Local Survey at the Effelsberg Radio Telescope 1997 - Preliminary Results

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Abstract

In summer 1996 a major repair of the Effelsberg 100 m radio telescope's ground track had to be carried out due to cracks in the tracks surface. This led to a significant permanent displacement of the VLBI reference point. A local survey was, therefore, organized to measure the position of the reference point with respect to three permanent ground markers which had also been used in earlier measurements of this type. Since the reference point is not accessible physically an excentric target mark close to the reference point had to be used which complicated the work extraordinarily. For the analysis of the measurements a model is developed which a) describes the movements of the excentric target mark when the telescope is moved in azimuth and elevation and b) which corrects for thermal expansion effects. In order to compare the 1997 survey with another one carried out in 1992 a re-computation of the earlier measurement is done on the basis of the model mentioned above. The comparison of the two surveys yields a significant increase in height of the Effelsberg telescope of $+25.4 \pm 3$ mm from 1992 to 1997.

Fig. 1: Location of target mark at telescope in the middle of the cross-bar

1 Introduction

After 24 years of operation the Effelsberg 100 m radio telescope of the Max- Planck-Institute for Radio Astronomy suffered severe damage of the ground track on which the antenna rotates. Cracks in the metal distorted the horizontal plane and satisfactory pointing accuracy which is necessary at higher observing frequencies could not be maintained any more. The telescope was jacked up temporarily and

the track was replaced completely. In addition, the wheels were milled into a conical shape with the tip of the conus being fictitiously located at the azimuth rotation axis. Through these modifications the telescope could not be placed in the same position as before the repairs when it was lowered onto the track again.
In geodetic VLBI all parameters estimated in the data adjustments are refered to the so-called VLBI reference point. In the case of an azimuth-elevation mount as the Effelsberg telescope is constructed the reference point is either the point where both axis intersect or, if they do not intersect, it is the point of the azimuth axis where the distance to the elevation axis is minimal (e.g. MA 1978; NOTHNAGEL et al. 1995). This point is invariant to any antenna movements necessary for the observations. Since any man-made changes in the 3-dimensional position of the reference point causes discontinuities in the time series measured with geodetic VLBI the displacements have to be determined to permit a correction of the time series.

Fig. 2: Location of target mark within cross-bar. The little sphere is mounted at the end of the rod in the middle of the circular plate.

2 Measurement setup

The VLBI reference point of the Effelsberg 100 m telescope, as of almost all other telescopes, is, unfortunately, not physically accessible and has to be represented indirectly. Here, the reference point lies within the main support beam which serves as the physical elevation axis (Fig. 1). In 1978 an excentric marker was, therefore, brought in place by mounting a target mark to this beam relatively near the VLBI reference point (MIEBACH AND WERNTGEN 1980). The target consists of a little sphere of 15 mm in diameter (Fig. 2). In order to check the behaviour of the main beam the target was fixed to a rod which was mounted vertically in the beam and which has an additional target mark close to the geometrical elevation axis (Fig. 3). The rod was placed as centric as possible in the middle of the cross-bar supporting the vertex of the parabola. The middle of this intersection should mark the azimuth axis if the telescope points towards zenith.
However, measurements at the time of the implementation of the marker yielded an offset of the elevation axis in front of the azimuth axis of 10.3 mm. The mounting point of the rod holding the marker was determined to be 9.5 mm in front of the azimuth axis (Fig. 3). In the vertical the little sphere was mounted 1186.5 mm below the elevation axis.
The little sphere was used as the sole representation of the reference point. When the telescope is driven to different azimuth and elevation positions the little sphere describes a body with the VLBI reference point as the center. Therefore, the coordinates of the little sphere in different positions of the telescope had to be determined in a first step.

