Quasi-Optical Aberration Analysis for the Sardinia Radio Telescope

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***Abstract*—This report analyses the beam squint effect for the Sardinia Radio Telescope (SRT) when antenna is used for Telemetry Tracking & Command missions. This work studies the BWG components (i.e. elliptical and dichroic mirrors and feeds) and their displacement to get the correct beam aberration. To understand the importance of an engineered methodology of beam squint analysis, two main approaches in the quasi-optical path design are discussed. The first one is straightforward but very time consuming. The computing time is huge for a 64m reflector antenna like SRT and a new design way is needed. The second approach is presented: a good matching between two P.O. analysis on a fictitious planar grid along the BWG permits a fast design way. This method allows the implementation of automatic algorithms and routines so the design will be more efficient and accurate.**

Index Terms*—Reflector Antenna; Radio Astronomy; Sardinia Radio Telescope; Beam squint

I. Introduction

FROM 1960 to nowadays, the evolution of large reflector antennas for radio-astronomic and telecommunication use leads to an increase of main dish diameter together with the frequency bands. 35m antennas working in Ka-band (32 GHz) are usual but to reach better performance, a doubling of main reflector dimension is need. The Sardinia Radio Telescope is the example. SRT is under construction in San Basilio, a town 35 km north from Cagliari (ITA). It is a 64m gregorian double reflector antenna with a BWG that provides four different focal points. Two of them will be use by the Italian Space Agency (ASI) in cooperation with the European Space Agency (ESA) for TT&C operations but SRT is already working as a radio telescope with the other two focal points.

The design of the BWG for extra-planetary missions support will take in account two operation bands: X and Ka. As the theory report, if in an aperture antenna the main reflector doubling its dimension compared to the wavelength and operates at high frequency bands, i.e. over 32 GHz, his gain will increase a lot. SRT performances lead a nominal gain over 80 dB and consequently a sharp -3dB beamwidth. For this reason a beam aberration is request because a contemporary up-link and down-link between the ground station and a spacecraft is impossible. The powerlessness of a full duplex link is due to the strong gain loss provides by the beam sharpness. This fact leads the demand of TX beam squinting to follow the spacecraft when it is travelling at high speed along the transversal main dish direction.

II. Beam Waveguide

Newer large reflector antennas are equipped with a quasi-optical path called beam waveguide. The BWG approach permits many advantages for example a multi-frequency operations or a better environment for the feeding systems. The microwave circuitry could be install without space constrains due to a larger rooms where the feeds are placed. Also the hindrance of cooling systems for the LNAs will not be problematic anymore thanks to the BWG that move the focal point from the gregorian one to a large room under the antenna's building.

The BWG system is composed by elliptical mirrors that guide the electromagnetic fields along the quasi-optical path and by dichroic mirrors. Also know as frequency selective surfaces (FSS), a dichroic mirror could act as a high pass filter (inductive) or low pass filter (capacitive). In the first case the FSS is a metal plate with arbitrary thickness where a periodic pattern of apertures is produced. The thickness together with the shape of apertures establishes the cut off frequency. At the opposite, if a periodic structure of metallic patches is printed on a dielectric substrate, the FSS acts as a low pass filter. An efficient multi frequencies feeding system is possible thanks to the dichroic mirrors that ensure different focal points for different frequency bands.

In the case where beam aberration is required, such as SRT, the BWG has the assignment to divide the transmission path (TX) from the receiving (RX) path. In SRT this task is demanded to an inductive FSS called M8 [Fig.1] that separate Ka-TX (34.45 GHz) from Ka-RX (32.05 GHz) and permits the squint of the TX beam without tilt the RX. The TX beam aberration is possible thanks to the coordinate displacement of two solid. Due to the sensitivity of the mirrors angle rotation versus the TX beam squint, an efficient and automatic routine is needed to get the movement that ensures the correct squint with the minimum gain loss.

A mirror displacement leads an unavoidable gain loss. This is caused by phase's mismatches on the aperture electromagnetic fields that occur when nominal geometry is perturbed. Only a small fraction of gain loss is caused by a spillover from mirrors. For these reasons the TX beam is squinted and the RX beam still remains in nominal position with maximum gain. During spacecraft tracking, the gain losses that affect the TX beam could be avoided by a boost of power supply but the receiving signal could not be amplified.

