Atacama
Large
Millimeter
Array

NA FEIC Preliminary Beam Measurements

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Change Record

Version	Date	Affected Section(s)	Change Request #	Reason/Initiation/Remarks
A	2007-05-10	ALL	-	Initial version
A01	2007-05-31	ALL	-	Comments from KS and JW

Table of Contents

1.0 Introduction

This report summarizes the preliminary beam measurements of bands 3, 6, 7, and 9 made at the NA FEIC.

1.1 Reference Documents

The following documents contain additional information and are referenced in this document. The latest version should be used.

Reference	*Document Title*	*Date*	*Document ID*
[RD1]	North American Front End Integration Center Test and Measurement System Design	2005-07-27	FEND-40.09.03.00-002-A-DSN
[RD2]	Front End Acceptance Test Procedures	2007-03-22	FEND-40.00.00.00-079-A-PRO
[RD3]	Modifications to NA FEIC beam pattern measuring system	2007-03-20	FEND-40.09.03.00-033-A-REP
[RD4]	Band 6 Sidelobe Measurements Using a Room Temperature Receiver	2007-04-18	FEND-40.02.06.01-038-A-REP
[RD5]	Band 3 Cartridge Acceptance report (serial no 03)	2007-03-06	FEND-40.02.03.00-133-A-REP
[RD6]	ALMA front end optics design report appendix 3 Band3 optics measurement	2006-11-22	FEND-40.02.00.00-035-B-REP
[RD7]	ALMA front end optics design report appendix 7 Band7 optics measurement	2006-12-12	FEND-40.02.00.00-035-B-REP
[RD8]	ALMA front end optics design report appendix 9 Band9 optics measurement	2007-01-22	FEND-40.02.00.00-035-B-REP
[RD9]	ALMA front end band 3 and band 4 warm optics installation and adjustment procedure	2007-03-30	FEND-40.01.00.00-007-A-PRO

1.2 Abbreviations and Acronyms

ALMA	Atacama Large Millimeter Array
FEIC	Front End Integration Center
FETMS	Test and Measurement System
IF	Intermediate Frequency
NA	North American
RD	Reference Document
RF	Radio (Sky) frequency
S/N	Serial Number
WCA	Warm Cartridge Assembly

2.0 Test System

The major mechanical specifications for the NA FEIC beam scanner are listed below. Photographs of the complete measurement system are provided in Figure 1 and Figure 2. This is for the mechanical part. The FEIC is responsible for the sources and cabling, see [RD1]. The scanner was used to measure the beam pointing and sub-reflector illumination efficiency as described in [RD2].

Near-field beam measurement system

x-y-z scanner main specifications

- Scan area: 0.9 x 0.9 meter
- Mount: 3-point mounting support
- Weight: Approx 50 Kg
- Orientation: Horizontal, Vertical, and tiltable
- Planarity: 0.15 mm RMS typical
- Resolution (x, y): 0.02 mm
- Position repeatability 0.02 mm over 200 mm area within scan area
- Scan speed: 0.1 m/s
- Probe station: Rotatable (360 degrees rotation); 100 mm z travel, accuracy 0.005mm
- Probe station max load: 8 Kg

During measurements, the scanner moves approximately +/- 50 mm about the expected position of the beam (for each band) in a raster scan, scanning first in either the x or the x

direction, and then stepping in the other direction. Two x, y raster scans are made at two z distances approximately a quarter of a wavelength apart. These two scans are combined in the software to reduce the effects of standing waves between the source and the receiver. The expected position is determined by placing a laser on the scanner stage with the correct tilt angle, and the stage is moved until the laser spot is on the center of the relevant window. The RF signal sources for each band consist of a signal generator (locked to the common 10 MHz reference of the whole system) followed by a multiplier chain (different for each band, due to the fact that a different multiplication factor is required for each band). The signal processing required to obtain relatively phase stable signals (especially for the higher frequencies) is described in [RD3]. The beam patterns are produced with the software delivered with the scanner, and further processed (to obtain sub-reflector illumination efficiencies and beam pointing angles) in Excel spreadsheets.
Care was taken to ensure that cable flexure did not affect the measurements, especially as movement of the scanner could cause a modulation of the force on the sources, possibly affecting their output, or causing a hysteresis in the scanner motion.

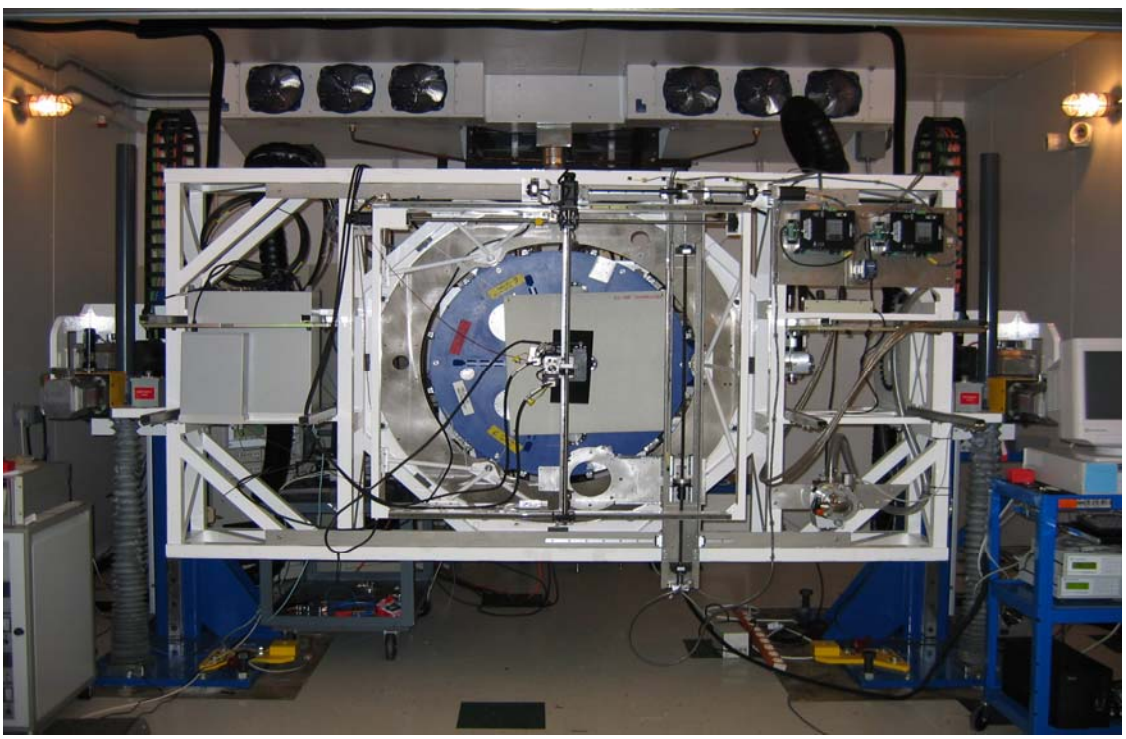

Figure 1 shows the beam scanner arrangement over the top of the ALMA cryostat.

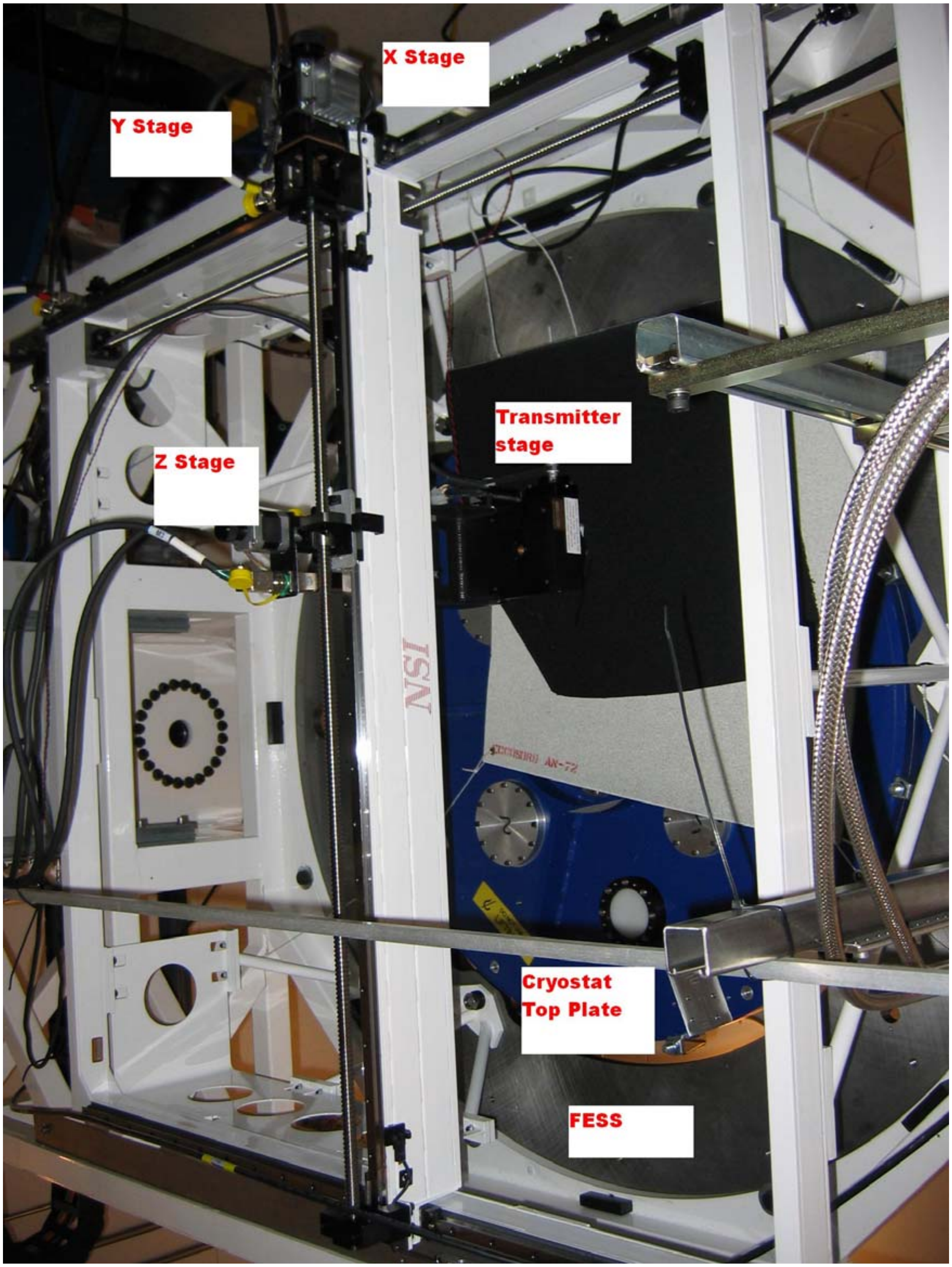

Figure 2 NSI scanner mounted on receiver.

