High Gain Antenna for Sub-Millimeter Wave Communications

A. Martínez[1], I. Maestrojuan[1], D. Valcazar[1], J. Teniente[2]
[1] Anteral S.L., Campus de Arrosadía, 31006, Pamplona, Spain, e-mail: aitor@anteral.com
[2] Electric and Electronic Engineering Department, Public University of Navarra,
Campus de Arrosadía, 31006, Pamplona, Spain, e-mail: jorge.teniente@unavarra.es

***Abstract*— Nowadays the increase of high data rate communication applications requires high bandwidth at sub-millimeter wave frequencies and above, therefore high performance antennas are needed. This paper presents the design, fabrication and test of a high gain offset parabolic reflector antenna at sub-millimeter wave frequencies using typical machining techniques. The high gain antenna is focused on a 330 GHz communication link test with up to 60 GHz bandwidth with the goal to set up a 50 Gbit/s data rate link, over 100 m distance.**

***Index Terms*— parabolic antenna, antenna, communication, measurements.**

I. INTRODUCTION

Development of millimeter and sub-millimeter wave components grows up for applications such as astronomy, space science, security, medical applications and communications [1]. In the case of communications systems at millimeter and sub-millimeter wave operating frequencies, high gain antennas would be required in order to compensate the large propagation losses. The goal of this paper is to present the design, manufacture and test of a high gain offset reflector antenna used for point-to-point sub-millimeter wave communication systems at high frequencies, specifically at 330 GHz. The objective has been to manufacture it using typical fabrication techniques, to reduce mechanical complexity compared with cassegrain dual reflector configurations used at lower frequencies, where high alignment precision between feed, sub-reflector and main reflector is needed and finally reduce the cost

At present, there are many proof of concept research projects such as M3Tera [2] and communication systems in R&D state [3] [4] focused on high frequency (above 100 GHz) and high bandwidth communication links, in order to obtain real time high data rates (> 10 Gbit/s) and providing feasibility test of systems operating at those high frequency bands. The design presented in this paper has the purpose of extending the range of such communication links under development now-a-days.

II. HIGH GAIN ANTENNA SPECIFICATIONS

A high gain horn antenna with more than 50 dBi gain which could be the antenna part of a POC (proof of concept) 330 GHz (50 Gbit/s rate) communication system is presented here.

The initial reflector and feed horn electrical specifications are gathered in Table I, and other mechanical requirements and limitations are depicted in Table II.

TABLE I. HIGH GAIN ANTENNA ELECTRICAL REQUIREMENTS

Parameter	***Value***
Central frequency	335 GHz
Bandwidth	60 GHz
Gain	> 50 dBi
Polarization	Single linear horizontal
Input waveguide	Standard WR-2.8

TABLE II. REFLECTOR AND FEED HORN MECHANICAL REQUIREMENTS

Parameter	***Value***
Feed horn interface	UG387 U/M
Manufacturing material	Aluminum
Reflector maximum diameter	20 cm
Reflector weight	< 2.5 Kg
Input waveguide	Standard WR-2.8

III. DESIGN OF REFLECTOR ANTENNA AND FEED HORN

A. System design

In addition to the electrical and mechanical requirements the manufacturing easiness has been a key point in the design process as well as the frequency scalability to other operational frequency bands.

In this way, a parabolic off-axis or offset reflector configuration has been chosen to obtain the required high gain where the side-lobe levels and maximum cross polar level are not significant parameters. According to this, to feed the parabolic offset reflector, a pyramidal feed horn with 15 dBi directivity, that maximizes the final directivity of the complete configuration, has been designed with at least 60 GHz bandwidth and phase center near to its aperture, see Fig. 1a and 1b for the feed hon antenna details.