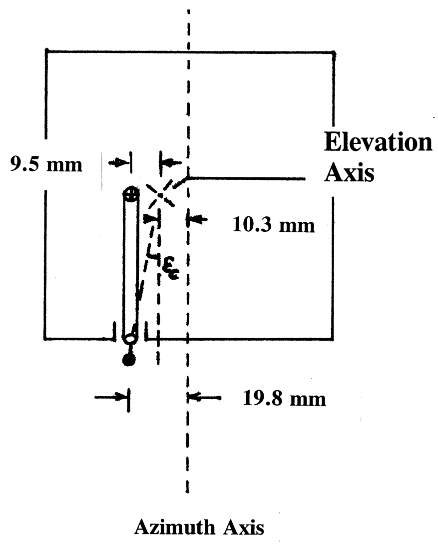

Fig. 3: Location of target mark at the end of the vertical rod at the bottom of the main support beam as seen from elevation bearing.

On the basis of earlier measurements three ground markers served as the ground network which was checked by precise angle and distance measurements before and after the locations of the target mark were measured. For the determination of the coordinates of the target mark the three ground points were occupied with electronic theodolites (2 Wild TC 1600, 1 Geodimeter 520 S). In order to compute the horizontal coordinates of the sphere by the surveying method of "Cut by Angles" in each position the sphere had to be aimed at by at least two theodolites simultaneously. The vertical positions were determined by measuring zenith distances.

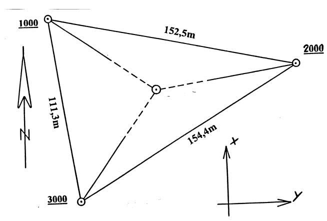

Fig. 4: Layout of ground network.

From an error propagation point of view it would have been preferable to determine coordinates of the sphere with a homogeneous distribution of azimuth and elevation angles. However, the beams of the parabola support structure and the extended dimensions of the elevators at the elevation bearing towers inhibited an unobstructed view onto the sphere in all orientations of the telescope. During a five hour period the little sphere was aimed at in 52 different positions simultaneously by pairs of theodolites. Only for three positions at elevation angles above 85° elevation the sphere was visible by all three theodolites and the respective redundant readings could be taken.

3 Data reduction

The initial reduction of measurements and the computations of the set of coordinates of the sphere yields a cloud of raw point coordinates. In order to end up with the coordinates of the VLBI reference point there has to be a two step approach. In a first step the raw points have to be corrected for thermal expansion of the telecope and for gravitational deformation of the main support beam. In a second step the movements of the sphere when the antenna turns in azimuth and elevation has to be modelled in order to estimate the VLBI reference point which is, as mentioned already, invariant against any movements of the telescope.

3.1 Temperature corrections

The thermal expansion of a telescope depends on the temperature of the metal rather than on the ambient temperature which needs some time to creep into the metal structure. The metal temperature was available from several sensors mounted at different locations of the telescope structure and an average was computed for further use. During the course of the measurements which started at 8h00 in the morning the temperature rose steadily from 8° to 13° C at 1h00 p.m.. Due to the height of the support beams of 50 m a temperature correction of

$$dh[mm] = -0.625 \cdot (T - T_0)[^\circ C] \tag{1}$$

had to be applied leading to a 3 mm height difference between the beginning and the end of the measurements.

3.2 Bending corrections

The main reflector surface of the Effelsberg radio telescope is constructed as a paraboloid which, if tilted, will always appear as a paraboloid but with slightly different parameters and a different focal point owing to homologeous deformation. Most of the weight of the reflector, therefore, presses upon the center of the main horizontal support beam. Although manufactured as rigid as possible the middle of the beam encounters a vertical bending of 19 mm with respect to a straight line when the antenna points at zenith (Miebach and Werntgen 1980). At the same time the beam is not bent horizontally or, in other words, it lies in a vertical plane (Fig. 5a).

