3.3 Optics Requirements

This section applies only to the operational mode.

3.3.1 Beam performance

Several of the requirements in this category are verified by numerically computing the relevant quantities based on the 2D beam pattern measurements, which were measured and are plotted in figures below:

Band 3

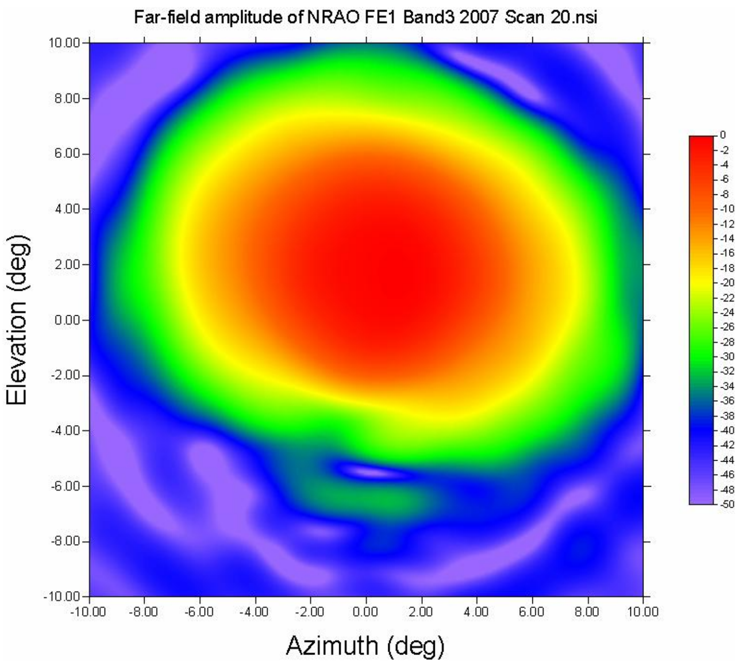


Figure 78 86 GHz Pol 0 Co-pol. elevation 45

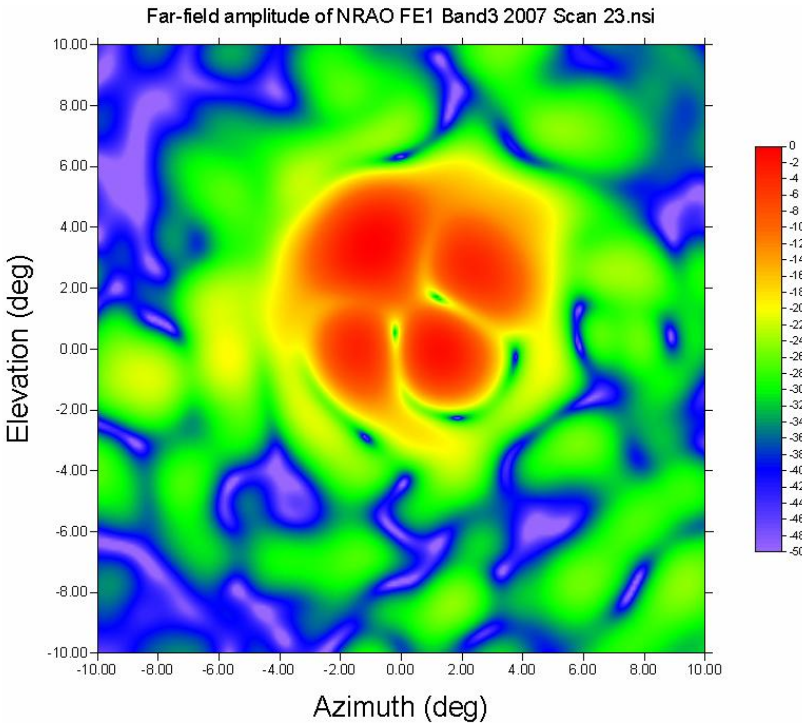


Figure 79 86 GHz Pol 0 Cross-pol. elevation 45

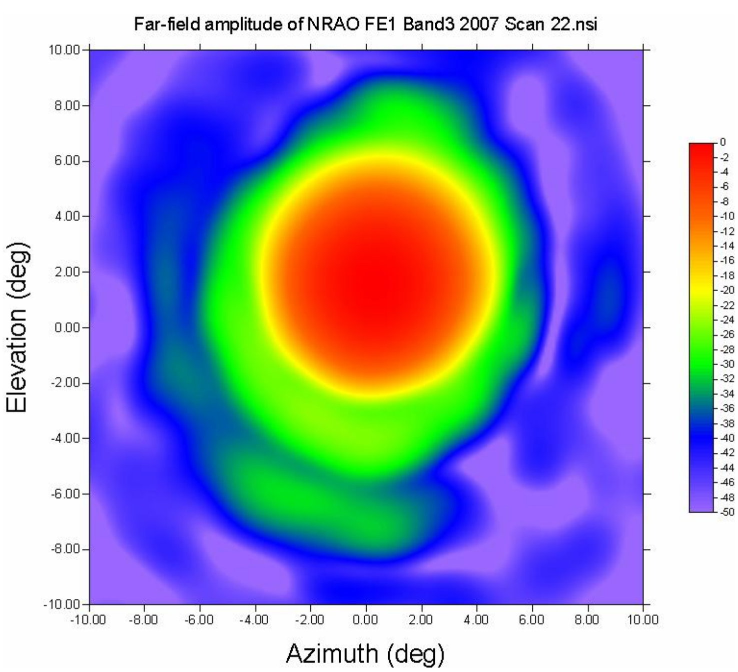


Figure 80 86 GHz Pol 1 Co-pol. elevation 45

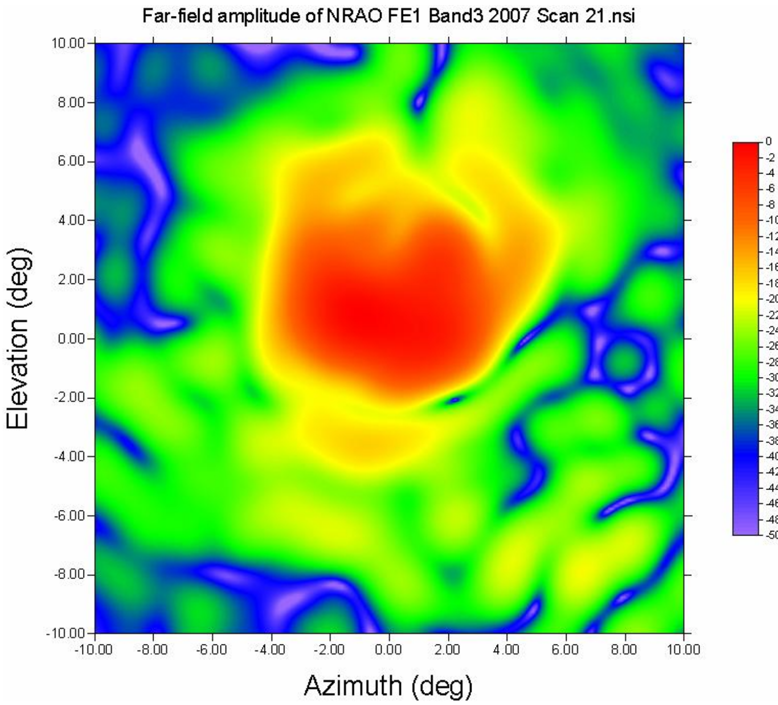


Figure 81 86 GHz Pol 1 Cross-pol. elevation 45

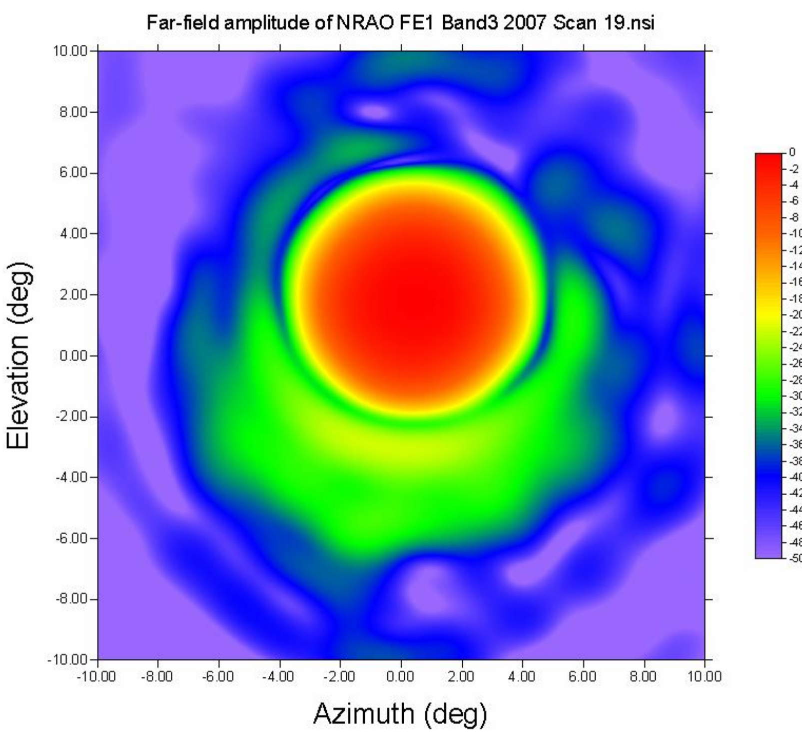


Figure 82 94 GHz Pol 0 Co-pol. elevation 0

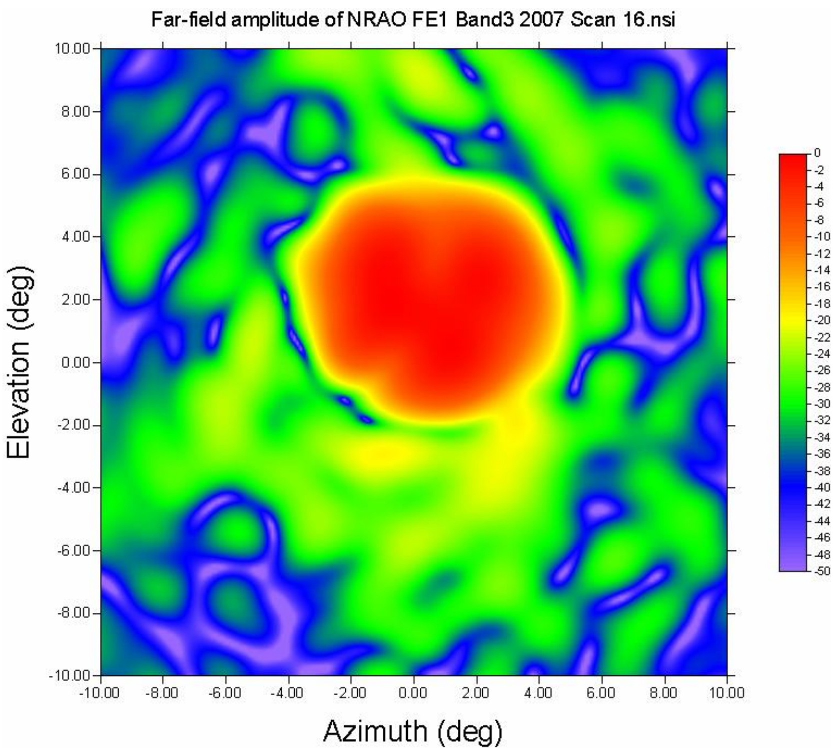


