The CDT Ultra Wide-Band Anechoic Chamber

Félix Tercero, José Manuel Serna,
Tim Finn, J.A.López Fernández
INFORME TÉCNICO IT - OAN 2011 - 13

Contents

1. Introduction.

The National Centre for Technological Development (CDT), a branch of the National Geographic Institute (IGN), has spent the past 2 years, in collaboration with industry, developing a new anechoic chamber at the CDT in central Spain. This facility will be unique in Spain due to its very large operating bandwidth. In principle the chamber will cover 2-140 GHz and will be used primarily for the assembly, integration and verification of new and existing receivers at the CDT´s 40 meter and 14 meter radio telescopes.

Millimeter and sub-millimeter wave technological developments are principally driven by Earth observation and radio astronomy applications. Based on the electrical antenna aperture sizes all of these applications qualify as high gain test cases, and are therefore ideally suited for planar near-field testing [1]. This type of test also has the added advantage that it does not require motion of the antenna, which as is the case in this application, often involves bulky cryostat and heavy fixturing. However, motion of the near-field probe requires flexure of the radiofrequency (RF) path and this introduces uncertainty in the measurement. Also, aspects such as thermal structural change, RF cable phase instability, and scanner planarity combine to make the design, manufacture and installation of these systems an engineering challenge [2].

2. Radio Astronomical receivers in the CDT.

The CDT operates a new 40 meter radio telescope at Yebes (Guadalajara, Spain). The facility also includes a 14-m radio telescope, which has been a network station of the IVS, participating regularly in the geodetic VLBI campaigns until 2003, and will now be refurbished to become a tracking station for the next space VLBI radio telescope VSOP-2. In 2012 two further 12 meter radio telescopes will be constructed for the VLBI 2010 geodetic programme (RAEGE project) [3] greatly expanding the current operations of the observatory and requiring further design and characterisation of new receiver systems.

Fig 1 – CDT 40 meters Radio telescope

The new 40 meters radio telescope is equipped with state-of-the-art receivers in the 2 to 140 GHz range and is part of the astronomical and geodetic VLBI networks (EVN and IVS).
The new anechoic chamber will allow the characterization of the whole feeding system of the radio telescopes (composed by waveguide passive components, feeding horns and reflectors of the focal zone).

Frequency range	2-140 GHz
Waveguide components	Polarizer and OMTs
Horn antennas	Single feed antenna at room temperature/ cryogenic temperature
Feeding systems	Horn + reflectors (or dichroic mirror)
	Horn (and lens) inside of cryostats

Table I – Hardware Specifications

What is immediately evident is the variety of the hardware (directivity, mechanical complexity) each of which requires a different measurement method. Thus it has been necessary to design the anechoic chamber with a high degree of operational flexibility in order to allow the measurement of different systems and to obtain the desired parameters that are important for radio astronomical application:
- Far field patterns (Co and Cross-polarization): standard antenna verification.
- Near field patterns: Gaussian beam mode propagation in the radio telescopes feeding system.
- Axial ratio: verification of polarizer and OMTs measured in free space.

Figure 2 illustrates the receivers cabin in the CDT 40 meters diameter radio-telescope.

Fig 2 – CDT 40 meters Radio telescope Receivers Cabin

3. Main system parameters selection.

Two main receiver topologies have been defined, each of which is appropriate to a specific chamber configuration.

- Cryostats and high directivity horns: in this case the probe scans the aperture field over a plane. These near field (NF) parameters are then transformed to the far field (FF). One advantage of this system is that NF measurements can be done directly at several distances from the AUT (Antenna Under Test). Additionally phase incoherent noise does not transform to the far-field improving the SNR
- Low directivity antennas: The AUT scans the plane wave from the Standard Gain Horn (SGH) which is fixed on the scanner. This is a classical FF measurement.

In both cases, the AUT can be measured in transmitting or receiving mode.

The dimensions of the anechoic chamber were selected in order to match the requirements associated with the different hardware configurations present in the 40 meter radio telescope. The main parameters are presented in Table II.