3.0 Measurements

The measured results for the four bands are presented below. Note that the measurements are not presented in the chronological order in which they were made but are given in band order. The Chronological order of the measurements was as follows

1) band 6
2) laser interferometer planarity measurements
3) scanner removed and remounted
4) band 6
5) band 7
6) band 9
7) receiver and scanner dismounted, FESS replaced with final version and receiver with scanner remounted.
8) band 3
9) band 3, 6, 7 and 9 confirmation with cold load

Further details will be given in the relevant sections.

All scans were made with the tilt table at elevation 0 degrees unless otherwise noted.

3.1 Band 3

(Cartridge S/N 002 with WCA S/N 4 and Bias module S/N C2-16)

The band 3 receiver (employs warm optics) was first measured without the external mirrors and then with them.
Due to the arrival of the final FESS prior to these measurements, the receiver, scanner and provisional FESS were dismounted from the tilt table, the final version of the FESS installed and the receiver and scanner were remounted before these measurements were made.

3.1.1 Band 3 Horn alone (i.e. no warm optics)

The beam pattern of the horn – lens combination was measured at LO frequency 106 GHz, LSB (RF = 100 GHz).
Figure 3 shows the far field pattern of the horn alone. This had a beam center at -0.6684 degrees in Azimuth and -0.0666 degrees in Elevation: the nominal position is 0.0 degrees Azimuth and 0.0 degrees in Elevation. Note the absolute pointing angle is incorrect due to (as yet unmeasured) tilts of the beam scanner with respect to the FESS.
Due to time constraints the signal-to-noise ratio was not optimized to be better than about 30 dB, which resulted in some structure seen at the -20 dB level in the far field transform.

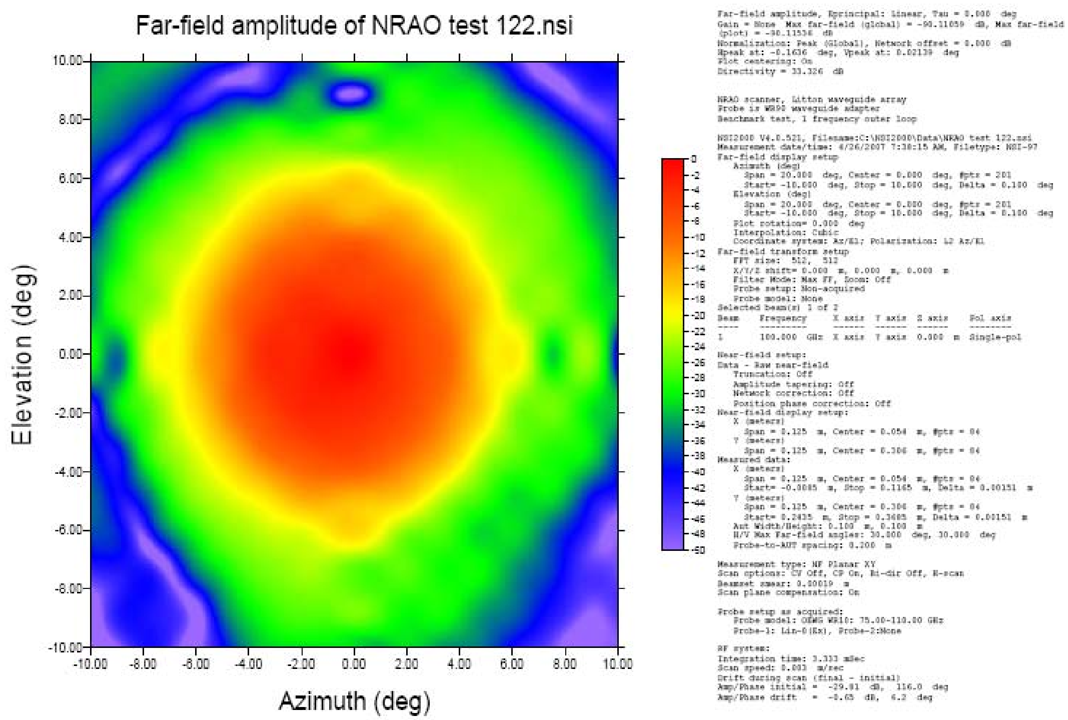

Figure 3 Far field amplitude of the band 3 horn-lens at 100 GHz.

Measurements were made at 0, 45 and 90 degree tilt angles. After several cycles the cartridge beam had moved to Azimuth -0.15, Elevation -0.23 degrees, repeatable to 0.02 degrees in both planes and changing by less than 0.04 degrees with tilt table angle; see the following table for details.

Azimuth angle degrees	Elevation angle degrees	Tilt table elevation degrees
-0.186	-0.194	0
-0.115	-0.313	45
-0.158	-0.246	90
-0.173	-0.238	0

This gives a beam waist, w0, of 10.5 mm for the horn lens combination, which is in agreement with the measurements made by the Band 3 cartridge group [RD5] but does not agree with the IRAM (room temperature) measurements of 9 mm waist [RD6].

3.1.2 Band 3 with warm Optics

The tilt angle on the horn beam pattern from the cold cartridge led to great difficulties in aligning the warm optics. The beam did not move with changing x or y of the mirror position and if the mirror was moved by more than 2 mm the beam became distorted. Finally, the correct beam position was determined to be x = -0.5 mm, y = 0.5 mm, from the nominal zero position given by the warm optics alignment procedure [RD9].

Measurements were made with the band 3 warm optics at three tilt table elevation angles (0 and 90 degrees) to determine if there was any variation with gravity vector; the results are tabulated below.

Azimuth angle degrees	Elevation angle degrees	Tilt table elevation degrees
0.591	2.114	0
0.531	2.096	45
0.468	2.213	90

Figure 4 shows the measured far field beam with the warm optics in its final position. The efficiency on the sub-reflector is 95% with an edge taper of between 14 and 16 dB. The dynamic range is not good and there are residual reflections in the central part of the beam, which have not been taken out by the software, even though two measurements were made at different z distances and combined in the software.

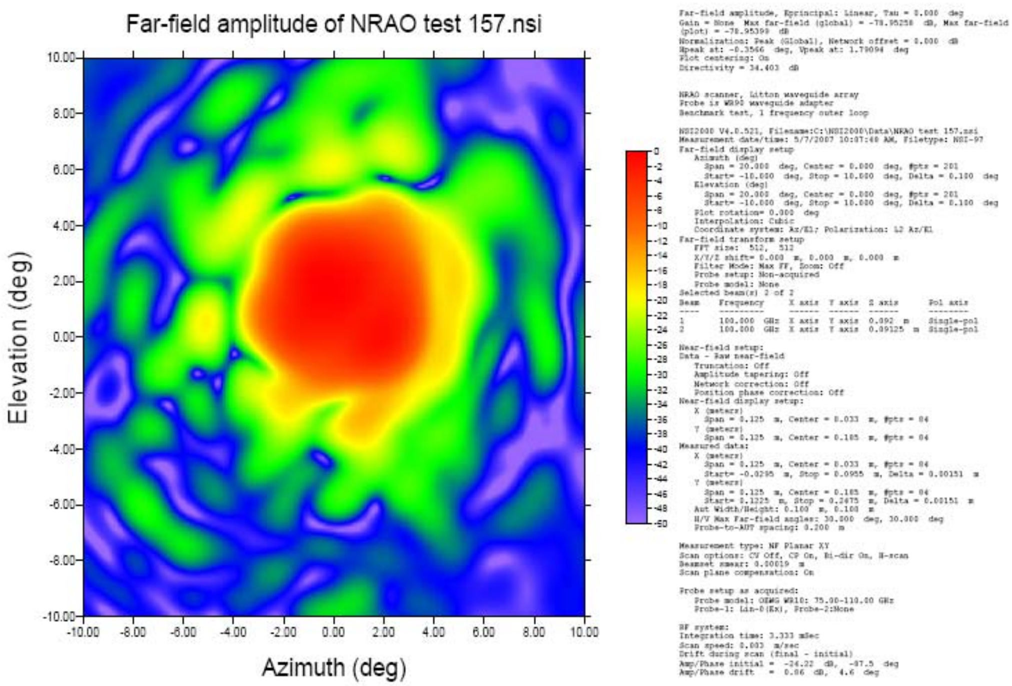

Figure 4 Far field amplitude of band 3 with warm optics at 100 GHz (combination of two z distances separated by lambda/4).

3.2 Band 6

(Cartridge S/N 004 with WCA S/N 6 and Bias module S/N C2-5)

The patterns were measured at the following frequencies

LO frequency	RF frequency	Comments
223.0 GHz	217.0 GHz	Lowest LO possible at the FEIC, 6 GHz LSB
235.0 GHz	229.0 GHz	6 GHz LSB
265.0 GHz	259.0 GHz	Highest LO possible at FEIC, 6 GHz LSB

Note the LO frequency range is set by the tuning range of the YIG oscillator in the WCA.

The following measurements were made with an unmodified cartridge for which the sidelobe is a known problem. The cause of the sidelobe has been determined (see [RD4]) and the cartridges will be modified in due course. It should be noted that the sidelobe amplitude seen in the near field agrees well with those measured by the band 6 cartridge group using an amplitude only beam measuring system. The sidelobe structure can also be seen in the far field transform.

Care should be exercised when examining the results as the near field scans are given in XY coordinates of the scanner positioners and Azimuth and elevation are angles as seen looking out from the receiver.

RF frequency 217 GHz results.

Figure 5 shows the measured near field pattern for this frequency.

