Atacama Large Millimeter / submillimeter Array

< Comparison of FETMS Beam Efficiency Calculator versions 1.x and 2.0.x >

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Change Record

Version	Date	Affected Section(s)	Author	Reason/Initiation/Remarks
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A2	2016-01-14		M. McLeod	Minor edits and typos
A3	2016-01-26		Jee	Added Executive Summary
A4	2016-01-26		M. McLeod	Minor edits, comments from Saini and Effland
A5	2016-03-03	all	M. McLeod	Comments from Alvaro Gonzales, reprocessed band 1 data with 2.0.4

1 Executive Summary

Software to calculate beam efficiency from measured patterns for ALMA front ends was rewritten to improve maintainability and usability, and several new features have been added. This document describes the regression test results that compares the new software to the old software and shows that generally the software duplicates the efficiency percentages to within 4 or 5 decimal places, which his at the limit of the single-precision used for most of the calculations. Comparisons for Band 1, Band 2, and Band 6 are shown.

Minor discrepancies are found in calculating the phase center and consequently phase fit and phase efficiency. The phase center is determined from an optimization routine that maximizes phase efficiency and is sensitive to the initial phase center guess (Section 4.3). Hills warns that the phase center z-distance has large uncertainty [RD3, Section 4] because the large f/D = 8 for ALMA antennas results in little phase change across the aperture for significant changes in z. Also, phase wrapping causes uncertainty and consequently, the optimization routine is sensitive to initial conditions, as described in Section 4.3. Although large discrepancies occur for the Band 1 case (Figure 8), those are likely due to different initial conditions, and differences in Band 2 (Figure 9) and Band 6 (Figure 10) are small.

The amplitude fitting function (Section 4.4) has discrepancies, but this fit to an ideal Gaussian beam is not used in any calculations and is retained in the updated software only for completeness.

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2 Introduction

2.1 Purpose

This report gives the change history of the FETMS Beam Efficiency Calculator software application, also called "BeamEff" in this document, starting with the versions widely used during the FE construction phase (1.0.6, 1.0.7, 1.0.8) through the newest version, about to be released (2.0.x). Analysis results from these versions plus some intermediate versions are compared to show that the new version is suitable for use at the ALMA OSF and all ALMA partner sites. Some new features are described, along with some minor interface changes, and areas having room for more improvement.

2.2 Software Version History:

2010-Feb, 1.0.2: The original Beam Efficiency Calculator was an ANSI C program developed by Todd Hunter, Josh Crabtree, and Geoff Ediss for use as part of the FETMS analysis software suite. It was developed using Bloodshed Software Dev-C++ which is a Windows port of the GNU GCC toolchain. It was trivially ported to Linux using standard GCC and GNU Make tools. The source code version 1.0.2 was released to ALMA EDM as an attachment to the user manual page at [AD1]. Version 1.0.2 is the only version ever to be distributed as source code on ALMA EDM.

2011-Jan, 1.0.2ACA: Developed by Masahiro Sugimoto based on the 1.0.2 source code. [RD2] describes the modifications he made to support calculating vs. the ACA 7 meter antenna optics rather than the ALMA 12 meter antenna. He used it to analyze scans of bands 3, 4, 6, 7, 8, 9, and 10.

2012-Feb, 1.0.7: Version deployed to EA-FEIC and used in the NA-FEIC for the majority of Front End construction at those two sites. It was built on Linux at NA-FEIC, and on Windows using MinGW at the EA-FEIC. At both sites it was run as part of the FETMS Database/Configuration Management web application.

2012-May, 1.0.8: Development taken over by Morgan McLeod. First FEIC version to support band 10.

through 2013-May, 1.0.9 - 1.1.2: Source code control moved to GitHub; Some minor code cleanup and refactoring changes. https://github.com/morganmcleod/ALMA-FETMS-www These versions were only built for Linux and were tested at the NA FEIC and deployed to the ALMA OSF.

through 2015-Dec, 1.3.6: Source code moved out of the FETMS web app project to a dedicated GitHub project. https://github.com/morganmcleod/ALMA-FETMS-beameff These versions were only built for Linux and were tested at the NA FEIC and deployed to the ALMA OSF. The latest versions:

- Merged in the ACA 7 meter antenna calculation methods.
- Clarified the difference between the TICRA and "alternative" methods for computing Spillover and Polarization Efficiency, as originally documented in [AD2]. Conclusion was that the TICRA Polarization Efficiency on the Subreflector is the figure to be compared with the Front End Polarization Efficiency specification.
- Added an option to specify the scanner probe Z distance from the receiver under test. This is used as part of the starting point for the Phase Fit algorithm.
- Added a pointing option for the ASIAA band 1 test cryostat.

2016-Jan, 2.0.x: At this point I tried to share the code developed so far in 1.3.6 with our ASIAA colleagues for use in their band 1 testing campaign. They had previously been using modified 1.0.6 source code and compiling on Windows with Code::Blocks, another Windows and cross-platform GCC package. They attempted to compile the 1.3.6 sources and were having problems with the software crashing. I had also seen occasional crashes on Linux and was able to reproduce the crashes on Windows using MinGW/GCC 3.4.5. After some investigation I determined that there was some kind of heap corruption occurring. (It would crash when freeing a FILE handle, for example.) In my experience these kinds of bugs are very difficult to find without specialized memory bounds-checking tools. Since I had considerable misgivings about the quality of the existing codebase I decided at this time to do a clean port of the source code to C++ using MinGW/GCC 3.4.5. This was tested first on Windows as version 2.0.0 and then ported to Linux.

