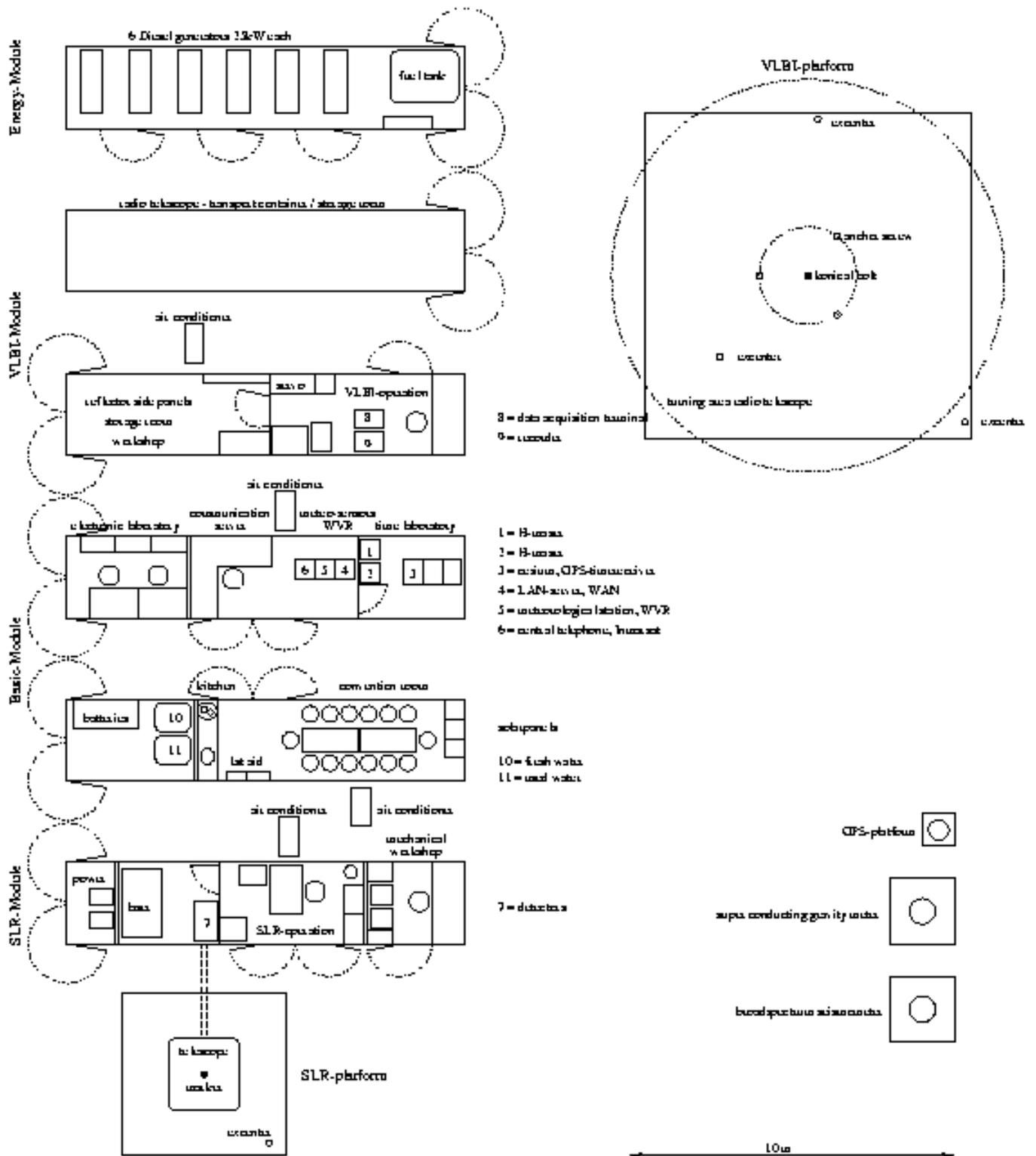


Fig. 6: Map of TIGO. The containers transform after transportation into operation and storage rooms. Containers and the telescope platforms are linked by underground channels for cables. The mount of the radio telescope requires a special constructed platform.