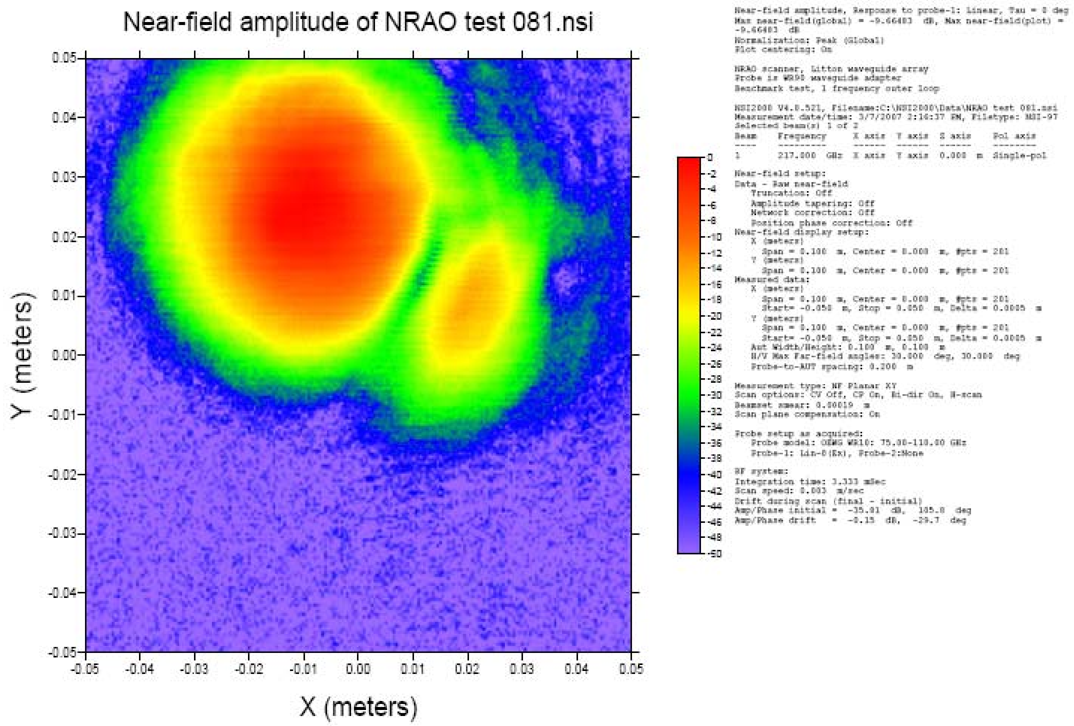

Figure 5 Band 6 beam at 217 GHz, near field

The side-lobe level is 15 dB below the peak

Figure 6 shows the far field pattern (using two near field scans separated by lambda/4 to remove scanner reflections).

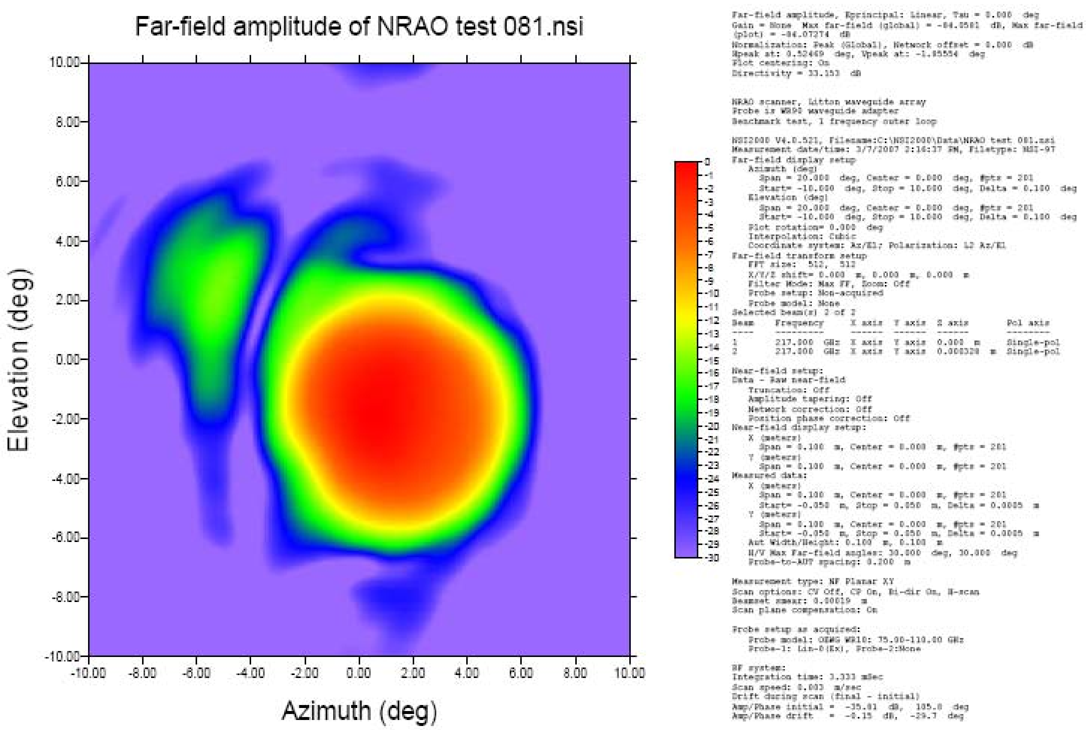

Figure 6 Band 6, 217 GHz Far field (two z distances).

Note the absolute pointing angle is incorrect due to (as yet unmeasured) tilts of the scanner with respect to the FESS. This issue will be discussed later.

Figure 7 gives the beam on the secondary (assuming the beam is pointing at the center of the secondary - yet to be confirmed). The plot is truncated at the angular size of the sub-reflector, so the plot provides an indication of the illumination pattern on the secondary (with the above assumption). The edge taper varies between 8.5 and 13 dB. The beam efficiency on the subreflector was calculated to be 88.85 %. This low value is mainly due to the beam being too wide and not due to the sidelobe which, despite its high power level does not cover much of the angular space; therefore it contributes little to the integrated power missing the telescope secondary.

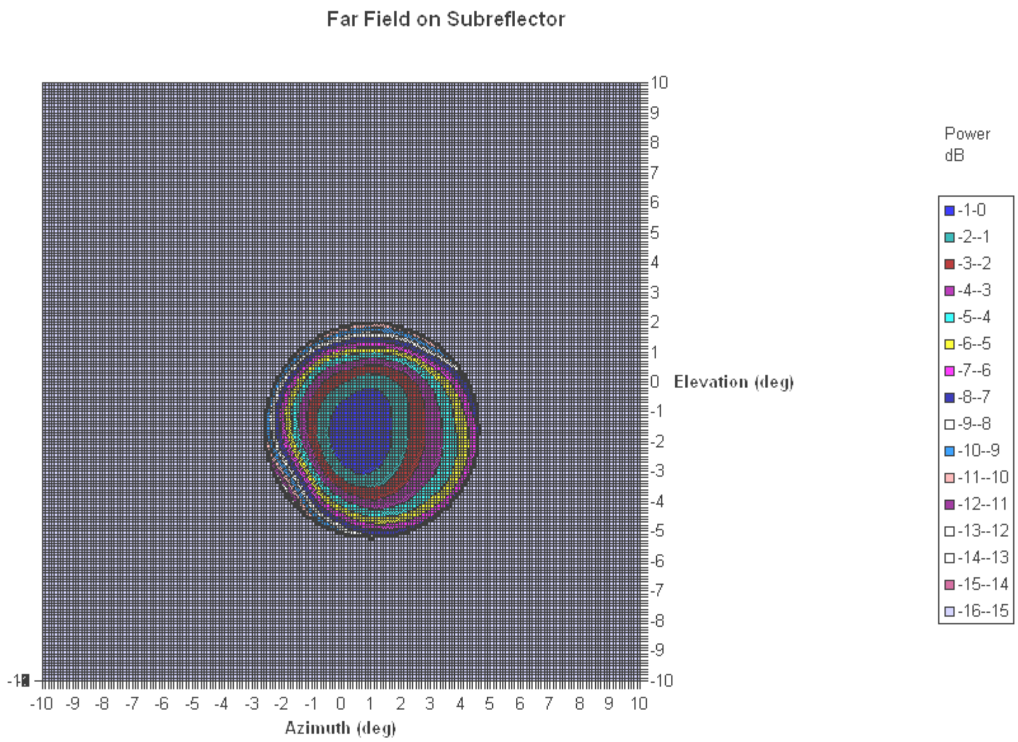

Figure 7 Beam on subreflector (power is set to -50 dB outside subreflector) each contour 1 dB.

RF frequency 229 GHz results.

Figure 8, Figure 9 and Figure 10 give the near field, far field and subreflector illumination at 229 GHz. The efficiency on the subreflector is 89.8 %.

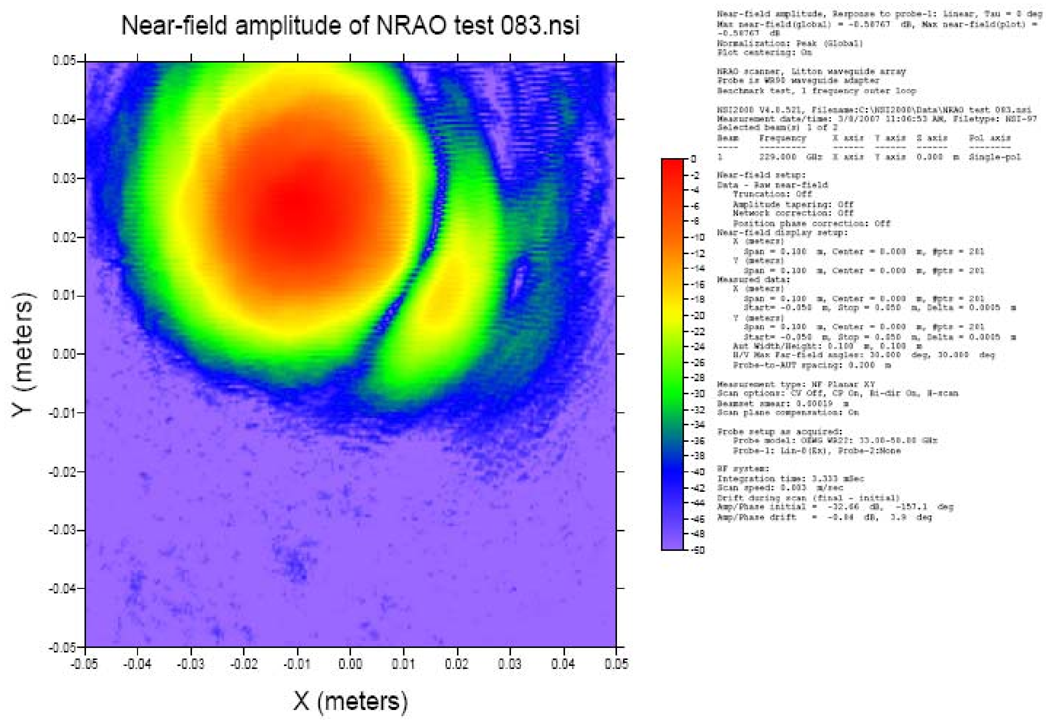

Figure 8 Band 6, 229 GHz near field.