2.3 Scope

This document compares results generated by BeamEff versions 1.0.6 on Windows (as modified by ASIAA) and 1.3.5 and 1.3.6 on Linux with version 2.0.x on Windows.

Sample data sets for Band 1 (ASIAA prototype), Band 2 (NRAO prototype), and Band 6 are compared.

2.4 Applicable documents

The following documents are part of this document to the extent specified herein. If not explicitly stated otherwise, the latest issue of the document is valid.

Appl.	Document Title	ALMA Doc. Number
[AD1]	FETMS Beam Efficiency Calculator User Manual	FEND-40.09.00.00-014-B-MAN
[AD2]	"Calculation of Efficiencies, etc, from Beam-Scanning Data", Richard Hills 2008-06-22	NRAO Public Wiki Page

2.5 Reference documents

The following documents contain additional information and are referenced in this document.

Table 1 – Reference Documents		
Reference	**Document Title**	**Document ID**
[RD1]	Beam Efficiency Calculator LabView GUI User Manual	FEND-40.09.00.00-015-B-MAN
[RD2]	20110106Beam_efficiency_calculator_ACA7m Masahiro Sugimito	no ALMA doc number
[RD3]	Analysis of FEIC Efficiency Calculator Alvaro Gonzalez, 11 Jan 2011	NAOJ TN9
[RD4]	Antenna beam pattern evaluation of ALMA band 9 subsystem at North American Integration Center A. Baryshev, 13 June 2008	NRAO Public Wiki Page
[RD5]	Wiki Page, FE Beam Scanning Group	NRAO Public Wiki Page

2.6 Acronyms

For a complete set of acronyms and abbreviations, please go to the ALMA Acronym Finder web page.

3 Identification of data sets

3.1 Band 1

Data sets provided by the Band 1 group at ASIAA:

- Band1-SN03-RF35 measured 2015-09-23 11:09:47
- Band1-SN03-RF42.5 measured 2015-09-22 08:39:46
- Band1-SN03-RF50 measured 2015-09-23 07:51:28

The Band 1 data sets are dual-Z scan sets which have been preprocessed by NSI2000 V4.6.3 to combine the two Z distance scans into one. Section 4.10 below will investigate using the Beam Efficiency Calculator to combine the dual-Z scans instead of using NSI2000 for that purpose.

3.2 Band 2

Data sets for the prototype Band 2 cartridge measured in the NA FEIC test cryostat:

- Band2-TDH17429-RF90 measured Thu 2015-05-28 14:18:24
- Band2-TDH18144-RF88 measured Wed 2015-12-09 08:57:31, illustrating a dip in phase efficiency
- Band2-TDH18147-RF88 measured Wed 2015-12-09 17:06:20, illustrating a dip in phase efficiency

3.3 Band 6

- Band6-TDH14050-RF243 measured Thu 2012-08-09 17:29:50 in FE-61

4 Comparison of analysis results

The following sections each cover a subset of the Beam Efficiency Calculator application results.

4.1 Spill-over and Polarization efficiencies

When using the “actual” pointing option, both the 1.x and 2.0.x versions use the center-of-mass of the far-field amplitude for calculating Spill-over and Polarization, as well as Amplitude Taper, Edge Taper, and Illumination efficiency. The center-of-mass is shown as ff_xcenter and ff_ycenter in the tables in this and the next section. When using the “nominal”, “ACA7meter”, or “band1test” pointing option, the efficiencies are calculated relative to the expected subreflector direction; the center-of-mass values are reported but not used for any calculations.

Figure 1 below is an excerpt from Richard Hills’ 2008 memo “Calculation of Efficiencies, etc, from Beam-Scanning Data” [AD2]. The equations we will refer to in this section are numbered. Alvaro Gonzalez, in recent correspondence points out:

(2) Should be called ‘Eta_spillover_co+xs’ This is different from the Eta_spillover usually used within ALMA. It is called ‘eta_spill_co_cross’ in the results tables below.

(3) Should be called ‘Eta_polarization_sec’. The integral is only on the secondary. It is called ‘eta_pol_on_secondary’ in the results tables below.

(5) Is the polarization efficiency to be used for computing aperture efficiency, whereas (3) is the result to use when comparing to the polarization efficiency specification.

(4) & (5) The product of the two will be the same as the product of (1) & (2) even though the individual numbers can differ considerably.

