Status of the Twin Telescope Wettzell Project

H. Hase, R. Dassing, G. Kronschnabl, T. Klügel, C. Plötz
Bundesamt für Kartographie und Geodäsie
Geodätisches Observatorium Wettzell, Sackenrieder Str. 25, D-93444 Bad Kötzting, Germany

A. Neidhardt, P. Lauber, R. Kilger
Forschungseinrichtung Satellitengeodäsie, Technische Universität München
Geodätisches Observatorium Wettzell, Sackenrieder Str. 25, D-93444 Bad Kötzting, Germany

Abstract. The Twin Telescope Wettzell Project (TTW) is a rigorous realization of the VLBI2010 vision of the International VLBI Service. The project execution takes place in the period of 2008-2011. The status report includes background information how the product specification of the IVS translated via the IVS Vision VLBI2010 into the TTW project. Some of the technical characteristics of the new instruments and the actions taken for the realization of the TTW are presented.

Keywords. TTW, twin telescope, ring focus, VLBI2010, IVS, Wettzell

1 Introduction

The *International VLBI Service for Geodesy and Astrometry* (IVS) was founded in 1999. Since then the geodetic and astrometric VLBI became an official international service within the *International Association of Geodesy* (IAG) and the *International Astronomical Union* (IAU). The IVS Directing Board created in 2001 its Working Group 2 to define "Product Specifications and Observing Programmes". The IVS-WG2 Report (Schuh et al. 2002) had been presented in 2002, concluding the future demands of the service products. Several products, like station coordinates, episodic events, Earth rotation velocity, rotational pole position, nutational parameters as well as geophysical properties of the ionosphere and troposphere demand a continuous 7 days per week observation.

The global VLBI network infrastructure is not yet prepared to accomodate a continuous service, although several a fortnight long continuous observation programmes had been successfully executed in 2002, 2005, 2008. The experience gained by previous so called CONT experiment series and the desire to incorporate upcoming new technologies into the VLBI process lead to the creation of the IVS Working Group 3 "VLBI 2010" in September 2003. The IVS WG3 "examined current and future requirements for VLBI geodetic systems, including all components from antenna to analysis, and produce a report with recommendations for a new generation of systems". The final report had been presented in 2005 (Niell et al. 2005). The recommendations of the IVS-WG3 had been constraint not only by the outcome of the IVS-WG2 product specification but also on the requirements of the Global Geodetic Observing System (GGOS) project of the IAG and the science driven geodetic goals outlined in the NASA Solid Earth Science Working Group Report (SESWG). The envisaged goals are:

- 1 mm measurement accuracy on global baselines,
- continuous measurements for time series of station positions and Earth orientation parameters,
- turnaround time to initial geodetic results of less than 24 hours.

2 The Wettzell 20 m Radio Telescope

Since 1983 Wettzell is participating with its 20 m radio telescope in geodetic VLBI measurements. At the time of its construction it was the first radio telescope which design criterias considered geodetic aspects, such as the possibility to measure the materialized invariant point in the intersection of the azimuth/elevation axis with respect to a geodetic local survey network. One end of the geodetic baseline measured by VLBI

Figure 1. Geodetic Observatory Wettzell. In the foreground the 20 m radio telescope. In the backyard the acquired plot of land for the Twin Telescope Wettzell Project.

methods could therefore be easily tied with the national, respectively the continental, geodetic reference network.

Even with the existence of Global Navigation Satellite Systems of today the issue of connecting different geodetic space techniques by a local geodetic survey remained as an essential task for the production of the terrestrial reference frames by the *International Earth Rotation and Reference System Service* (IERS).

According to the statistics of the IVS (IVS-Webpage) the Wettzell 20 m radio telescope has been so far the most frequent scheduled VLBI station of the IVS network. With more than 130 observation days (24h) plus the daily Intensive series (INT1, INT2, INT3) troughout the years the Wettzell radio telescope is operating at its technical limits and is serving for more than 25 years.