Baseline → 40m Cassegrain, F_e/D = 7.909, w_0 =5.5λ	
Planar scanner (Reflector D = 22λ at Cassegrain Focus)	
f=2 GHz (λ= 15cm)	D=3.3m
f=3.6GHz (λ= 8.3cm)	D=1.8m
f=5 GHz (λ= 6cm)	D=1.3m
Z-axis railway (NF measurements up to the confocal distance [$zc=\pi w_0^2/\lambda=95\lambda$])	
f=2 GHz (λ= 15cm)	zc=14.2m
f=3.6GHz (λ= 8.3cm)	zc=7.9m
f=5 GHz (λ= 6cm)	zc=5.7m
Far spherical (FF measurements at $R=2D^2/\lambda$ distance for D=8λ [»25 dBi directivity])	
f=2 GHz (λ= 15cm)	R=19.2m
f=3.6GHz (λ= 8.3cm)	R=10.67m
f=5 GHz (λ= 6cm)	R= 7.6m
Range Dimensions	**7.4m Length (AUT to SGH)**
	4.3m Width & Height (absorbers)

Table II – CDTAC Baseline Requirements

w_0 is the beam waist in the quasi-optical system [4]. This value is required to illuminate the 40 meters radio-telescope with -12dB taper at the subreflector edge. This Gaussian beam size is related with the typical reflector sizes in the receivers cabin of the 40m radio-telescope and thus is used as a starting design parameter. The size of the planar scanner (1.83x1.83m) is related with the maximum diameter of the reflector under test (f_{min}=3.6GHz, λ=8.32cm). In table II several low frequencies are used to calculate the needed scanner area. The confocal distance (the edge point between far-field and near-field in quasi-optics) is used to determine the railway length (7.4m chamber length and 5.5 chamber width) in order to do quasi-optical measurements in the near-filed of the feeding system (f_{min}=3.89GHz, λ=7.7cm).

A compromise between cost and low frequency was reached selecting these values.

4. Anechoic chamber characteristics.

Since the objective of the CDT´s anechoic chamber is to measure different hardware and receiver configurations under different conditions, the architecture of the chamber was designed in order to be the most versatile possible. The general system design is shown in Figure 3 [5].

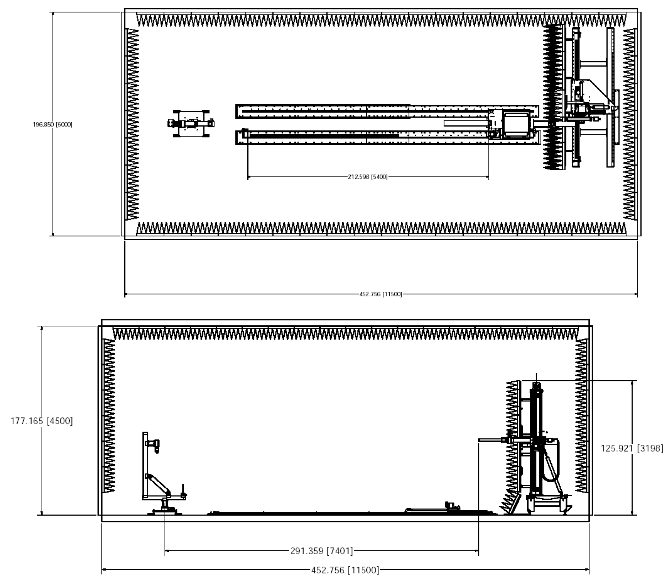

Fig 3 – CDT Anechoic Chamber Architecture

The CDT anechoic chamber dimensions are 11.5x5x5 meters and utilizes a 1.83x1.83 meter planar scanner with a positional accuracy and planarity after correction selected in order to have a maximum of λ/16 error at the higher working frequency (140GHz). A sliding rail allows the receiver's displacement from the waveguide probe used to sample the field in either reception or transmission, depending on the configuration, in both the near and far field by up to 5.5 meters. Additionally the chamber is conditioned for a future upgrade to a spherical scanner (distance between AUT and probe will be 7.4m).