Figure 83 94 GHz Pol 0 Cross-pol. elevation 0

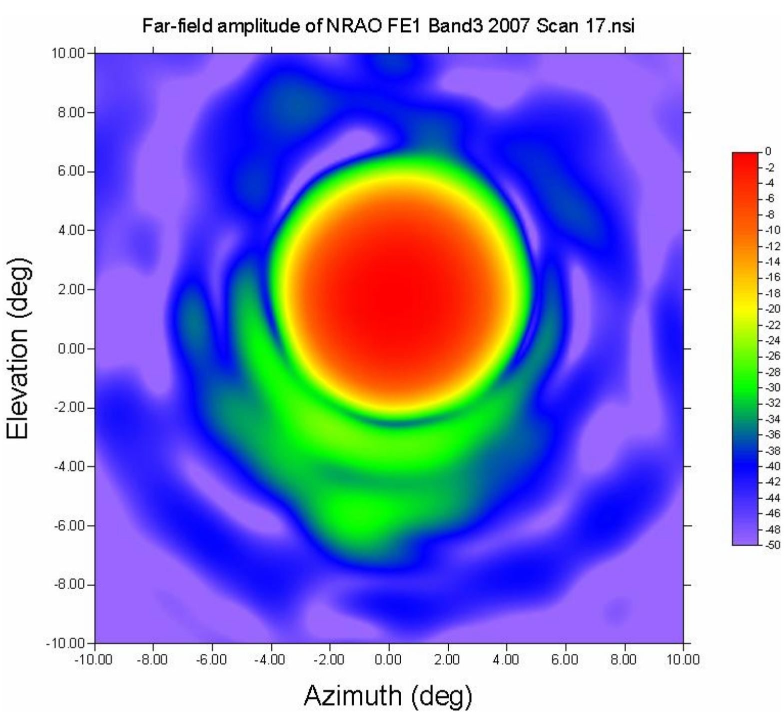


Figure 84 94 GHz Pol 1 Co-pol. elevation 0

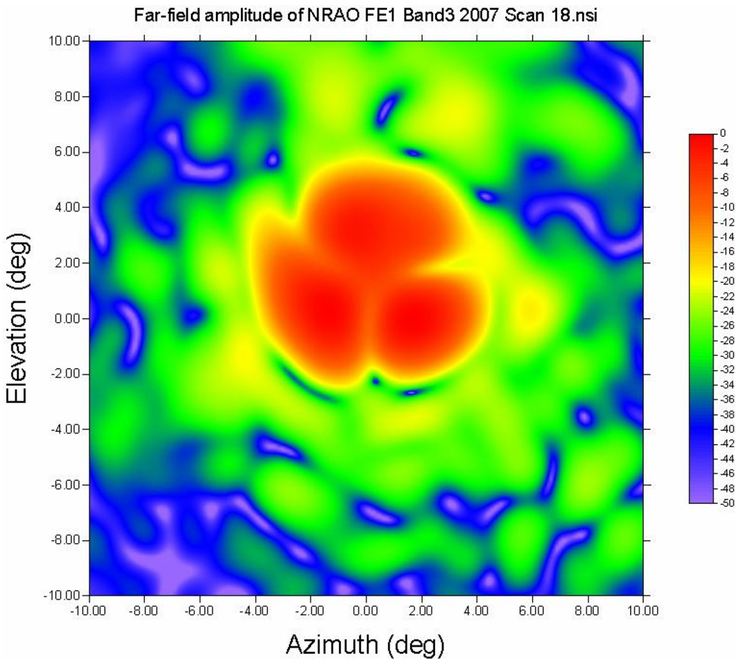


Figure 85 94 GHz Pol 1 Cross-pol. elevation 0

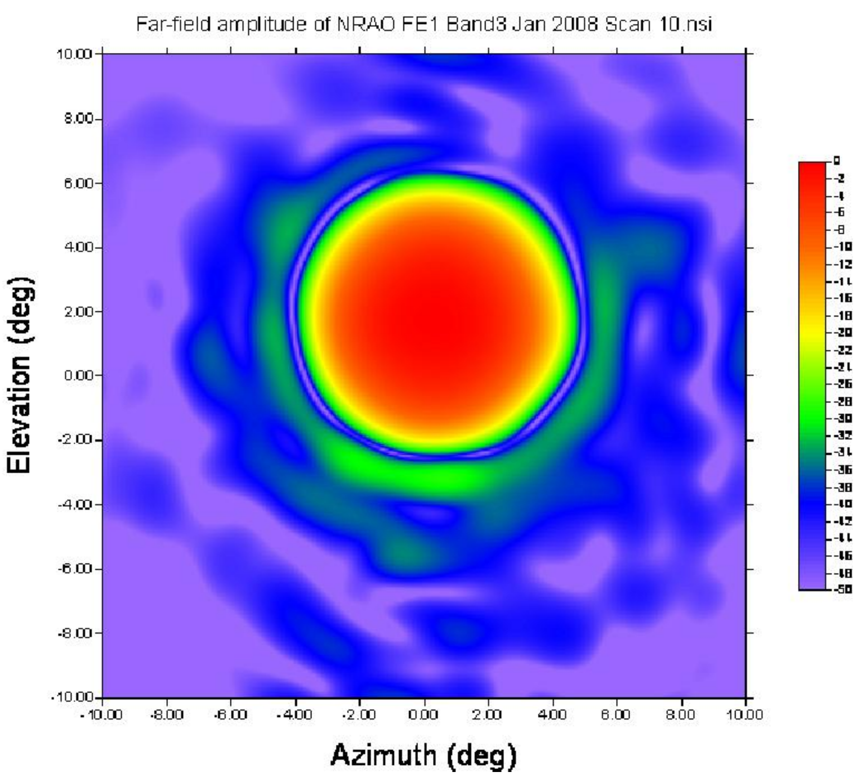


Figure 86 94 GHz Pol 0 Co-pol. elevation 45

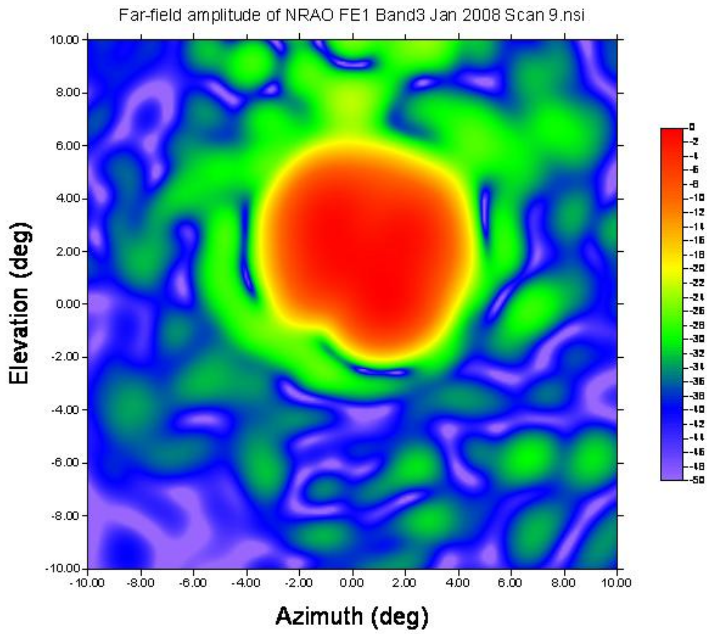


Figure 87 94 GHz Pol 0 Cross-pol. elevation 45

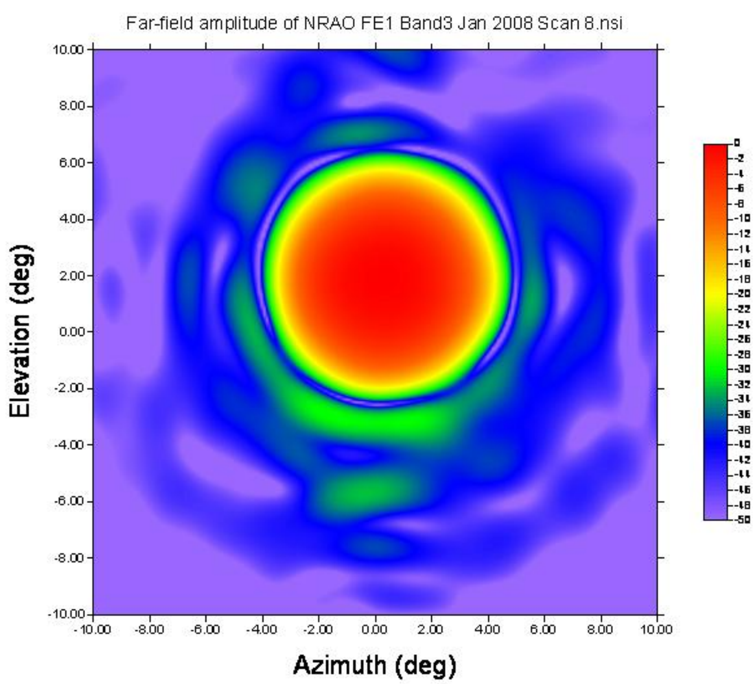


Figure 88 94 GHz Pol 1 Co-pol. elevation 45

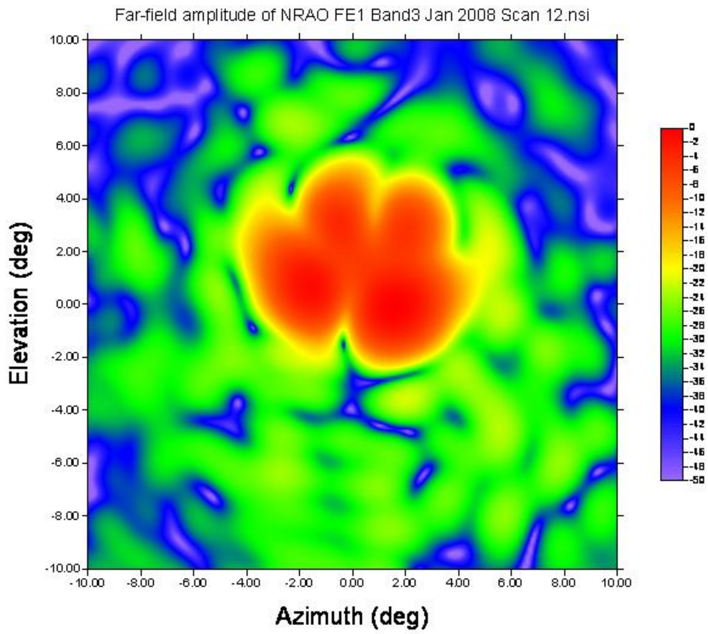


Figure 89 94 GHz Pol 1 Cross-pol. elevation 45

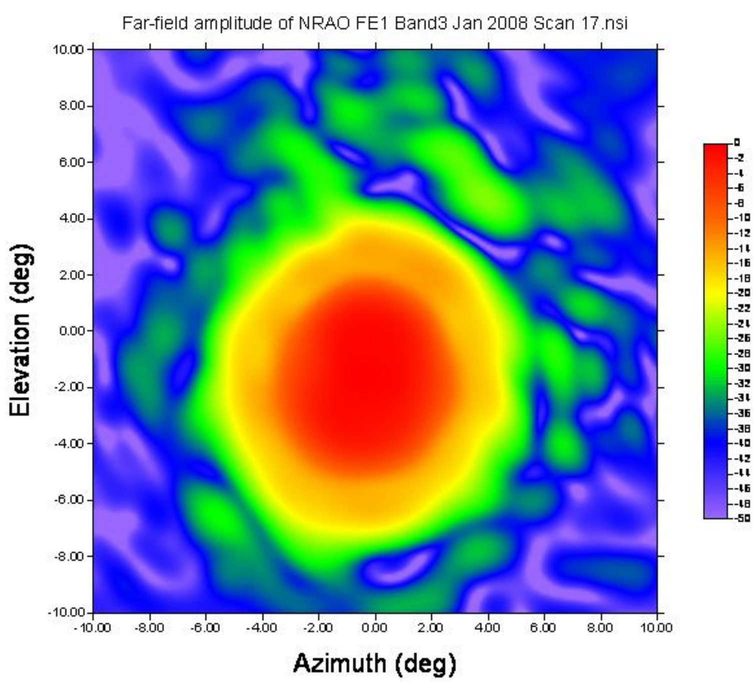


Figure 90 115 GHz Pol 0 Co-pol. elevation 45

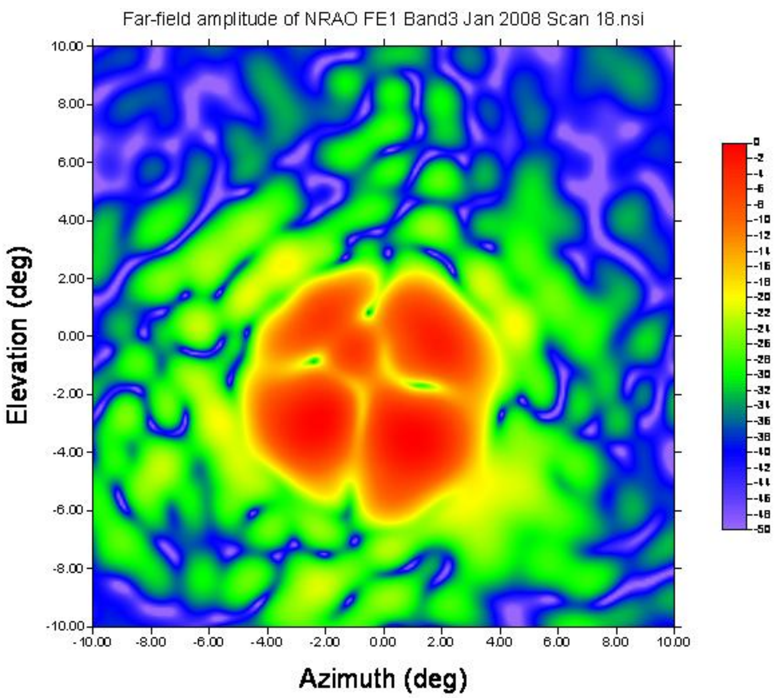


Figure 91 115 GHz Pol 0 Cross-pol. elevation 45

