IETR millimeter-wave Compact Antenna Test Range implementation and validation

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Abstract: In order to improve its capabilities in measuring millimeter-wave antennas, the Institute of Electronic and Telecommunications of Rennes has implemented a Compact Antenna Test Range (CATR) in one of its anechoic chamber. This paper describes the main lines of this project, from the technical requirements to the verification of the CATR performances. Measurements of the Quiet Zone (QZ) in V-band are presented to show the performances of this equipment.

I. INTRODUCTION

Since 20 years the Institute of Electronic and Telecommunications of Rennes (IETR) has developed a research topic dealing with millimeter-wave range antenna [1][4]. The contributions of IETR cover a broad panel: modelization, design, manufacturing and characterization of antennas. With this expertise, IETR can carry out projects from the antenna draft to the prototype validation. This capability is enabled thanks to important investments made in prototyping equipments and characterization facilities. As an example, the institute has a far field anechoic chamber dedicated to millimeter wave antenna characterization since the beginning of the 90's.

Even if this chamber has been upgraded continuously, a new step has to be surmounted in order to fulfill the always more demanding project challenges. There is a growing need to improve the measurement capabilities of the laboratory, in terms of antenna size as well as operating frequency. This is why IETR defined a few years ago the project of acquiring a Compact Antenna Test Range (CATR) dedicated to millimeter wave antenna characterization.

II. COMPACT ANTENNA TEST RANGE PROJECT

The CATR project has two main constraints. It should first provide a facility to contribute in a significant manner to the scientific activities of IETR. This criteria is fulfilled as the CATR project comes from the prospective phase which analyses the needs of the laboratory.

Secondly, the financial investment has to be kept reasonable and the operating costs should be as limited as possible. This requirement is achieved by re-using and adapting the existing equipments. The CATR is indeed implemented in the existing anechoic chamber. This solution limits the investment to the reflector and the feeding parts only. The existing Antenna Under Test (AUT) positioning system is used. It results that the final facility exhibits two characterization capabilities: a classical far field system and a CATR.

A. Far field antenna test facility

The characteristics of the existing chamber dedicated to the antenna millimeter-wave measurement are reported in TABLE I. The distance between emission and reception parts can vary as the AUT positioning system is located on rails.

TABLE I. FAR FIELD ANTENNA TEST RANGE CHARACTERISTICS.

Chamber size (without absorbers)	9.8 x 3.5 x 3.05 m^3
Chamber size tips to tips	9.4 x 3.1 x 2.65 m^3
AUT /Probe positioning systems	Elevation over Roll over Slide over Azimuth / Roll axis
Frequency range	[18-110]GHz
Distance between emission and reception parts	1 to 7 m

B. Description of the CATR project

The CATR project deals with the characterization of high gain antenna (gain above 35dBi). Considering the dimensions of the chamber where the reflector has to be installed, the Quiet Zone (QZ) is a 600mm diameter and a 600mm depth cylinder. These dimensions are fitting both the scientific goal and the technical constraints. Moreover, the CATR has to be usable up to 300GHz in order to further increase the frequency range measurement capabilities of IETR. The technical requirements concerning both the QZ and the reflector are reported in TABLE II. and TABLE III. respectively.

TABLE II. QUIET ZONE SPECIFICATIONS

shape	Cylindrical
Size (diameter x depth)	600 mm x 600mm
Magnitude taper	<1dB
Magnitude ripple	<0.4dB
Phase ripple	<10°
Max cross polar component	<-30dB
Frequency range guarantee by constructor	[10-110]GHz
Foreseen frequency range	[10-300]GHz

TABLE III. REFLECTOR SURFACE MECHANICAL ACCURACY REQUIREMENTS (PEAK TO PEAK)

Zone 1: central square of side 300mm	<15µm
Zone 2: zone between 300mm and 600mm (from the center to the flat side)	<30µm
Zone 3: outer region	<50µm
Room temperature	24±1°C

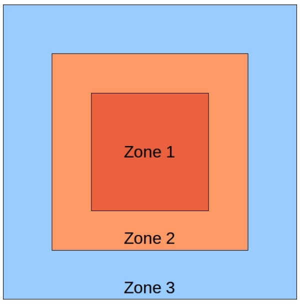

Figure 1. Reflector sub-areas.

C. Technical solutions

The system consists of the main following hardware elements:

- A AL-25202 1.2m x 1.2m rolled edge corner-fed compact range reflector.
- A Reflector pedestal.
- A Pedestal and a manual slide for the feed rotator.