Given the IVS-initiative VLBI2010 and concerns about the age and observation load of the 20 m radio telescope led the VLBI group of the Geodetic Observatory Wettzell to the creation of the Twin Telescope Wettzell Project as a midterm replacement.

3 Twin Telescope Wettzell - TTW

The Twin Telescope Wettzell Project (TTW) started in 2006 with a careful analysis of the IVS-WG3 VLBI2010 vision and the product catalog of IVS-WG2 in mind. In conclusion a few characteristics made clear that a new type of radio telescopes needed to be constructed. The stringent requirements are:

- Radio telescopes are needed as long term geodetic monuments. With respect to the challenges of GGOS to establish an observing system which will achieve on the global scale accuracies better of 1 mm for the position error and 1 mm/year for the site velocity error the construction of the radio telescope itself should guarantee and maintain the stability of the invariant point as reference during lifetime of the instrument (20 years for TTW).
- Continuous observations of Earth orientation parameters contradict with necessary maintenance cycles of the radio telescope. Maintenance moments or days are necessary to refresh the cryogenic cooling system, to maintain the mechanical parts of the radio telescope, to perform system checks and pointing tests. If any geodetic observatory shall provide observational data continuously to the IVS, then more than one radio telescope is needed at one site. Therefore it was decided to construct two identical radio telescopes featuring the VLBI2010 goals. This concept of twin radio telescopes enables new observation modes, when no maintenance has to be performed. Both radio telescopes can be used simultaneously at one source ("array mode") to increase the sensitivity. If both radio telescopes point to different sources then different subnets are tied at the same time. If the source change will be scheduled, while the other radio telescope is still tracking a source, then the "continuous" observation gets a new content, because one of the twin radio telescopes always hooks at a source. Hence continuous interferogrammes of Earth rotation can be realized by VLBI and compared with those of laser gyroscopes.
- The 1 mm accuracy can be achieved only with more observations per time unit (Petrachenko et al. 2008). Likewise GNSS antennas observe simultaneously at different directions and achieve therefore a good geometric stability for the position determination, VLBI suffers the handicap utilizing radio telescopes with a strong directivity. In order to make VLBI as omnidirectional as possible the approach is to make the radio telescopes much faster. Instead of 8–12 observations per hour it is suggested to approach with 30 s slew-track cycles per source

up to 120 observations per hour (10 times more). With respect to the necessary signal to noise ratio at the correlator output, the suggested diameter of 12 m and kinematic parameters of $6-12^o/s$ for both axes were specified. These parameters take into account that the necessary integration time to detect the radio source and the dimensions of the radio telescope (aperture diameter, accelerating masses) needed to be compromised.

- Reduced susceptibility to external interference challenges the entire IVS network. The commercial exploitation of the microwave spectrum does unfortunately not exclude the radio window of the electromagnetic spectrum. Geodetic VLBI uses since more than three decades the S-band spectrum at $2.2-2.35$ GHz and the X-band spectrum at $8.1-8.9$ GHz. The lower S-band frequencies are increasingly effected by radio frequency interference. Hence in the future it will be more and more difficult for the IVS to continue observing as before. This situation is one reason for the IVS to suggest the development and implementation of so called wideband feeds which cover ideally the radio window of $2-18$ GHz. If the radio telescope can be equipped with such a wideband feed, then unpolluted spectra can be used and correlated for VLBI. In addition a wider spectrum enables a better phase connection among the correlated spectral channels. Using then the phase delay instead of the group delay in the analysis of VLBI observation, will result in higher accuracy - as demanded. The fact of favourizing wideband feeds has a direct impact to the radio telescope optics. Wideband feeds have a larger opening angle. For this reason the optics of suitable radio telescopes are much different with respect to the existing VLBI radio telescopes which limits the possibility to upgrade the old once. Hence new optimized constructions will be necessary at several existing radio telescope sites, when wideband observations after a period of transition will become the IVS standard.

