OVLBI-ES MEMO NO. 29

Comparison of RF Methods for Testing of a Space Radio-Telescope Antenna on the Ground.

Calgary, May 1992

V.Altunin, Astro Space Centre, USSR.

Y.Belov, Radio Physics Research Institute,USSR.

K.van 't Klooster, ESA-Estec Netherlands.

O.Litvinov, VEGA Scientific Industrial Union,USSR.

1 Abstract

Electrical testing methods are outlined for the pre-launch characterisation of space-based radio telescope antennas. More specifically, the testing is discussed with the test of the radio-telescope antenna for the RadioAstron project in mind. It is concluded, that near-field type testing methods (amplitude and phase) and radio-astronomical methods are most suitable for RF characterisation of such type of antenna.

2 Introduction

Inflatable and deployable antennas with a diameter around 10 meter or more have been proposed in recent studies for space-based radio telescope antennas, operating in frequency bands up into the millimeter wave region [1,2,3]. It is obvious, that electrical performances must be well assessed before launch. The accuracy of the radio-astronomical instrument depends for a major part on the accurate evaluation of its sensor, which is the overall antenna-configuration (reflector with feed). Such testing is essential for the success of the complete mission.

Testing problems arise for such large antennas on the ground because of a number of reasons, among which:

- The necessity of **gravity compensation**,
- The necessity of protection against **environmental influences**, like weather (if outdoor testing is considered, rain, wind, temperature variations, etc.).
- **unique nature** of each antenna, implying specific measures to be taken, due to its particular size or application.

2.1 Gravity compensation

The space-based radiotelescope antenna has to operate under zero-gravity conditions. Obviously, limitations on mass and volume to be launched put constraints on the stiffness of the antenna construction. It may therefore be not sufficiently strong enough to allow a deformation-free situation during all testing on the ground. Special equipment is required to compensate the deformations due to gravity. Such equipment is even more special, when a movement of the complete antenna is required during the testing. The impact and need, if any, of such compensation equipment has to be taken into account during the testing on the ground.

2.2 Environmental effects

The influence of the environment on the antenna under test presents another important problem, in particular on an outdoor testrange (weather). It is clear, at present, that carbon fibre reinforced plastic (CFRP) is an important material for such type of antennas. Characteristics of CFRP material depend on humidity.

Loading conditions due to wind may lead to additional deformations. Protection of the antenna must be considered, for instance using a RF transparent radome in such situations. A radome supported by a tubular network of metal bars is another potential error source, which needs to be checked.

Carrying out the tests in an anechoic chamber provides another way-out to the latter problem. Combination of the special equipment for gravity compensation and the precautions against environmental influences may have to be considered, depending on the actual testing method.

2.3 Antenna specific precautions

The antenna is unique, only one flight specimen will be made for the given space experiment. It is obvious, that there is a necessity to carefully evaluate the electrical performances of the antenna. This can be realised at instrument level or at antenna sub-system level. In the former method the existing receiving equipment is used in a configuration adapted to the evaluation of the antenna: the radio-astronomical receiver itself is used for the test. It should be clear, that then the receivers have to be fully calibrated over the dynamic range, in order to separate the various effects associated with receiver or antenna. When the antenna is tested as a separate subsystem, it can be fully optimised for its function as sensor in the radio-astronomical instrument. This is preferred from antenna point of view.

An overview of RF testing methods for large reflector antennas for space is reported in [4]. Radiotelescope antennas for space have some specific features, which distinguish them from other types of reflector antennas for space. The radiotelescope antenna is supposed to operate over a wide frequency band. This is not at all the case for a communication antenna. The radiotelescope antenna must have an as high as possible effective receiving area. For application as an element in a VLBI network, the effective receiving area has to be as high as possible.

Operation is required in two orthogonally polarised channels, usually circular polarisation. Low cross polarisation is required in order to allow a correct measurement of polarisation characteristics of the radio source emissions [3,5]. Evaluation of polarisation aspects is mandatory in the testing activities. All these factors have a direct influence on selection of the testing method and the design of the actual test configuration. The mechanical considerations play an important role in the realisation. Some test-configurations are more suitable than others.

3 Testing Methods for the RadioAstron Antenna.

The RadioAstron antenna is considered as antenna under test in the comparison of various RF testing methods. The antenna design is described in [6]. It is a 'sunflower'-type antenna with a diameter of 10 meter. The f/D ratio is 0.422 and a prime focus operation is foreseen with application of a quadruple-frequency ringfeed [Dr.V.Dikij], which is housed in the focal container. The reflector consists of a central fixed part of 3 meter diameter with 27 deployable panels mounted around the periphery of the fixed part. The antenna has to operate at wavelengths from 1.35 cm to 92 cm. The reflector will be made out of CFRP.