The sidelobe level is 20 dB down from the peak

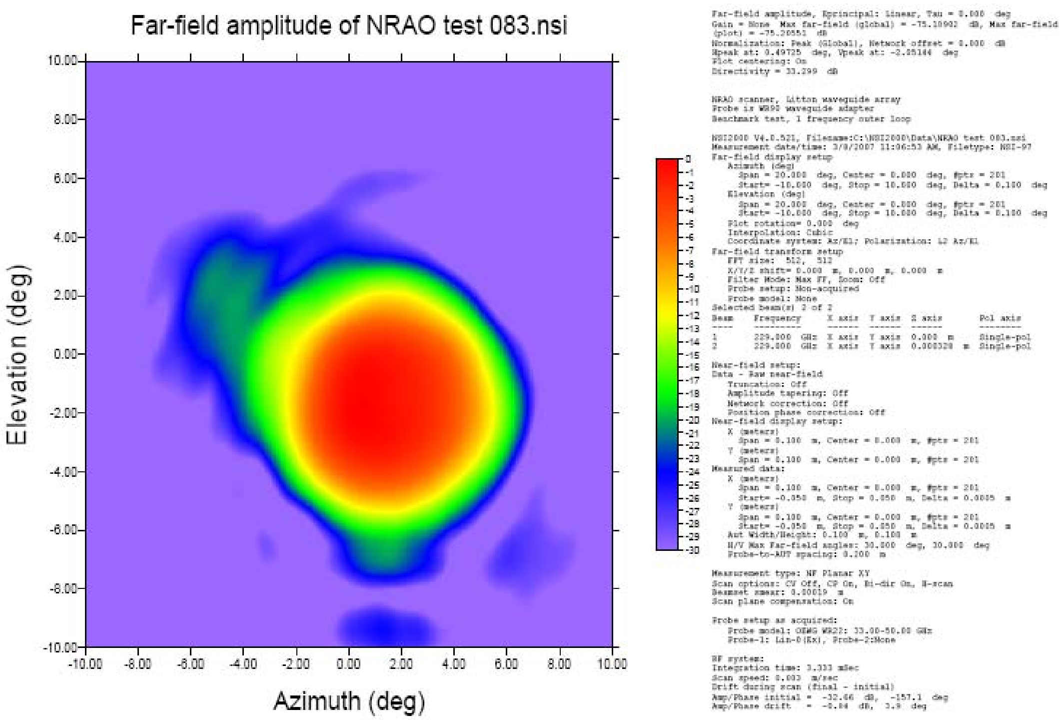

Figure 9 Band 6, 229 GHz Far field (two z distances).

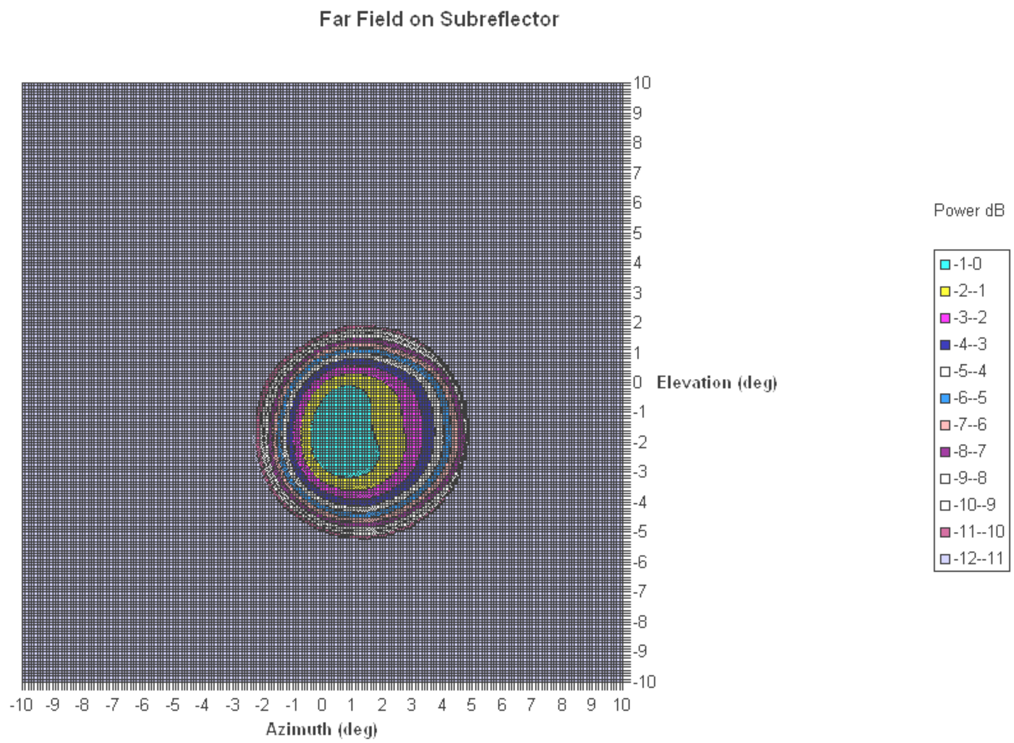

Figure 10 Beam on subreflector (power is set to -50 dB outside subreflector) each contour 1 dB.

RF frequency 259 GHz results.

Figure 11, Figure 12 and Figure 13 give the near field, far field and subreflector illumination at 259 GHz. The efficiency on the subreflector is 91.78 %.

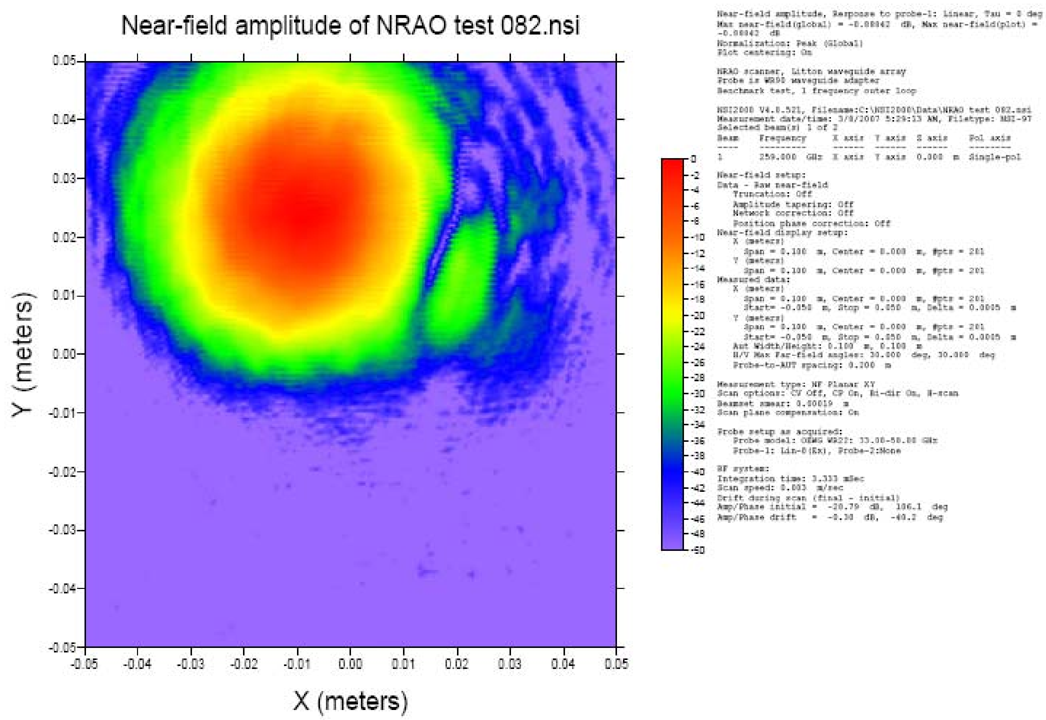

Figure 11 Band 6, 259 GHz near field.

The sidelobe level is 18 dB down from the peak

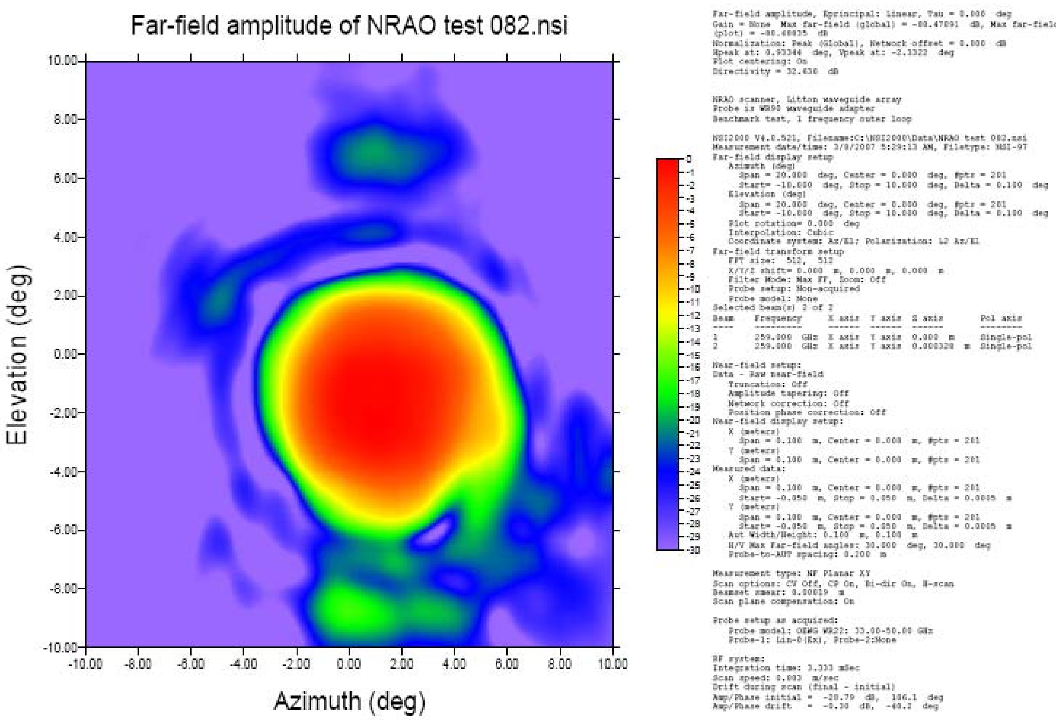

Figure 12 Band 6, 259 GHz Far field (two z distances).

