

Sensor Measurements up to 200 GHz in the Compensated Compact Range with Broadband Transmit and Receive Modules

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ABSTRACT

The measurement of the characteristic antenna data by means of conventional far-field ranges in frequencies up to 200 GHz requires measurement distances of some kilometers. The high atmospheric attenuation and the low available transmit power limit the dynamic range of the measurements considerably. The DASA Compensated Compact Range (CCR) [1] is a high precision test facility; which avoids these disadvantages and allow measurements with considerably higher accuracy under controlled environmental conditions. The precision reflectors have an extremely high surface accuracy of 25 μm RMS, which allow their use even in the mm-wave range. For the frequency band of about 200 GHz, the relative roughness is in the order of $\lambda/60$. This results in considerably lower degradation for the DASA CCR compared to the typical degradation on far-field ranges ($\lambda/16$).

For mm-wave application the test facility is equipped with broadband transmit and receive moduls, which covers the frequency range from 75 to 220 GHz. The basic transmit frequency is generated in a tunable Gunn oscillator, which is phaselocked to an externally supplied 10 MHz reference signal. This optimized concept allows measurements with a dynamic range of more than 60 dB at 200 GHz. For a cost efficient solution the complete equipment for the transmit and receive moduls consists of commercial components.

Keywords: MM-Wave Antenna Measurement,
Compensated Compact Range,
MM-Wave Transmit Module
Tracking Converter

1. INTRODUCTION

Today, the standard facility for accurate satellite antenna testing is the Compensated Compact Range. The Antenna Department of Dornier Satellitensysteme GmbH (DSS) in Ottobrunn, Germany, a division of Daimler-Benz

Aerospace (DASA) has developed this type of test facility and sold to other space companies like S/S Loral, SPAR, Lockheed-Martin, Aerospatiale and Intespace. All these test ranges are delivered to run in the frequency range between 2 and 18/40 GHz. In 1989 DASA qualified its CCR in Ottobrunn for measurements up to 204 GHz for the test campaign of the Microwave Atmospheric Sounder (MAS). Today it is equipped with its own transmit and receive modules working in the frequency range between 1 - 50 GHz and 75 - 220 GHz. For receive instruments with free running oscillators and no possibility to synchronize with the transmit equipment, a tracking receiver was developed to synchronize the transmit and the receive frequency.

The specific features and applications of this type of test facility and the mm-wave equipment will be explained and presented in detail. Furthermore, qualification results will be presented in the range up to 204 GHz. To verify the excellent properties in the mm-wave region, some antenna measurement results of the engineering model MHS (Microwave Humidity Sounder) will be presented.

2. REFLECTOR CONCEPT

The DASA Compensated Compact Range (CCR) is a high precision test facility with a quiet zone of 5.5 x 5.0 x 6.0 m (w x h x d). The system consists of two doubly curved reflectors, which generate a coherent electromagnetic field (quiet zone) from a spherical wave. The basic geometry is shown in figure 1. The reflector design prevents inherent cross-polarization and creates a highly constant amplitude and phase distribution in the quiet zone. The co-polar pattern is symmetric in both principle planes.

The relevant geometry and electrical characteristic data of the CCR are summarized in table 1.

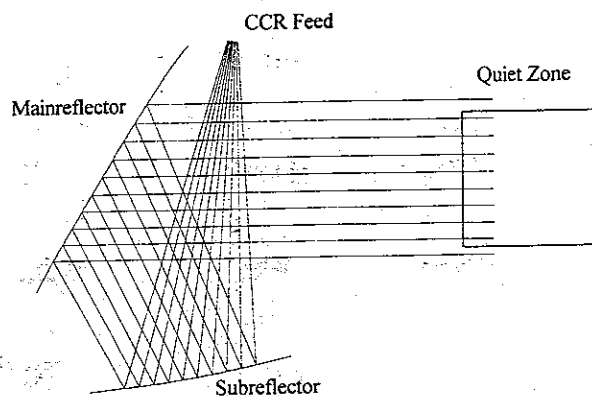


Figure 1: Basic geometry of CCR (Top View).