The two main factors that affect the CATR performances are: the aperture blockage and the edges diffraction. The aperture blockage is reduced by using a corner-fed reflector system. The edges diffraction is reduced thanks to either rolled or serrated edges.

The serrated edge reflectors have limited accuracies in the serrations (transition from parabola to serration; serration surface) which can impact the QZ performances at high frequencies. Because of its dimensions, the rolled edge reflector is made from a single piece, with good accuracy on its total surface.Therefore a rolled edge reflector has continuously good performance well above 100 GHz. ORBIT/FR's single reflector compact range series is based on a manufacturing technology developed in recent years by ORBIT/FR GmbH in Munich, Germany. It is based on high accuracy milling directly from stress relieved aluminum alloy blocks as used in advanced prototyping for the high-end German aerospace and automotive industries.

The installation of the reflector and the feed positioner has been performed using a laser tracker. The alignment results of the installation are reported TABLE IV.

TABLE IV. ALIGNEMENT RESULTS

Feed pointing error	0.04°
Alignment to rails of the chambre (used to define the optical axis) : pointing angle and lateral offset	0.0281° 1.8mm
Alignment to gravity : vertical tilt	-0.022°

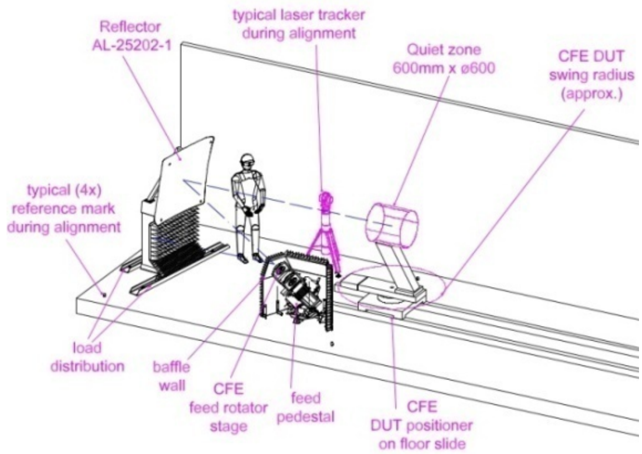

Figure 2. Overall view of the Compact Antenna Test Range.

III. PLANAR SCANNER FOR CATR QUIET ZONE PROBING

A. Geometrical requirements

The QZ compliance is based on complex measurements in order to verify that both magnitude and phase fulfill the CATR design criteria: a magnitude ripple lower than 0.4dB; a phase variation lower than 10° peak to peak.

The most restrictive parameter concerns the phase measurement as it implies a high measurement accuracy. The phase measurement errors are produced by three main factors: the positioning error of the probe used for the field measurement; the measurement system error introduced by its dynamic range; the thermal drift of the system; the effect of cables and rotary joints.

The thermal drift issue is minimized as both the chamber and the control room on which the receiver is localized, are thermally controlled. The dynamic range is optimized using a 20dBi Standard Gain Horn as a field probe, and applying a low IF filter (lower than 10Hz) during the measurements. The cable stress effects are minimized using high curvature radius. Moreover the measured signal is down-converted enabling cable characterization.

The phase measurement errors are thus mostly affected by the positioning errors. These errors are of two kinds:

- The misalignment of the scanning plane according to the chamber coordinate system.
- The planarity errors introduced in the scanning plane by the mechanically moving system.

The verification of the scanning plane can be done using a laser tracker by checking several points of the sampling plane. But it has to be mentioned that the accuracy of such tool depends on the distance between the tracker and the optical target, and the resulting accuracy could be insufficient for very high frequencies purposes [5].

The planarity errors are directly linked to the scanning system design. Considering both the requirements of the QZ and the frequency of interest, the maximum value of planarity default can be computed. The planarity requirements are summed up in TABLE V. : the error targeted after compensation corresponds to a ±1° phase error at 200GHz.

TABLE V. PLANARITY ERROR REQUIREMENTS

Characteristic	requirement
Planarity absolute error (ie peak to peak)	<0.2 mm
Planarity absolute error after compensation	<0.01mm
Planarity error determination accuracy	<0.005mm

B. 2D scanner architecture

The design of the scanner follows three kinds of technical requirements: the application needs due to the CATR design; the geometrical constraints enforced by the QZ measurements; the electrical problems related to the measurement of moving structures.