The chamber is constructed from a modular panel system which guarantees a shielding performance of at least 90 dB at 40 GHz at leaky locations such as doors, shield penetrations and a selection of available panel joints.

The chamber interior is covered with 8 inch pyramidal absorbers in non-critical areas and unpainted 12 inch pyramidal absorbers in directly illuminated areas, guaranteeing the low desired reflexion level. The RF systems nominal design permits a dynamic range of at least 60-90 dB in the entire 2-140 GHz range allowing highly sensitive measurements to be performed. A completely automated system both pre and post measurement has been installed to facilitate the acquisition and processing of data and ensuring a quick turn-around time.

The anechoic chamber is ready for a future spherical measurement system upgrade installation.

5. Positioning system characteristics.

The antenna measurement system consists of the following elements [6]:

- 1.83x1.83 meter vertical mm-wave planar near-field scanner.
- Probe rotation (polarization) stage.
- Probe Z-axis linear translation stage (25.4cm).
- AUT linear translation stage (5.5 meters).

The main parameters of the scanner are presented in Table III.

Features	X	Y	Z	AUT Z	Roll
Travel	1,83m	1,83m	0,25m	5,48m	360º
Resolution	25um	25um	6um	50um	0,0125º
Speed (cm/sec)	25,4	38	1,3	25,4	40º/sec
Accuracy(rms)	50um	50um	50um	50um	0,05º
Planarity (rms)			76um		
Corrected planarity (rms)			25um		

Table III – CDTAC Planar Scanner Parameters

The scanner is an inverted T, steel made design with pinion drive stepper motors [6]. For high stability a welded dual pontoon base is used. Probes as large as WR-650 can be mounted on the scanner Z-stage. The mechanical and thermal stability is 0,03mm/mºC. The AZ/EL AUT positioner allows ±1° adjustment for both axes and allows for provisional alignment with dowel pins. The design is presented in Figure 4.

Fig 4 – AUT AZ/EL Positioner

The travel distance of the AUT translation stage is 5.48 meters with a load capacity of 1000Kg. The azimuth positioning error in 5.48 meters is 8 mm, equivalent to an angular error of 5 arcmin.

6. Radio frequency system design.

The RF system is based on the following Agilent instrumentation [7]:

- E8364B PNA with 014, 080, 081, UNL, H11, 010, 016 and 083 options (up to 50GHz).
- 85309A LO/IF distribution unit.
- 85320A test mixer module.
- 85320B reference mixer module.

The maximum measurement frequency is 140GHz. In order to achieve this value three OML microwave heads are used [8]:

- N5260AW15: 50-75GHz T/R module.
- N5260AW10: 75-110GHz T/R module.
- N5260AW8: 90-140GHz T/R module.

The system configuration depends on the working frequency and the AUT transmission or reception mode. Below 50GHz, the mixers are needed and above 50GHz the mm-wave heads are the responsible for the frequency conversion.
The basic parameters of the frequency configuration can be consulted in Table IV.

	RF (GHz)	Harmonic	LO (GHz)	Harmonic
2-50GHz	2-20	N=1	2-13,5	N=1
	20-40	N=2	13,5-40	N=3
	33-50	N=4	33-50	N=5
50-75GHz	50-75	N=4	50-75	N=5
75-110GHz	75-110	N=6	75-140	N=8
90-140GHz	90-140	N=10	75-140	N=10