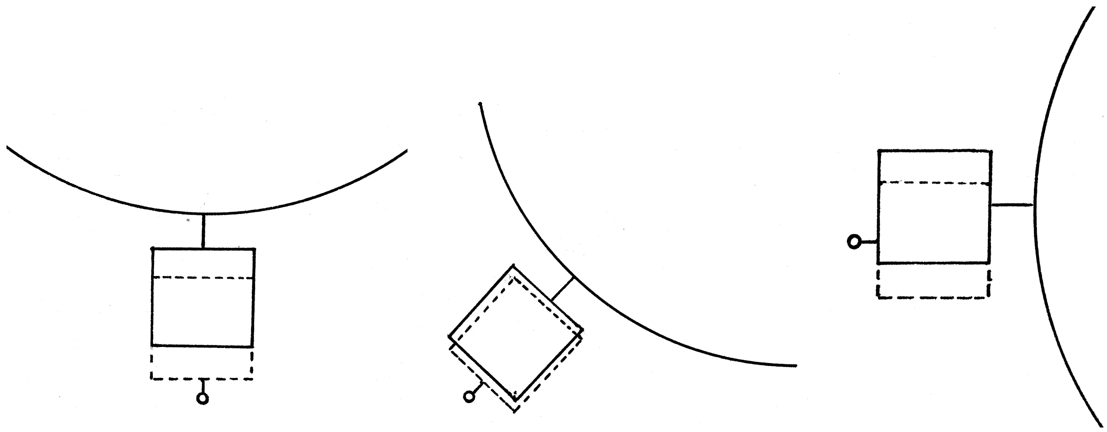

Fig. 5: Displacement of reference point due to gravitational bending as seen from one of the elevation bearings. The dashed profile represents the middle of the beam where the target is mounted.

When the antenna points at a lower elevation the main beam relaxes towards the radio source but, at the same time, bends towards the ground in the direction perpendicular to the main axis (Fig. 5b). In the extreme case of an observation at zero degrees elevation there is maximum bending towards the ground and zero bending in the direction where the antenna points at (Fig. 5c). Earlier measurements of a reference marker in the middle of the hollow beam produced a non-linear relationship between the position of the marker and the elevation (Fig. 6) (Miebach and Werntgen 1980). With a semi-analytical function the corrections in the vertical and in the direction of the tilted telescope were computed and applied as corrections to the respective local coordinates of the target points.

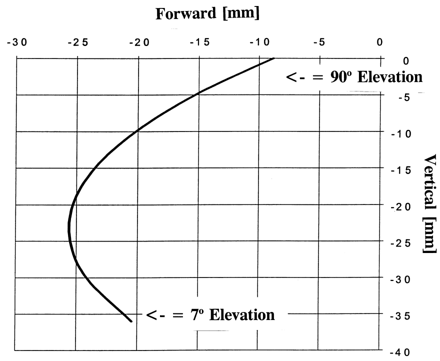

Fig. 6: Movement of a point in the middle of the main beam depending on the elevation angle of the telescope. Forward in this context means towards the tilting direction. The zero point for the vertical is chosen for the geometry when the telescope aims at zenith.

3.3 Envelope model

After correcting the raw coordinates the target sphere is supposed to describe an envelope which consists of two components. When the telescope points at zenith and rotates about the azimuth axis the target mark describes a circle due to the excentricity of the marker. A second component is added when the telescope turns about the elevation axis rotating the target mark upwards on a segment of a circle (Fig. 7).

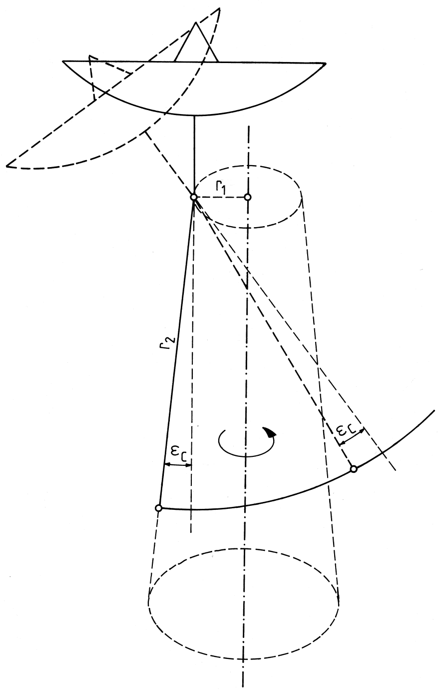

Fig. 7: Geometry of the target mark relative to elevation bearing. When the telescope points at zenith and it is turned about the azimuth axis the r_2 vector with the target mark at the end describes a conus. Tilting the telescope about the elevation axis moves the target mark on a circle about the elevation axis with the radius r_2.