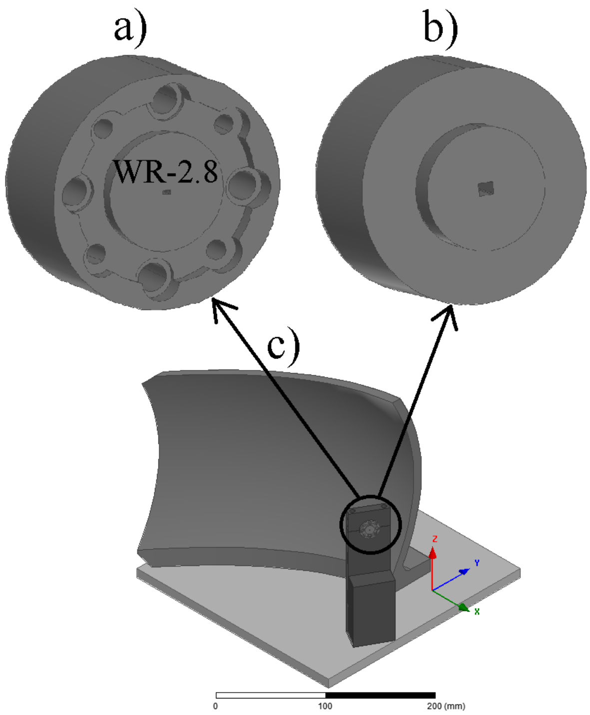

Fig. 1. Offset parabolic reflector with the clamping base plate and feed horn placed in the focal point.

Fig. 1c shows the 3D model of the RX reflector antenna formed by the parabolic reflector, pyramidal feed horn and the clamping base plate where the RF modules would be placed.

TABLE III. REFLECTOR AND FEED HORN DIMESIONS AND PARAMETERS

Parameter	*Value*
Reflector maximum diameter	200 mm
Reflector focal length	85 mm
Offset angle	30 degrees
Feed horn aperture size	1.25 mm x 1.05 mm
Feed horn length	10 mm
Base plate – feed horn distance	107 mm

B. *Simulation results*

The parabolic reflector has been designed and optimized using Ticra`s GRASP software and the feed horn using ANSYS HFSS. In order to have accurate results the feed horn radiation patterns have been exported to GRASP, which allows a complete system configuration simulation.

The simulated far field radiation pattern of the high gain antenna at 330 GHz, is presented in Fig. 2

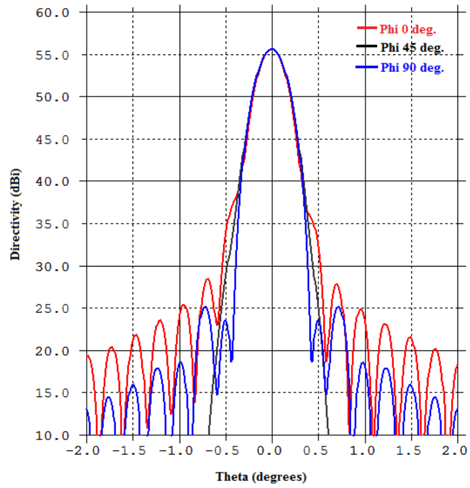

Fig. 2. Far field radiation pattern of the high gain antenna at 330 GHz.

IV. HIGH GAIN ANTENNA MANUFACTURING

A. *Offset parabolic reflector manufacturing*

The high gain antenna has been fabricated in aluminum. Moreover, the reflector has been manufactured using a high precision milling process followed by a polishing process. The polishing process has no effect in the reflector surface dimensions because it is simply applied to eliminate the micro-ridges resulting from the machining process. The reachable surface roughness is N3 with Ra = 0.1 microns and the fabrication tolerances are +/- 15 µm. Those surface roughness and shape values are supposed to be enough to avoid relevant losses in the reflector [5]. The achieved quasi-optical reflecting surface allows a laser verification of the reflector focal point using a visible light laser pointer as reference.

B. *Piramydal feed horn manufacturing*

Concerning the feed horn manufacture, an electrode discharge machining process has been employed, with different electrodes to enhance the surface finishing. In this case, the inner surface roughness is N4 (Ra = 0.2 microns) and mechanical tolerances of +/- 20 µm are obtained.