Geometry	Front-Fed Cassegrain
Mainreflector Dimensions (w x h) Focal Length No. of Segments	Offset Parabola 7.5 x 6.0 m 40 m 3
Subreflector Dimensions (w x h) Focal Length No. of Segments	Offset Hyperbola 5.6 x 5.3 m 30 m 2
Serration Length	1.5 m
Quiet-Zone (w x h x d)	5.5 x 5.0 x 6.0 m
Frequency Range verified	1.5 - 800 GHz 1.5 - 204 GHz
Quiet-Zone Performance Max. Amplitude Ripple Max. Phase Ripple Max. Crosspolar	(1.5 - 50 GHz) ± 0.5 dB ± 5 degree -40 dB
Scan Angle Accuracy	3/10000 degree

Table 1: Main Characteristics of DASA CCR

3. SPECIFIC FEATURES OF THE REFLECTOR SYSTEM FOR MM-WAVE ANTENNA TESTING

3.1 Reflector Surface Accuracy

The Compact Range Reflectors are produced of special cast iron elements with a highly stiffened supporting structure at the rear to guarantee for long term mechanical

stability. The mechanical design of the reflectors together with the

- machining accuracy of the reflector surfaces by means of a 5-axes laser controlled milling machine and
 - the spatial temperature profile produced by a special air conditioning system in the chamber
- guarantee for the high accuracy of the test system. Within the test chamber environment a surface deformation of $\leq 20\mu\text{m}$ was calculated [1/].

The limit for the highest operational frequency in the Compact Range is given by the amplitude and phase error distribution in the quiet zone. In the lower frequency range up to 10 GHz the error contributions are mainly caused by diffractions of the reflector geometry and the serrations and they decrease with increasing frequency. Above 10 GHz the amplitude and phase ripple remain nearly the same for all frequencies. In the mm-wave region one contribution for the phase error linearly depends on the main- and subreflector surface accuracy. Table 2 summarizes the measured surface accuracies and roughness figures of the DASA CCR reflectors.

Measured Surface Accuracies	Mainreflector	Subreflector
RMS	13 μm	18 μm
MAX	41 μm	48 μm
Roughness	1 μm	1 μm

Table 2: Figures of Measured Roughness and Surface Accuracies of the DASA CCR Reflectors

The overall RMS figure of the reflector system yields to 22 μm . If this value is applied for a test frequency of 200 GHz, the relative surface accuracy is in the order $\lambda/70$, which results in a phase error of approx. 5 degrees. Even for a test frequency of 800 GHz the resultant phase error is 20 degrees RMS, which is lower than the typical phase degradation of about 22.5 degrees for a far field test range assuming a minimum distance between test and range antenna of $2 \cdot D^2/\lambda$ (D=antenna diameter).

3.2 Free Space Attenuation

The free space attenuation of the test facility influences directly the dynamic range of the pattern measurements. A conventional far field test range requires a minimum test distance between the range and the test antenna of $2 \cdot D^2/\lambda$.

- passive Antennas
- active Antennas
 - o Antenna + RF-Amplifier
 - o Antenna + Downconverter
(locked to ext. reference frequency)
 - o Antenna + Downconverter
(free running conversion oscillators)

On the active antennas also G/T - measurements can be performed.

Testing of an Antenna + Downconverter with free running conversion Oscillators poses a problem, which is briefly addressed below.

This DUT - Configuration with free running conversion - LO's applies especially to Radiometers, where e.g. at 183 GHz a frequency stability of only about 50 MHz is required. In this case the DUT output signal exhibits a considerable residual FM - modulation originating from the free running conversion LO's (e.g. DRO's).

If a dynamic range of e.g. 60 dB is required for the pattern measurements, the FM - corrupted DUT output signal cannot be used directly for testing. The level measurement of the FM - signal requires a much wider measurement bandwidth, than a clean/stable CW - signal. This in turn decreases the available signal to noise ratio in the measurement bandwidth, and thus limits the dynamic range to much less than the required 60 dB.

