Surveying the GPS-VLBI Eccentricity at Medicina: Methodological Aspects and Practicalities

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Summary: This paper describes our experiences in measuring the GPS-VLBI eccentricity at Medicina (Italy). It has been re-measured yearly during three different terrestrial surveys (2001, 2002 and 2003) and corresponding SINEX files with full variance covariance information were produced. The eccentricity vector connecting the GPS and the VLBI reference points has been measured within slightly different local ground control networks and high accuracy has been sought since the first campaign. The methodology has been refined year after year. We describe the choices that concern stationing, selection of instruments, devices and surveying strategies.

1 Introduction

Local ties link together single technique solutions and play an important role in order to reach the highest accuracy in combined multi-technique geodetic products.

In order to measure the relative positions of reference points of co-located techniques, we have developed a surveying strategy that is closely linked to the geometrical model that we have adopted. Moreover, a rigorous statistical approach for the estimation of the eccentricity vector along with a complete variance covariance information must be applied.

It is essential to maintain and regularly survey local networks in order to monitor the stability of the eccentricity and of the co-location site itself. The time spanning between successive surveys is related to the observed stability of the site: Medicina, due to the presence of land subsidence, requires yearly repeated measurements.

Taking into account the short distances that characterize the extension of the local ground control network, which are below a few hundreds meters, local ties can be performed using only terrestrial observations. In order to make the tie effective for an accurate use in ITRF combination, (Altamimi et al., 2002), an accuracy of 1 mm level should be the target.

We identify few successive steps in performing a local tie:

- site surveying and related issues (instruments, devices, surveying strategy, etc…)
- data reduction and least squares estimation of observed targets coordinates
- 3-D least squares geometrical modelling of previously estimated coordinates
- SINEX generation.

A detailed description of the methodology can be found in Sarti et al., 2004. We are presenting here the surveying approach we have developed at Medicina Observatory during 2000, 2001, 2002 and 2003 campaigns (Sarti et al., 2000, Vittuari et al., 2001) along with some selected results.

The eccentricity vector at Medicina was previously observed by other groups applying different methodologies (Cenci et al., 1998; Del Rosso and Ambrico, 1995; Nothnagel and Binnenbruck, 2000).

2 Local terrestrial survey for GPS-VLBI eccentricity determination

We determine the coordinates of the targets that identify the local ground control network in which the eccentricity is framed and measured.

The choice on the number and quality of instruments and devices is crucial in order to ensure the highest precision.

Our surveying approach is strictly related to the geometrical definition and realization of non-materialised antenna reference points. We make wide use of symmetry considerations in surveying both VLBI and GPS antenna reference points.

2.1 Control network

The Medicina control network is formed by three concrete pillars with Wild-type forced centring markers. These pillars are far from establishing a well-designed local ground control network and this causes a critical lack of standpoints when surveying the eccentricity. The inhomogeneous distribution of observations on the East side of the VLBI antenna can be avoided using temporarily installed tripods. All targets are surveyed searching for the largest redundancy, using forward intersection, measuring azimuth and zenith angles and distances.

In ITRF computation, the tracking points of each technique are uniquely identified using a DOMES (Directory Of MErit Sites) number assigned by the International Earth rotation and Reference systems Service (IERS). In order to establish a local reference frame and supply further information concerning stability and deformations at the site, we have recently request DOMES numbers for the pillars P1, P2, P3 of the ground control network: P1