C. *Support and clamping structures*

Regarding the reflector and feed horn support structures, traditional machining process has been employed with surface grinding post-process, which has been of great importance to obtain good perpendicularity between baseplate and feed horn support structure. Using a visible light laser pointer, the focal point of the reflector has been verified in the exact point of the horn support structure.

The feed horn placed in the support structure (parabolic focal point) and the reflectors are presented in detail in Fig. 3. Some pictures of the fabricated reflector, feed horn antenna and support structures once assembled together are presented in Fig. 4.

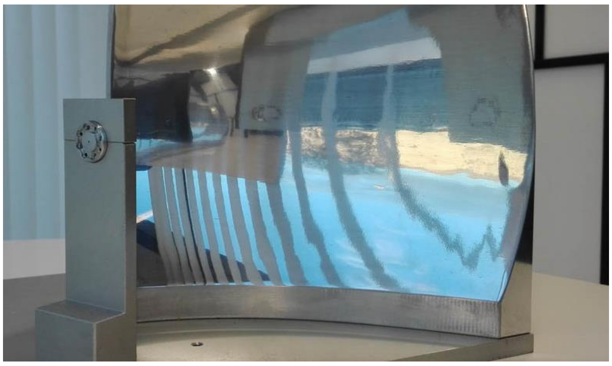

Fig. 3. Feed horn interface and parabolic reflector with polished surface.

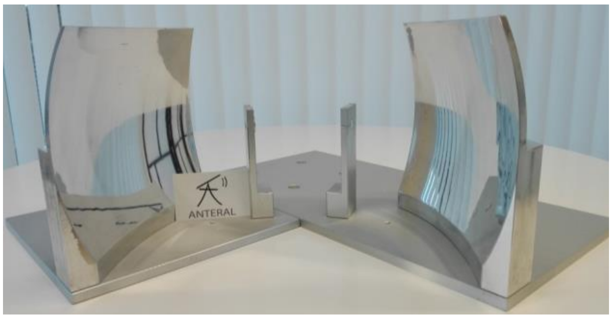

Fig. 4. Manufactured TX and RX high gain antennas with polished surfaces, base plates and feed horn clamping structures.

V. HIGH GAIN ANTENNA MEASUREMENTS

A. Planar near field measurement

Radiation pattern measurement has been carried out using a planar near field measurement system. The complete operational band has been measured (305 to 370 GHz). A near field probe made with WR-2.8 open ended waveguide has been required to record the planar near field. This near field probe has been manufactured using innovative metal additive manufacturing (AM) techniques and post processing finish. This near field probe is presented in Fig. 5. Planar near field has been recorded at 40 cm distance from the parabolic reflector; a size of 250 mm by 224 mm area with spacing of 0.4 mm between measurement points has been obtained. After near field data recording, far field transformation is applied obtaining a 2D far field radiation pattern, where the E and H plane cuts can be extracted, see Fig. 6.

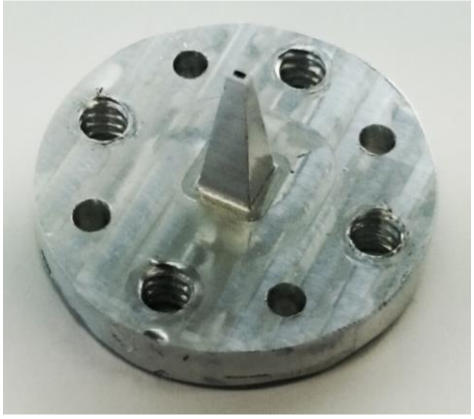

Fig. 5. WR-2.8 wave guide Near Field Probe manufactured using innovative additive manufacturing techniques in aluminium alloy.