The combination of spill-over and polarization is then found from:

(1) $$\text{Eta\_spill+pol} = \Sigma_{sec} |E_{co}|^2 \ / \ \{ \Sigma_{all} |E_{co}|^2 + \Sigma_{all} |E_{cross}|^2 \}$$

Note that by if we want to have the spill-over and polarisations as separate items, then according to TICRA’s formulation we should proceed by:

(2) $$\text{Eta\_spill-over} = \{ \Sigma_{sec} |E_{co}|^2 + \Sigma_{sec} |E_{cross}|^2 \} / \{ \Sigma_{all} |E_{co}|^2 + \Sigma_{all} |E_{cross}|^2 \} \text{ and then}$$

(3) $$\text{Eta\_polarization} = \Sigma_{sec} |E_{co}|^2 \ / \ \{ \Sigma_{sec} |E_{co}|^2 + \Sigma_{sec} |E_{cross}|^2 \}$$

The alternative is to work only with the co-polar pattern in estimating the spill and make a separate estimate of Eta_polarization using the whole pattern:

(4) $$\text{Eta\_spill-over} = \Sigma_{sec} |E_{co}|^2 \ / \ \Sigma_{all} |E_{co}|^2 \text{ and then}$$

(5) $$\text{Eta\_polarization} = \Sigma_{all} |E_{co}|^2 \ / \ \{ \Sigma_{all} |E_{co}|^2 + \Sigma_{all} |E_{cross}|^2 \} .$$

The product of the two, i.e. Eta_spill+pol, will still be the same even though the individual numbers will be slightly different. Since both the spill-over and the cross polar loss end up on the sky and both are small there is no practical effect on the estimated performance.

Figure 1: Spill-over and Polarization efficiency equations, excerpt from [AD2]

4.1.1 Band 1

The three band 1 data sets were processed on Windows using a modified v1.0.6 calculator which uses the band 1 test cryostat nominal pointing angles as the values for "nominal" pointing. For comparison I used 2.0.4 using the pointing option "band1test". Results are shown in Figure 2. The numbers in parentheses in the first column indicate which equation from Figure 1 is shown on each row.

Figure 2: Band 1 Spill-over and Polarization efficiencies using "band1test" pointing option

Data Set	**Band1-SN03-RF35**		**Band1-SN03-RF42.5**		**Band1-SN03-RF50**	
RF sideband	2=LSB		2=LSB		2=LSB	
IFAtten diff (copol-xpol)	0		0		0	
Pointing option	nominal	band1test	nominal	band1test	nominal	band1test
SW Version	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4
Platform	Windows	Windows	Windows	Windows	Windows	Windows
Pol0						
ff_xcenter	-0.004813	-0.004813	-0.077196	-0.077196	0.008936	0.008936
ff_ycenter	2.391570	2.391571	2.453457	2.453458	2.429252	2.429250
eta_spillover (4)	0.883987	0.883987	0.911300	0.911300	0.912889	0.912889
eta_pol (5)	0.994403	0.994403	0.991357	0.991357	0.986763	0.986763
eta_spill_co_cross (2)	0.879281	0.879281	0.904462	0.904462	0.902693	0.902693
eta_pol_on_secondary (3)	0.999725	0.999725	0.998852	0.998852	0.997909	0.997909
eta_pol_spill (1)	0.879040	0.879040	0.903424	0.903424	0.900805	0.900805
Pol1						
ff_xcenter	-0.184377	-0.184377	-0.184981	-0.184981	-0.000280	-0.000280
ff_ycenter	2.342544	2.342542	2.402930	2.402930	2.319701	2.319702
eta_spillover (4)	0.876281	0.876281	0.906065	0.906065	0.912953	0.912953
eta_pol (5)	0.993066	0.993066	0.994835	0.994835	0.985524	0.985524
eta_spill_co_cross (2)	0.870551	0.870551	0.901980	0.901980	0.902486	0.902486
eta_pol_on_secondary (3)	0.999602	0.999602	0.999340	0.999340	0.996955	0.996955
eta_pol_spill (1)	0.870205	0.870205	0.901385	0.901385	0.899737	0.899737

4.1.2 Band 2

The first band 2 data sets are from early prototype measurements and so do not include pol1 results. The second two are more recent measurements. In these examples, the band 2 efficiencies are calculated using "actual" beam pointing, so the beam center-of-mass pointing is shown as (ff_xcenter, ff_ycenter).

Figure 3: Band 2 Spillover and Polarization efficiencies using "actual" pointing option

Data Set	**Band2-TDH17429-RF90**		**Band2-TDH18144-RF88**		**Band2-TDH18147-RF88**	
RF sideband	1=USB		1=USB		1=USB	
IFAtten diff (copol-xpol)	10		10			
Pointing option	actual	actual	actual	actual	actual	actual
SW Version	1.3.6	2.0.0	1.3.5	2.0.0	1.3.5	2.0.0
Platform	Linux	Windows	Linux	Windows	Linux	Windows
Pol0						
ff_xcenter	-1.132141	-1.132141	-0.673845	-0.673845	-0.660653	-0.660653
ff_ycenter	1.479218	1.479218	1.741938	1.741938	1.740237	1.740237
eta_spillover (4)	0.915341	0.915341	0.908063	0.908063	0.908383	0.908383
eta_pol (5)	0.980519	0.980519	0.983024	0.983024	0.982959	0.982959
eta_spill_co_cross (2)	0.903124	0.903124	0.897336	0.897336	0.897650	0.897650
eta_pol_on_secondary (3)	0.993783	0.993783	0.994775	0.994775	0.994713	0.994713
eta_pol_spill (1)	0.897509	0.897509	0.892648	0.892648	0.892904	0.892904
Pol1						
ff_xcenter			-0.452249	-0.452249	-0.455661	-0.455661
ff_ycenter			1.702948	1.702948	1.706975	1.706975
eta_spillover (4)			0.917462	0.917462	0.917308	0.917308
eta_pol (5)			0.985306	0.985306	0.985377	0.985377
eta_spill_co_cross (2)			0.907806	0.907806	0.907661	0.907661
eta_pol_on_secondary (3)			0.995787	0.995787	0.995851	0.995851
eta_pol_spill (1)			0.903981	0.903981	0.903894	0.903894

4.1.3 Band 6

The band 6 data set uses the “nominal” pointing option for efficiency calculation.