In order to cope with a small measurement bandwidth, as to meet the dynamic range requirement the FM - signal has to be tracked in a special test receiver/converter. This unit puts out a stable cleaned up CW signal for level measurement. Details are given later in the description.

4.3 Test Set - up

The principle test set-up as used for antenna pattern testing is shown in the blockdiagram of figure 4. The DUT may in this case be passive or active, but there occurs no frequency downconversion with free running LO's within the DUT. The TX - frequency is generated with a GUNN - LO, phaselocked to a 10 MHz reference signal. The GUNN output signal is either used directly or it drives a subsequent frequency multiplier. The receive module uses a harmonic downconverter and delivers the IF- output signal to a spectrum analyzer. This analyzer is used in zero - span mode to measure the receive signal level.

In case, where the DUT consists of an Antenna with a frequency downconverter, which cannot be phaselocked or

synchronized to an external reference frequency a test set-up according to figure 5 is used for pattern measurements. The special test receiver used to track and thus to clean up the FM - corrupted DUT output signal is a dual channel tracking converter. In this unit the input signal is tracked and processed in two signal paths :

- a fixed gain channel,
which delivers the cleaned up IF - signal for measurement purposes
- the tracking channel,
which incorporates a PLL for tracking and a coherent AGC - loop with about 70 dB dynamic level range.

4.4 Signal Characteristics

As an example the signal characteristics of the DUT (Radiometer) output signal (tracking converter input) and the resulting tracking converter output signal are given in figures 6 and 7, referring to a DUT RF-input of 186.4 GHz. The figures 8 and 9 apply for a DUT RF-input of 191.1 GHz. There are two different downconverters in the DUT for these frequencies. This is the reason for the large difference in residual FM of the DUT output signals.

With the test set - up according to figure 5 a pattern measurement dynamic range of ≥ 60 dB was realized. It should be noted that the worst case residual FM of the DUT output signal is about 40 kHz for a 191.1 GHz input (see figure 8).

4.5 Detailed Blockdiagrams

A functional blockdiagram of the transmit module is given in figure 4. The GUNN oscillator is mechanically tuned to the approximate transmit frequency and the PLL locks the GUNN to the reference frequency by proper control of the supply voltage.

The receive module blockdiagram of figure 4 shows a standard circuit configuration.

A detailed functional blockdiagram of the dual channel tracking converter is shown in figure 10. The nominal input frequency of the converter is 770 MHz. If the DUT output frequency is different an external mixer associated with a synthesizer is used for the required frequency conversion to 770 MHz. The tracking range of the converter is $F_c \pm 250$ kHz. The search sweep speed is about 50 MHz / sec. The AGC response time is about 0.5 msec and the coherent AGC range is about 70 dB.