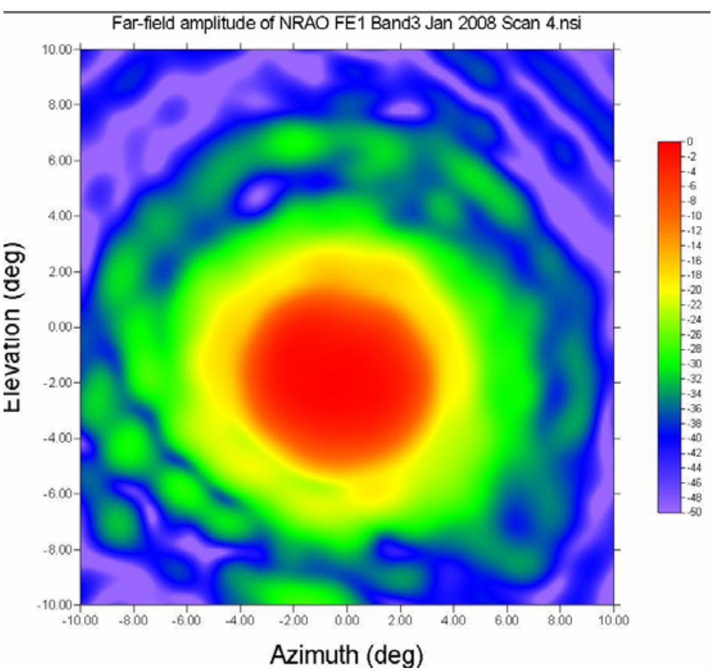


Figure 92 115 GHz Pol 1 Co-pol. elevation 45

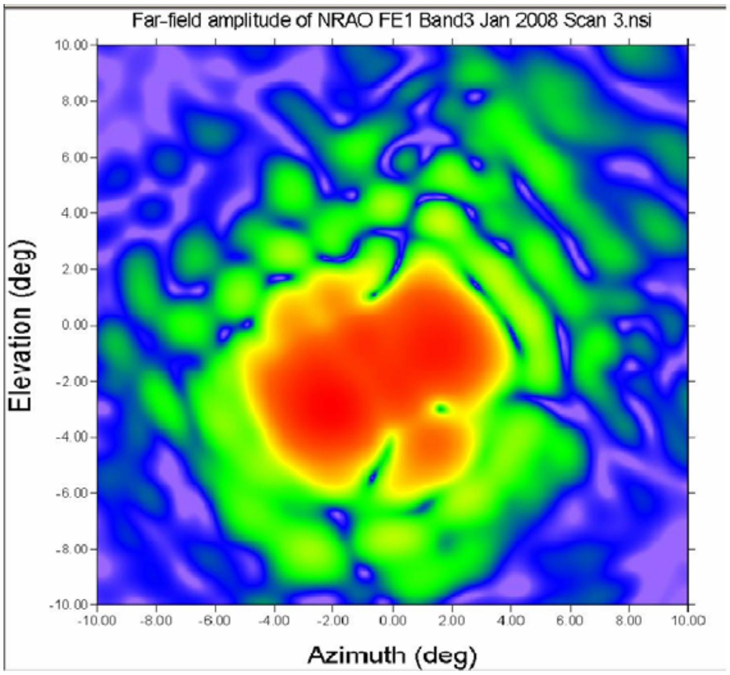


Figure 93 115 GHz Pol 1 Cross-pol. elevation 45

Band 6

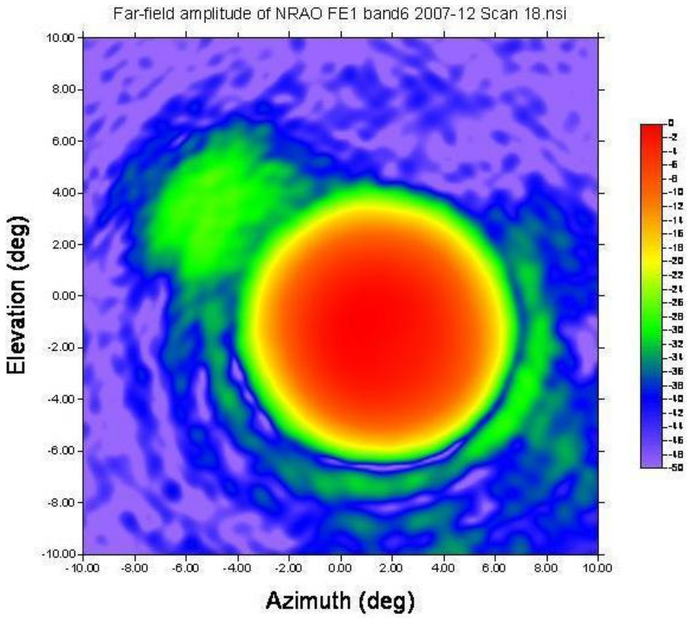


Figure 94 239 GHz Pol 0 Co-pol. elevation 45

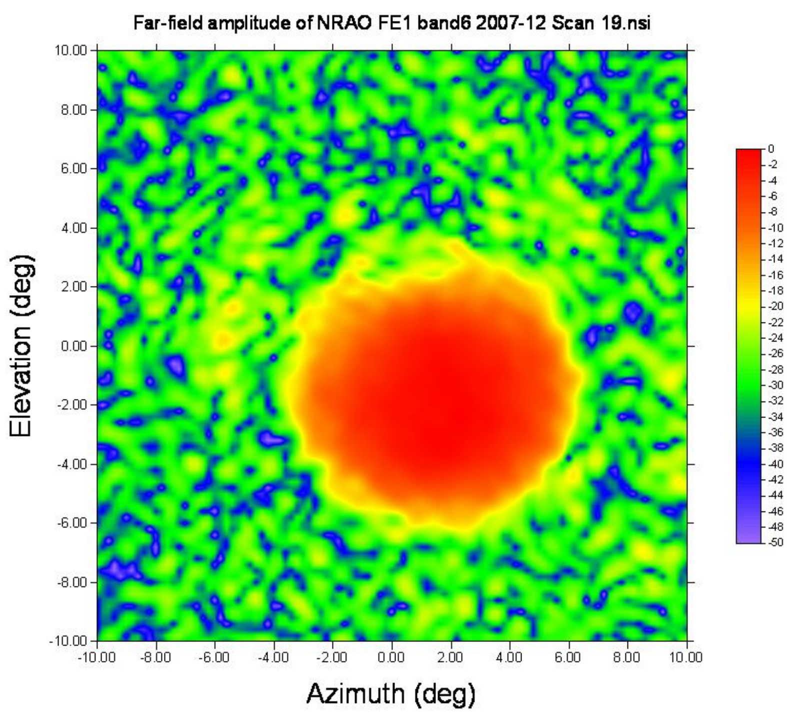


Figure 95 239 GHz Pol 0 Cross-pol. elevation 45

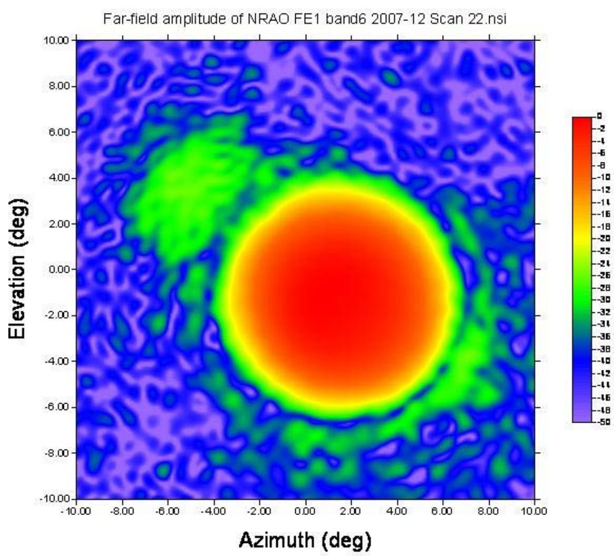


Figure 96 239 GHz Pol 1 Co-pol. elevation 45

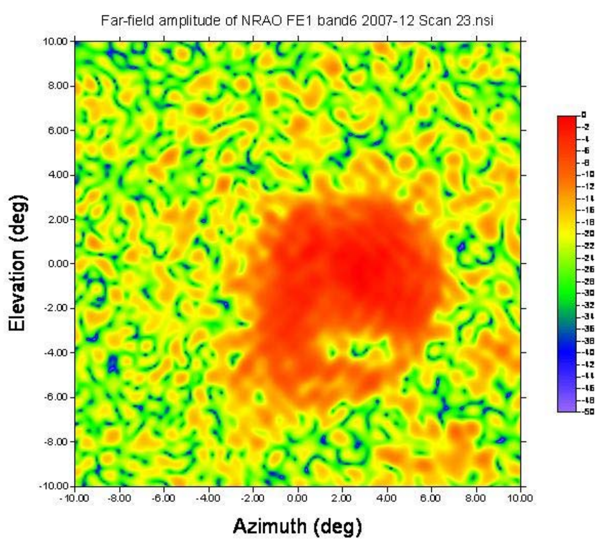


Figure 97 239 GHz Pol 1 Cross-pol. elevation 45

Band 7

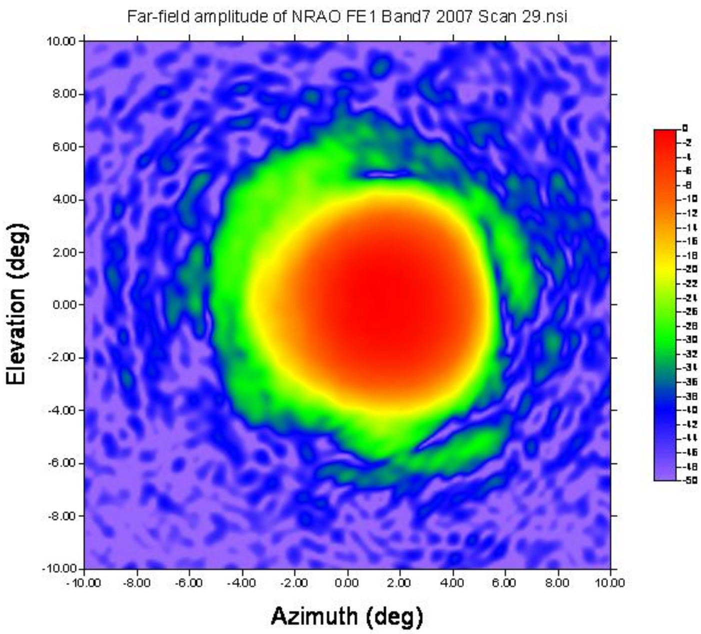


Figure 98 277 GHz Pol 0 Co-pol. elevation 45

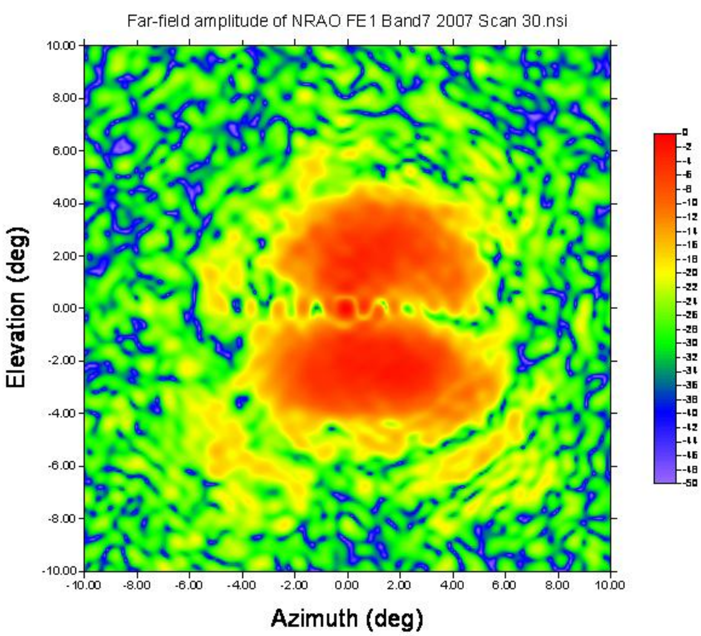


Figure 99 277 GHz Pol 0 Cross-pol. elevation 45

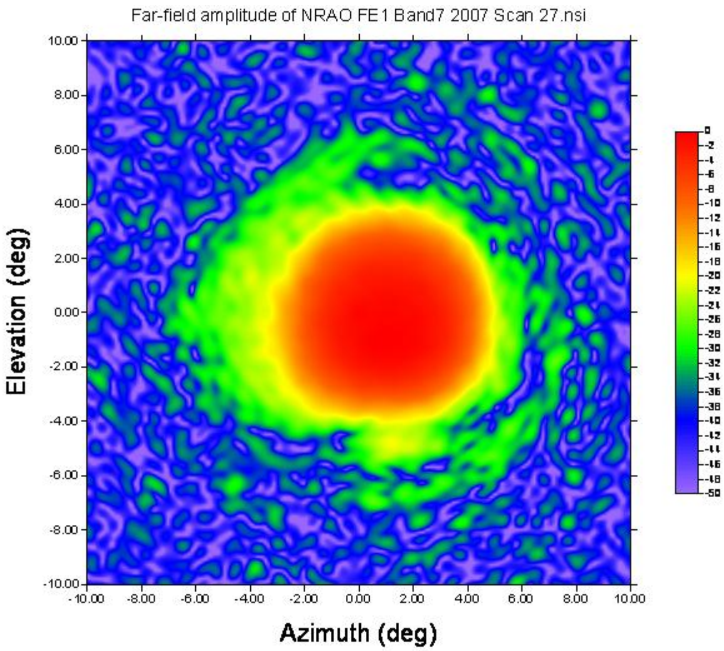