Figure 4: Band 6 Spillover and Polarization efficiencies using the “nominal” pointing option

Data Set	**Band6-TDH14050-RF243**	
RF sideband	2=LSB	
IFAtten diff (copol-xpol)	10	
Pointing option	nominal	nominal
SW Version	1.3.6	2.0.0
Platform	Linux	Windows
Pol0		
ff_xcenter	2.158020	2.158020
ff_ycenter	-2.023237	-2.023238
eta_spillover (4)	0.919811	0.919811
eta_pol (5)	0.989766	0.989766
eta_spill_co_cross (2)	0.918398	0.918398
eta_pol_on_secondary (3)	0.991289	0.991289
eta_pol_spill (1)	0.910398	0.910398
Pol1		
ff_xcenter	2.115269	2.115271
ff_ycenter	-2.065860	-2.065861
eta_spillover (4)	0.923252	0.923252
eta_pol (5)	0.991839	0.991839
eta_spill_co_cross (2)	0.922369	0.922369
eta_pol_on_secondary (3)	0.992788	0.992788
eta_pol_spill (1)	0.915717	0.915717

4.2 Amplitude Taper, Edge Taper, and Illumination efficiency

4.2.1 Band 1

Figure 5: Band 1 Taper, Edge, Illumination efficiency

Data Set	**Band1-SN03-RF35**		**Band1-SN03-RF42.5**		**Band1-SN03-RF50**	
SW Version	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4
Platform	Windows	Windows	Windows	Windows	Windows	Windows
Pol0						
eta_taper	0.916026	0.916026	0.905239	0.905239	0.891435	0.891435
eta_illumination	0.809755	0.809755	0.824944	0.824944	0.813781	0.813781
edge_db	-9.133569	-9.134	-9.980988	-9.981	-10.763277	-10.763
Pol1						
eta_taper	0.915318	0.915318	0.902723	0.902723	0.892080	0.892080
eta_illumination	0.802076	0.802076	0.817926	0.817926	0.814428	0.814428
edge_db	-9.282266	-9.282	-10.099223	-10.099	-10.630156	-10.630

4.2.2 Band 2

Figure 6: Band 2 Taper, Edge, Illumination efficiency

Data Set	**Band2-TDH17429-RF90**		**Band2-TDH18144-RF88**		**Band2-TDH18147-RF88**	
SW Version	1.3.6	2.0.0	1.3.5	2.0.0	1.3.5	2.0.0
Platform	Linux	Windows	Linux	Windows	Linux	Windows
Pol0						
eta_taper	0.895675	0.895675	0.907164	0.907164	0.907099	0.907099
eta_illumination	0.819848	0.819848	0.823763	0.823763	0.823994	0.823994
edge_db	-10.307546	-10.308	-9.900264	-9.900	-9.922522	-9.923
Pol1						
eta_taper			0.896612	0.896612	0.897027	0.897027
eta_illumination			0.822608	0.822608	0.822851	0.822851
edge_db			-10.505737	-10.506	-10.408564	-10.409

4.2.3 Band 6

Figure 7: Band 6 Taper, Edge, Illumination efficiency

Data Set	**Band6-TDH14050-RF243**	
SW Version	1.3.6	2.0.0
Platform	Linux	Windows
Pol0		
eta_taper	0.908229	0.908229
eta_illumination	0.835399	0.835399
edge_db	-9.060763	-9.061
Pol1		
eta_taper	0.904364	0.904364
eta_illumination	0.834956	0.834956
edge_db	-9.168405	-9.168

4.3 Phase Fit and Phase efficiency

The phase fit finds the location of the phase center with respect to the measurement plane using the far field phase data. The center is expressed as (delta_x, delta_y, delta_z) in mm. The algorithm maximizes the output variable eta_phase, which is the phase efficiency. The algorithm is sensitive to finding a local minimum near the starting guess values. Beginning with version 1.3.3 the program reads the “zdistance” key from its input file and uses that to initialize the phase fit. The band 1 data sets below are not properly initializing the zdistance so there may be room for improvement in those results. Zdistance defaults to the old hard-coded value of 260 mm if not provided. Why 260 mm was chosen, whereas 200 mm was hard-coded in some of the other calculations, is unclear.