Based on those documents a technical specification for the new radio telescopes was finished in 2007 (Dassing R. et al. 2007). The technical specification of the Twin Telescope Wettzell was used for an open bidding. From five interested companies only two German companies had been able to fulfill the technical specifications. By the end of 2007 the company Vertex Antennentechnik GmbH in Duisburg was contracted by the Bundesamt für Kartographie und Geodäsie for the Twin Telescope Wettzell Project. The execution time was set to the period 2008–2011.

4 The first project year, 2008

4.1 Construction of the radio telescopes

The Kick-Off Meeting took place in January 2008 at Wettzell. The participants agreed on a time schedule which fixed the design review to December 2008. Based on the contracted offer several simulations had to be made in order to proof the concept of the twin radio telescopes and to optimize constructive parameters.

The offered design contains the following characteristics:

- Number of identical radio telescopes: 2
- Main reflector size: 13.2 m
- Mount: elevation over azimuth (identical to ALMA)
- Kinematics: Velocity: Az $12^o/s$, El $6^o/s$, Acceleration: Az, El $3^o/s^2$
- Optics: Axially displaced ellipse reflector or ring focus
- Subreflector with hexapod mount
- Path length error: < 0.3 mm
- 3D reference point: < 1 mm (accessible and measurable with respect to a local survey network)
- Life time: > 20 years

Compared to the characteristics of existing radio telescopes for VLBI, the characteristics of VLBI2010 going beyond the state-of-the-art in radio telescope constructions. One difficult criteria is the reliable continuous frequent movement during lifetime. The accumulated movements in the period of more than 25 years of the 20 m Wettzell radio telescope shall be reached within less than 1.5 years given the envisaged VLBI2010 observation schedules with continuous