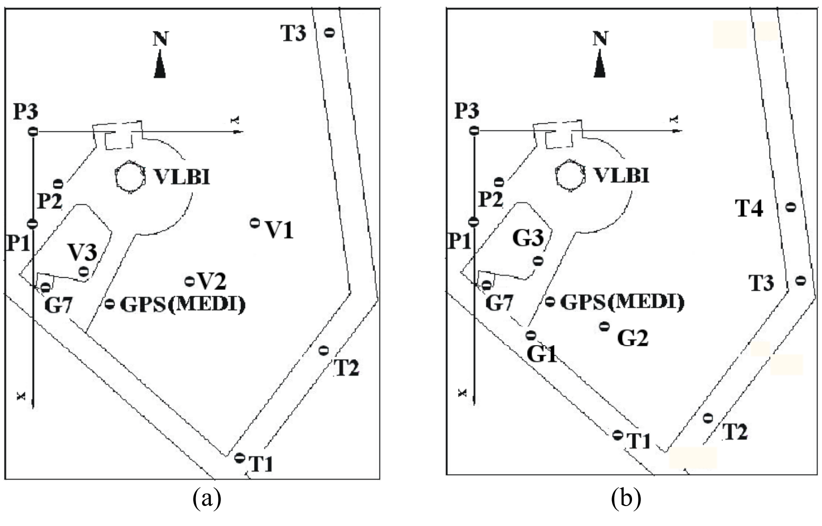


Fig. 1: Schemes of the Medicina ground control network (P are permanent concrete pillars defined by an ITRF DOMES, G7 is the height reference point, T and V are temporary points materialized by tripods). a) Ground control network used in 2001 survey, b) Ground control network of 2003 survey (G1, G2, G3 tripods used to enforce the topographic connection to the external shape of the GPS antenna).

DOMES Number: 12711M004; P2 DOMES Number: 12711M005; P3 DOMES Number: 12711M006. Sketches of local ground control points used for terrestrial measurements in 2001 survey and 2003 survey are shown in Fig. 1a and 1b, respectively.

The design of the ground control network has a remarkable impact on the correlation matrix associated to the eccentricity vector. In Fig. 1 it is possible to spot the difference between the networks of 2001 (Fig. 1a) and 2003 (Fig. 1b) surveys. In particular, in 2003 survey we have used special care in surveying the GPS antenna within the control network: we have increased the number of tripods around the GPS antenna and it has been connected with a larger redundancy and a well distributed set of observations.

2.2 Instruments and accessories

All accessories, devices and instruments used during the measurement procedure must fulfil the goal of high accuracy: in order to be effective, local ties must be determined aiming at 1 mm accuracy.

At the same time, field activities have to be planned and optimised in order to ensure short periods of VLBI antenna inactivity. Thus, modern and precise topographical instruments are fundamental tools for a quick and reliable survey.

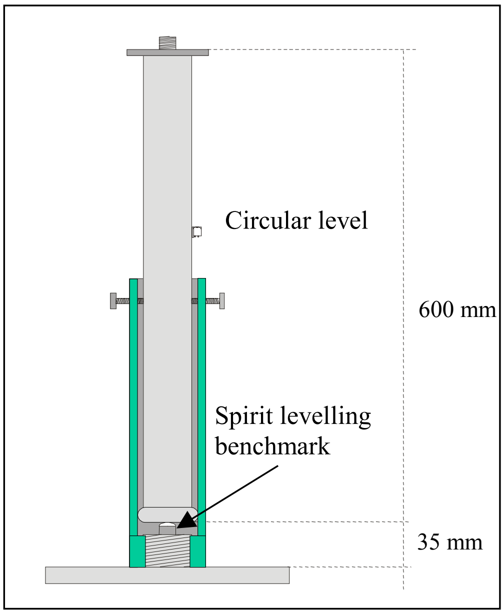
The most common surveying techniques involved in local ties on short distances are trilateration, triangulation and spirit levelling. Our measurements were performed mainly through trilateration and triangulation.

High accuracy total stations were used, in particular Leica TD and TC series (TDA5005, TCA2003 and TC2003). These instruments fulfil the precision's requirements in terms of angular resolution (0.15 mgon) and in terms of the Electronic Distance Meter (EDM), capable of ensuring a precision of ±1 mm on short distances (±0.2 mm using high accuracy corner cube reflector on distances up to 120 m). The instruments are equipped with a biaxial compensator installed to correct angular readings for residual errors. We used this tool for achieving an accurate set-up of accessories (i.e. preliminary set-up of all tribrachs on markers).

Self-centring devices ensure a reliable 2-D stability. Accurate height readings are critical because of the change of instrumental height caused by different standings. We approached this problem using three-dimensional self centring devices (Fig. 2b) in order to be able to treat successive stations on the same marker as the same point of the network in the adjustment procedure: we only need to change the instrumental height, if necessary. Elevations are determined as differences with respect to a fixed vertical target installed on marker G7 (DOMES 12711M007): a special support of fixed-height (Fig. 2a) holds a retro-reflecting circular prism in a vertical position above a spirit levelling bolt.

Distances are measured using retro-reflecting prisms for all points of the local ground control network and for points installed on the VLBI antenna structures. Prisms' constants were verified in laboratory and EDM of both instruments were compared on length of common baselines.