The 2D scanner architecture relies on two high precision slides axis fixed orthogonally to each other and perpendicular to the optical axis of the CATR. The right-angle bracket has been manufactured in-house, using aluminum plates of 20 mm thickness. Each slide axis is a Newport Micro-Contrôle M-IMS 600PP model. The characteristics of this model are reported in TABLE VI.

TABLE VI. SLIDE AXIS CHARACTERISTICS.

Characteristic	Constructor guarantee	from control report
On axis accuracy	20µm	<3 µm
Absolute accuracy	20µm	<3 µm
Repeatability	2.5µm	<1 µm
Minimal step	1.25µm	1.25µm
Yaw (max)	125µrad	<100 µrad
Pitch (max)	125µrad	<100 µrad

C. Planarity check procedure

Considering that the main contributors to the planarity error are the pitch angle error of the x axis, and the straightness error of each axis, we can write the planarity error p as reported in (1), corresponding to the simplified model reported Figure 3.

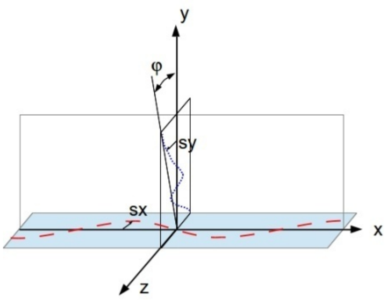

Figure 3. Simplified model of the 2D scanner.

$$p(x,y) = y \tan(\varphi(x)) + sx(x) + sy(y) \quad (1)$$

with: x and y are the positions on the x and y-slide axis respectively; φ is the pitch angle of the x-slide axis; sx and sy are the straightness errors of the x- and y-slide axis.

The determination algorithm of each source of error is very simple:

• The pitch error φ is x-dependent and its effect is a linear function of y : for each xi position, the determination of the regression line from the values p(xi, yj) obtained for the yj sampling points, gives the tan(φ(xi)) values and the offset rj corresponding to the constant parameter of the regression line.

• The knowledge of the couple (tan(φ(xi)); rj) enables to determine the location of the origin of the y axis of the model. This origin is the point y0 where the standard deviation of the planarity error p(xi, y0) obtained using the regression line approximation is minimized. At the location y0, the variation of the planarity as a function of x is the straightness error of the x-slide axis of the model.

• The determination of sy is obtained compensating the straightness and pitch errors of the x-slide axis for several positions x, and performing an average of the planarity errors for the dataset obtained for each yj.

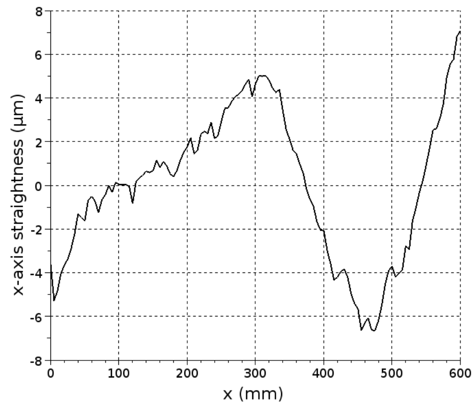

Figure 4. Mechanical probing procedure : x axis straightness results.

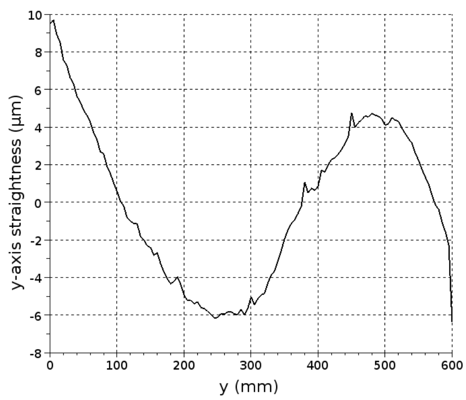

Figure 5. Mechanical probing procedure : y axis straightness results

The measurement procedure and related equipments have been chosen considering that the scanning plane is limited to 600x600 mm^2. In that case, it is possible to use a mechanical reference plate (800x600 mm^2 black granite reference plate, 00 precision, absolute planarity error lower than 5 µm) coupled with a high precision digital indicator (Mitutoyo ID-H 543-561D, accuracy lower than 2µm). The results of the probing procedure are reported Figure 5. and 5. In Figure 6. are also reported the results obtained using the high precision 2 axis electronic leveler Wyler Blue Level 2D.