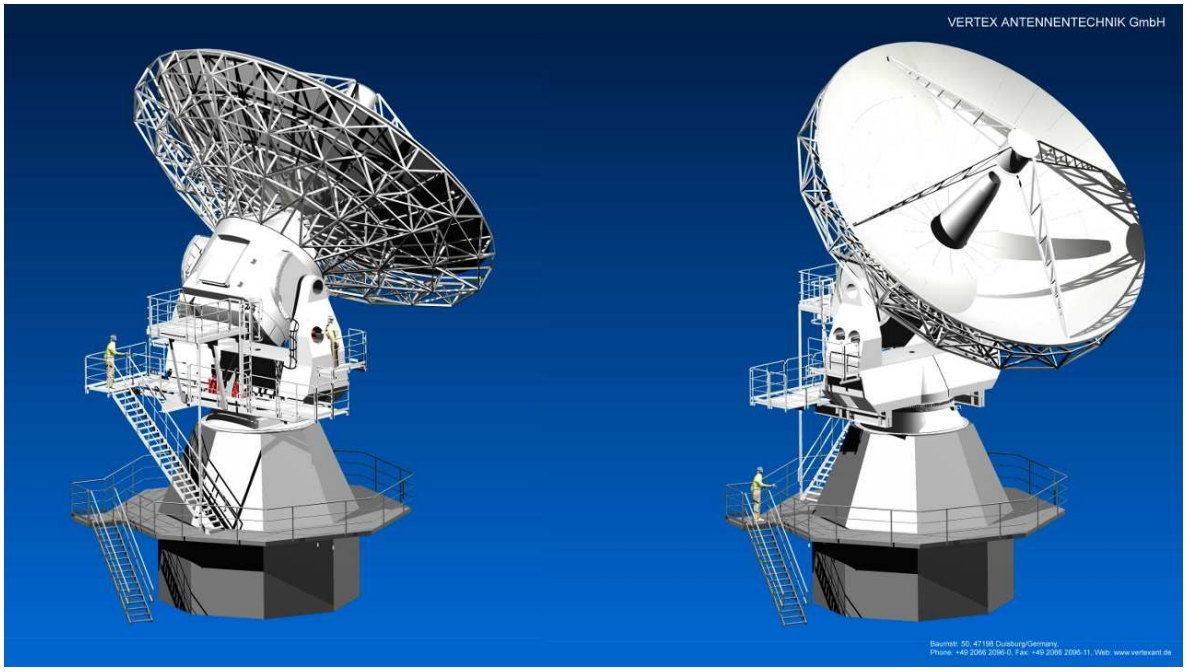

Figure 2. Simulated view of the twin telescope. The radio telescopes use a primary ring focus and a secondary point focus. The subreflector is very close to the wideband feed, which has a half opening angle of about 65^o.

30 s slew/track cycles. This observation load combined with 3-times higher acceleration and 4-times higher velocities means an enormous increase of mechanical stress which the construction will have to withstand.

Another important mechanical parameter is the specification of the path length error to be < 0.3 mm. The radio telescope must be very stiff in order to be robust against varying gravitational loads (due to elevation) and environmental forces (wind, snow, rain, hail, ice). A small path length error is specially important for VLBI, as the quality of time delay and phase delay measurements are directly influenced by it. This specification can be achieved with an optimized construction and a moveable subreflector which is mounted on a hexapod in order to compensate for tiny remaining deformations of the main reflector.

The optics of the radio telescope are based on the concept of an axially displaced ellipse reflector. The vertex of the rotating parabel defining the surface of the main reflector is shifted about 0.72 m from the line of sight. Therefore the primary focus becomes a ring structure if the parabel rotates with this offset. This is called ring focus design. Consequently the shape of the subreflector must bring the primary focal ring into a secondary focal point. This is achieved by a rotating ellipse, which secondary focus intersects with the line of sight as rotational axis.

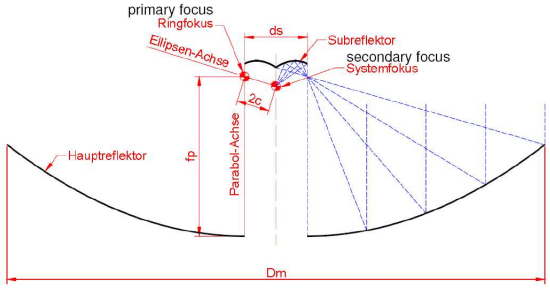

Figure 3. The optics of the Twin Telescope Wettzell. The parabel is shifted apart by the distance of ds. Therefore the subreflector in the central part does not shadow the illumination of the main reflector.

The advantages of the ring focus optics are threefold:

- The subreflector does not shadow the main reflector. Only the supports of the subreflector are going to shadow small areas of the subreflector.
- The feed horn can be positioned close to the subreflector as needed for wideband feeds.

- The shape of of the subreflector minimizes backward reflection towards the feed horn (in contrast to a usual Cassegrain optics).

- Rays from the main reflector rim illuminate the pointed vertex of the subreflector, while rays from the central area illuminate the subreflector rim. The provoked electrical field within the feed is dominated by the outer main reflector surface, which has more reflecting surface than the central area. Therefore the ring focus optics optimize the feed illumination and a high effenciency above 70% seems to be feasible.

In summary: The TTW radio telescope design for geodetic VLBI is a rigorous attempt to realize the aims of VLBI2010. The VLBI2010 specifications request a new design of radio telescopes meeting these challenging criterias.

4.2 Preparation for the constructions at Wettzell

The twin telescope needs additional and suitable space at the Geodetic Observatory Wettzell. Therefore an adjacent plot of land to the Observatory was acquired during 2007. In order to find the best locations at the new land for a solid foundation which is stable to the millimeter level during the coming two decades (lifetime of TTW) a profound soil analisis was made during 2008. A total number of more than 15 drillings down to a depths of 16 m gave a clue about the underground situation. Based on this analysis the final positions for the two radio telescopes and the operation building could be defined.