The phase fit is also sensitive to the sign of the raw phase data. The application rotates the input scan data for USB scans. In early versions it did this by checking whether the sign of the Az and El beam center-of-mass are as expected and then rotated the scan if not. This was error prone for cases where either Az or El angles are expected to be zero. Since version 1.0.7 the program requires an input key “sb=1” meaning USB, to cause scan rotation. If “sb=2” or some other value, or is not provided then the scan will not be rotated. When the scan is rotated, the sign of Az, El, and Phase are inverted. Not carefully controlling this input may be the cause of negative values for delta_z in some of the results below. The resulting delta_z is used in the defocus efficiency calculation so errors can cascade from this step to that one.

Small differences in phase fit outputs may be caused by differing fencepost conditions between the 1.x and 2.0.x implementations: The 1.x versions were iterating over indices [1...n], ignoring valid data at index [0] and including random invalid data at index [n]. The 2.0.x version properly iterates over C-style arrays in [0...n-1]. Small differences may also be caused by differing implementation details between the compilers and C standard libraries used.

4.3.1 Band 1

Figure 8: Band 1 Phase fit and Phase efficiency

Data Set	**Band1-SN03-RF35**		**Band1-SN03-RF42.5**		**Band1-SN03-RF50**	
RF sideband	2=LSB		2=LSB		2=LSB	
SW Version	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4
Platform	Windows	Windows	Windows	Windows	Windows	Windows
Pol0						
delta_x	-0.156177	0.038202	0.448918	-0.410590	-0.218366	-0.242147
delta_y	0.508143	0.062144	-0.065562	-0.006384	-0.801928	-0.790897
delta_z	-251.856079	-252.299026	-67.211189	-67.299263	76.280540	75.947166
eta_phase	0.999621	0.999519	0.998240	0.998242	0.996582	0.996581
Pol1						
delta_x	0.663651	0.684766	-0.526495	-0.427017	0.156029	-0.161215
delta_y	0.043917	0.113406	0.152122	0.219109	-1.182380	-1.159157
delta_z	-273.724701	-269.297546	-44.204220	-44.923901	59.632511	60.701668
eta_phase	0.999880	0.999886	0.997589	0.997596	0.995319	0.995321

4.3.2 Band 2

Figure 9: Band 2 Phase fit and Phase efficiency

Data Set	Band2-TDH17429-RF90		Band2-TDH18144-RF88		Band2-TDH18147-RF88	
RF sideband	1=USB		1=USB		1=USB	
SW Version	1.3.6	2.0.0	1.3.5	2.0.0	1.3.5	2.0.0
Platform	Linux	Windows	Linux	Windows	Linux	Windows
Pol0						
delta_x	5.253736	5.249891	-4.458621	-4.449640	-4.498350	-4.496921
delta_y	-6.849226	-6.852728	-0.251290	-0.266534	-0.264454	-0.260256
delta_z	140.739182	141.108917	129.421463	130.046448	130.009094	129.961639
eta_phase	0.995755	0.995756	0.991454	0.991454	0.991546	0.991547
Pol1						
delta_x			-4.927614	-4.929317	-4.881707	-4.896201
delta_y			-1.077089	-1.095087	-1.071629	-1.101976
delta_z			139.403305	139.308365	139.490753	138.960587
eta_phase			0.997198	0.997199	0.997178	0.997179

4.3.3 Band 6

Figure 10: Band 6 Phase fit and Phase efficiency

Data Set	Band6-TDH14050-RF243	
RF sideband	2=LSB	
SW Version	1.3.6	2.0.0
Platform	Linux	Windows
Pol0		
delta_x	-4.302466	-4.300562
delta_y	1.645738	1.649204
delta_z	254.427399	254.353271
eta_phase	0.999692	0.999692
Pol1		
delta_x	-4.472124	-4.469915
delta_y	1.648429	1.649992
delta_z	254.664230	254.545670
eta_phase	0.999570	0.999570

4.4 Amplitude Fit

The far field amplitude is fitted to a theoretical Gaussian beam, but as explained in [RD3, Section 3] it is unclear whether the method here is typical or best for the purpose. The resulting value, ampfit_amp plus five other parameters, express how well the far field matches the Gaussian model. Richard Hill writes in [RD3, Section 3]: “One can also do things like fit a Gaussian and find how wide that is (for comparison with theory)” so these results are included in the output but are not used for any subsequent efficiency calculations. The important edge taper is calculated using a different method.

As with the Phase Fit, small errors may be accounted for by differing fencepost conditions between the 1.x and 2.0.x algorithms. Small differences may also be caused by differing implementation details between the compilers and C standard libraries used.