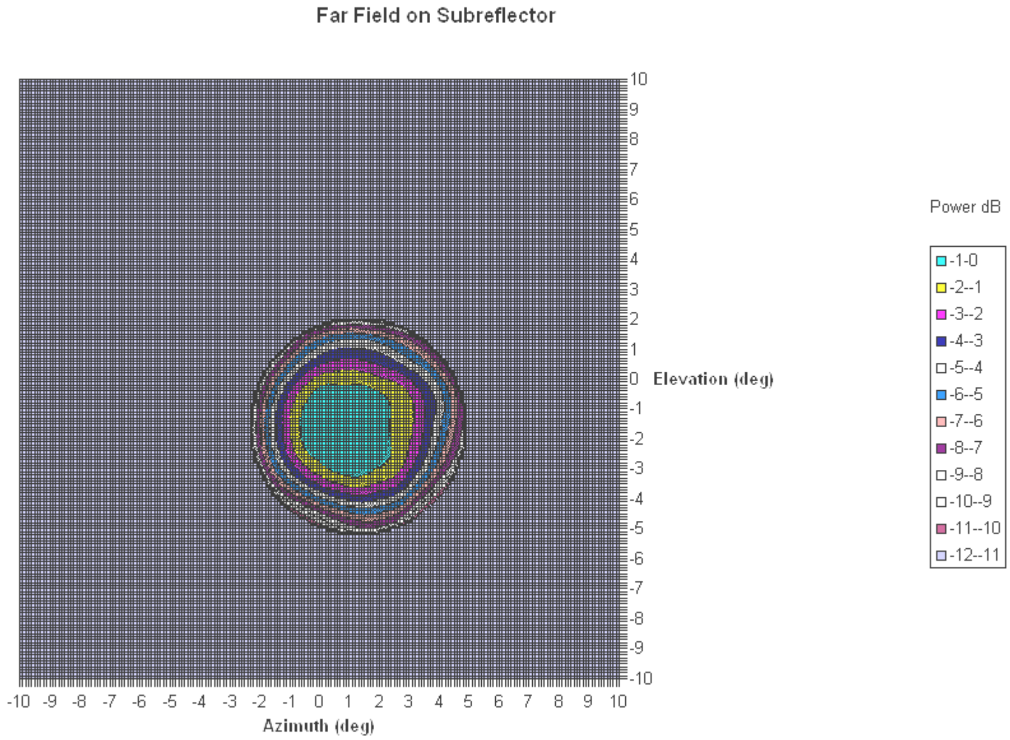

Figure 13 Beam on subreflector (power is set to -50 dB outside subreflector) each contour 1 dB.

3.2.1 Beam pointing

During the measurement sequence the beam scanner was detached from and remounted to the FESS (for various reasons associated with the construction of a cold load scanner and installation of the final FESS).
This was used to determine the variation of the pointing angle due to the accuracy at which the scanner/FESS could be remounted.
Prior to any changes the band 6 beam at 229 GHz RF the beam center was determined to be at Azimuth 2.035 degrees and Elevation -1.308 degrees; after remounting the scanner it was found to be Azimuth 1.251 degrees and Elevation -1.629 degrees (the nominal Azimuth is 1.6867 degrees and Elevation -1.6867 degrees). Giving a change of -0.78 degrees in Azimuth and -0.321 degrees in Elevation, indicating that the position of the scanner should be remeasured with a laser alignment system every time it is moved to insure beam pointing accuracy.
The measurements prior to any changes are fully consistent with measurements of the scanner positions made with a laser interferometer system (during a sales representative demonstration of the system, so not as accurate as could be made with more time), which

gave an error in Azimuth of + 0.51 degrees and in Elevation of +0.43 degrees (Azimuth = 2.035 - 0.51 = 1.525 degrees and Elevation = -1.308 - 0.43 = -1.738 degrees compared to the nominal values an error of -0.16 degrees in azimuth and -0.05 degrees in elevation).

3.2.2 Beam pointing measurement repeatability

Two scans were made at 229 GHz several hours apart to determine the repeatability of the measurement of the beam angles and secondary illumination efficiency. The Azimuth varied by 0.006 degrees between the two scans and the Elevation by 0.043 degrees.(0.75 mRadians). The efficiency calculated varied by 0.63 % between the two scans (assuming the beam center was centered on the secondary).

3.3 Band 7

(Cartridge S/N 001 with WCA S/N 2 and Bias module S/N C2-3)

The patterns were measured at the following frequencies

LO frequency	RF frequency	Comments
283.0 GHz	277.0 GHz	6 GHz LSB
320.0 GHz	314.0 GHz	6 GHz LSB
363.0 GHz	357.0 GHz	6 GHz LSB

RF frequency 277 GHz results.

Figure 14 shows the measured near field pattern for this frequency.

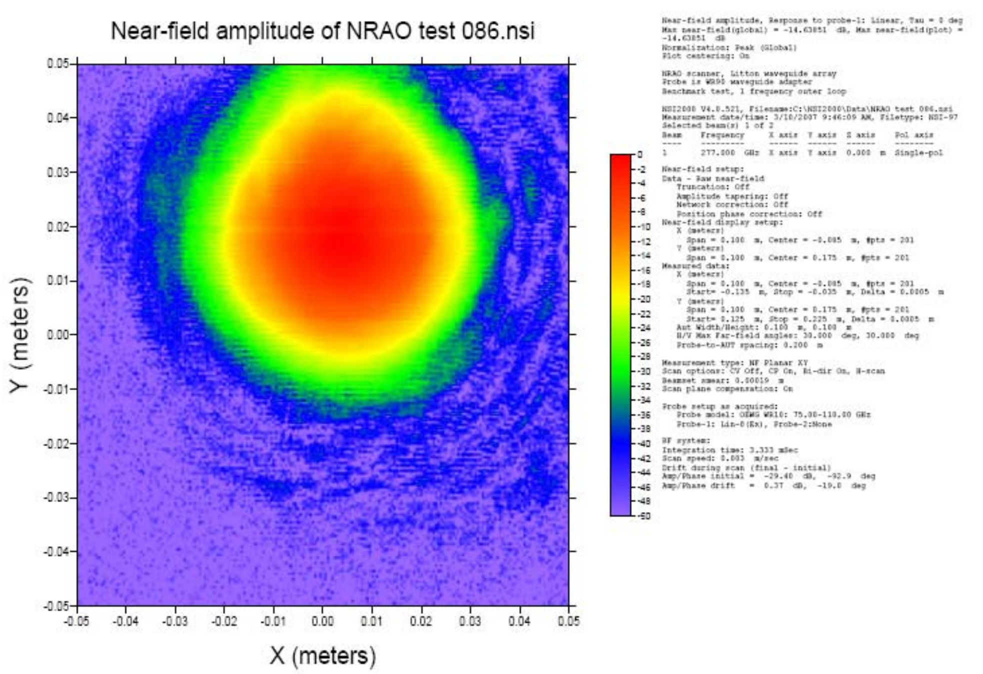

Figure 14 Band 7, 277 GHz near field

Note No sidelobe seen

Figure 15 shows the far field pattern (using two near field scans separated by lambda/4 to remove scanner reflections).

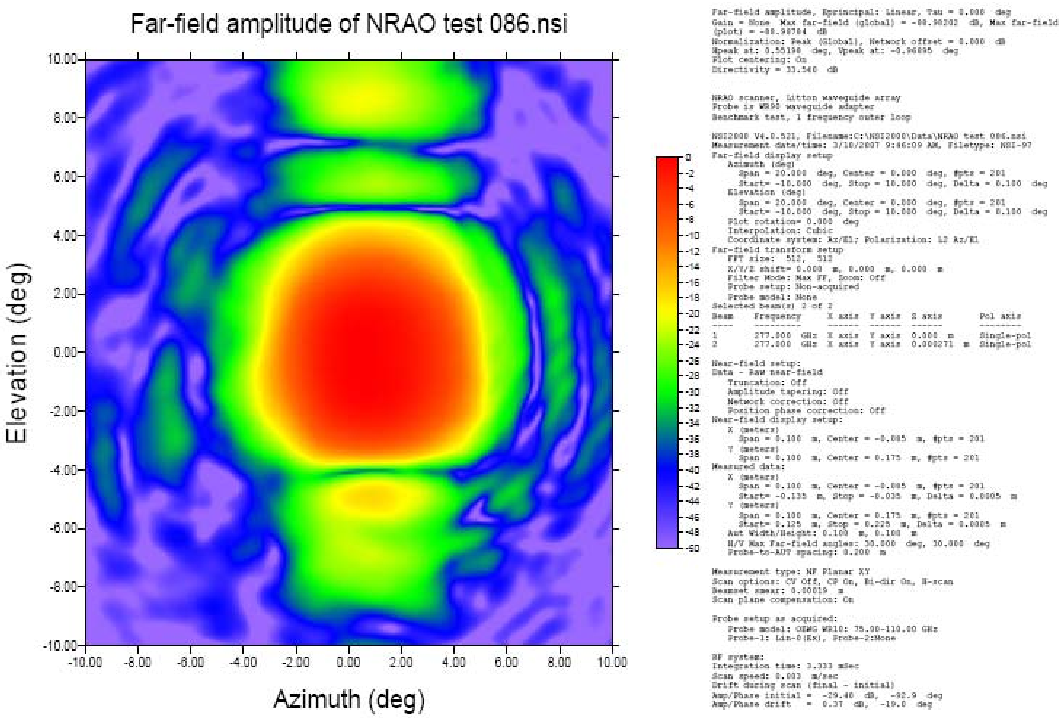

Figure 15 Band 7, 277 GHz Far field (combination of two z distances).

Note the absolute pointing angle is incorrect due to (as yet unmeasured) tilts of the scanner with respect to the FESS.

Figure 16 gives the beam on the secondary (assuming the beam is pointing at the center of the secondary - yet to be confirmed). The efficiency on the subreflector is 95 %. The measured centers of the beams are low in azimuth, and elevation by 0.2 mRadians at 277 GHz and 314 GHz. 357 GHz shows the beam is off by + 7 mRadians in azimuth and -8 mRadians in elevation, but the measurements at this frequency were severely affected by frequency instabilities.