One of the telescopes will be setup close to the gravity meter house of the Geodetic Observatory. As the constructions might have an impact to the long standing observation series, a new gravity meter house closer to the "quiet" area of Wettzell next to the laser gyroscope was built. It is planned to continue with measurements of gravity at both sites and study the impact of the TTW. If the TTW will have an intollerable impact to the gravity measurements, then the observation might be discontinued at the old gravity site.

Figure 4. Drilling cores of three drillings ($0-16$ m) indicating stable rocky underground to define one radio telescope location. Each box corresponds to one meter depth from surface (most upper box) to -16 m (bottom box).

5 The second project year, 2009

5.1 Construction of the radio telescopes

After the design review by the end of 2008, first telescope parts will be manufactured during 2009. An open item was the front end for the TTW. The reason for this is the non-existence of an appropiate feed horn which covers the spectral range $2-18$ GHz and has one focal point for any frequency. The decision on the future feeds the IVS depends also on the future observation modes which are planned to be executed. The IVS organized with the local staff of the Geodetic Observatory Wettzell a *Workshop on Future Radio Frequencies and Feeds* on March 18-20, 2009. This workshop came up with a recommendation which was adopted at the IVS-Directing Board meeting in Bordeaux on March 23, 2009. The content of the recommendation is:

- *The initial implementation of the VLBI2010 system needs to be capable of observing the broadband range of 2.2 to 14 GHz.*

- *The VLBI2010 system needs to be capable of S/X operation.*

- *The antenna should allow for a possible future inclusion of Ka-band (32 GHz) operation.*

- *The complete end-to-end operation of the VLBI2010 system should be demonstrated in*

a campaign in early 2012. As many antennas as possible should participate.

- *A plan should be established for the transition from the legacy S/X system to the VLBI2010 broadband delay system. Such a transition plan can be beneficial for obtaining future funding and will support a timely changeover.*

Based on these recommendations the TTW project group is specifying now the feed and receiver parts. Two concurrent feed designs are currently under discussion (FRFF 2009): A proposed variation of the Eleven-feed of Prof. Per-Simon Kildal from Chalmers University in Gothemburg, offering the one continuous spectral band from 2.2–14 GHz. A prototype is under development and will be tested during 2009. A cooled version will be developed in 2010. As an alternative a triple band feed is proposed by Mirad AG in Switzerland. This proposal will cover an extended S-band (~ 2 GHz) and X-band ($\sim 8-9$ GHz) plus a third Ka-band (~ 32 GHz). Both development options will be tailored to the given geometrical constraints of the telescope optics and later be considered for implementation.

5.2 Constructions at Wettzell

For 2009 it is scheduled to start with the preparation of the construction area. Infrastructure (electricity, communication, water, etc.) has to be layed to the new property. The concrete fundaments for the radio telescopes and the concrete towers should be constructed during 2009. It is planned to complete the towers in 2010. Therefore the platforms for constructing the main reflector must be prepared as well as the underground to host a heavy crane when the moment of reflector installation comes. The operations building shall be part of the constructions which are planned also to begin in 2009.

6 Conclusion

The Twin Telescope Wettzell Project is an ongoing project, scheduled for the period 2008-2011. It is a first rigorous attempt to realize the aspects of the VLBI2010 vision of the IVS. It involves new optics for VLBI radiotelescopes which are crucial for the use of new wideband feeds operating in the spectrum of at least $2.2-14$ GHz. The radio telescopes will be constructed of a long lasting geodetic monument capable to resist continuous (7/24) very fast movements minimizing the slewing from source to source. The construction needs to be extremely stiff to minimize deformations and to enable phase delay observations. The sum of these criterias cannot be addressed with an upgrade of an existing radio telescope - it makes a new construction necessary.

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