4.4.1 Band 1

Figure 11: Band 1 Amplitude Fit

Data Set	**Band1-SN03-RF35**		**Band1-SN03-RF42.5**		**Band1-SN03-RF50**	
RF sideband	2=LSB		2=LSB		2=LSB	
SW Version	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4
Platform	Windows	Windows	Windows	Windows	Windows	Windows
Pol0						
ampfit_amp	0.904550	0.907915	0.912948	0.911655	0.863167	0.863936
ampfit_width_deg	2.796225	2.786794	2.714162	2.714826	2.668487	2.667616
ampfit_u_off_deg	-0.024225	0.006460	-0.073749	0.000910	0.006290	-0.005249
ampfit_v_off_deg	-0.101580	-0.012251	-0.028002	-0.002463	-0.048167	-0.003016
ampfit_d_0_90	0.000426	0.011082	-0.007426	-0.012557	-0.117894	-0.116096
ampfit_d_45_135	0.010064	0.007677	-0.000230	-0.000664	0.007268	0.007921
Pol1						
ampfit_amp	0.901536	0.907535	0.902467	0.904276	0.890520	0.874327
ampfit_width_deg	2.815391	2.796830	2.723751	2.715622	2.632942	2.668068
ampfit_u_off_deg	-0.182562	-0.002223	-0.185902	-0.004943	-0.019499	0.009124
ampfit_v_off_deg	-0.146568	-0.016154	-0.085281	-0.009839	-0.182308	-0.014746
ampfit_d_0_90	-0.013208	-0.010906	0.032804	0.035841	0.066948	0.084092
ampfit_d_45_135	0.012297	0.001379	-0.002577	-0.004672	0.025876	0.010926

4.4.2 Band 2

Figure 12: Band 2 Amplitude Fit

Data Set	Band2-TDH17429-RF90		Band2-TDH18144-RF88		Band2-TDH18147-RF88	
RF sideband	1=USB		1=USB		1=USB	
SW Version	1.3.6	2.0.0	1.3.5	2.0.0	1.3.5	2.0.0
Platform	Linux	Windows	Linux	Windows	Linux	Windows
Pol0						
ampfit_amp	0.917362	0.917361	0.904073	0.904179	0.904937	0.904902
ampfit_width_deg	2.685581	2.685634	2.739820	2.739568	2.739286	2.739384
ampfit_u_off_deg	0.008526	0.008507	-0.001978	-0.002267	-0.004008	-0.004195
ampfit_v_off_deg	-0.007758	-0.008045	-0.000330	0.000019	0.002575	0.002761
ampfit_d_0_90	0.032462	-0.032112	-0.004193	-0.004385	-0.005897	-0.005623
ampfit_d_45_135	-0.144370	-0.144393	-0.058025	-0.057936	-0.056946	-0.056973
Pol1						
ampfit_amp			0.912972	0.913056	0.920222	0.920247
ampfit_width_deg			2.672367	2.672015	2.671852	2.671773
ampfit_u_off_deg			0.007128	0.006710	0.006788	0.006576
ampfit_v_off_deg			0.007308	0.007678	0.006312	0.006561
ampfit_d_0_90			-0.032866	-0.032729	-0.033130	-0.033064
ampfit_d_45_135			-0.060931	-0.061019	-0.061351	-0.061483

4.4.3 Band 6

Figure 13: Band 6 Amplitude Fit

Data Set	**Band6-TDH14050-RF243**	
RF sideband	2=LSB	
SW Version	1.3.6	2.0.0
Platform	Linux	Windows
Pol0		
ampfit_amp	0.975581	0.973423
ampfit_width_deg	2.888116	2.898223
ampfit_u_off_deg	0.507183	0.046521
ampfit_v_off_deg	-0.372522	-0.039420
ampfit_d_0_90	0.005092	0.006907
ampfit_d_45_135	-0.025427	-0.027616
Pol1		
ampfit_amp	0.971604	0.970095
ampfit_width_deg	2.863711	2.870235
ampfit_u_off_deg	0.465844	0.040181
ampfit_v_off_deg	-0.406785	-0.034250
ampfit_d_0_90	0.000630	-0.000207
ampfit_d_45_135	0.028266	0.021248

4.5 Defocus efficiency and Subreflector Shift

These calculations are based on the average of the two polarizations delta_z from the Phase Fit, which is given in the results as nominal_z_offset. The discussion in the Phase Fit section above about sources for error in delta_z therefore also affects these values. The other results are:

- defocus_efficiency is calculated based on the difference between each polarization's delta_z and the average of the two delta_z, so this result is not sensitive to the magnitude of nominal_z_offset. In the case of data set Band2-TDH17429-RF90 where the pol1 data is not valid, this value is also invalid.
- shift_from_focus_mm is the difference between delta_z and the probe distance. For 1.x the probe distance is a hard-coded 200 mm. For 2.0.x it is the "zdistance" parameter from the input file which defaults to 260 mm if not provided. So at least 60 mm of discrepancy is expected. This calculation does not seem correct in either version of the software.
- subreflector_shift_mm is the subreflector shift needed to achieve the shift_from_focus_mm. This value is therefore also problematic in all versions of the software.
- defocus_efficiency_due_to_moving_the_subreflector has a long name and still might not express what it really means. I think it is the defocus efficiency if the subreflector could not be shifted.

Version 2.0.x of the software expresses defocus_efficiency and defocus_efficiency_due... in [0...1] like the other efficiencies rather than in percent. Presentation software will have to adapt to this change.