Proper angular readings are difficult to perform on VLBI antenna structure because of the change in orientation of the targets. We therefore decided to perform angular readings at the centre of the prism: it is possible to identify the centre because there is a radial symmetry of the face edges.



(a)

(b)

Fig. 2: Three-dimensional self-centring devices. a) System installed on a pillar of the laser pad (point G7) used as vertical reference for local surveys. b) System used for total station centring on concrete pillars and for instrumental height determination.

This operational procedure is similar in both manual and automatic collimations. As a matter of fact, during all campaigns two total stations were contemporarily employed; one of the two has an Automatic Target Recognition (ATR) capability. The ATR allows the user to automatically measure distances, horizontal and vertical angles. These measurements are quickly and easily recorded on a memory card and are taken at the centre of the circular prisms: an infrared bundle is sent from the total station and returned by the reflector, the motors turn the telescope to the centre of the light bundle and a circle reading gives the final pointing. Collimations were repeated three times in direct and reverse position of the total station thus completing three sets.

2.3 GPS Antenna Reference point surveying

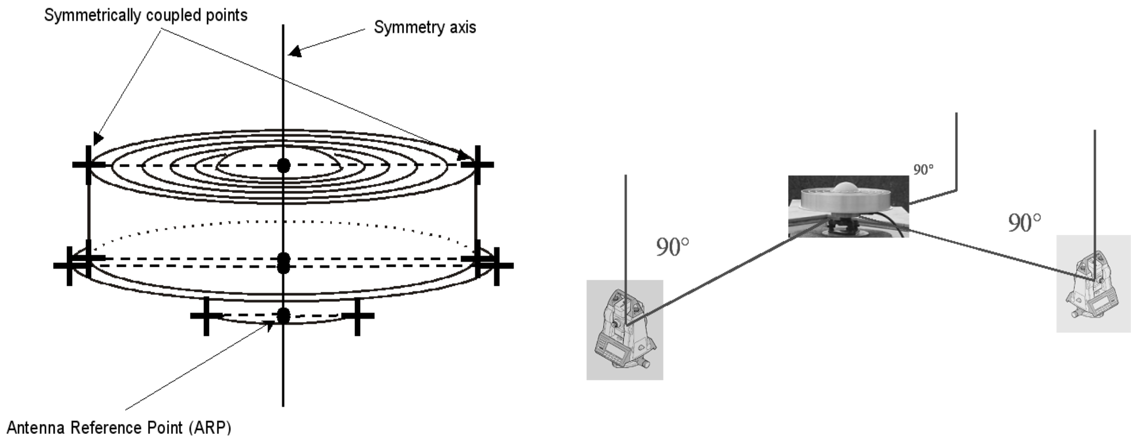
The position of the GPS Antenna Reference Point (ARP) can be connected, through common observations performed from the control network, to the VLBI antenna's invariant point.

The strategy we have developed for measuring GPS choke ring antennas is based on the symmetry of its external structure. A clear and immediate advantage is related to the fact that the ARP position can be measured without removing the antenna itself. The advantage is clearly related to the operational characteristics of permanent networks for which an interruption of system functioning is an undesirable event.

The GPS ARP position can be derived triangulating points on the external structure of the GPS antenna. In particular, for each couple of points symmetrically measured with respect to the vertical axis of the antenna, it is possible to refer the averaged angular readings to a fictitious point that lies along the vertical axis (Fig. 3a). Triangulating from more then two tripods, properly distributed around the GPS antenna, it is possible to perform redundant observations for each fictitious point.

In order to obtain a reliable determination of the height of the GPS ARP, it is necessary to use the total station as a level: particular care has to be taken when installing the tripods around the GPS antenna, making sure that the instrumental reference point is approximately at the same height of the GPS ARP. The operational procedure is based on changing the instrumental height adjusting the lengths of tripod's legs and refining using the tribrach's basal screws. It is important to ensure that a 90° reading on the vertical circle corresponds to a position of the horizontal wire as close as possible to the antenna ARP (Fig. 3b).

An analogous approach can be implemented through a small spirit levelling network.



(a) (b)

Fig. 3: a) Scheme of measured points with respect to the GPS antenna vertical axis. b) Triangulation scheme of the GPS ARP performed from tripods of the ground control network.