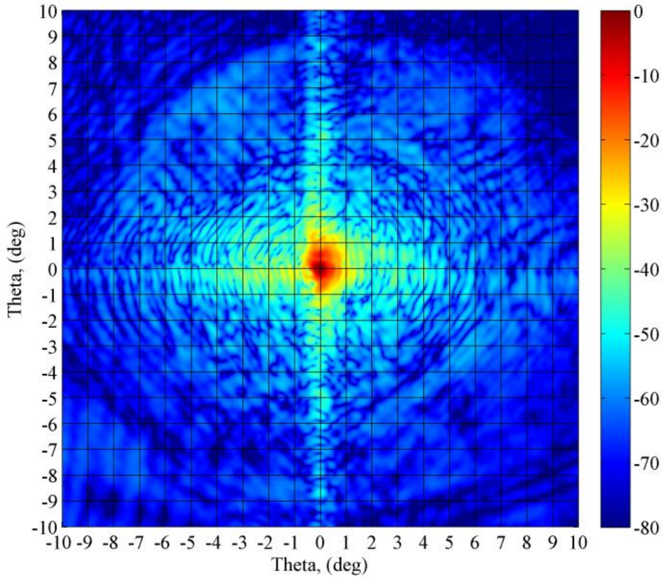

Fig. 6. Measured 2D far field radiation pattern at 330 GHz.

B. Measurement results

The final far field cuts are presented in Fig. 7, 8 and 9 at 310 GHz, 330 GHz and 360 GHz respectively. All of them have side lobes around -10 dB and a FWHM (full width at half maximum) around 0.4 degrees.

The directicity of the antenna has been calculated by means of the radiation pattern integration, see Figure 10. The full 2D far field radiation pattern obtained from the planar near field measurment transformation has been used for this calculation to enhance the accuracy of the result.

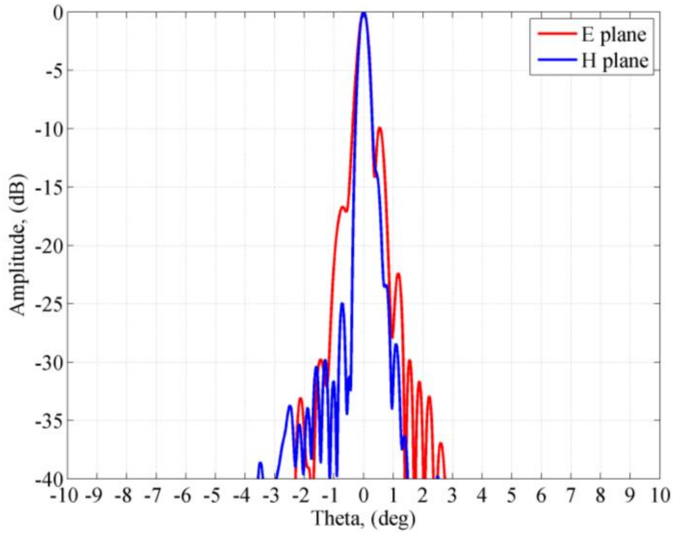

Fig. 7. Measured far field radiation pattern at 310 GHz.

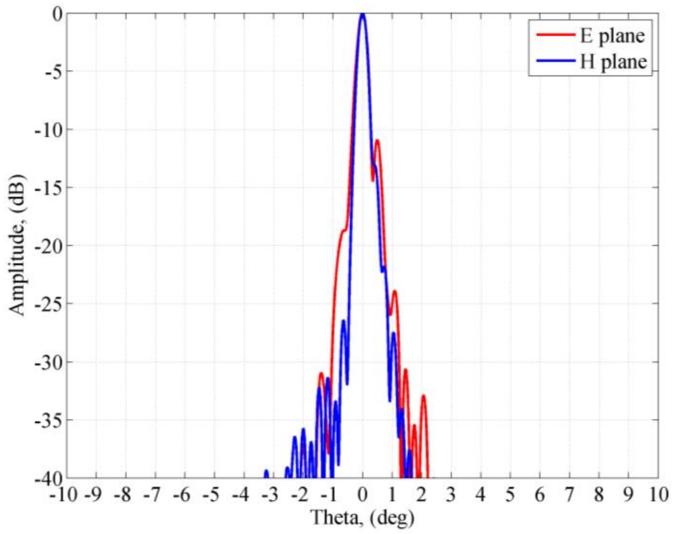

Fig. 8. Measured far field radiation pattern at 330 GHz.