4.5.1 Band 1

Figure 14: Band 1 Defocus efficiency

Data Set **RF sideband**	**Band1-SN03-RF35** 2=LSB		**Band1-SN03-RF42.5** 2=LSB		**Band1-SN03-RF50** 2=LSB	
SW Version	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4
Platform	Windows	Windows	Windows	Windows	Windows	Windows
nominal_z_offset	-262.790405	-260.798279	-55.707703	-56.11158	67.956528	68.324417
Pol0						
defocus_efficiency	99.998158	0.999989	99.997067	0.999972	99.997824	0.999982
shift_from_focus_mm	-451.856079	-512.299011	-267.211182	-327.299255	-123.719460	-184.052826
subreflector_shift_mm	1.569599	1.779558	0.928203	1.136930	0.429761	0.639339
defocus_efficiency_due_to_moving_the_subreflector	97.399834	0.969610	98.801048	0.981609	99.634369	0.991913
Pol1						
defocus_efficiency	99.998158	0.999989	99.997067	0.999972	99.997824	0.999982
shift_from_focus_mm	-473.724701	-529.297546	-244.204224	-304.923889	-140.367493	-199.298340
subreflector_shift_mm	1.645563	1.838605	0.848285	1.059205	0.487590	0.692297
defocus_efficiency_due_to_moving_the_subreflector	97.399834	0.967590	98.997726	1.059205	99.529564	0.990524

4.5.2 Band 2

Figure 15: Band 2 Defocus efficiency

Data Set **RF sideband**	**Band2-TDH17429-RF90** 1=USB		**Band2-TDH18144-RF88** 1=USB		**Band2-TDH18147-RF88** 1=USB	
SW Version	1.3.6	2.0.0	1.3.5	2.0.0	1.3.5	2.0.0
Platform	Linux	Windows	Linux	Windows	Linux	Windows
nominal_z_offset	492.675049	493.346313	134.412384	134.677399	134.749924	134.461121
Pol0						
defocus_efficiency	87.391633	0.873700	99.997574	0.999979	99.997813	0.999980
shift_from_focus_mm	-59.260818	-118.891083	-70.578537	-129.953552	-69.990906	-130.038361
subreflector_shift_mm	0.205853	0.412988	0.245167	0.451416	0.243125	0.451710
defocus_efficiency_due_to_moving_the_subreflector	99.727707	0.989081	99.630898	0.987536	99.637009	0.987520
Pol1						
defocus_efficiency			99.997574	0.999979	99.997813	0.999980
shift_from_focus_mm			-60.596695	-120.691635	-60.509247	-121.039413
subreflector_shift_mm			0.210493	0.419243	0.210189	0.420451
defocus_efficiency_due_to_moving_the_subreflector			0.997278	0.989241	99.728584	0.989179

4.5.3 Band 6

Figure 16: Band 6 Defocus efficiency

Data Set	Band6-TDH14050-RF243	
RF sideband	2=LSB	
SW Version	1.3.6	2.0.0
Platform	Linux	Windows
nominal_z_offset	254.545807	254.449463
Pol0		
defocus_efficiency	99.999988	1
shift_from_focus_mm	54.427399	-5.646729
subreflector_shift_mm	0.189063	0.019615
defocus_efficiency_due_to_moving_the_subreflector	98.336090	0.999820
Pol1		
defocus_efficiency	99.999988	1
shift_from_focus_mm	54.664230	54.545670
subreflector_shift_mm	0.189885	0.189474
defocus_efficiency_due_to_moving_the_subreflector	98.321686	0.983289

4.6 Total Aperture efficiency

The total aperture efficiency is the product:

total_aperture_eff = eta_phase • eta_spillover • eta_taper • eta_pol • defocus_efficiency

4.6.1 Band 1

Figure 17: Band 1 Total Aperture efficiency

Data Set	Band1-SN03-RF35		Band1-SN03-RF42.5		Band1-SN03-RF50	
SW Version	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4	1.0.6 modified	2.0.4
Platform	Windows	Windows	Windows	Windows	Windows	Windows
Pol0						
total_aperture_eff	0.804903	0.804827	0.816351	0.816353	0.800247	0.800250
Pol1						
total_aperture_eff	0.796404	0.796414	0.811715	0.811722	0.798863	0.798867

4.6.2 Band 2

Figure 18: Band 2 Total Aperture efficiency

Data Set	**Band2-TDH17429-RF90**		**Band2-TDH18144-RF88**		**Band2-TDH18147-RF88**	
SW Version	1.3.6	2.0.0	1.3.5	2.0.0	1.3.5	2.0.0
Platform	Linux	Windows	Linux	Windows	Linux	Windows
Pol0 total_aperture_eff	0.699539	0.699366	0.802838	0.802841	0.803087	0.803089
Pol1 total_aperture_eff			0.808230	0.808233	0.808512	0.808515

4.6.3 Band 6

Figure 19: Band 6 Total Aperture efficiency

Data Set	**Band6-TDH14050-RF243**	
SW Version	1.3.6	2.0.0
Platform	Linux	Windows
Pol0 total_aperture_eff	0.826595	0.826595
Pol1 total_aperture_eff	0.827786	0.827785

4.7 Beam Squint and Phase Center Correction

Beam squint was not fully or correctly calculated by the BeamEff 1.x applications. It was not corrected for rotational asymmetry of the scanner probe. Instead the FETMS Database web application (PHP) software would call the BeamEff application twice: first with the Pol0 and Pol1 scans and a then with only an 180-degree copol scan (from either polarization). The PHP code would then perform the probe asymmetry correction and compute squint.