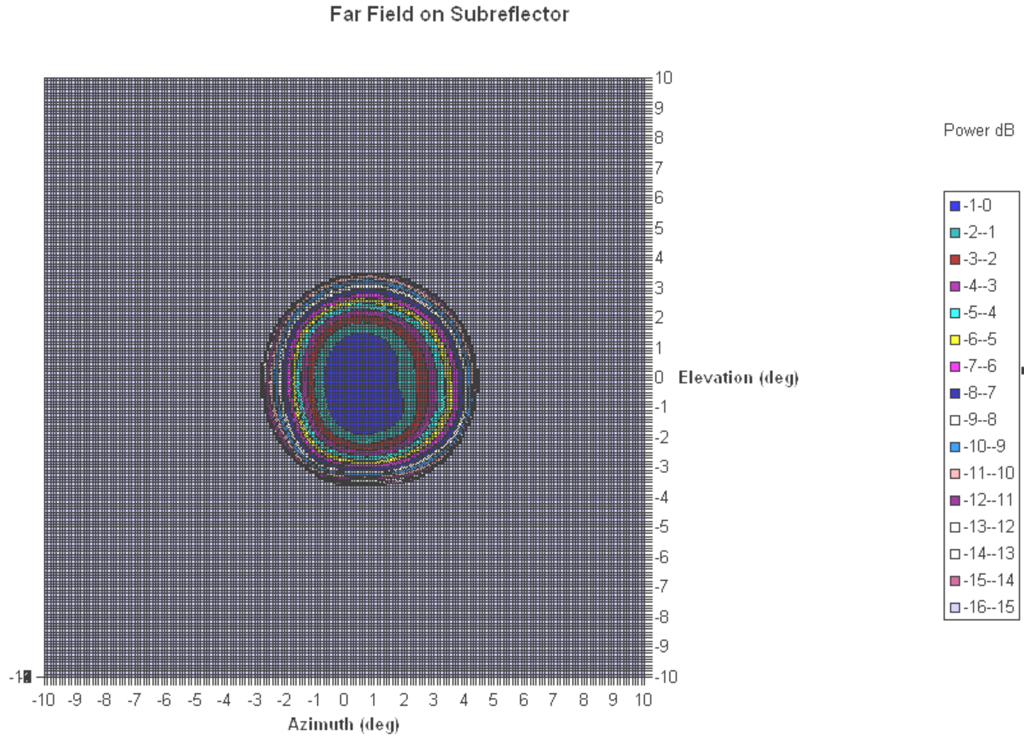

Figure 16 Beam on subreflector (power is set to -50 dB outside subreflector) each contour 1 dB.

Figure 17 shows a representative cross-polar pattern taken at this frequency. Due to time constraints no other cross-polarization scans were made. The cross-polar peak is only 16 dB below the co-polar (but is not fully calibrated). This result is compatible with the band 7 measurements, but does not match the design values.

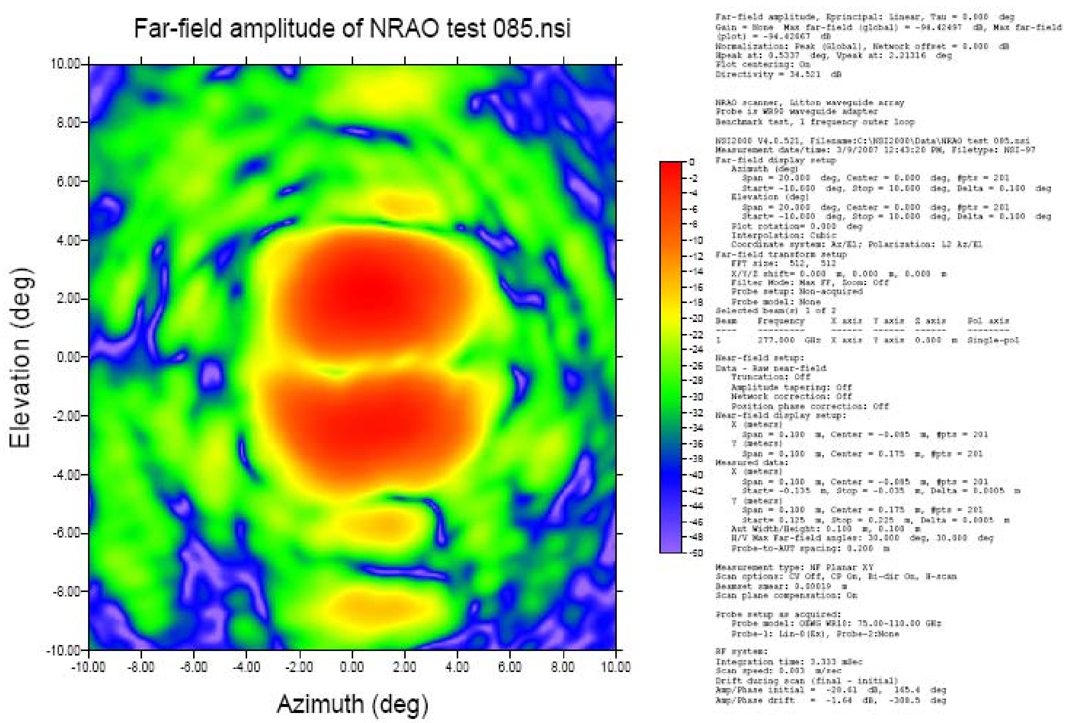

Figure 17 Band 7 cross polar pattern at 277 GHz.

RF frequency 314 GHz results.

Figure 18, Figure 19 and Figure 20 give the near field, far field and subreflector illumination at 229 GHz. The efficiency on the subreflector is 93.5 %.

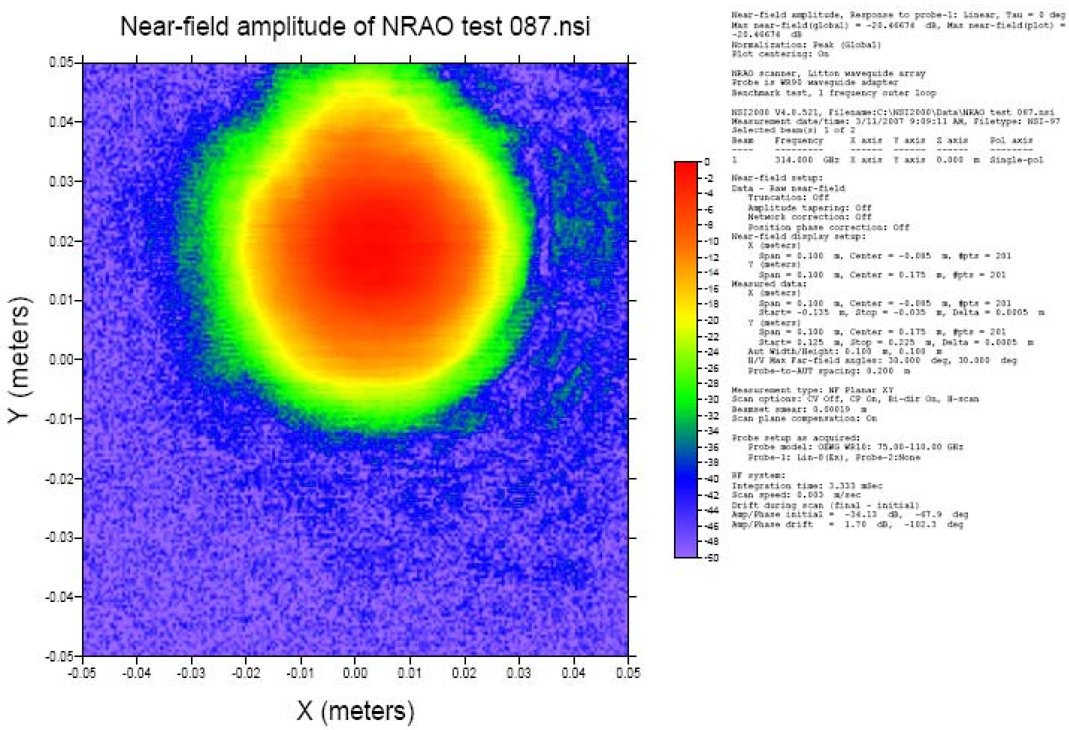

Figure 18 near field amplitude for band 7 at 314 GHz.

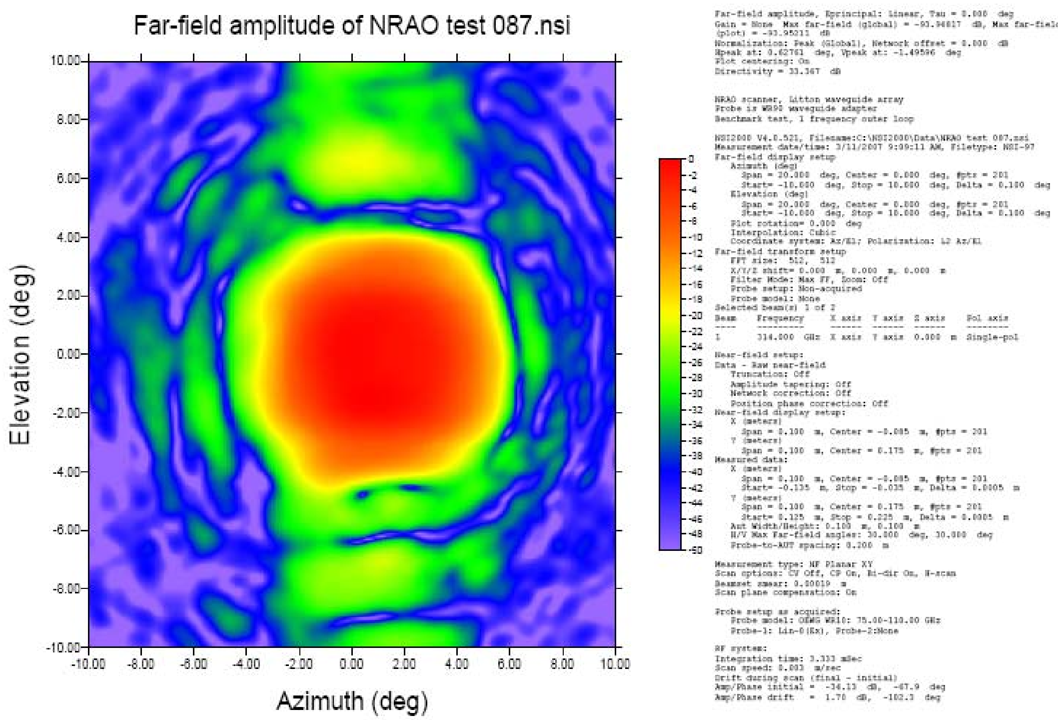

Figure 19 Band 7 far field amplitude at 314 GHz.