Technical aspects of the RF testing method for the Radio Astron antenna were described in [7]. Criteria like quality, cost and simplicity are important, when discussing the testmethods in comparison.

In order to carry out radiative testing of the RadioAstron radiotelescope antenna on the ground, with complete compensation of the gravitational deformation, the reflector is put in a deployed configuration, using special jigs, such as to insure, that the shape of the antenna surface is preserved during any required movement for the testing (like rotation of an azimuth turntable). In such a way pre-flight operations with the antenna with 'regulated' distorted geometry can be carried out in the presence of gravity forces.

Gravitational deformations produced due to the tilting of the antenna on an elevation type of positioner leads potentially to an increase of surface errors. As has been proved by statistical data for different radio telescope antennas, the antenna gain can depend on the antenna orientation wrt the zenit direction, even up to an order of a few dB's [8]. To exclude the influences due to the weather conditions, the testing of the RadioAstron antenna should be carried out in a closed environment or under protection of a radome. Clean room circumstances deserve attention to be considered. Such radome is also necessary, when testing is carried out with natural or artificial celestial sources. Humidity absorption of CFRP has been mentioned already.

To summarize various testing methods, one could follow the following subdivision:

Direct testing:

- far-field
- defocussing

- collimation

Indirect testing:

- near-field
- partial testing, combined with calculations

3.1 The radio astronomical method

can be categorized under *'far-field' methods.* Here the antenna under test is moved on the positioner under the radome, using gravity compensation devices. The latter devices might be complex due to the need to move in elevation in directions not necessary to zenith. The sensitivity of the receiver for the space radio telescope ($0.02 - 0.07K$ as a function of the wavelength $\lambda = 92cm$ to $1.35cm$) permits us to measure the antenna effective area (gain measurement) by using strong sources ($3C461, 3C405$), the antenna pattern (boresight deviation) and the first sidelobe levels. Also such type of radio astronomical method permits to determine the basic parameters of the overall space-telescope without disconnecting the RF-lines by using the internal astronomy receivers. Dynamic range is not too high and accurate polarisation testing is not good.

The method doesnot allow to measure antenna polarisation characteristics and that the measurements at λ= 1.35 cm would be strongly influenced by the weather conditions and by the water vapour content along the line of sight. Also it is most likely impossible to exclude the effects of gravitational deformations, which will thus have an impact on the pattern. The latter because of the complicated combination of gravity compensation and movement of the total antenna during the actual testing. (The strong celestial sources are not necessarily localised in the zenith direction).

Furthermore, the sidelobe levels are modified due to the effects of the radome, the latter even in a very undesired way, when the radome is wet. (A few dB change in level has been observed, in case a wet radome was used in front of the antenna).

3.2 The Holographic Method

This method is usually aplied in a far-field configuration. In a far-field configuration, this method is realised with the help of an additional antenna, which is positioned next to the antenna under test. Both antennas are connected to a correlation receiver [10,18]. This method, where phase and amplitude is measured, requires a two channel receiver. It allows to obtain a surface map for the reflector, based on which corrections in the reflector configuration could be applied, like for instance at panel level.

The extension of the radio astronomical method to obtain a surface-error map is possible using phase retrieval methods. The distorsion of the antenna surface profile is determined form processing of data-sets taken for different positions of the feed in the focus. Good results have been obtained, for instance on the Pico-Veleta radio telescope (Baars, Morris). They were also the first to report about errors and their impact as well as accuracy of the method [18]. Even retrieval from single amplitude data has been reported [9].

Measurements obtained with celestial sources at different latitude positions could be useful for the investigation of the influence of gravitational deformations. Also , one needs an enough large 'signal to noise'-ratio in this method to achieve sufficient accurate results.

In the case of the $10m$ antenna for RadioAstron, it would be us-ful to use satellite signals at the frequencies as foreseen for RadioAstron. For a surface maps with good quality in the resolution of the errors after processing, large amounts of data are required with the automatic consequences also for the data-collection time.