Figure 100 277 GHz Pol 1 Co-pol. elevation 45

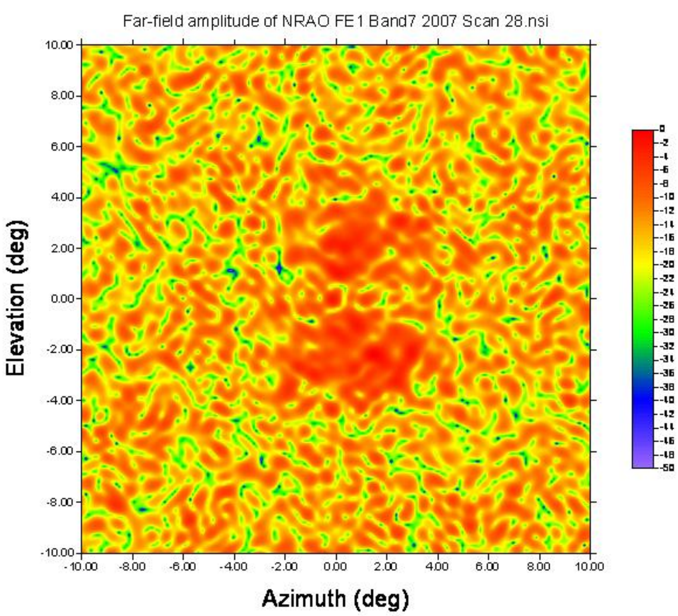


Figure 101 277 GHz Pol 1 Cross-pol. elevation 45

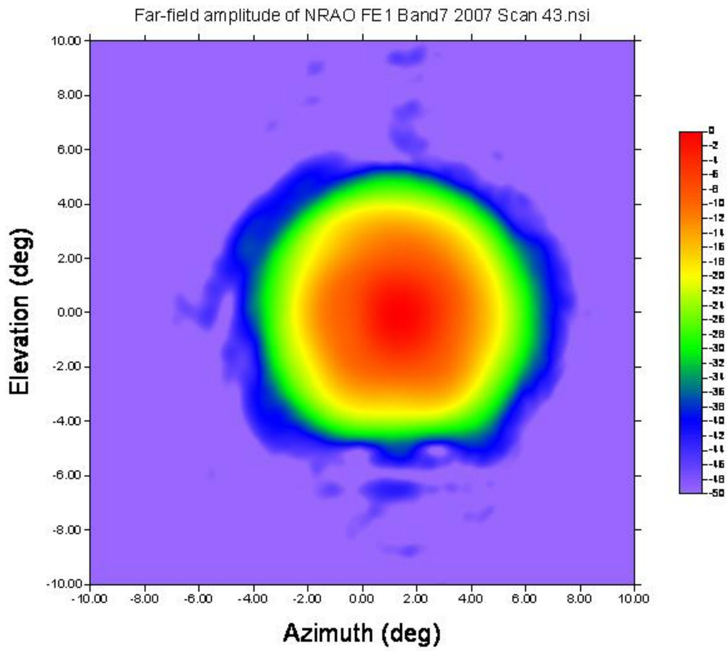


Figure 102 317 GHz Pol 0 Co-pol. elevation 0

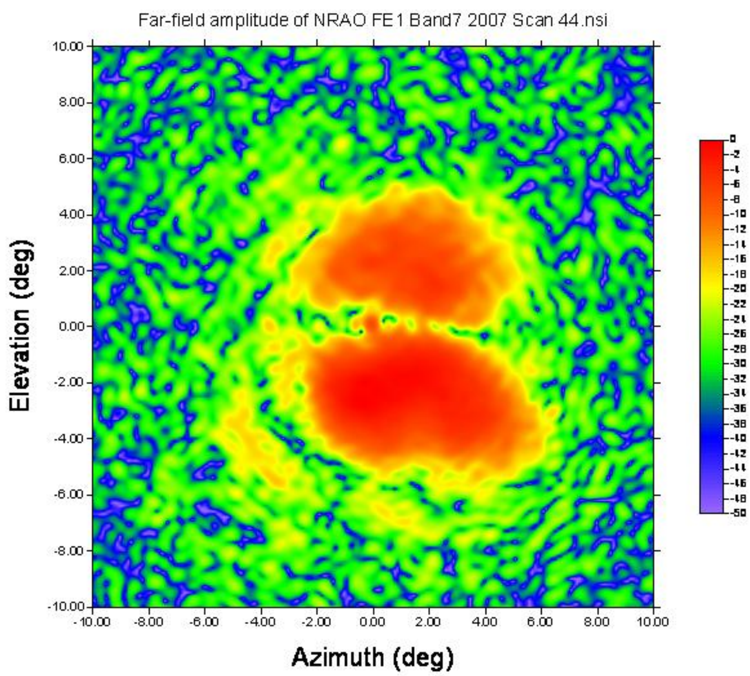


Figure 103 317 GHz Pol 0 Cross-pol. elevation 0

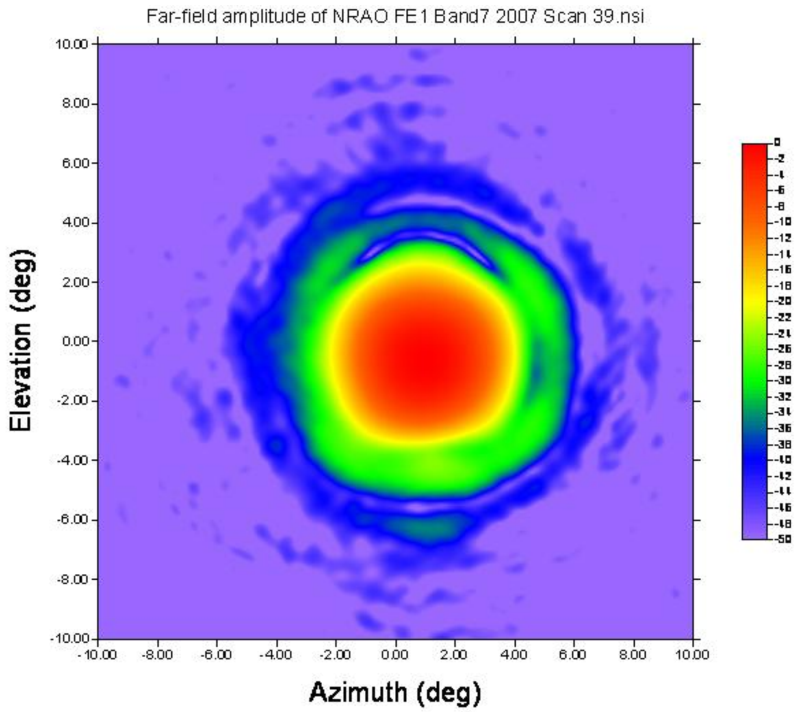


Figure 104 317 GHz Pol 1 Co-pol. elevation 0[6]

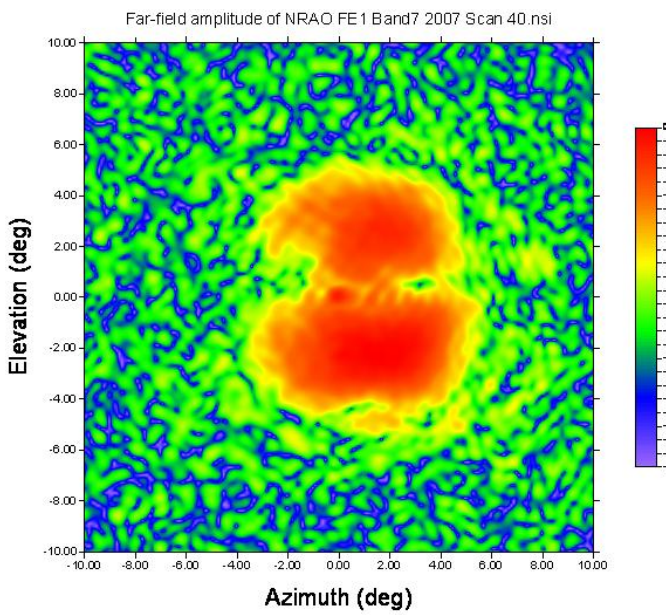


Figure 105 317 GHz Pol 1 Cross-pol. elevation 0

[6] The results for 317 GHz are suspicious, and may be due to difficulties in use of the upper sideband.

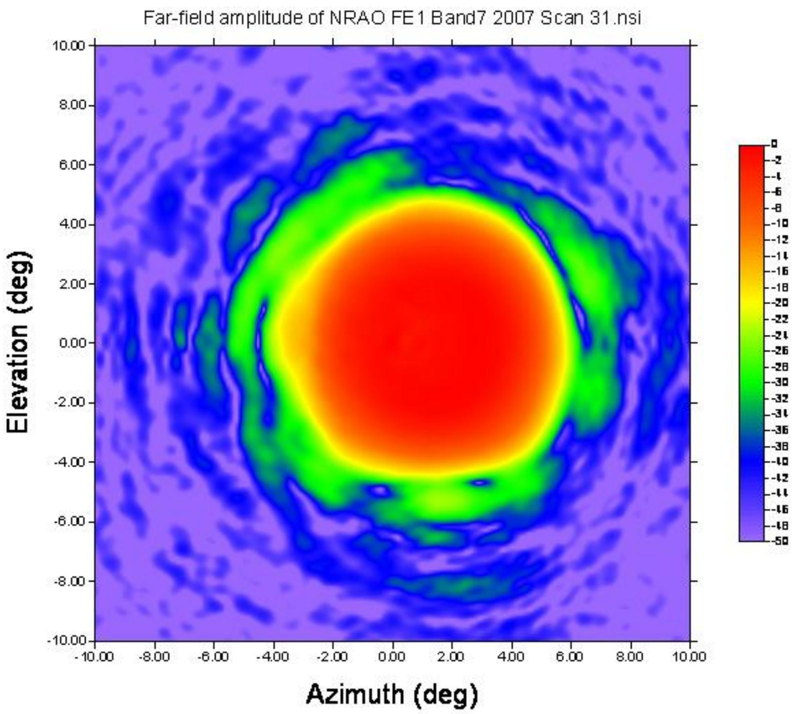


Figure 106 317 GHz Pol 0 Co-pol. elevation 45[7]

[7] The results for 317 GHz are suspicious, and may be due to difficulties in use of the upper sideband.