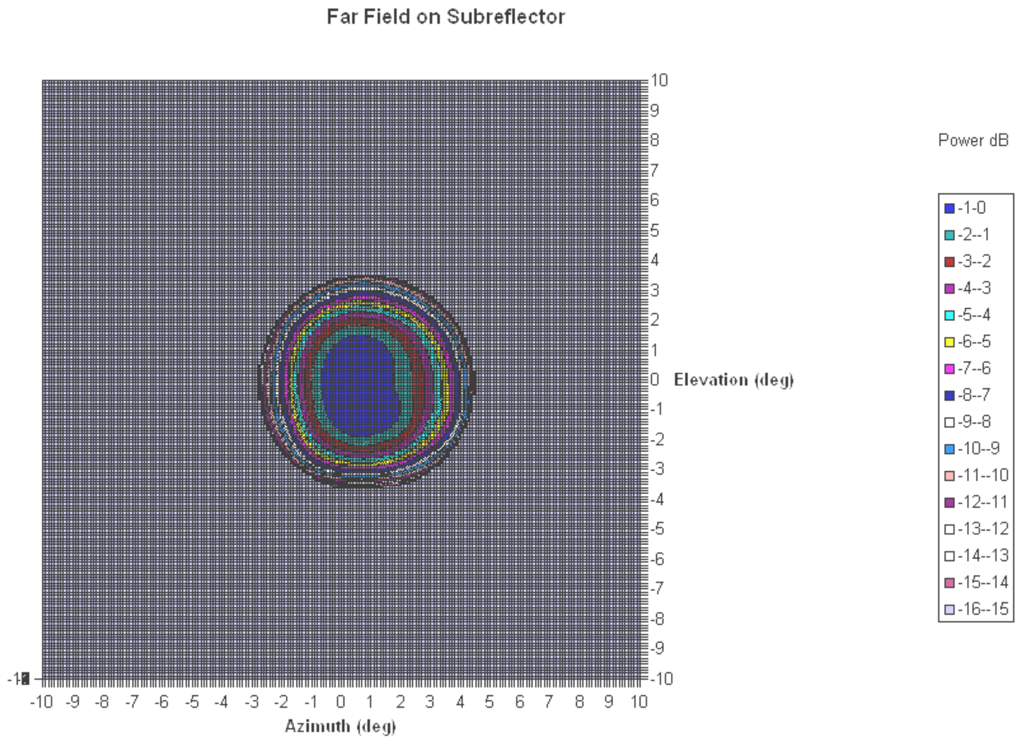

Figure 20 Beam on subreflector (power is set to -50 dB outside subreflector) each contour 1 dB.

RF frequency 357 GHz results.

Figure 21, Figure 22 and Figure 23 give the near field, far field and subreflector illumination at 259 GHz. The efficiency on the subreflector is 91.5 %. Note that at this frequency the YIG oscillator was not as frequency stable as for the other frequencies.

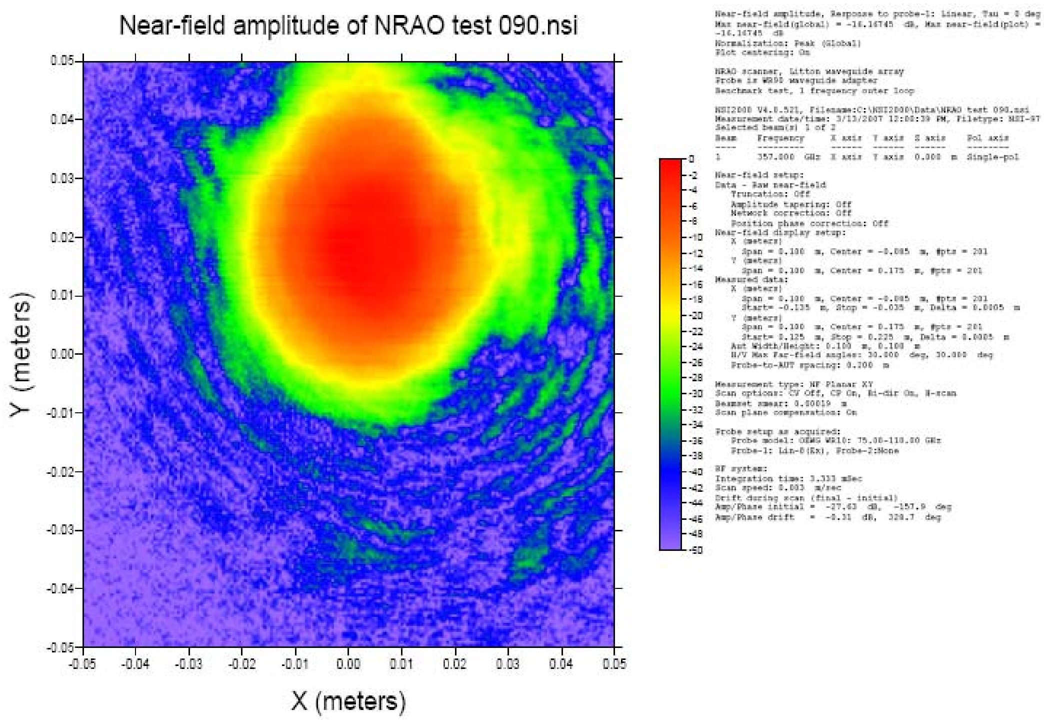

Figure 21 Band 7 near field amplitude at 357 GHz.

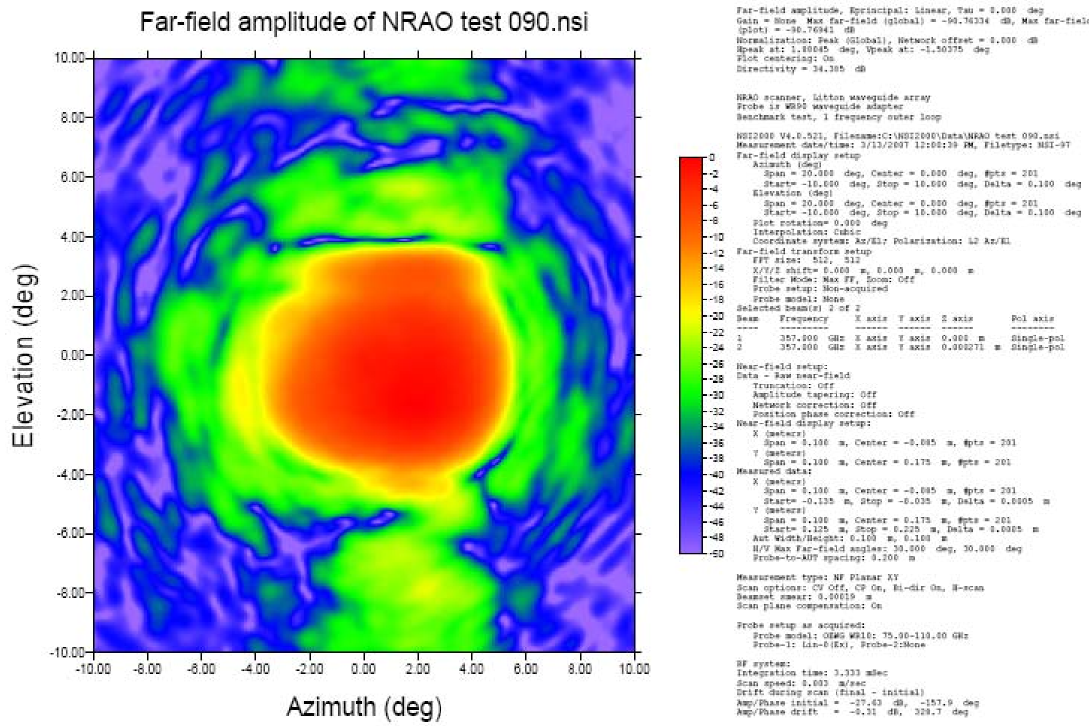

Figure 22 Band 7 far field at 357 GHz.

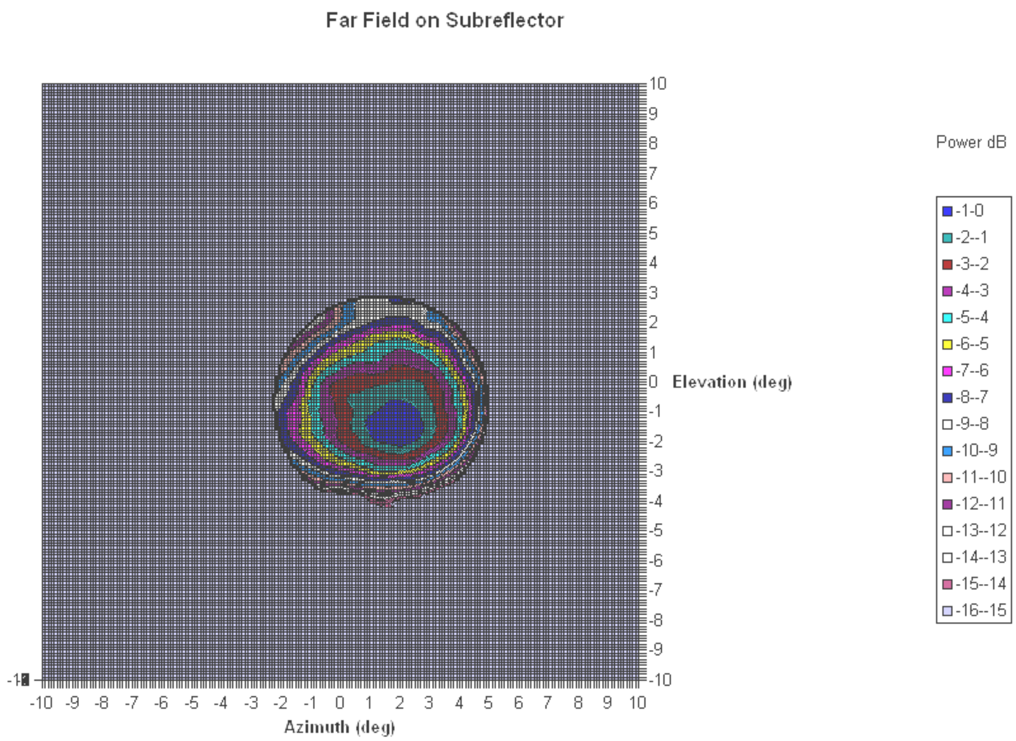

Figure 23 Beam on subreflector (power is set to -50 dB outside subreflector) each contour 1 dB.

As an indication of the phase stability of the system Figure 24 gives measured the near field phase at 377 GHz.