3.3 Defocussing

This method has been applied, but requires a test set-up distance in the order of a few aperture diameter. [See book Prof.Tseytlin, chapter 8]

3.4 (Auto)-Collimation

The group of methods, where there are no (artificial) celestial sources used in the far-field are the so-called *collimation and auto-collimation* methods. An anechoic chamber is required. The effects of gravitational deformations can be reduced in the 'auto-collimation' method by using a measurement scheme with the antenna under test directed to zenith and with the plane mirror mounted above the antenna under test, acting as a collimator. Measurements are realised in principle by tilting the antenna under test or by tilting the reflecting plate. A circular polarised signal transmitted by the antenna is reflected by the plate and has after reflection the opposite orientation of the circular polarisation. It is obviously received in the other channel (orthogonal polarisation). The main problem of this method is the crosstalk between the orthogonal channels, which is a direct limitation for the dynamic range in the test. The presence of potential diffraction effects at the edges has to be evaluated (plate, antenna) as it could lead to errors in the test.

The collimation method (Compact Range) needs a collimator with a size of approximately two times the size of the antenna under test. The collimator must have a good acuracy in order to reproduce a good 'artificial' plane wave. The errors in the antenna pattern measurement are proportional to the rms deviations in the plane wave field distribution illuminating the antenna under test. For example, in order to have the gain error less than 1 dB, one must have the amplitude error in the plane wave zone (= testzone) below 7 % [11]. This leads to a necessity to determine the quiet-zone field distribution.

It makes the autocollimating method more expensive and complex than the radio-astronomical method, but it yields potentially better accuracy. It is also interesting to observe, that there is a need for a field scanner to evaluate the quiet zone field, when the best accuracy is required.

Some suggestions have been made to combine various methods for the evaluation of the RadioAstron antenna, but such approach complicates the issue, when the antenna with positioner has to be moved from one testing location (collimator) to the other one (astronomical method under a radome). Usually, large antennas are installed very accurately on massive supporting structures.

3.5 Near-Field Methods

are not free from gravitational deformations in the case of cylindrical or spherical scanning. A minimum distortion is achieved, when the antenna is kept fixed during the test.

Planar near-field scanning provides in principle an interesting configuration When the antenna is directed towards zenith, the effect of the gravitational forces is minimised. Moreover, the effects of gravitational forces stays the same, when the antenna would be rotated about its vertical axis. The measuring probe has to move over the aperture plane in front of the antenna.

The most simple version from mechanical point of view of near-field scanning in a planar fashion was implemented by the Institute for RadioPhysics in Niznij Novgorod [12]. They were the first to implement the particular scheme ('bipolar). Here the aperture plane is sampled by a probe, which is mounted on a boom, which can be rotated over the antenna under test in a bi-polar fashion. The antenna under test is mounted with its bore-sight towards zenith and can rotate on an azimuth positioner.

Combination of the movement of the probe on the boom and the rotation of the antenna under test provide the possibility to sample the aperture plane. Only two rotations are involved, therefore this method was named by J.E. Hansen 'Bipolar Near-Field Scanning' (Goteborg 1988). Lateron this method was described as being 'novel' again (IEEE-AP 1991). From the measured data, the far-field can be predicted, using a dedicated near-field to far-field transformation, which was first derived by the above mentioned institute for this configuration [12].

It must be mentioned, that one can also arrive at predicted results by transformation in a very simple way the NF data, which were obtained after resampling of the measured NF data. [13].

Plane-polar scanning, where the probe moves linearly along the radius is an alternative configuration with slightly more mechanical complexity, as an accurate linear movement along one dimension is needed.

Probe positioning

has to be very accurate to within $\frac{\lambda}{120}$, obviously related to the accuracy objective to be realised. It is circa 0.1 mm for the RadioAstronantenna in the 22 GHz band and an equivalent relative value at 5 GHz. The total aperture plane to be sampled has to be larger than the antenna itself, in this case about 12 m would be sufficient. The sample point distance would be selected in relation with the needed region of validity, within which useful information would be needed. For the 'bi-polar' method, the probe would be moved along trajectories, which areparts of a circle (arc), with radius 'a' (boom length), while the antenna rotates. The arc intersects with the vertical rotation axis of the antenna positioner within an accuracy of a fraction of λ.

Implementation of the near-field method requires also the implementation of the algorithms to calculate the far-field performances. Such algorithms are available.

Very good experiences with near-field scanning are available. The ERS-1 Synthetic Aperture Radar antenna (10 meter long, 5.3 GHz) was measured on a planar near-field range with high accuracy and some further data processing was applied to derive the aperture field distribution from a backward transformation [19]. The method allows to evaluate the full polarisation properties, as well as the effective area or absolute gain. Moreover, with the knowledge available from experience, the near-field method is extremely useful, already without near-field to far-field transformation.

The algorithms for various configurations (rectangular, polar, bi-polar) have been explored and used at various places [15,16,17,20] and more than one variant in each case is available.

The planar type of near-field scanning is a good add or would even replace the radioastronomical method and can be more accurate, since the antenna is not tilted, but is kept zenith-oriented.