Table IV – Frequency Configuration

For planar mm-wave near-field testing, the system dynamic range is greater than 90 dB for all frequencies above 50 GHz and greater than 60dB for all frequencies up to 33GHz dropping by 1dB at 40GHz and by only 4 dB at 50GHz for both AUT transmit and AUT receive.
For all configurations, the system dynamic range can be increased by reducing the IF bandwidth. For example, if the IF bandwidth is changed from 1KHz to 100Hz this will provide a 10dB lower noise floor and as such a 10dB larger signal to noise ratio. Thus, reducing the IF bandwidth to 300Hz will increase the SNR to satisfy the stated 60 dB dynamic range level for the planar near-field case. However the trade-off comes in the form of an increase in the acquisition time required for the receiver.
It is well known that planar near-field measurements are impacted by cable flex induced amplitude and phase instabilities. Many different techniques have been proposed in the past to counter this problem and these techniques have had various degrees of success [9]. Since the impact of cables flex are most pronounced for very high frequency applications, e.g. V or W-band RF systems particular care has been taken with the design of the flexible guided wave path within the proposed system.
In this system, a phase stable dual rotary joint configuration is used. This enables the radius of curvature within the flexible RF cable to be maximised so that the flexing within the cable is minimised during an acquisition. Furthermore, as cable routing and stress free operation is of great importance for accurate and repeatable amplitude and phase performance rotary joints will be used at either end of the cable to guarantee that this requirement is satisfied.
A set of Open Ended Waveguide Probes (OEWP) have been acquired covering the frequency bands between 1.7 and 140GHz. These OEWP have been specifically

designed for the purpose of taking near-field measurements and have a chamfered aperture to reduce undesirable scattering.

7. Control system design.

The hardware involved with interfacing the individual parts of the antenna measurement facility are:

•Workstation with interface to RF system and positioner controller which communicates with the antenna range controller to drive the five axes of the chamber.

•Hand held remote control.

The basic scheme of the control system is shown next.

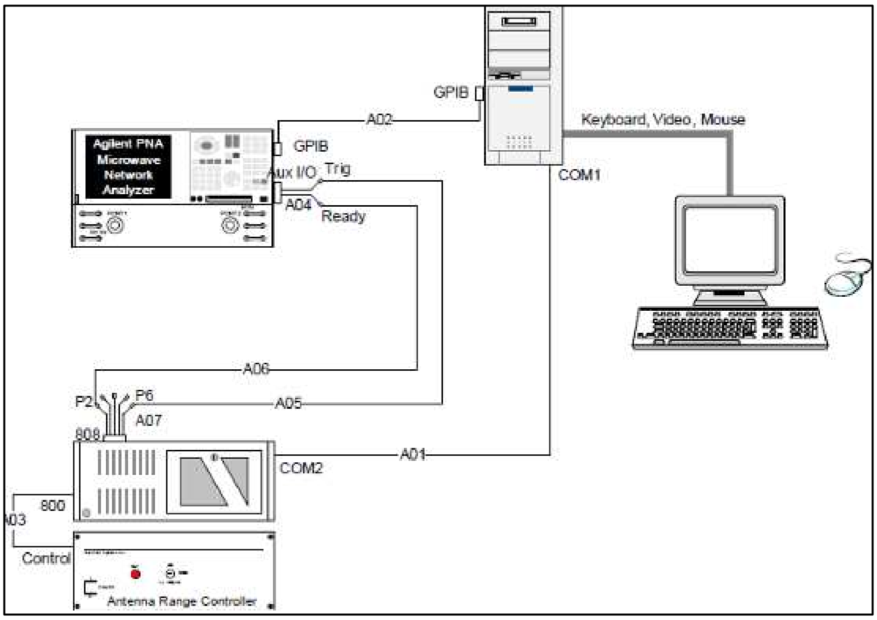

Fig 5 – CDTAC Control System Design

The positioning system is based in the use of stepper motors (reliable and fast system, while maintaining very accurate control of axis position and small following errors). Open loop stepper motors allow to avoid positioning problems which result from closed loop feedback such as dead-bands and hunting [10].

8. Software.

Windows program performs data acquisition, analysis and simulation all within a single fully integrated intuitive application. The professional edition allows system configuring and data acquisition and can execute scripts in "batch" mode. It also allows data visualization and manipulation [6].

The main characteristics of the software are:

• Advanced scripting features.

• Powerful beam table generator for multi-beam and multi-frequency measurements.

• NSI software error correction (on-the-fly correction for X, Y and Z probe position errors, beam and frequency multiplexing, Motion Tracking Interferometer-MTI for thermal control). Measures time varying AZ, EL and Z motion between AUT and NF scanner. Errors corrected by a time-varying near field phase adjustment during processing.