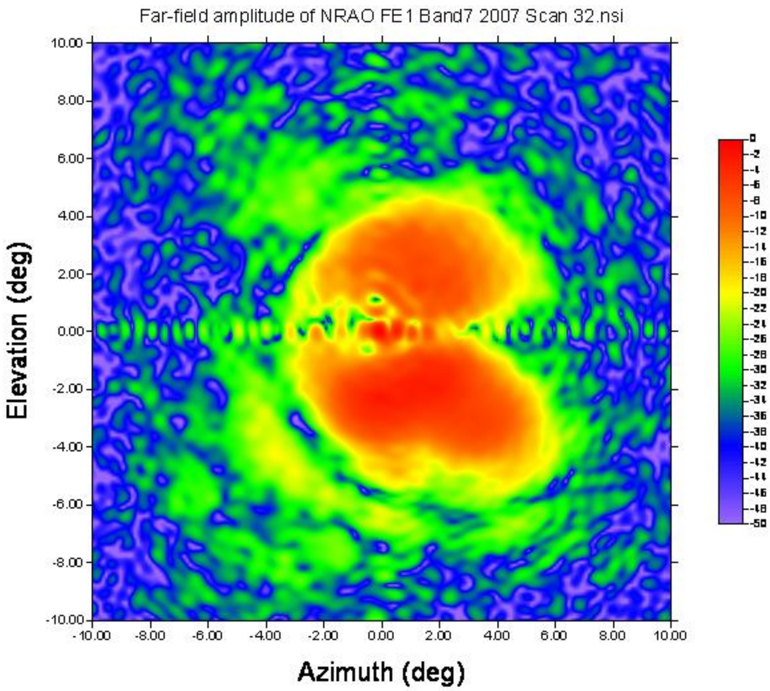


Figure 107 317 GHz Pol 0 Cross-pol. elevation 45

Band 9

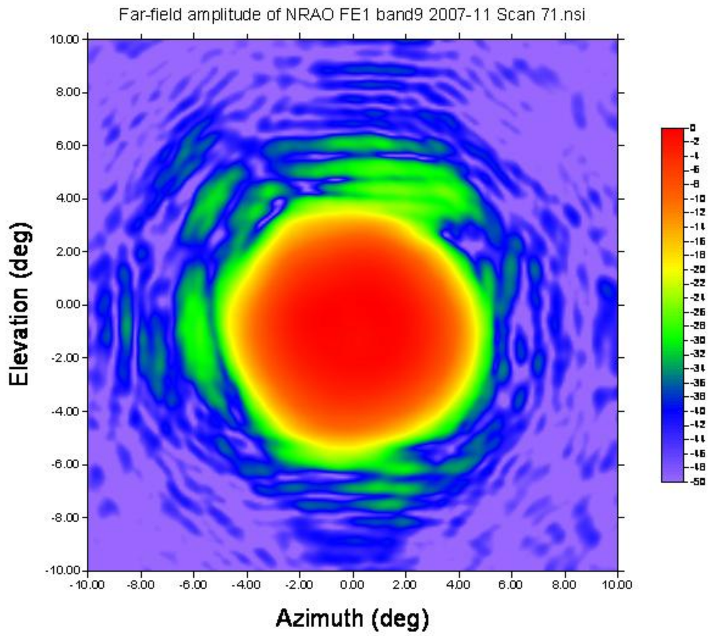


Figure 108 620 GHz Pol 0 co-pol. elevation 45

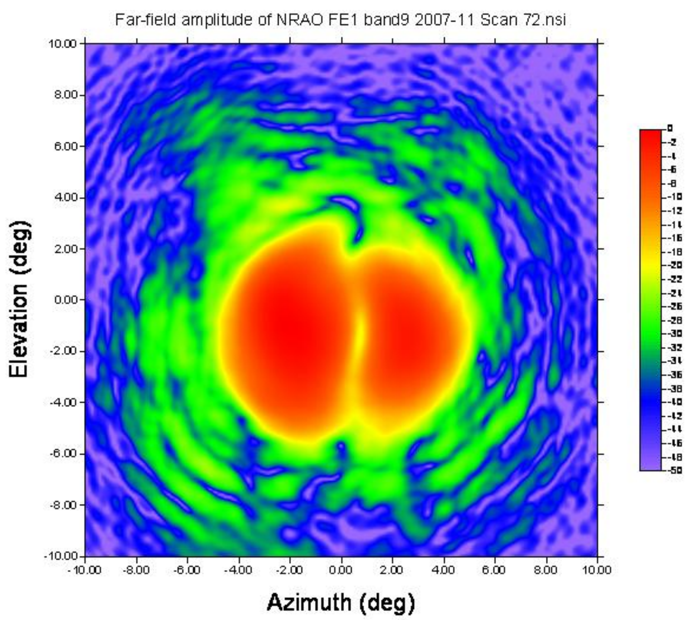


Figure 109 620 GHz Pol 0 cross-pol. elevation 45

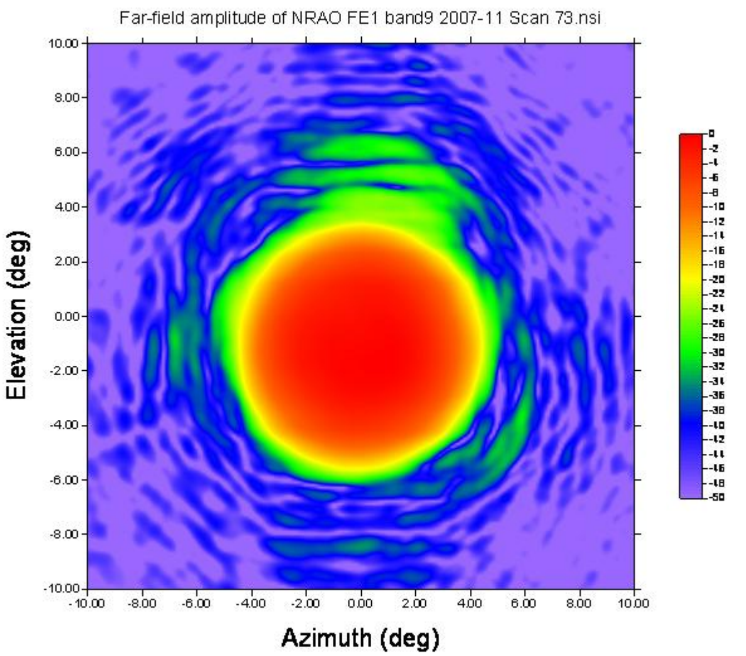


Figure 110 620 GHz Pol 1 co-pol. elevation 45

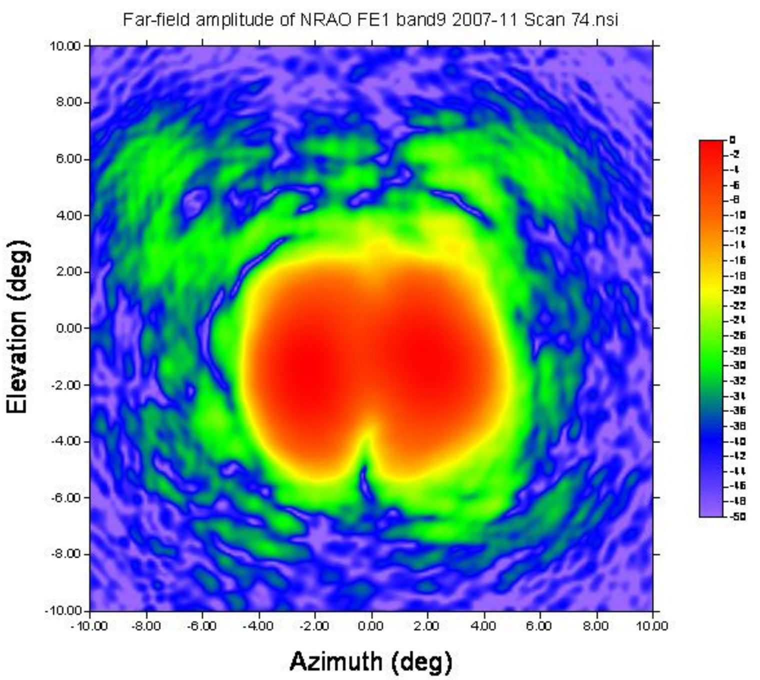


Figure 111 620 GHz Pol 1 cross-pol. elevation 45

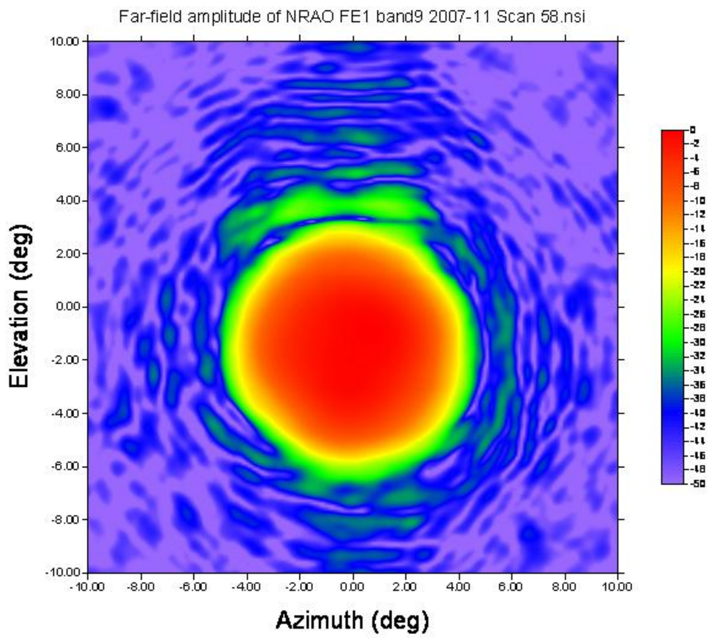


Figure 112 661 GHz Pol 0 co-pol. elevation 0

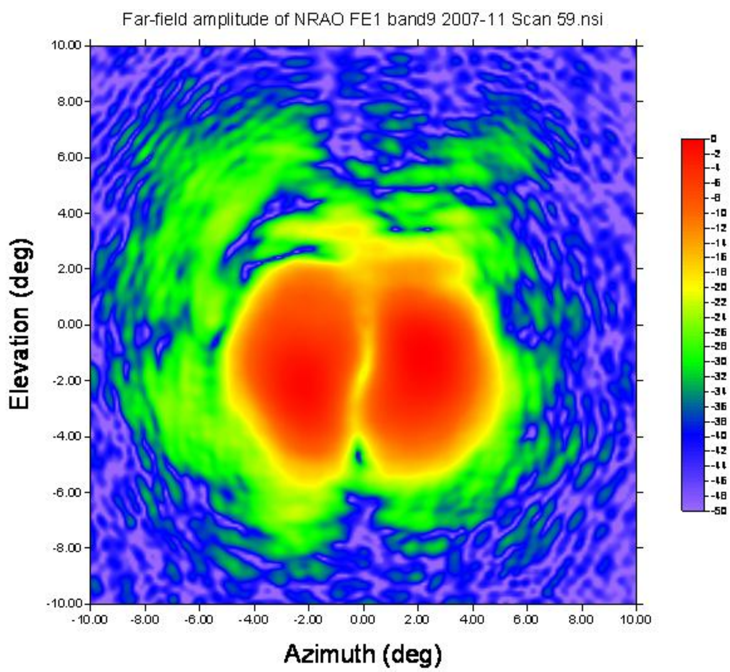


Figure 113 661 GHz Pol 0 cross-pol. elevation 0

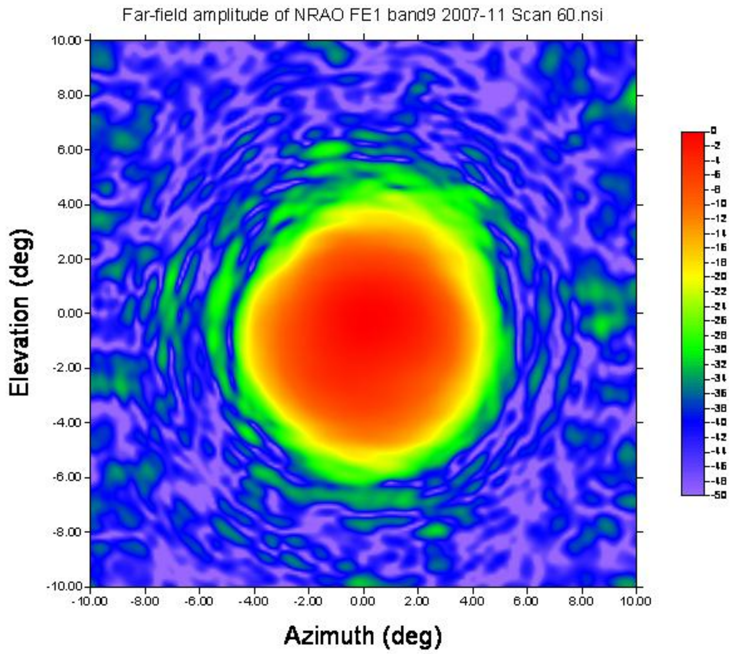


Figure 114 661 GHz Pol 1 co-pol. elevation 0

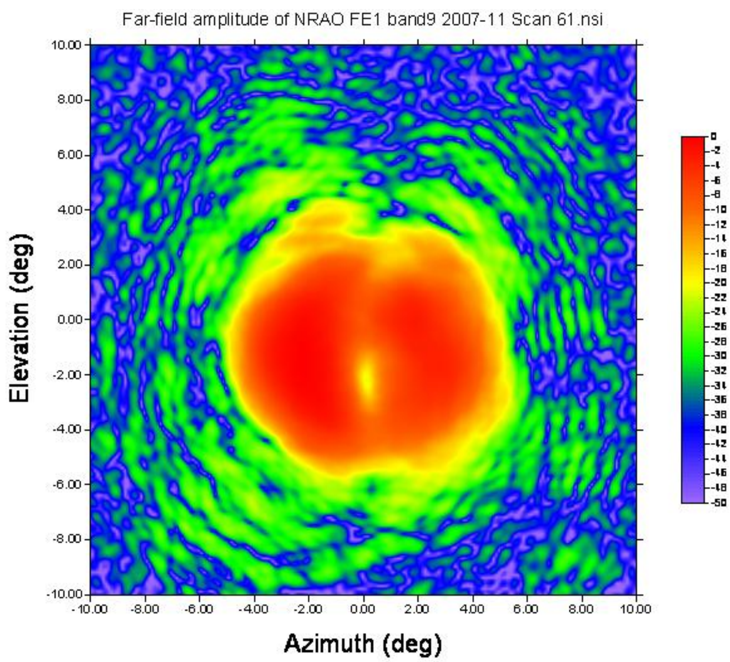


Figure 115 661 GHz Pol 1 cross-pol. elevation 0

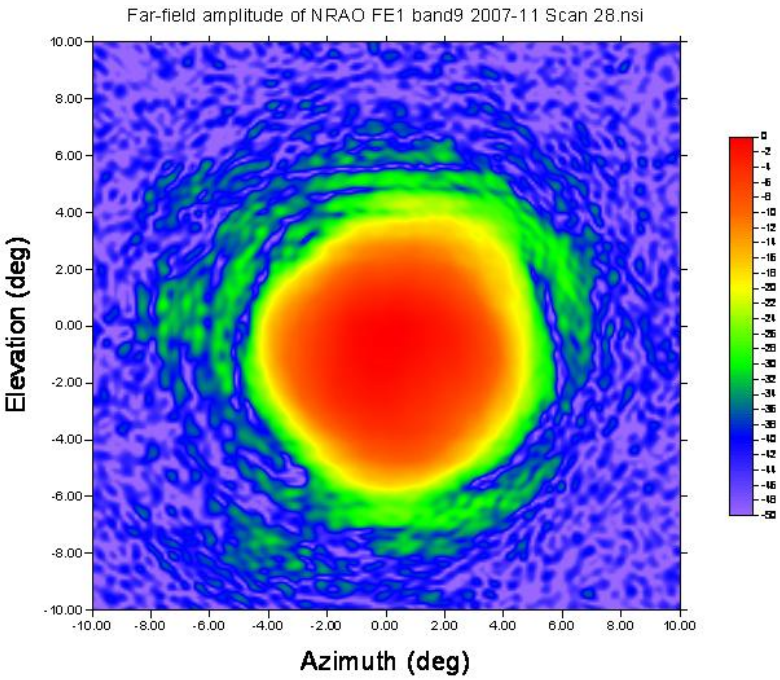


Figure 116 661 GHz Pol 0 co-pol. elevation 45