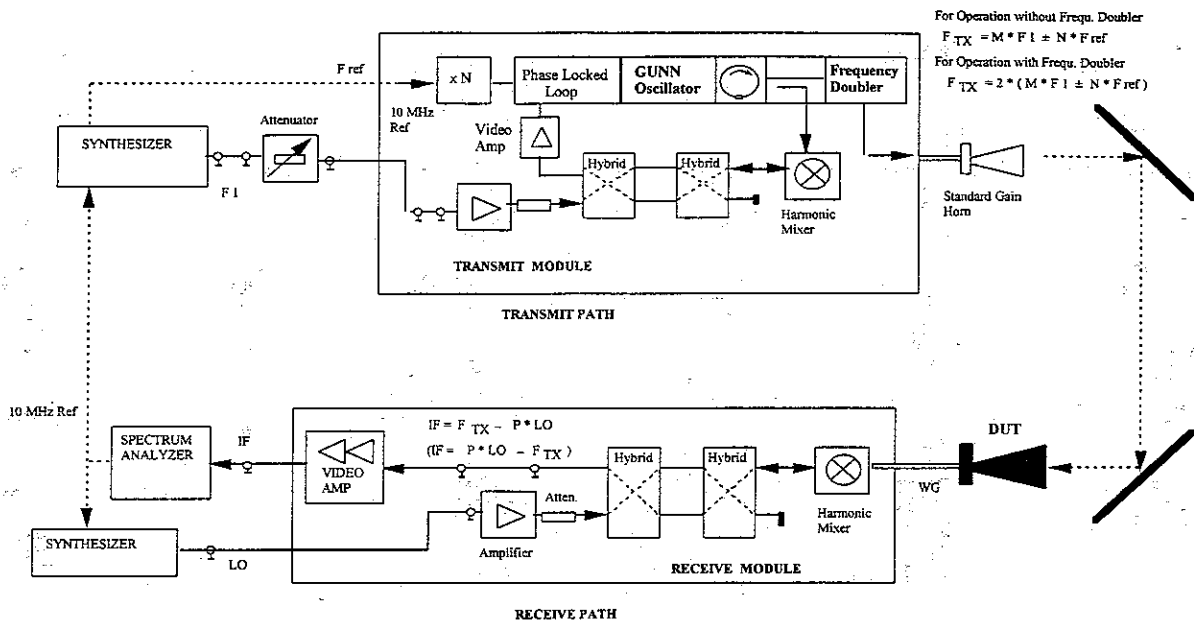


Figure 4: Principle Test-Setup Blockdiagram

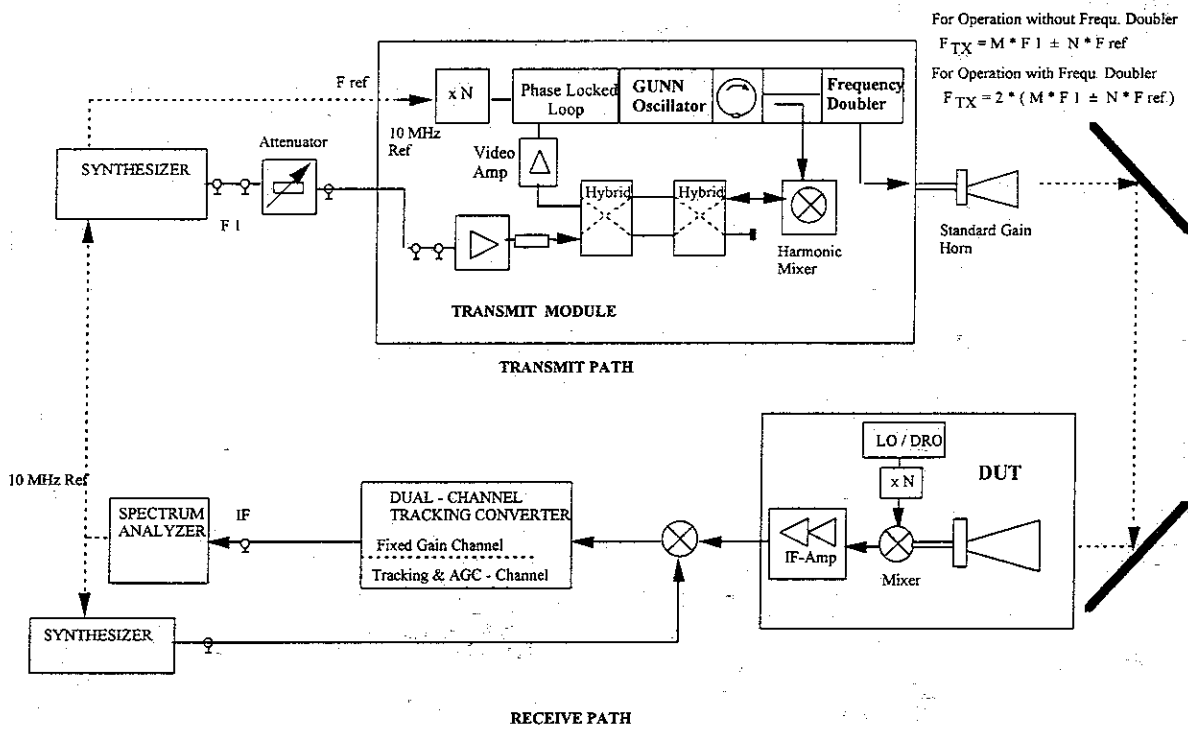


Figure 5: Principle Test-Setup Blockdiagram if DUT comprises a Downconverter with free running Conversion Oscillator