2.4 VLBI invariant point surveying

Several geometrical approaches can be used in order to recover the VLBI invariant point position. The strategy that we have chosen is suitable for AZ-EL telescopes: we place retro-reflecting prisms both on the lower structure (elevation fixed) and on the upper structure (elevation free) of the radiotelescope. Within a local frame, when the antenna rotates in azimuth maintaining a fixed elevation, the prisms describe horizontal circles with centres aligned along the azimuth axis of the telescope (fig. 4). In a similar manner, when the antenna moves in elevation maintaining a fixed azimuth, prisms describe circles with centres aligned along one particular position of the elevation axis (fig. 4). The invariant point is defined trough these telescope axes: the Reference (Invariant) Point is the point of the azimuth (fixed) axis which has minimum distance from the elevation (moving) axis.

In order to recover the Reference Point we install ten retro-reflecting prisms on the antenna structure. According to our processing procedure it is fundamental to ensure a certain degree of symmetry around the a priori horizontal and vertical position of the sought Reference Point. This is necessary in order to take into account the presence of a possible bending or a possible skew angle which would otherwise cause a biased estimate of the Reference Point position.

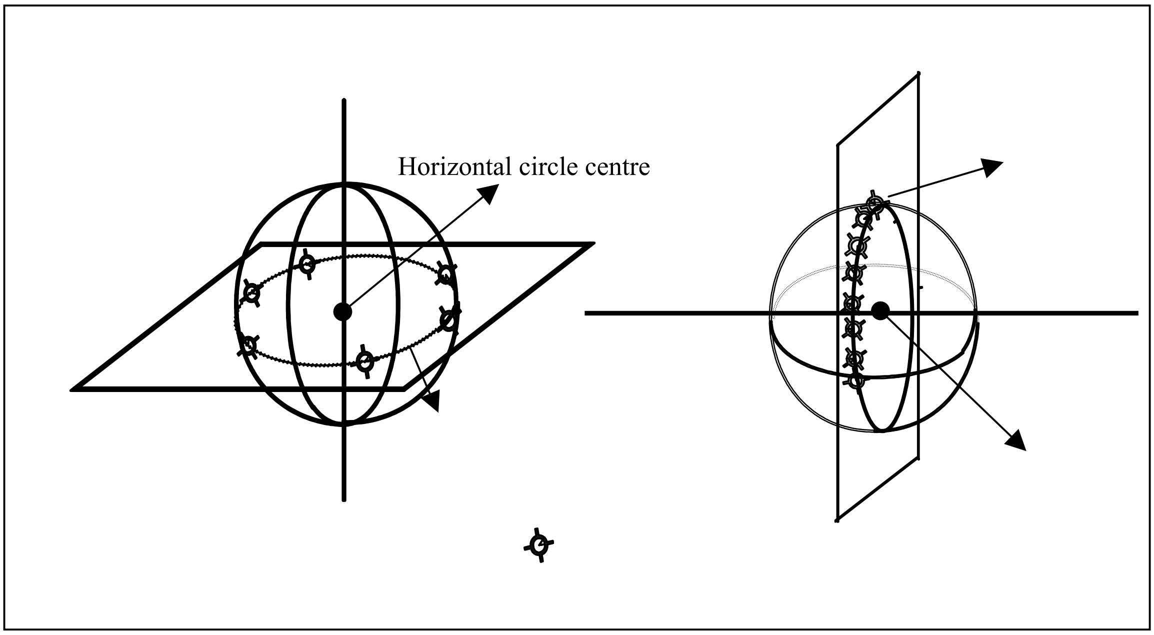


Fig. 4: Horizontal and vertical circles described by the rotation of one target around the azimuth or the elevation axis.

3 Data processing

STAR*NET least squares software has been used to perform the loosely constrained adjustment of acquired terrestrial measurements. In Figure 5 the sketch of the local ground control network used in 2002 survey is shown along with the observed points on the VLBI antenna, GPS antenna and all the measured connections. The local frame is defined fixing the horizontal coordinates of pillar P3 and the height of point G7; bearing is from point P3 to point P1. This is probably not the best way to define the local frame: its realization is affected by possible movements of ground pillars that are suggested by results obtained from 2001, 2002 and 2003 surveys and shown in Table 1. An extension of the network with pillars having a substructure of triplets of micro-poles is planned in the near future: this would considerably facilitate site monitoring and defining a good local reference frame.