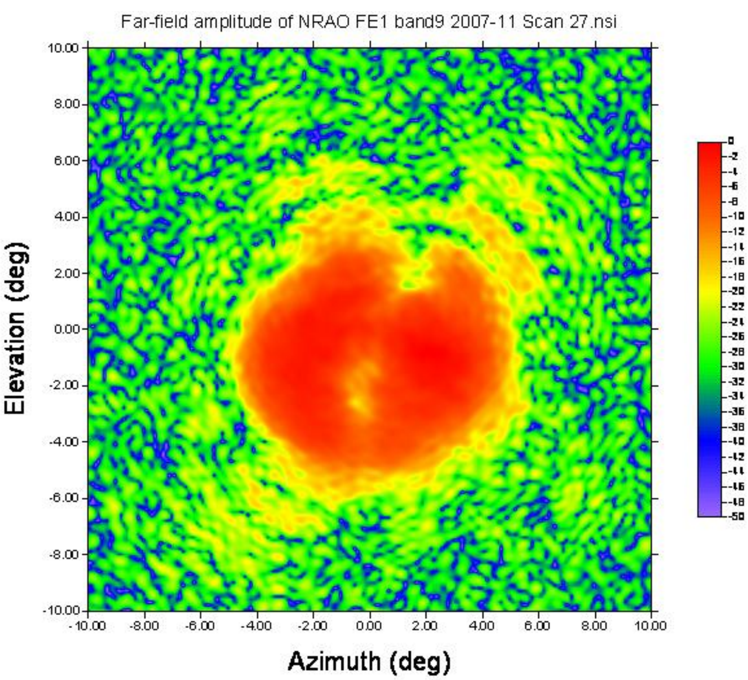


Figure 117 661 GHz Pol 0 cross-pol. elevation 45

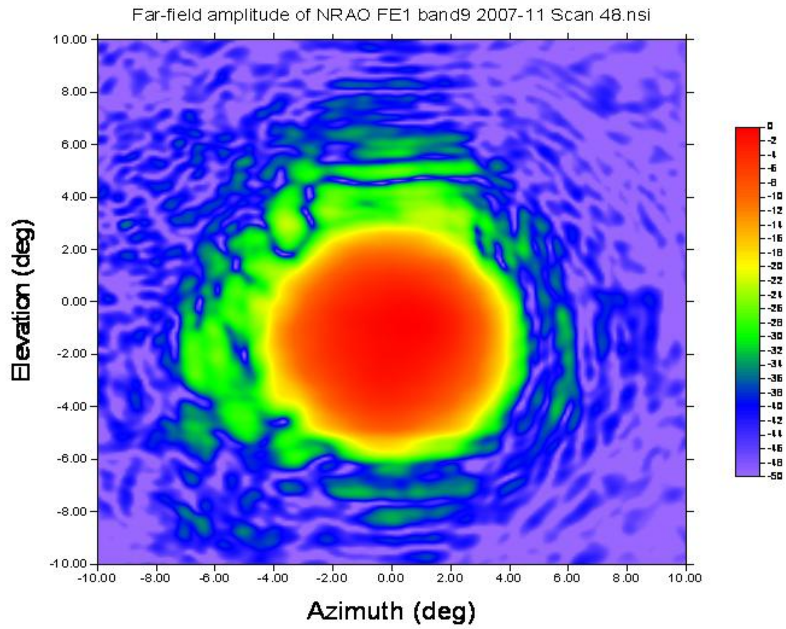


Figure 118 661 GHz Pol 1 co-pol. elevation 45

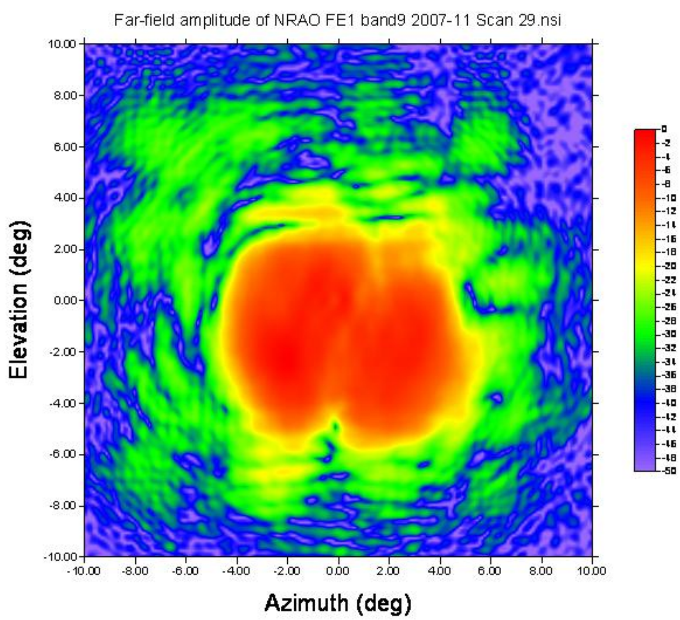


Figure 119 661 GHz Pol 1 cross-pol. elevation 45

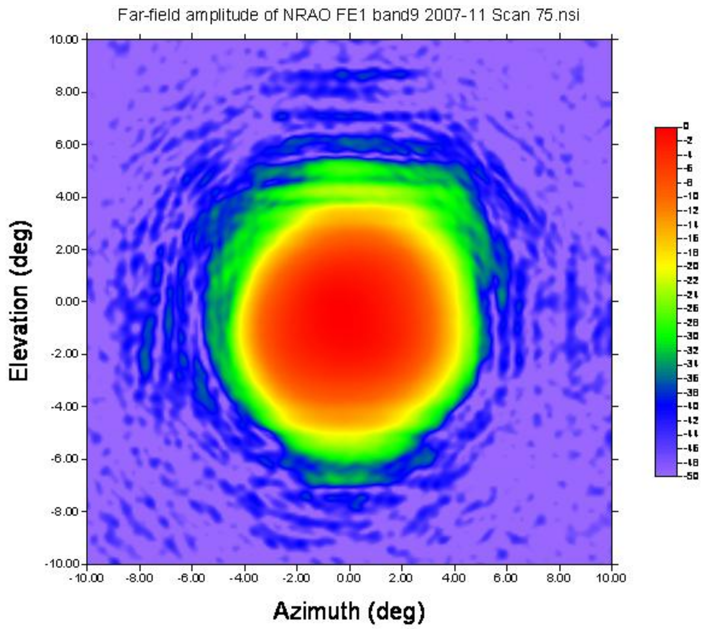


Figure 120 700 GHz Pol 0 co-pol. elevation 45

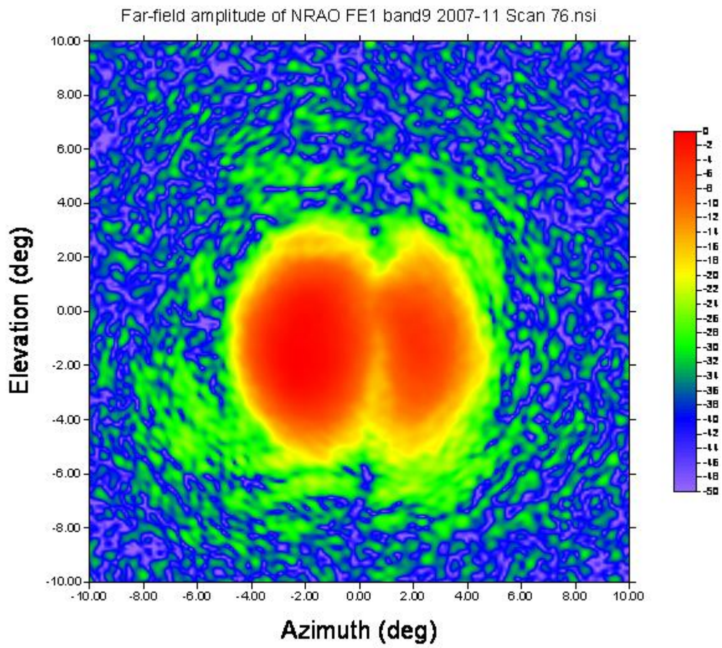


Figure 121 700 GHz Pol 0 cross-pol. elevation 45

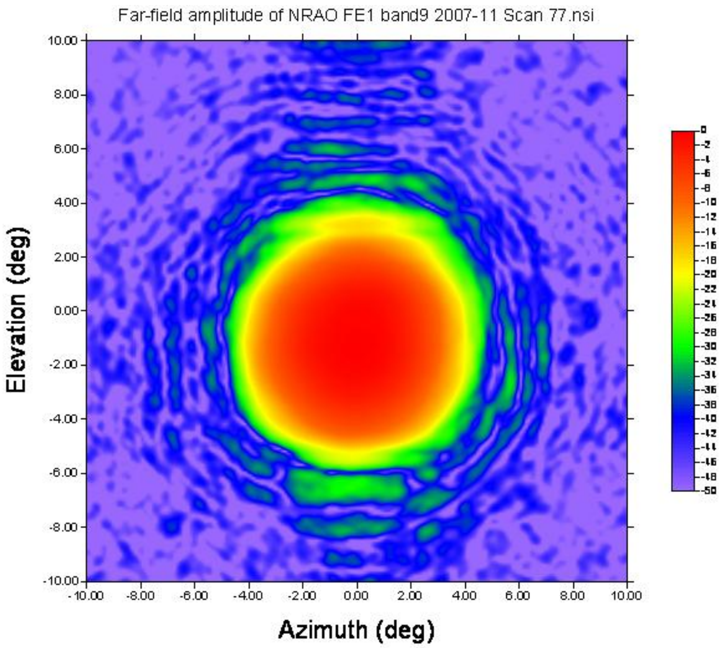


Figure 122 700 GHz Pol 1 co-pol. elevation 45

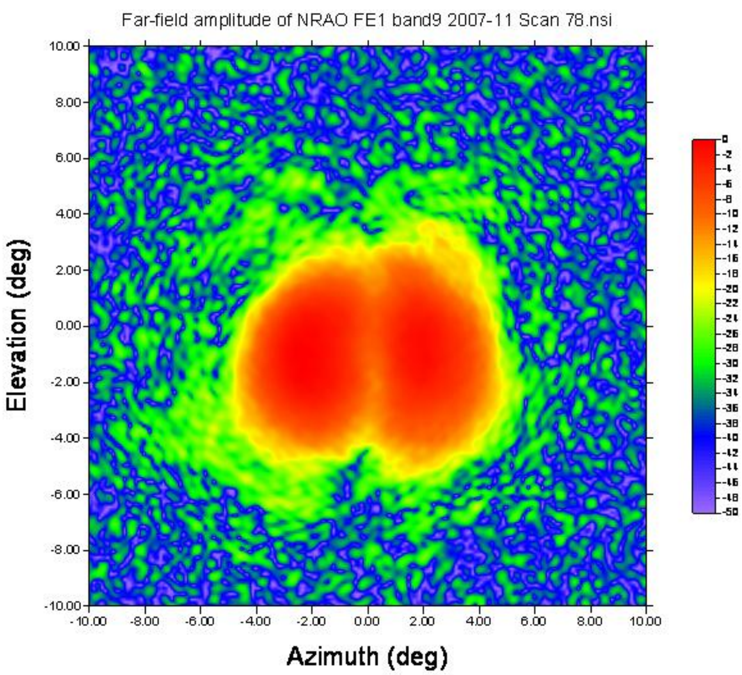


Figure 123 700 GHz Pol 1 cross-pol. elevation 45

3.3.1.1 Aperture efficiency FE assembly contribution

[FEND-40.00.00.00-00220-00 / A]

Specification to be verified: The aperture efficiency factor due to the optics of the FE assembly shall exceed 80 % (TBC) for all ten bands, with frequency ranges as defined by requirement [FEND-40.00.00.00-00060-00 / R].