The scanning scheme permits to move the probe out from the aperture plane, thus still allowing other type of testing to be carried out, for instance if astronomical type of testing would be requested.

3.6 Partial Testing

A surface accuracy assessment of the reflector is of course a good initial possibility; but for a perfect overall antenna RF assessment it is not the most accurate. Addition of the measured feed performances into the analysis is a step forward, but accurate analysis of blockage effects remains an error source, in particular, when it concerns (de-)polarisation effects.

4 Conclusion

A number of testing methods has been indicated with remarks concerning the accuracy of the method. A suitable method for a 10 meter class antenna could be a combination of near-field scanning with an astronomical type of testing. Near-field testing should suffice alone as well to evaluate the performances. Holographic testing may lead to difficulties to attribute the errors to either the feed, configuration aspects or reflector. Amplitude and phase measurement over a large near-field measurement plane is demanding at the higher frequencies a.

5 Acknowledgement

The following note presents the topics discussed during the Radio-Astron meeting in oct. 1990 in Moscow. Dr.Yu.Belov is acknowledged for elaborating the text, Dr.O.Litvinov and Dr.V.Altunin for their contributions.

References

[1] V.V.Andreyanov, N.S.Kardashev, 'RadioAstron Project', Astron.Journ., 63,850,1986.

[2] H.Hirabayashi, 'VLBI Activities in Japan and a projected Space VLBI Programme', NRO Report 146, 1987.

[3] IVS, An Orbiting Radio Telescope, ESA Assessment Study Report. 1991.

[4] Y.Rahmat-Samii, 'Large Antenna Measurement and Compensation Techniques', WWP-01 Proc. 11th ESTEC Antenna Workshop on Antenna Measurements, Gothenburg, Sweden, June 1988.

[5] V.Altunin, V.Andreyanov, E.Bitushan, e.a. 'The RadioAstron Antenna System', IKI Preprint Pr-1297, 1987.

[6] E.Bitushan,S.Sayapin,V.Altunin, 'Design of a Deployable Radio Telescope Antenna', IKI Preprint No-1243, 1987.

[7] A.Kalinin, Yu.Belov, V.Altunin, 'RadioEngineering Testing of a Space Radio Telescope Antenna System for the RadioAstron Project', IKI Preprint, No-1244, 1987.

[8] W. Christiansen, J.Hogbom, 'Radiotelescopes', Cambridge University Press, 1987.

[9] K.McCormac, A.Anderson, 'Phase Retrieval Microwave Metrology of Reflector Antennas from a Single Amplitude Data Set', WWP-01 Proc. 11th ESTEC Antenna Workshop on Antenna Measurements, Gothenburg, Sweden, June 1988.

[10] D.Tarchi, G.Comovetto, ' Holographic Measurement of the Medicina VLBI Radio Telescope', Arcetri Techn. Rep. No16,1990

[11] L.D.Bakhrakh,ed.'Measurement Methods of RF System Parameters in the Near Zone. Nauka, 1985.

[12] Yu.Belov, A.Kalinin, E.Kalinina, 'The Use of Jacobi-Bessel Series', Isvestia, Boesov.Radiophysika, 30,1286,1987.

[13] E.van Lil,C.Cao, A.van der Capelle, K. van 't Klooster, 'A Fast Interpolation Procedure for Plane-Polar Near-Field to Far-Field Transformation', IEEE-AP Symposium, Dallas, May 1990.

[14] L.D.Bakhrakh, O.Litvinov, 'Algorith for the Determination of the Near-Field Distribution along ..', Radioelektronika, 6, 12, 1982.

[15] L.D.,Bakhrakh, O. Litvinov, ' Calculation of the radiation diagram in radial aperture sectors ',
Radioelektronika, 21, 40, 1978.

[16] L.D.Bakhrakh, O.Litvinov,
DLI SSSR, 312, 841, 1990.

[17] K.van 't Klooster, W.Rits, E.Pagana, P.Mantica, M.Bernasconi,
'Inflatable Parabolic Reflector Antenna, Realisation and Electrical Predictions',
Proc. URSI Conf. 'Mirror Antennae Constructions', RIGA, Sept. 1990.

[18] D.Morris 'Telescope Testing by Radio Holograophy',
International Symposium on Millimeter and Submillimeter Wave Radio Astronomy',
Granada, September 1984.

[19] 'Holography Testing of Large Radio Telescopes'
SAO Ratan-600, N.Arkhyz, 1990.

[20] 'Antenna Measurements'
Prof. Tseytlin, NIRFI, Nizhnij Novgorod.