A large redundancy of observations has always been sought during the surveys (see Table 2).

The adjusted positions of all targets and the complete variance covariance matrix are used in a post processing procedure that allows the rigorous estimation of the GPS-VLBI eccentricity vector along with its correlation matrix. In Table 3 the eccentricities for the three latest surveys are shown.

The SINEX file obtained from 2002 survey data is shown in the appendix. Analogous files have been produced for 2001 and 2003 surveys.

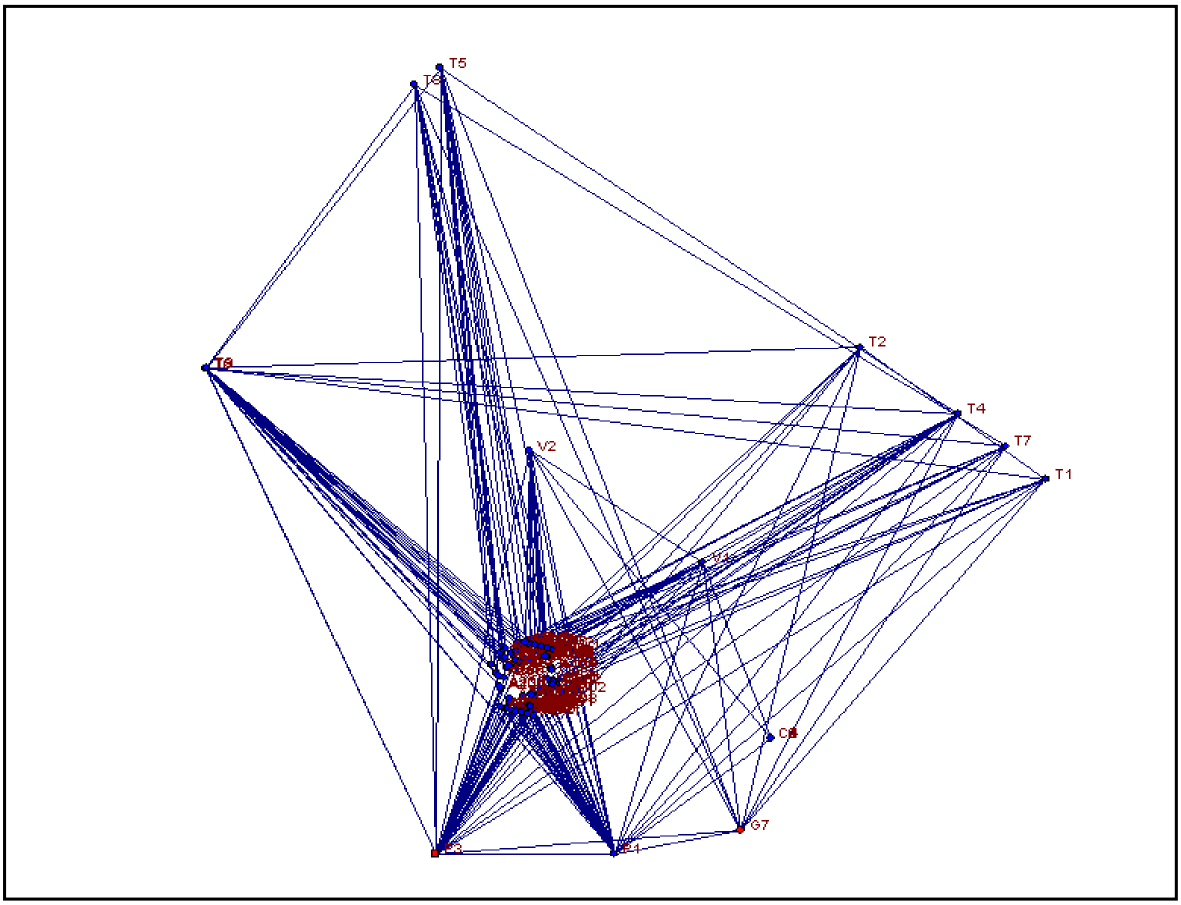


Fig. 5: Local ground control network and connections of 2002 campaign

Table 1: Local coordinates of the permanent ground control network markers

Survey / Coordinates	2001	2002	2003
X_{P1} (m) (fixed)	0.0	0.0	0.0
Y_{P1} (m)	42.6586±0.0002	42.6628±0.0002	42.6636±0.0002
Z_{P1} (m)	2.0772±0.0003	2.0783±0.0003	2.0772±0.0002
X_{P3} (m) (fixed)	0.0	0.0	0.0
Y_{P3} (m) (fixed)	0.0	0.0	0.0
Z_{P3} (m)	2.0195±0.0003	2.0177±0.0003	2.0154±0.0003
X_{G7} (m)	6.1261±0.0005	6.1309±0.0002	6.1386±0.0003
Y_{G7} (m)	72.7897±0.0006	72.7924±0.0002	72.7907±0.0003
Z_{G7} (m) (fixed)	0.0	0.0	0.0

Table 2: Number of observations carried-out in 2001, 2002, 2003 campaigns

	Local tie		
	2001	2002	2003
Points	110	105	236
Azimuth angles	297	308	549
Zenith angles	289	339	554
Distances	272	327	561
Unknowns	324	312	705

Table 3: Eccentricities for the 2001, 2002 and 2003 campaigns

Local tie / Eccentricity	2001	2002	2003
X_{VLBI} (m)	45.5356±0.0003	45.5360±0.0002	45.5384±0.0001
Y_{VLBI} (m)	21.5805±0.0004	21.5825±0.0003	21.5764±0.0001
Z_{VLBI} (m)	17.6995±0.0008	17.7024±0.0006	17.7003±0.0003
X_{GPS} (m)	29.9692±0.0010	29.9692±0.0008	29.9848±0.0003
Y_{GPS} (m)	79.9215±0.0011	79.9268±0.0006	79.9209±0.0003
Z_{GPS} (m)	0.5699±0.0008	0.5701±0.0005	0.5684±0.0003

4 Conclusion

The methodology that has been developed for the GPS-VLBI eccentricity at Medicina has proved to be precise for all surveys. High precision has been the aim in all campaigns: standard deviations have decreased approximately 20% in 2003 with respect to 2002 and approximately the same amount between 2002 and 2001.