The contribution to the aperture efficiency within the FE assembly is split into the following components:

- Taper efficiency η_t: factor expressing the signal power loss due to 1) non-uniform amplitude distribution over the secondary reflector and 2) the field across the secondary reflector not being in phase everywhere;
- Spillover efficiency η_s: fraction of the total power that is radiated by the tertiary optics, intercepted and collimated by the secondary reflector;
- Polarization efficiency η_p: factor expressing the signal power lost in cross-polarized fields over the antenna aperture plane;
- Focus efficiency η_f: factor expressing the signal power loss due to focus errors, both radial as well as axial, of the tertiary optics relative to the secondary reflector.

The requirement can be summarized by the following expression:

$$\eta_t \,.\, \eta_s \,.\, \eta_p \,.\, \eta_f = \eta_{ap\_FE} > 80\ \%$$

The ohmic losses of all tertiary optics and feeds are included in the T_{rx} as specified in section 4.1.1 and do not contribute to an aperture efficiency degradation.

This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.

Result:

Please note these numbers are still in flux as we are working on the analysis program.

Band 3

Frequency GHz	Polarization	Tilt angle degrees	Aperture efficiency %
86	0	45	66.00
86	1	45	56.95
94	0	0	56.96
94	1	0	59.45
94	0	45	52.29
94	1	45	57.82
115	0	45	55.63
115	1	45	55.63

Band 6

Frequency	Polarization	Tilt angle degrees	Aperture efficiency %
239	0	45	70.04
239	1	45	69.90
239	0	0	65.64
239	1	0	70.87

Band 7

Frequency	Polarization	Tilt angle degrees	Aperture efficiency %
277	0	45	61.99
277	1	45	62.70
317	0	0	37.71
317	1	0	31.21
317	0	45	75.58

The results for 317 GHz are suspicious, and may be due to difficulties in use of the upper sideband.

Band 9

Frequency	Polarization	Tilt angle degrees	Aperture efficiency %
620	0	45	57.97
620	1	45	57.63
661	0	0	60.53
661	1	0	58.99
661	0	45	64.73
661	1	45	59.86
700	0	45	60.49
700	1	45	58.22

Individual requirements are defined for the following efficiency contributions:

3.3.1.2 Taper efficiency

[FEND-40.00.00.00-00222-00 / AT]
Specification to be verified: The taper efficiency of the tertiary optics inside the FE assembly shall exceed 80 % for all ten bands. This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.
Result:

Band 3

Frequency GHz	Polarization	Tilt angle degrees	Taper efficiency %
86	0	45	84.60
86	1	45	62.06
94	0	0	58.76
94	1	0	60.84
94	0	45	74.87
94	1	45	59.35
115	0	45	63.79
115	1	45	62.89

Band 6

Frequency	Polarization	Tilt angle degrees	Taper efficiency %
239	0	45	76.42
239	1	45	75.61
239	0	0	71.48
239	1	0	76.98

Band 7

Frequency	Polarization	Tilt angle degrees	Taper efficiency %
277	0	45	65.25
277	1	45	65.25
317	0	0	38.89
317	1	0	31.45
317	0	45	85.18

Band 9

Frequency	Polarization	Tilt angle degrees	Taper efficiency %
620	0	45	62.08
620	1	45	65.19
661	0	0	67.03
661	1	0	63.05
661	0	45	70.80
661	1	45	66.23
700	0	45	64.41
700	1	45	60.78

3.3.1.3 Spillover efficiency

[FEND-40.00.00.00-00224-00 / AT]
Specification to be verified: The spillover efficiency of the tertiary optics inside the FE assembly shall exceed 80 % for all ten bands. This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.

Result:

Band 3

Frequency GHz	Polarization	Tilt angle degrees	spillover efficiency %
86	0	45	78.40

86	1	45	92.38
94	0	0	97.82
94	1	0	98.38
94	0	45	96.28
94	1	45	98.41
115	0	45	93.35
115	1	45	96.18

Band 6

Frequency	Polarization	Tilt angle degrees	spillover efficiency %
239	0	45	91.92
239	1	45	92.71
239	0	0	92.09
239	1	0	92.33

Band 7

Frequency	Polarization	Tilt angle degrees	spillover efficiency %
277	0	45	96.23
277	1	45	96.29
317	0	0	97.00
317	1	0	99.41
317	0	45	92.03

Band 9

Frequency	Polarization	Tilt angle degrees	spillover efficiency %
620	0	45	93.44
620	1	45	90.87
661	0	0	92.29
661	1	0	94.92
661	0	45	93.44
661	1	45	96.43
700	0	45	96.06
700	1	45	96.07

3.3.1.4 Polarization efficiency

[FEND-40.00.00.00-00226-00 / AT]

Specification to be verified: The polarization efficiency of the tertiary optics system shall exceed 99.5 % for all ten bands.
This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.

Result:

Band 3

Frequency GHz	Polarization	Tilt angle degrees	Peak cross polar level	Polarization efficiency %
86	0	45	-22.92	99.5
86	1	45	-21.75	99.3
94	0	0	-20.4	99.1
94	1	0	-21.75	99.3
94	0	45	-19.43	98.9
94	1	45	-19.99	99.0
115	0	45	-17.7	98.3
115	1	45	-15.9	97.4

Band 6

Frequency	Polarization	Tilt angle degrees	Peak cross polar level	Polarization efficiency %
239	0	45	-25.38	99.71
239	1	45	-22.23	99.40

Band 7

Frequency	Polarization	Tilt angle degrees	Peak cross polar level	Polarization efficiency %
277	0	45	-18.97	98.73
277	1	45	-28.19	99.85
317	0	0	-35.08	99.97
317	1	0	-27.39	99.82
317	0	45	-14.45	96.41

Band 9

Frequency	Polarization	Tilt angle degrees	Peak cross polar level	Polarization efficiency %
620	0	45	-31.28	99.92
620	1	45	-15.66	97.28
661	0	0	-16.65	97.84
661	1	0	-18.47	98.58
661	0	45	-16.69	97.85
661	1	45	-12.03	93.74
700	0	45	-16.51	97.76
700	1	45	-18.81	98.68

3.3.1.5 Focus efficiency

[FEND-40.00.00.00-00228-00 / AT]

Specification to be verified: The focus efficiency of the tertiary optics system shall comply with the following expression for all ten bands:

$$\eta_f > 80\ \% / \eta_t \cdot \eta_s \cdot \eta_p$$

This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.

Result:

Determination of the flattest phase profile is difficult and has an error of +/- 25 mm.) In overall efficiency tables defocus efficiency was set to 100 %, as the subreflector can be moved to improve this (by the amount given in the table). The offset is measured from the focal plane towards the subreflector.

Band 3

Frequency GHz	Polarization	Tilt angle degrees	Offset from nominal focus mm	efficiency %	efficiency =100% if subreflector moved by mm
86	0	45	30	99.96	0.08
86	1	45	-100	99.63	-0.25
94	0	0	50	99.89	0.13
94	1	0	-50	99.89	-0.13
94	0	45	-160	98.88	-0.40
94	1	45	-65	99.81	-0.16
115	0	45	250	95.95	0.63
115	1	45	250	95.95	0.63

Band 6

Frequency	Polarization	Tilt angle degrees	Offset from nominal focus mm	efficiency %	efficiency =100% if subreflector moved by mm

239	0	45	-100	98.53	0.25
239	1	45	-100	98.53	0.25
239	0	0	+50	99.17	-0.125
239	1	0	-100	98.53	0.25

Band 7

Frequency	Polarization	Tilt angle degrees	Offset from nominal focus mm	efficiency %	efficiency =100% if subreflector moved by mm
277	0	45	140	92.74	0.40
277	1	45	150	91.71	0.40
317	0	0	160	87.88	0.40
317	1	0	-20	99.80	-0.10
317	0	45	100	95.10	0.30

Band 9

Frequency	Polarization	Tilt angle degrees	Offset from nominal focus mm	efficiency %	efficiency =100% if subreflector moved by mm
620	0	45	100.0	82.39	0.30
620	1	45	100.0	82.39	0.30
661	0	0	100.0	80.21	0.30
661	1	0	50.0	94.68	0.10
661	0	45	80.0	86.89	0.20
661	1	45	80.0	86.89	0.20
700	0	45	-200.0	35.96	-0.10
700	1	45	-200.0	35.96	-0.10

3.3.2 Polarization requirements

3.3.2.1 Polarization State

[FEND-40.00.00.00-00250-00 / R]
Specification to be verified: The nominal polarization state of the front end optics shall be linear.

Result: This is a design verification task by review. This verification was not part of the FEIC acceptance tests / PAI. See [AD17].

3.3.2.2 Polarization Configuration

[FEND-40.00.00.00-00255-00 / RI]

Specification to be verified: For all frequency bands the Front End shall receive two orthogonal polarizations, designated “Polarization 0” and “Polarization 1”, with each one converted to one or more separate IF outputs depending on mixing scheme.

Result: This is a design verification task by review. This verification was not part of the FEIC acceptance tests / PAI. See [AD17].

3.3.2.3 Absolute Polarization Alignment Accuracy

[FEND-40.00.00.00-00260-00 / T]
Specification to be verified: The E vector of the polarization channel designated “Polarization 0” shall be aligned to within 2 degrees of the radial direction of the cryostat.

Result:

Not measured.

3.3.2.4 Relative Polarization Alignment Accuracy

[FEND-40.00.00.00-00265-00 / T]
Specification to be verified: The E vector of the polarization channel designated “Polarization 0” and the E vector of the polarization channel designated “Polarization 1” shall be orthogonal to within 2 degrees.

Result:

Not measured.

3.3.2.5 Cross talk between orthogonal polarization receiver channels

[FEND-40.00.00.00-00271-00 / AT]
Specification to be verified: The, uncorrected, cross talk between orthogonal receiver channels, RF and IF, inside the front end shall be less than -60 dB. The receiver channel is defined as the signal path starting at the RF waveguide input of either the low-noise amplifier (Bands 1 and 2) or SIS mixer (Bands 3-10) and ending at the IF output of the FE assembly.

Result: Not verified on the first article. See [AD17].