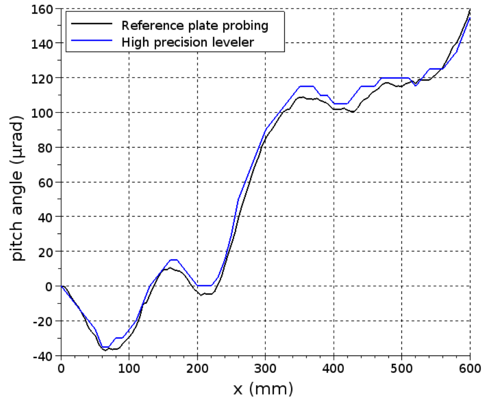

Figure 6. Mechanical (black curve) and 2-leveler pitch (blue curve) angle results comparison.

IV. CATR QUIET ZONE PROBING

The quiet zone probing [6] has been performed in three xOy cutting planes located at z=0, 300 and -300 mm inside the QZ, defining Oz as the optical axis and O as the centre of the QZ.

A. Probing procedure

As initial step for each cutting plane, the laser tracker has been used to determine the relationship between the coordinate system of the planar scanner and the one of the CATR. To perform this measurement, an optical corner has been fixed to the scanner, and an equi-spaced grid of 9 x 9 points has been measured.

Then for the three cutting planes z=0, 300 and -300mm, a field probing has been performed for the two feed main field orientations, i.e. vertical and horizontal orientations, and measuring both co- and cross-polarized field components. The sampling has been realized using two different strategies:

- Measurements on horizontal, vertical, +45 and -45° lines with at least half a wavelength step.
- Measurements on a full plane, with a coarse x and y step to have an acceptable measurement time cost.

The measured data have been post-processed in order to compensate: the existing deviation between the scanner and the CATR coordinate systems; the planarity errors of the scanner.

B. Results in V-band

The measurements have been performed between 50GHz and 75GHz with a 1GHz step. Results obtained at 60GHz on the cutting plane located at z=0 are reported below. For the presented results, a 10mm step has been used for both x and y axis. As explained in the section A, other measurements have been performed with a smaller distance of 2 mm between sampling points, and using the same frequency range.

The obtained magnitude results showed good agreements with simulation for all z positions. The maximum taper obtained for the regression parabola is lower than 0.8dB and the ripple between the measurements and the regression parabola is lower than 0.3dB peak to peak.

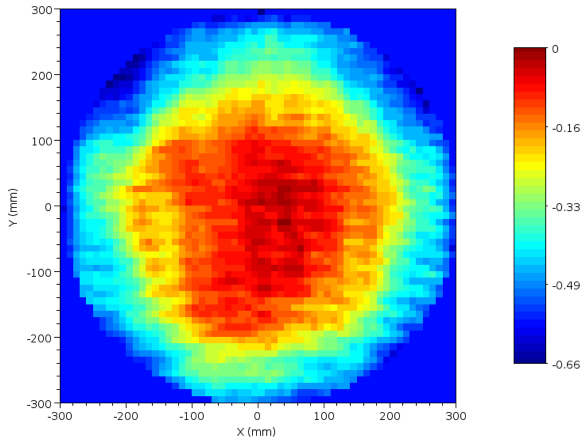

Figure 7. Horizontal field probe orientation: copolar magnitude in dB results limited to the QZ area.

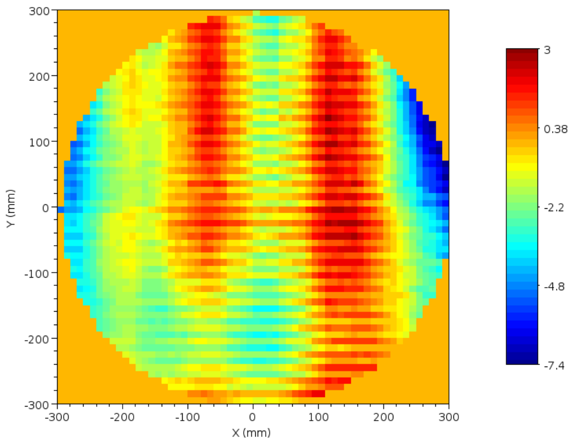

Figure 8. Horizontal field probe orientation: copolar phase results in degrees limited to the QZ area