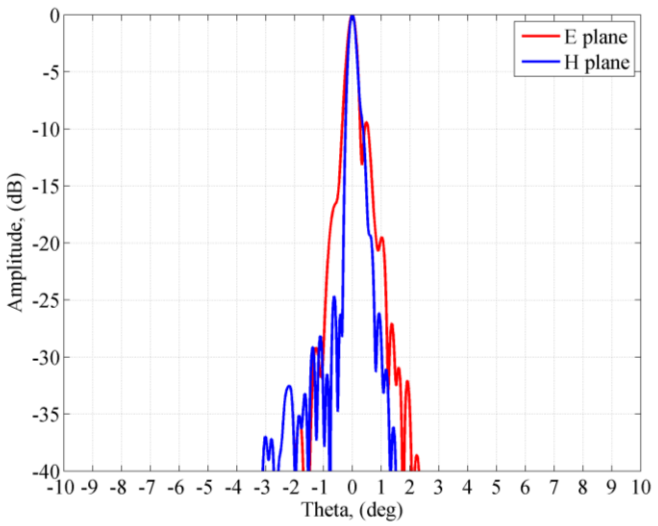

Fig. 9. Measured far field radiation pattern at 360 GHz.

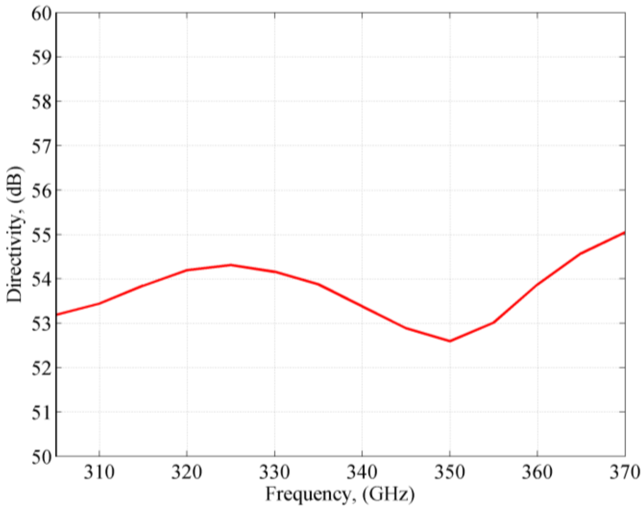

Fig. 10. Measured directivity in the whole operation bandwidth 305 GHz – 370 GHz

C. *Measurements data analisys*

The measured directivity and far field data shown in Fig. 7, Fig. 8, Fig 9 and Fig. 10 verifies that the manufacturing of the feed horn and reflector has been carried out with the desired dimensional precision. Note that the gain of the antenna has not been measured but considering that the directivity of the antenna is higher than 50 dB and that the surface roughness has been reduced in the polishing process, it is supposed to be quite similar to the directivity. The gain measurement, taking into account the antenna dimensions, supposes that far field distance is around 100 m. This distance results quite large to perform a standard three antenna gain measurement method.

The side lobe levels of the radiation patterns are due to little misalignments between reflector focal point (ideal) and the point where the feed horn is placed, no far sidelobes are found in measurements, see Fig, 6. This was taken into account in the design process and there is a safety margin of more than 250 µm of misalignment in 3 axes to keep the directivity of the antenna above 50 dBi.

VI. TEST UNDER REAL CONDITIONS

Two units of this high gain reflector antenna have been part of communication system, for a real time communication link test obtaining 50 Gbit/s data rate transmission at 100 m distance with a BER better than $9{\cdot}10^{-4}$ for an OOK modulation scheme and 50 µW transmitter power. This results are still unpublished so we cannot give more details about it.

VII. CONCLUSIONS

A high gain antenna at 330 GHz has been designed, manufactured and measured with satisfactory results, validating the manufacturing processes and reducing complexity and cost compared with other high frequency high gain antennas, present in the market.

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