A refined survey methodology has been developed: it takes advantages of the symmetry principles that can applied in rotational properties of VLBI antenna movements and GPS choke ring antenna features. Symmetry considerations have a major impact on the accuracy of the results: they can easily deal with the impact of bending or skew angle on the final estimate of the Reference Points.

Employing a couple of high precision total stations: three/ four days are enough to ensure a complete, redundant and rigorous local tie at Medicina.

The geometrical approach allows the computation of a full correlation matrix and consequently the production of the associated SINEX file which is the final fundamental requirement of an effective local tie.

References

Altamimi Z., Sillard P., Boucher C., (2002), "ITRF2000: A new release of the International Terrestrial Reference Frame for Earth Science Applications", J. Geophys. Res, vol. 107, No B10, 2214

Cenci A., Vicomanni G., Bianco G., (1998), "Determination of the invariant point and of the axes offset for the VLBI antenna at Medicina", Telespazio, Roma

Del Rosso D., and Ambrico F., (1995), "Survey of the Medicina site – September 1995", Nuova Telespazio, Roma

Nothnagel A. and Binnenbruck B., (2000), "Determination of the 1996 displacement of the Medicina radio telescope by local surveys"', in *Proc. of the XIV Working Meeting on European VLBI for Geodesy and Astrometry*, 61–66, Castel S. Pietro Terme (BO), Italy

Sarti P., Sillard P., Vittuari L., (2004), "Surveying co-located space-geodetic instruments for ITRF computation", J. of Geodesy (2004) 78:210–222 – DOI 10.1007/s00190-004-0387-0.

Sarti P., Vittuari L., Tomasi P., (2000), "GPS and classical survey of the VLBI antenna in Medicina: invariant point determination", Proceedings 14th Working Meeting on European VLBI for Geodesy and Astrometry, Castel San Pietro Terme (Bologna), Italia, 8–9 Settembre, pp. 67–72

Vittuari L., Sarti P., Tomasi P., (2001), "2001 GPS and classical survey at Medicina observatory: local tie and VLBI antenna's reference point determination" In: D. Behrend and A. Rius (Eds.): Proceedings 15th Working Meeting on European VLBI for Geodesy and Astrometry, Institut d'Estudis de Catalunya, Consejo Superior de Investigaciones Cientificas, Barcelona, Spain, pp. 161–167.

Appendix

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