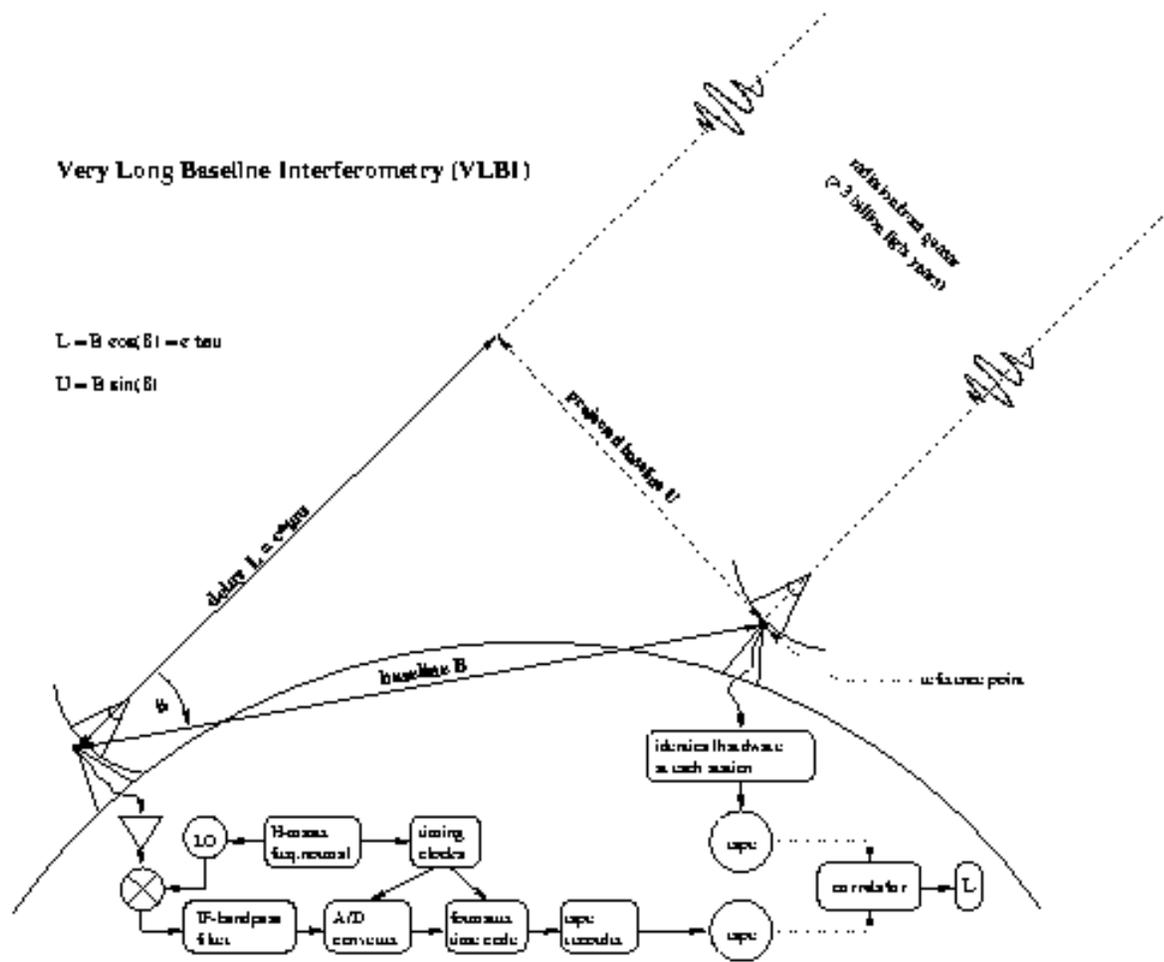


Fig. 7: Principle of Very Long Baseline Interferometry shown in a tape recorder correlation interferometer.