9. Mechanical and RF acceptance tests.

The mechanical calibration involves both characterization of and correction of errors.
The tests that were carried out are position repeatability (to prove axis repeatability to a known location), position accuracy (to prove scale factor and absolute accuracy of each axis), backlash (to measure position loss due to reversal of travel direction), planarity (measured deviation of scanner during X-Y movement relative to theoretical flat plane), run test (scanner axis movement performed for a specified amount of time or cycles) and limit test (to prove correct operation of all limit switches).
All the tests were carried out in both AUT Tx and AUT Rx modes.
The RF acceptance test consists of verifying the complete RF subsystem. In particular, LO and RF power budget (confirm that the transmit power meets the value shown in the theoretical power budget), frequency response (to check the integrity of all RF connections and cables in the system), stability (amplitude and phase), noise level in the test channel, linearity, pattern repeatability and leakage. The most relevant results are presented in Table V.

Parameter	Result
Stability test (1 hour @ 140GHz)	SNR>50dB
	ΔA_{pp}<0.2dB, $\Delta\varphi_{pp}$<2deg
Noise test @ 140GHz	N_{max}<-95dB
Pattern and repeatability test	f<50GHz → < -50dB
	f>50GHz → < -40dB
Leakage test	< -52dB worst case)
Power budget verification	RF/FI and LO signal levels
Frequency response (2-140GHz)	Noise free, no drop outs

Table V – RF acceptance test

10. First measurement results.

The first measurements in the anechoic chamber have been successfully carried out. The objective was to measure the performance of the 40 meter radio telescope X band antenna system. It is composed by a hyperbolic dichroic mirror and a corrugated conical horn antenna.
The measurements consist of radiation pattern cuts at 0 and 90 degrees in both copolar and cross polar. It also includes a directivity calculation. Finally a determination of the co/cross polar symmetry is determined by rotating the rectangular waveguide to coax transition to discriminate between the two polarisations.
The measured Antenna system is shown in Figure 6.

Fig 6 – Yebes 40m radio telescope X band receiver antenna system

The results of the measurement are presented in Table VI.

Frequency	8GHz
AUT-probe distance	0.111m = 2.96λ
IF Bandwidth	1KHz
Angular span	±50 deg

Antenna measurement results		
Directivity	25.06dB	
Beamwidth (-3dB)	E plane:	10.6 deg
	H plane:	9.06 deg
Pointing	E plane:	-5.44 deg
	H plane	0.22 deg
Sidelobes level (SLL)	E plane	-25.6dB (25.7deg)
	H plane:	-27.8dB (21.5deg)
Cp-Xp level	E plane	-22.2dB
	H plane:	-21dB