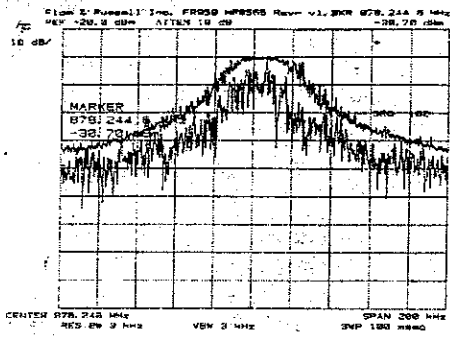


Figure 6: Output Signal of DUT for 186.4 GHz RF-Input (Input for Tracking Converter)

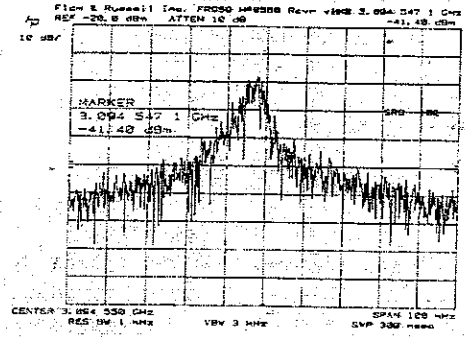


Figure 8: Output Signal of DUT for 191.1 GHz RF-Input (Input for Tracking Converter)

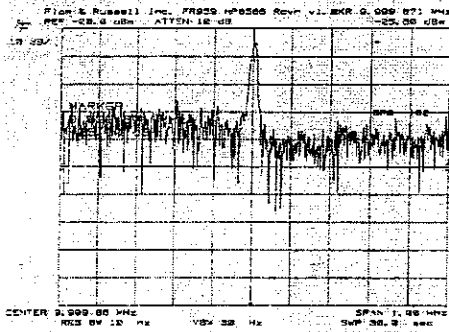


Figure 7: Output Signal of Tracking Converter (Response of figure 6)

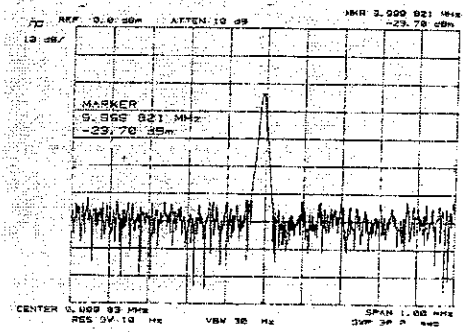


Figure 9: Output Signal of Tracking Converter (Response of figure 8)