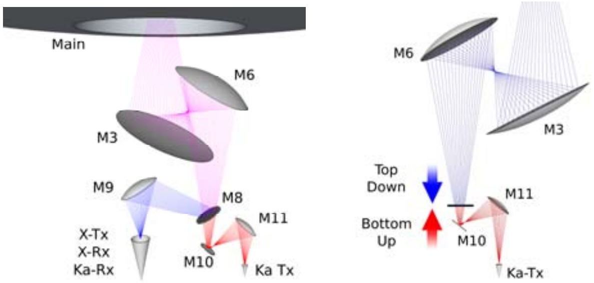

Fig.1 – proposed design of SRT BWG. On the left, a picture of the fictitious planar grid placed between M10 and M6.

III. Top down versus Bottom up

As the abstract introduced, the most straightforward methodology that could be applied in a BWG for beam squint design consists in several fully-electromagnetic simulations of the entire antenna. This algorithm requires the displacement of the BWG mirrors and the complete simulation of the antenna, from the feed to far field (complete bottom up analysis). A 64m double reflector antenna requires several hours of simulation to calculate the far field, and consequently the result of two mirrors rotation (in terms of beam squint angle).

The other methodology is called top-down. A plane wave comes from the sky and excites an electromagnetic field on main reflector. This field will be guided along the BWG system. The resulting field distribution (TD) is calculated on a fictitious planar grid [Fig. 1] placed along the quasi-optical path and between the main reflectors and the mirrors that act the TX beam squint. On the other side, the antenna is feed by his corrugated horn and the field propagates to the fictitious planar grid, where it is calculated too. This last simulation is called bottom up (BU) and is very fast, a few seconds, because only two mirrors are involved. The correct matching of BU with the TD on the planar grid ensure a far field close to the initially plane wave that produced the TD. If the plane wave is tilted by a few millidegrees the TD field on the grid changes. But this open the possibility of searching that mirrors configuration that produced a BU field that match with the TD one. The plane wave tilting simulated the beam aberration and in this way it is possible to get a BWG design that produce the requested squint angle.

The computational time request is high only for the TD but is reasonable to calculate only few cases of plane wave tilting, for example tens of mdeg. Otherwise, thousands of BUs (and consequently mirrors movements) will be calculate automatically with a batch mode simulation.

To compare all BUs with a single TD, an efficient and automatic routine is needed. The focal point of the proposed project is the algorithm that compares the BU with the TD. The proposed formulas calculate the geometrical positions of the maximum in magnitude and phase of BU and TD fields. Then the difference of these coordinates is estimated so the distance between the TD and BU maximums is calculated. Finally the sum of the distances of maximums in magnitude and phase is minimized and the BU that ensures the better matching with the TD is extracted.

Magnitude and phase matching [Fig. 2] permits the extract a BWG design that ensure the correct beam aberration angle with minimum gain loss.

IV. Simulation results

Thanks to this methodology, thousands of BWG configurations are studied. During the comparison between BU and TD, various mirrors displacement that squint correctly the TX beam are discovered. To set which design is better and to prove the correct beam aberration angle, a full antenna simulation is required. This kind of simulation permits the evaluation of the TX beam squint angle and the gain loss. Is precisely this last feature that set the quality of the BWG design for each simulation.

Applying the methodology presented above, the mirrors rotations that generate the required beam squint angle are calculated. A good matching between BU and TD ensure the movement that provides the lowest gain loss with the correct beam aberration. For example, a squint of 10 mdeg is gained with a rotation by 1.10° of elliptical mirror M11 together with a 1.20° rotation of plane solid mirror M10. The gain loss in this case is only 0.017 dB. For a 40 mdeg of aberration, M11 needs a rotation by 4.20° and M10 by 4.90° with a resulting gain loss of 0.755 dB.

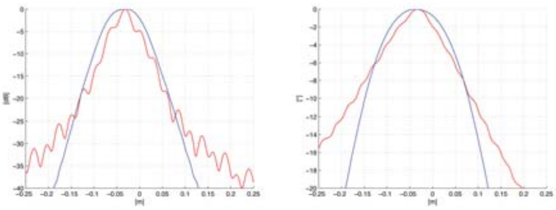

Fig. 2 – the right graph indicate the BU (blue line) matched with the TD (red) in mag. The left graph is referred to phases.

V. Conclusion

This project leads to a new efficient and automatic methodology in BWG design. The generally approach used to develop this algorithm made this project really suitable for every kind of BWG reflector antennas. Lasts simulations permits a beam squint analysis applied also to Deep Space Antenna 2 and the results will confirm the top down approach.

This work was the fundamental activity that leads to a scientific paper titled “Beam Squint Compensation Technique for the Sardinia Radio Telescope” presented at the 2012 European Microwave Conference, Amsterdam (Netherlands).

After this project, developed until my MS degree, my research program proceeds with a Ph.D. career at Microwave Laboratory, University of Pavia with Prof. Luca Perregrini as tutor.

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