Table VI – 40m radio telescope X band antenna system measurement

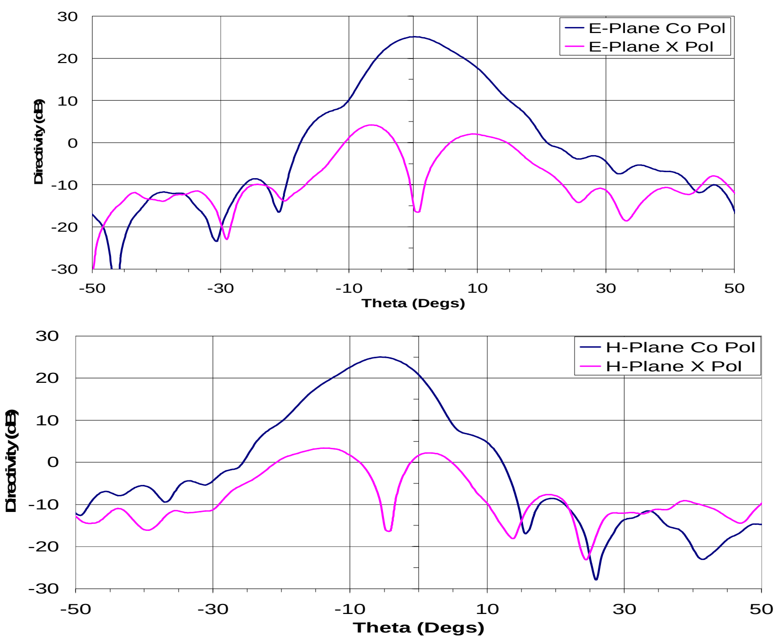

Fig 7 – The principal plane cuts of the cp and xp components

In the measured radiation pattern it is visible the offset pointing in the vertical cut with respect to the horizontal cut (5.66deg). It is a specification of the system imposed by the receivers cabin optical design (S/X band receiver system).

11. Summary.

A new planar near-field antenna measurement system up to 140GHz has been built in CDT Yebes Spain. The mechanical and radio frequency acceptance tests were carried out and the first measurements have been successfully executed. The errors associated with a planar near field antenna measurement system are more important as the working frequency increases (millimeter wavelength). This system will help to understand the different sources of error (multiple reflections, probe positioning, RF instrumentation errors and finite scan area) and advance the techniques to eliminate or minimize them at these short wavelengths.

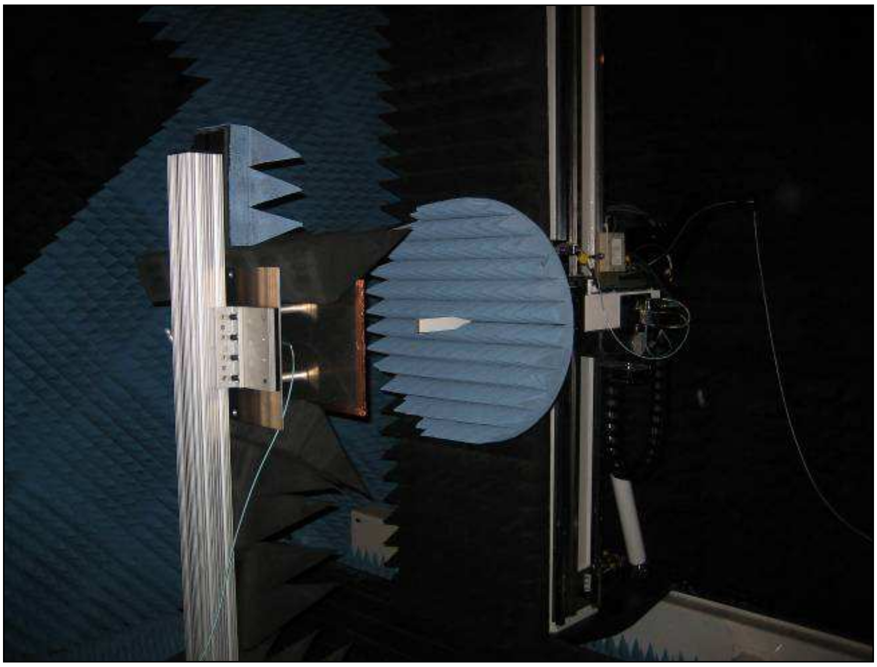

Fig 8 – CDT Yebes Anechoic Chamber Current Status

12. References.

[1] S. Gregson, "Principles of Planar Near-Field Antenna Measurements", IET Electromagnetic Wave Series 53.
[2] Gary E.Evans, "Antenna measurement techniques", Artech House IPF book, 1990.
[3] "VLBI2010 A Vision for Geodetic VLBI", 2005, IVS directing board.
[4] Paul F. Goldsmith, "Quasioptical Systems", IEEE Press, 1988.
[5] F. Tercero et al, "2-140GHz CDT Anechoic Chamber", 8th Radionet Engineering Forum.
[6] www.nearfield.com
[7] www.agilent.com
[8] www.omlinc.com
[9] Van Rensburg D.J., Hindman G., "An Overview of Near-Field Sub-mm Wave Antenna Test Applications", 2008 IEEE 14th Conference on Microwave Techniques.
[10] www.nearfield.com/FAQ/FAQ_NF.htm