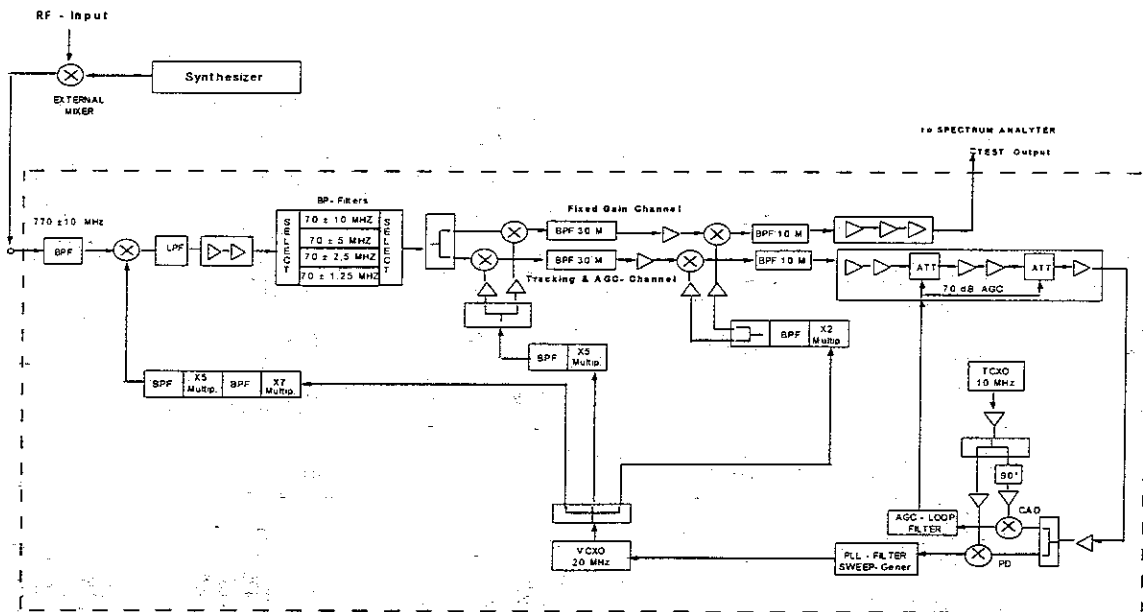


Figure 10: Functional Block Diagram of the Dual Channel Tracking Converter

5. MEASUREMENT RESULTS OF THE MICROWAVE HUMITY SOUNDER

The engineering model of the MHS (Microwave Humity Sounder) was measured in the DASA CCR in August 1997 ordered by Matra Marconi Space. The MHS consists of an offset reflector and a QON (Quasi Optical Network) with four different channels H1, H2, H3/4 and H5. The test frequencies are listed in table 4. The used test set-up can be seen in figure 5. The downconverted IF bands of the MHS Instrument were in between 0.1 and 3.5 GHz. The IF was cleaned up and down converted to 10 MHz by the tracking converter (see figures 7 and 9) and fed into a spectrum analyzer to measure the antenna pattern. Co- and crosspolar Raster Scans and Main Cuts were measured. Figures 11 and 12 show the co- and crosspolar rasterscan measurement at 158 GHz in an angular range of $\pm 2^\circ$ around the RF boresight. Figures 13 and 14 present main cut measurement at 157.3 GHz in an angular range of $\pm 90^\circ$. In this figures the excellent dynamic range of more than 65 dB of the test equipment can be seen. Also no chamber side wall reflections are present.

Channel	Test Frequencies
H1	88.0, 89.3, 90.0
H2	156.0, 157.3, 158.0
H3/4	180.21, 184.31, 186.41
H5	189.51, 190.61, 191.11

Table 5: Test Frequencies for MHS Pattern Measurements

6. CONCLUSIONS

The DASA Compensated Compact Range together with its mm-wave test equipment is an attractive candidate for testing mm-wave antennas. The advantages are the following:

- on-line far field testing in a closed anechoic chamber with controlled environmental conditions
- test distances of appr. 18 meter for antenna aperture diameters up to 5 meter
- pattern, calibration and system tests without movement of the device under test
- tracking converter for measurement of active mm-antennas with free running oscillators

The DASA CCR is qualified up to 200 GHz and the qualification and test results indicate that the realized overall system surface accuracy of appr. 20 μm allows the application of this facility for accurate mm-wave antenna testing up to a frequency of 800 GHz.

7. REFERENCE

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"Design, Development and Qualification of an advanced, large Compact Range"
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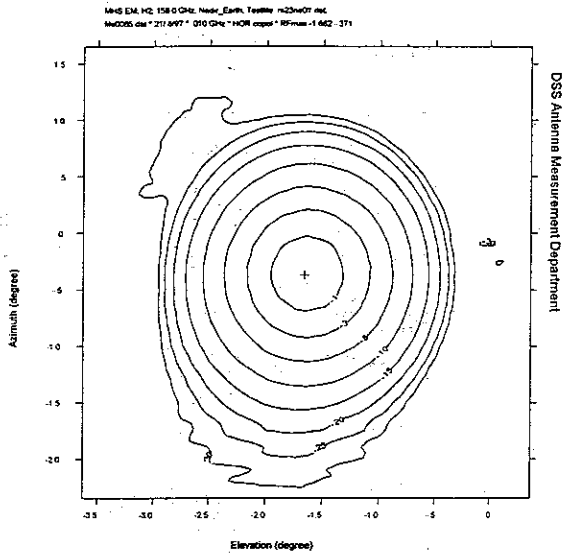