The movements of the target mark can be described by simple functions of three dimensional coordinates X_i, Y_i, Z_i depending on azimuth κ, elevation angle ϵ, the center point X_M, Y_M, Z_M, the excentricity r_1 and the length of the rod r_2. Due to the fact that the little sphere is not mounted directly vertically underneath the elevation axis an additional constant elevation angle $\epsilon_c = 0.46°$ has to be added.

$$X_i = X_M + r_1 \cdot cos\kappa - r_2 \cdot cos(\epsilon + \epsilon_c)\, cos\kappa \tag{2}$$

$$Y_i = Y_M + r_1 \cdot sin\kappa - r_2 \cdot cos(\epsilon + \epsilon_c)\, sin\kappa \tag{3}$$

$$Z_i = Z_M - r_2 \cdot sin(\epsilon + \epsilon_c) \tag{4}$$

Unfortunately, this function was available only shortly before the presentation of this paper. Therefore, a coarse approximation had to be used for the preliminary computations. In a least squares adjustment the coordinate triplets corrected in 3.1 and 3.2 served as observations with the above observation equations for the coordinates of the center point and the distance r_2 as unknown parameters. The least squares fit yielded the coordinates for the reference point in table (1).

Tab. 1: Preliminary coordinates of VLBI reference point in the Gauß-Krüger coordinate system from 1997 measurements

X_M	5 599 160,434 m	± 0.7 mm
Y_M	2 562 702,079 m	± 0.7 mm
Z_M	368,978 m	± 1.0 mm
r_2	1.1601 m	± 0.9 mm

It should be mentioned here that the vertical component is refered to a metal temperature of 0° C.

3.4 Recomputation of 1992 measurements

In order to determine the displacement of the VLBI reference point two sets of measurements, one before and one after the replacement of the ground track, have to be performed. In 1992 the surveying authority of the state of North Rhine-Westfalia had carried out a similar set of measurements which could be used as a zero-epoch basis. For a rigorous determination of the displacement these measurements were re-computed on the basis of the corrections and models described above.

Tab. 2: Preliminary coordinates of VLBI reference point in the Gauß-Krüger coordinate system from 1992 measurements

X_M	5 599 160,429 m	± 1.2 mm
Y_M	2 562 702,078 m	± 1.2 mm
Z_M	368,954 m	± 2.5 mm
r_2	1.1623 m	± 1.4 mm

Again the vertical component is refered to 0° C. However, the temperature correction could only be applied through an approximation since only one temperature reading was taken during the measurements. Thus, there is no way of correcting for any changes in temperature during the course of the measurements.

4 Results

Table 3 contains the differences in the local topocentric coordinates between the epochs of 1992 and 1997. Due to the fact that the model of the movement of the target mark with respect to the VLBI reference point as described in formulas (2) - (4) was applied only in a coarse approximation the results have to be considered preliminary and the formal errors were, therefore, inflated by a factor of 3.

Tab. 3: Preliminary coordinate differences between the 1997 and 1992 measurements in the sense 1997 - 1992

$\Delta North$	0,001 m	± 5 mm
$\Delta East$	0,005 m	± 5 mm
$\Delta Vertical$	0.0254 m	± 8 mm

Considering that the movements of the target within the main elevation axis support beam as described by figure 6 were determined already 20 years ago the results contain some further uncertainties. In order to check the response of the elevation beam to tilting in elevation the measurements within the beam as carried out by MIEBACH AND WERNTGEN (1980) should be repeated. In addition, the determination of the VLBI reference point within the adjustment of individual positions of the target mark has to be repeated with the correct model as described in formulas (2) to (4). Furthermore, this type of measurement has to be repeated in closer intervals in order to monitor the stability of the Effelsberg telescope with respect to the surroundings.

5 References

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