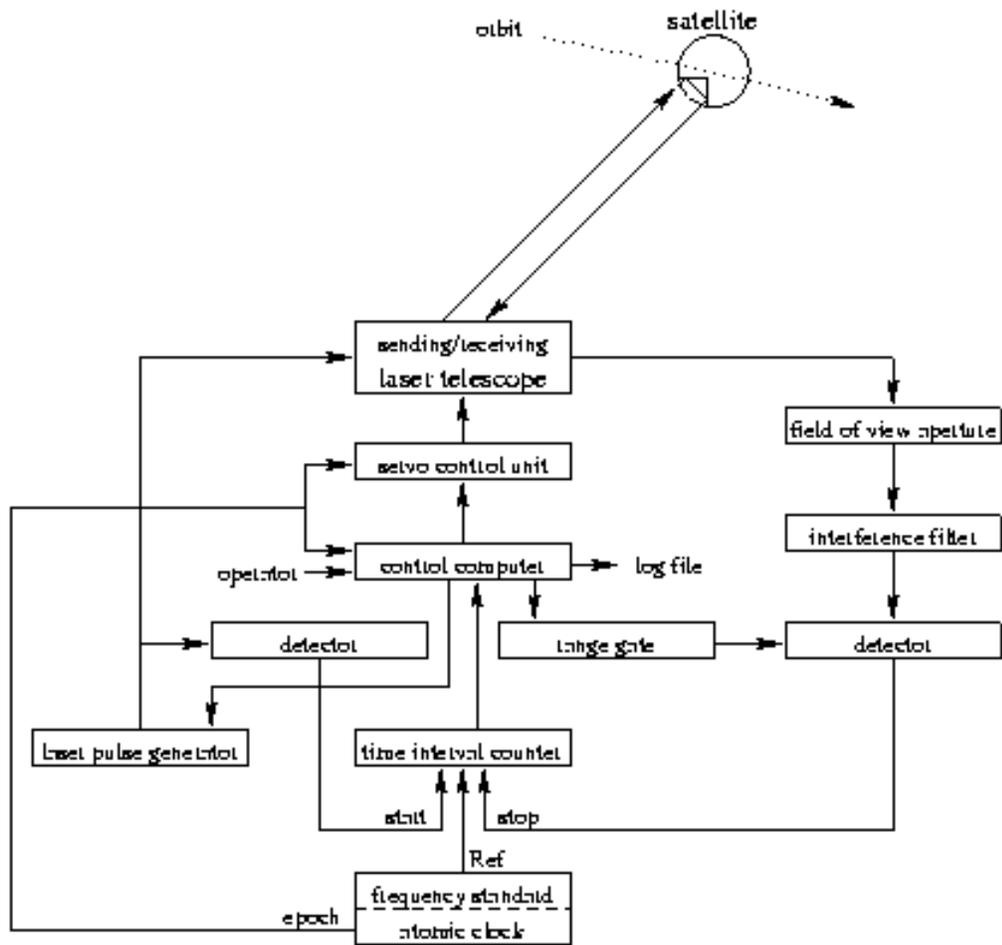


Fig. 8: Principle of Satellite Laser Ranging. The laser pulse from the generator is detected as start event. The telescope tracks the satellite and hence the pulse travels through atmosphere to the satellite. The retro reflector sends the pulse back to the telescope where the stop event is detected.



Fig. 9: TIGO SLR-module. The compact laser telescope is able to reach with its laser pulses geostationary satellites in about 36.000 km distance. The laser pulses are generated inside the container and guided through the tunnel into the telescope. The return signals enter the telescope and are guided backwards to the detectors inside the container. The telescope can be transported inside the container.



Fig. 10: Time keeping laboratory of TIGO. In the back one of two H-masers, in the foreground one sees one of the two cesium-standards and a number of clock-modules which provide precise Universal Time.



Fig. 11: Super conducting gravity meter to measure the Earth tides during operation at Wettzell.