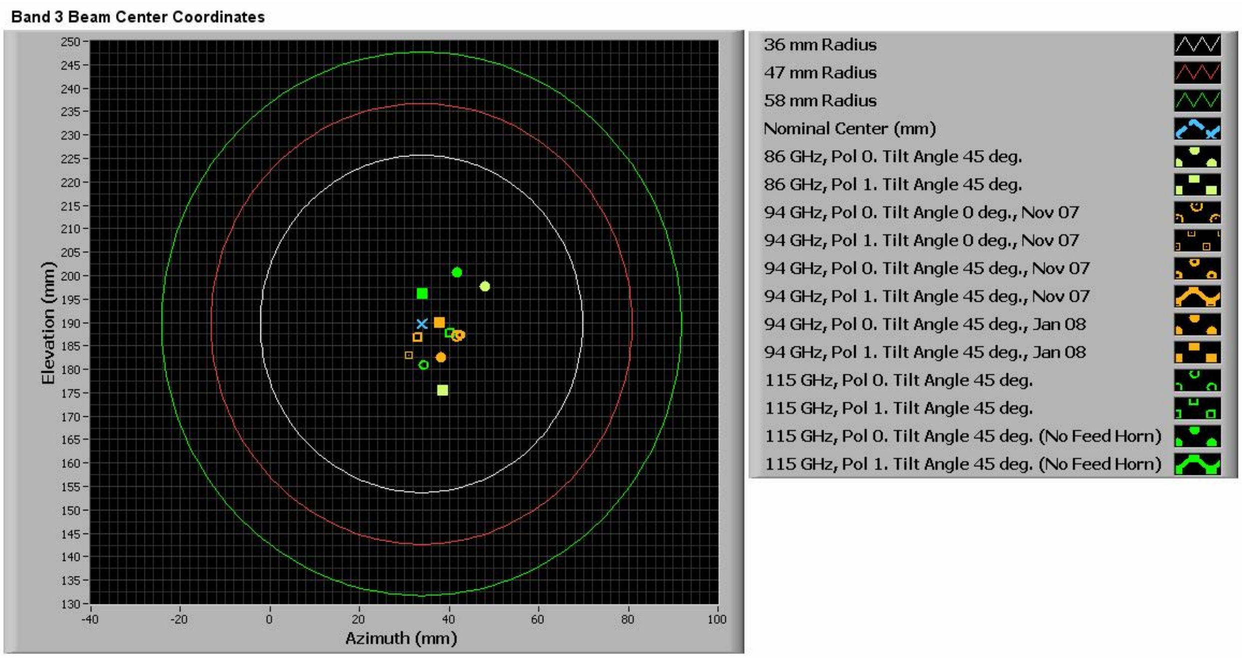
3.3.2.6 Beam squint

[FEND-40.00.00.00-00272-00 / AT]
Specification to be verified: The co-alignment, on sky, between the beams of the orthogonal polarization channels of one cartridge shall be less than 1/10 of the Full Width at Half Maximum (FWHM) of the primary beam. This requirement is applicable for Bands 1 through 10.

Result:

Band 3

On secondary



The 36 mm radius circle is the 1% efficiency loss on the subreflector. The 47 mm and 58 mm circles are the 2% and 3% loss circles respectively.

Tables give Polarization 0 – polarization 1 beam positions for azimuth and elevation.

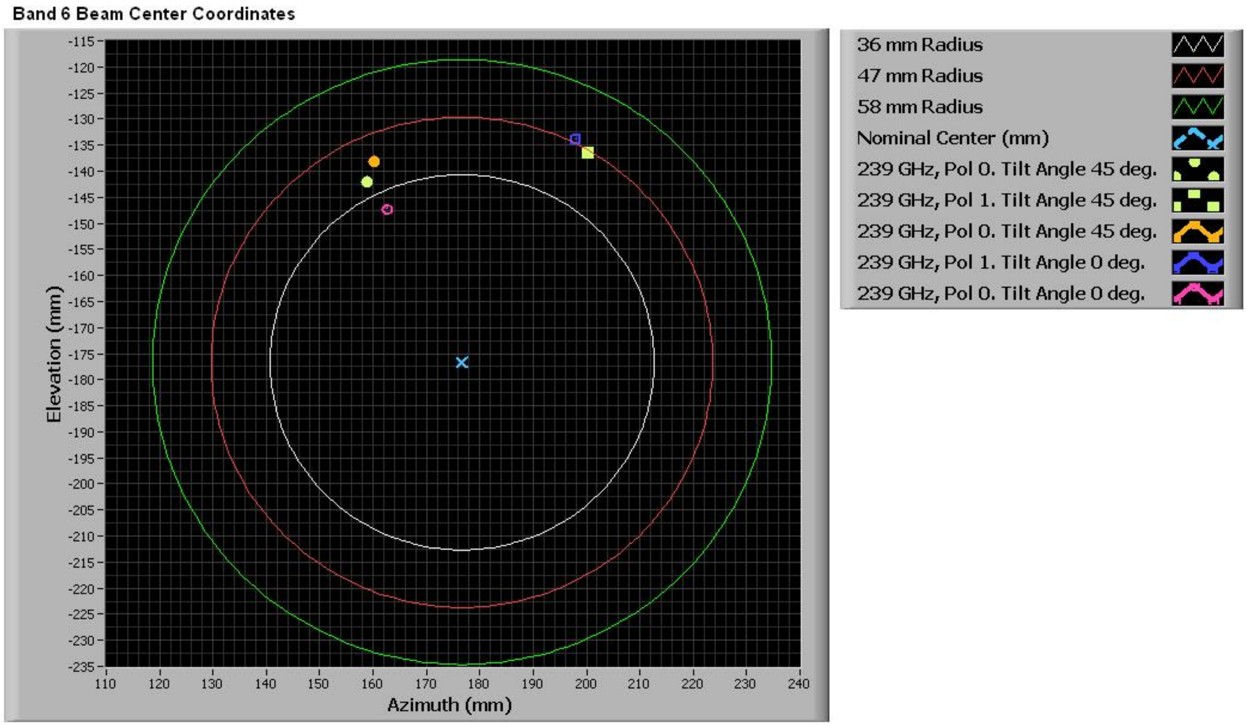
Frequency	Tilt angle degrees	Azimuth difference degrees	Elevation difference degrees
86	45	-0.09	-0.21
94	45	-0.01	-0.04
94	0	-0.09	-0.01
115	45	-0.07	-0.04

On sky
Taking the difference in x, y positions in the best focal plane for each frequency with a plate scale factor of 2.148 arcsec per mm, the squint between the two polarizations (in beam widths) on the sky is given in the following table.

Frequency	Tilt angle	Beam squint (% of FWHM)
86	45	4.96
94	45	3.70
94	0	9.56
115	45	2.85

Band 6

On secondary



The 36 mm radius circle is the 1% efficiency loss on the subreflector. The 47 mm and 58 mm circles are the 2% and 3% loss circles respectively.

Tables give Polarization 0 – polarization 1 beam positions for azimuth and elevation.

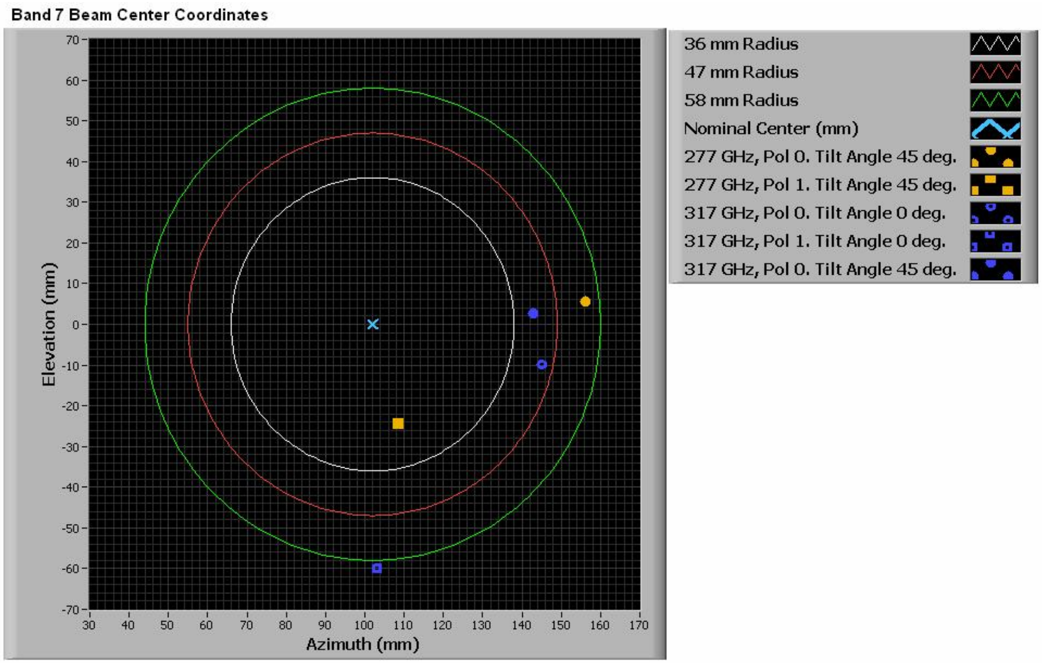
Frequency	Tilt angle degrees	Azimuth difference degrees	Elevation difference degrees
239	45	0.396	-0.053
239	0	0.368	-0.075

Taking the difference in x, y positions in the best focal plane for each frequency with a plate scale factor of 2.148 arcsec per mm, the squint between the two polarizations (in beam widths) on the sky is given in the following table.

Frequency	Tilt angle	Beam squint (% of FWHM)
239	45	6.76
239	0	15.60

Band 7

On secondary



The 36 mm radius circle is the 1% efficiency loss on the subreflector. The 47 mm and 58 mm circles are the 2% and 3% loss circles respectively.

Tables give Polarization 0 – polarization 1 beam positions for azimuth and elevation.

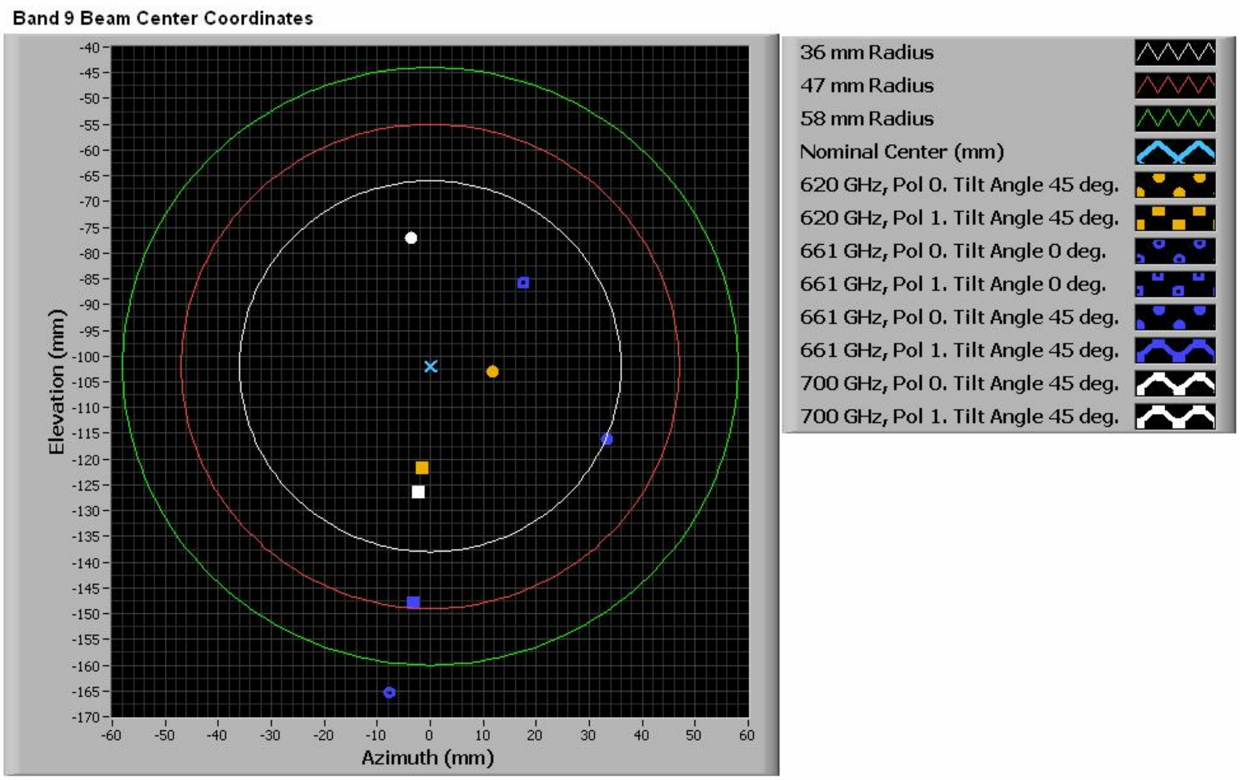
Frequency	Tilt angle degrees	Azimuth difference degrees	Elevation difference degrees
277	45	-0.45	-0.29
317	0	-0.40	-0.48

Taking the difference in x, y positions in the best focal plane for each frequency with a plate scale factor of 2.148 arcsec per mm, the squint between the two polarizations (in beam widths) on the sky is given in the following table.

Frequency	Tilt angle	Beam squint (% of FWHM)
277	45	5.35
317	0	12.88

Band 9

On secondary



The 36 mm radius circle is the 1% efficiency loss on the subreflector. The 47 mm and 58 mm circles are the 2% and 3% loss circles respectively.

Tables give Polarization 0 – polarization 1 beam positions for azimuth and elevation.

Frequency	Tilt angle degrees	Azimuth difference degrees	Elevation difference degrees
620	45	-0.13	-0.18
661	0	0.24	0.76
661	45	-0.35	-0.30
700	45	0.02	-0.47

Taking the difference in x, y positions in the best focal plane for each frequency with a plate scale factor of 2.148 arcsec per mm, the squint between the two polarizations (in beam widths) on the sky is given in the following table.

Frequency	Tilt angle	Beam squint (% of FWHM)
620	45	4.76
661	0	2.63
661	45	1.61
700	45	7.14

3.3.3 Widgets