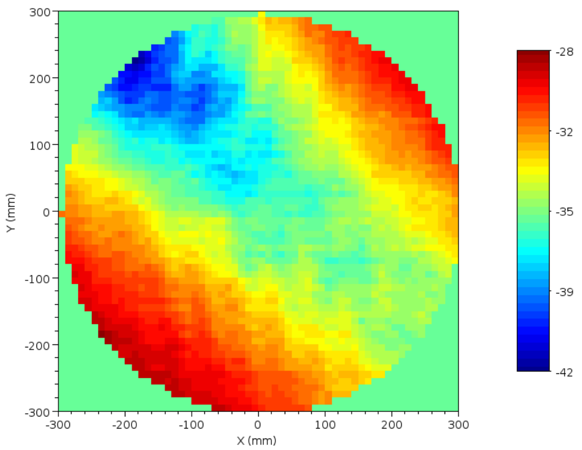

Figure 9. Horizontal field probe orientation: crosspolar magnitude results in dB limited to the QZ area

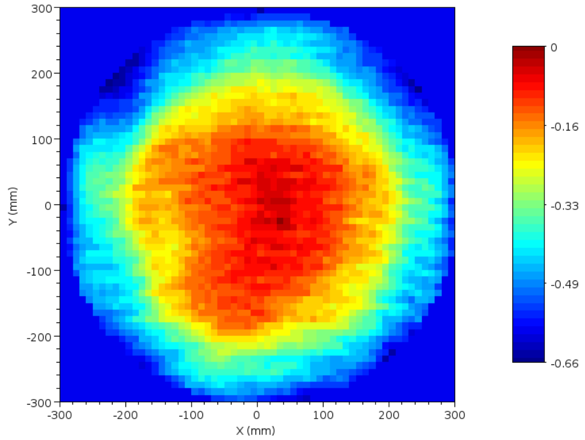

Figure 10. Vertical field probe orientation: copolar magnitude in dB results limited to the QZ area.

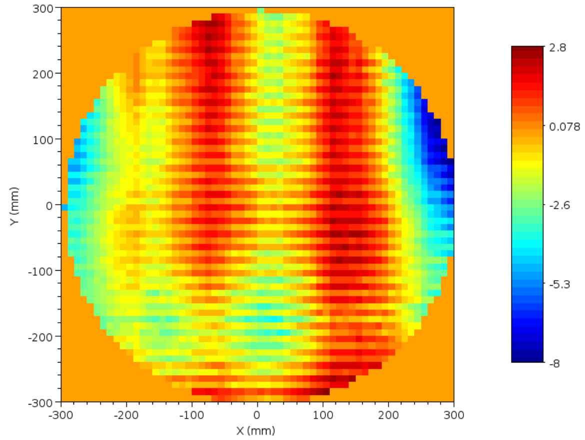

Figure 11. Vertical field probe orientation: copolar phase results in degrees limited to the QZ area

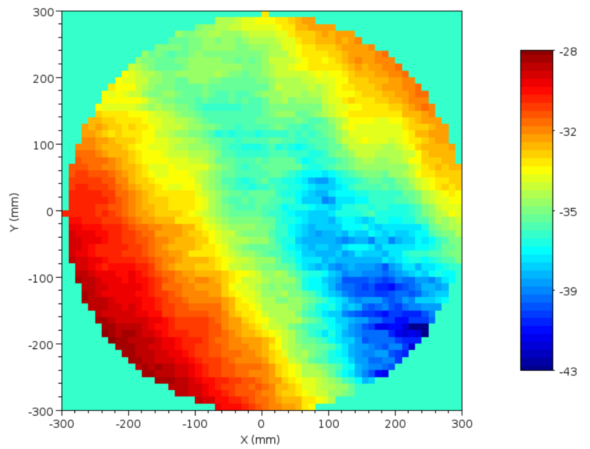

Figure 12. Vertical field probe orientation: crosspolar magnitude results in dB limited to the QZ area

The maximum peak to peak phase variation is lower than 15°. An additional compensation of the sampling plane level has been applied based on the analysis of the measurements. In fact, such an error corresponding to additional elevation and azimuth angle error of the sampling plane can be estimated as it is a geometrical error that do not depend on the frequency. It is worth to notice that no compensation of cable stress effects has been performed yet [7]] [8].

The cross-polar maximum level is lower than -25dB on the whole frequency range. This level is obtained on the outside part of the QZ area, and the orientation of the probe has been done according to gravity without any specific adjustment for each frequency.

V. CONCLUSION

The capabilities of the IETR millimeter-wave antenna test facility have been improved thanks to the implementation of a CATR. This additional equipment enables to characterize high gain antenna in the millimeter-wave range. The obtained QZ is a 600mm diameter by 600mm depth cylinder. The experimental assessment of the quality of the QZ confirms the expected results. Additional QZ probing measurements at higher frequency to determine the CATR capabilities up to 300GHz are scheduled in mid 2015.

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