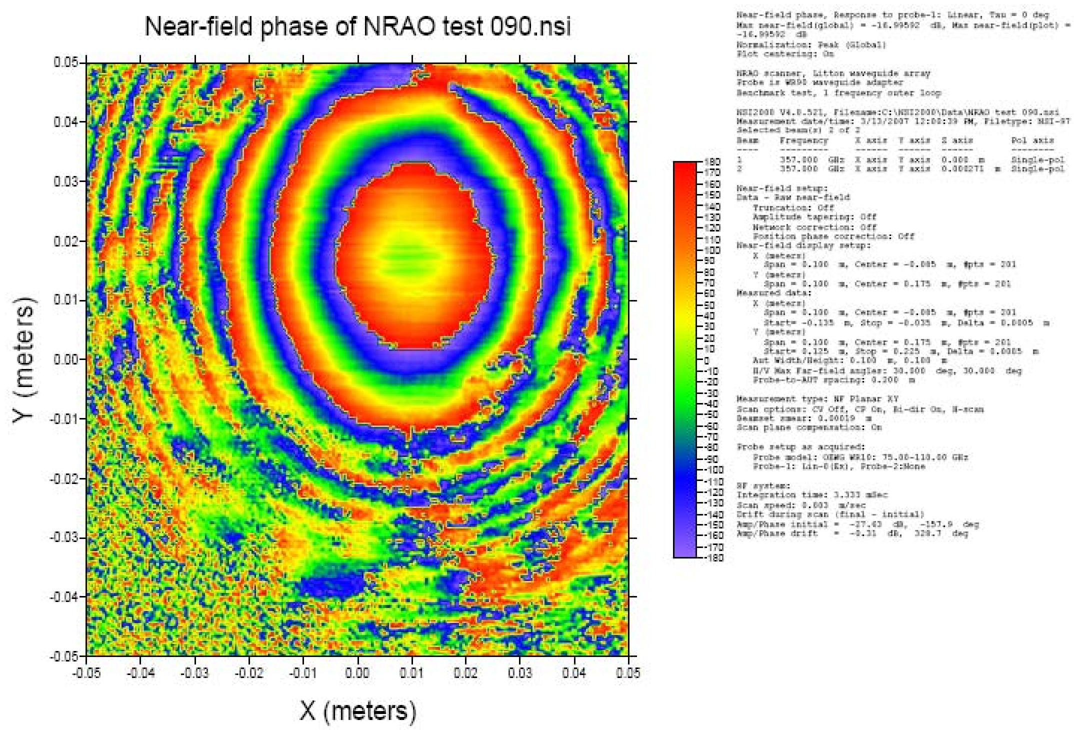

Figure 24 Band 7 near field phase at 357 GHz.

Band 9

(Cartridge S/N 001 with WCA S/N 1 and Bias module S/N C2-1)

Figure 25 gives the far field pattern of the band 9 beam at 656 GHz. The structure along the Elevation 0 degrees line is due to difficulties in maintaining the frequency of the YIG oscillator to 1 MHz, unlocked (multiplied by 54 in the final result). This gives structure in the near field amplitude and phase which is Fourier transformed to give structure in the slower scan direction. Work is in progress to improve the frequency stability of the system. This has minor effects on the beam pointing direction and secondary illumination efficiency (94.2%, which compares well with the band 9 cartridge group PAI number). The edge taper is 18 to 20 dB down from peak and the beam pointing is correct within the measurement offsets described in the band 6 measurements.

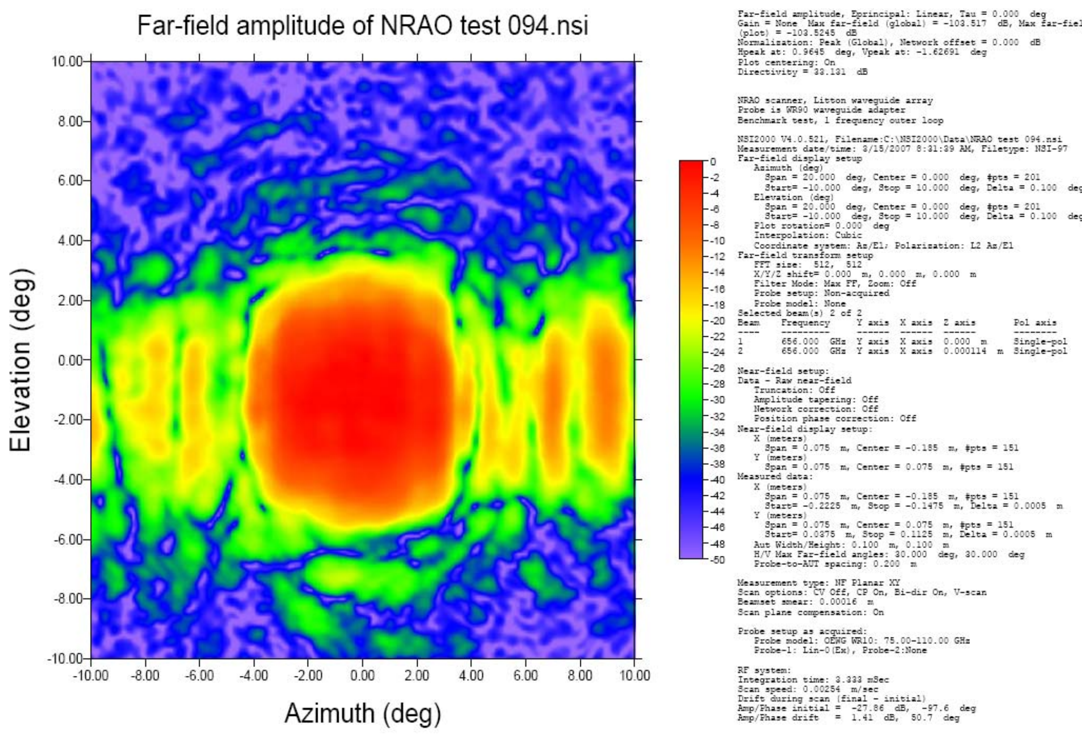

Figure 25 Band 9 Far field amplitude at 656 GHz.

4.0 Cold load at subreflector position

In the absence of the laser alignment scanner, an attempt was made to determine the absolute pointing of the beams by placing lasers with the correct tilt angles (to the machining tolerances) at the position of the water vapor radiometer pick-off mirror mounting screws (at the center of the cryostat top plate) and on the band 6 window. These cross each other at the distance of the sub-reflector (6000 mm). This was also confirmed with a measuring tape. A warm absorber was placed at this distance and the position of the beam center was determined by moving a cold load (AN72 absorber, diameter 160 mm, dipped in liquid nitrogen) over position of the beam and determining where the minimum signal was in relation to the laser determined center of the sub-reflector.

Figure 26 Shows the positions determined for bands 3, and 6 with the cold load, and the positions as determined from the far field patterns of the scanner.

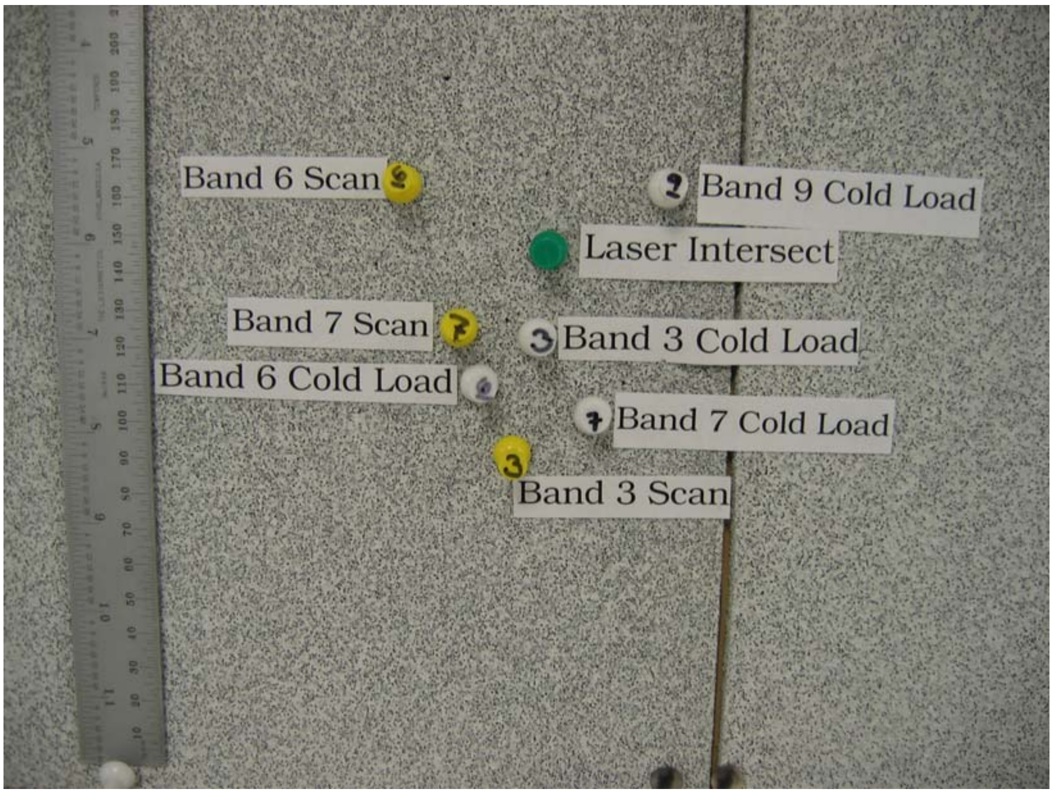

Figure 26

The point “Laser intersect” is the center of the sub-reflector determined from the two lasers.

The following table gives the measured offsets from the laser position for the cold load and for the scanner measurements. Also given is the offset of the pointing of the scanner

Band number	X mm from laser center	Y mm	Scanner offset (degrees) Azimuth	Scanner offset (degrees) Elevation
3 cold load	6	-25		
3 scanner	12	-50	0.06	0.24
6 cold load	18	-37		
6 scanner	45	16	0.26	0.51
7 cold load	-12	-40		
7 scanner	27	-22	0.37	0.26
9 cold load	-30	16		
9 scanner	-	-	-	-

Given the errors in the measurements (especially the determination of the cold load position as the change in signal level is only 0.3 dB for most of the bands) this indicates that the positioner is now offset in Azimuth by 0.23 degrees and 0.34 degrees in Elevation, both +/- 0.2 degrees. This is following several mountings and dismountings of both the scanner and the cryostat. This should be compared to 0.51 degrees in azimuth and 0.43 degrees in elevation measured initially by the laser scanner (see section 3.2.1)

5.0 Further measurements

Since the above measurements have been made the cryostat has been warmed up, Bands 3 has been removed and replaced, band 6 has been replaced by a cartridge with the modified horns (to remove the sidelobe) and band 7 was also removed and replaced.

The plan is to measure all the bands for acceptance.

This will also yield further information on the hysteresis effect on band 3, confirm the removal of the sidelobe in band 6, check the cross-polar problem with band 7 and make beam pointing measurements on band 9.