Figure 11: Copolar Raster Scan at 158 GHz

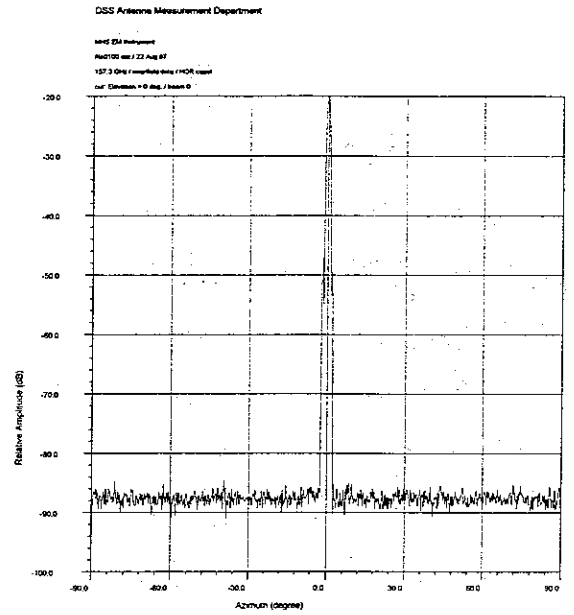


Figure 13: Copolar Main Cut at 157.3 GHz

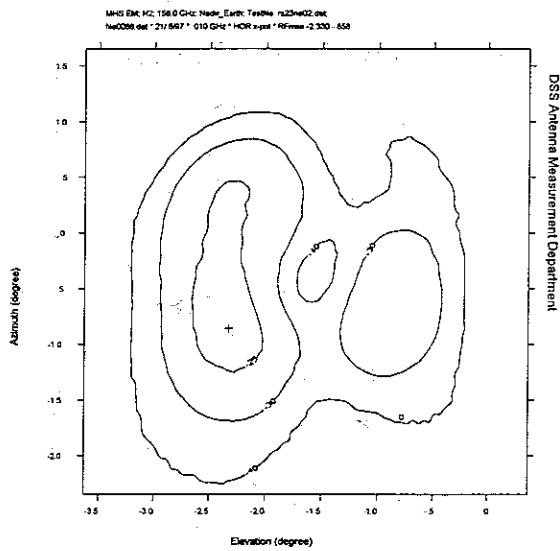


Figure 12: Crosspolar Raster Scan at 158 GHz

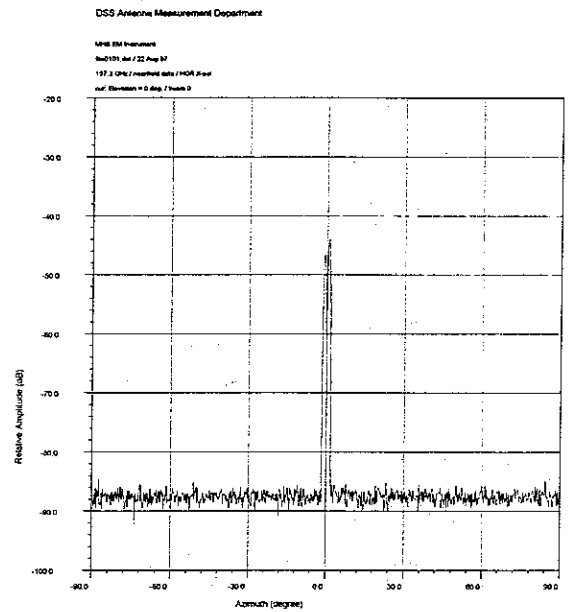


Figure 14: Crosspolar Main Cut at 157.3 GHz