BeamEff 2.0.x now accepts up to five input scans per ScanSet, one of which may be marked as "type=copol180". It uses this to perform the probe asymmetry correction and calculate the squint in the first pass. The PHP software no longer must call the application twice.

The results below compare data sets where the two-pass method was used with 1.x and the one-pass method with 2.0.x. The Band 1 and some of the Band 2 data sets do not include a "copol180" scan and so are not included in this section.

The phase center correction is represented by the following results:

- corrected_pol indicates which polarization's phase center was corrected. If the "copol180" scan is pol0 then pol1 will be corrected, and vice-versa.
- x_corr, y_corr are the amount of phase center correction in mm.
- dist_between_centers_mm is the distance between the phase centers after correction.

4.7.1 Band 2

Figure 20: Band 2 Beam Squint and Phase Center Correction

Data Set	Band2-TDH18144-RF88		Band2-TDH18147-RF88	
SW Version	1.3.5	2.0.0	1.3.5	2.0.0
Platform	Linux	Windows	Linux	Windows
corrected_pol	1	1	1	1
x_corr	0.28	0.289	0.25	0.265
y_corr	0.41	0.407	0.44	0.448
dist_between_centers_mm	0.45	0.463	0.39	0.416
squint_percent	1.44	1.480	1.23	1.330
squint_arcseconds	0.97	0.994	0.83	0.894

4.7.2 Band 6

Figure 21: Band 6 Beam Squint and Phase Center Correction

Data Set	Band6-TDH14050-RF243	
SW Version	1.3.6	2.0.0
Platform	Linux	Windows
corrected_pol	0	0
x_corr	0.02	0.021
y_corr	-0.13	-0.126
dist_between_centers_mm	0.23	0.229
squint_percent	2.03	2.010
squint_arcseconds	0.49	0.491

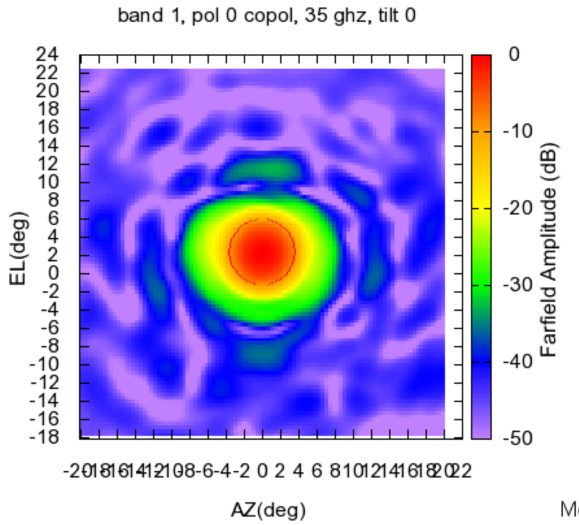
4.8 Amplitude and Phase plots

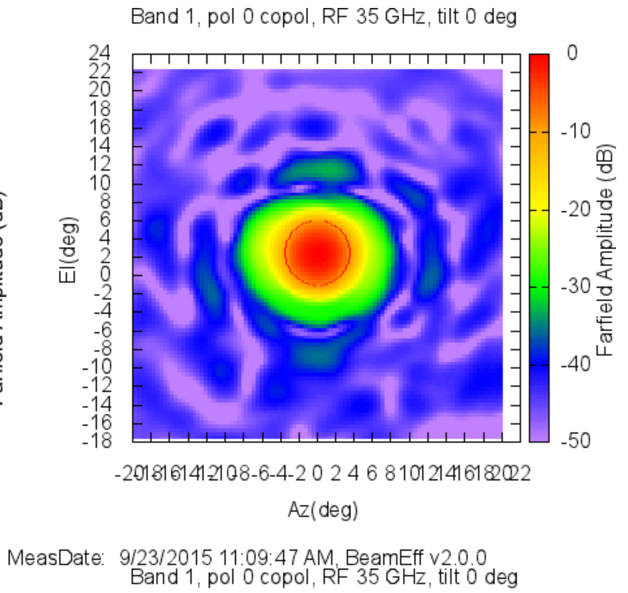
Only one data set is shown per band. Only Pol0 plots are shown.

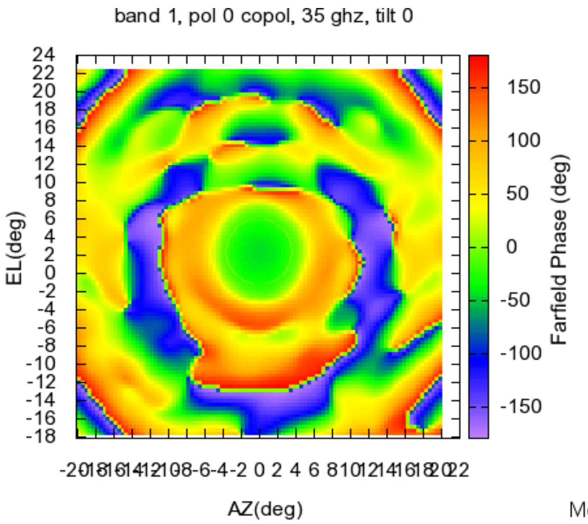
1.x plots are on the left. 2.0.x plots on the right.

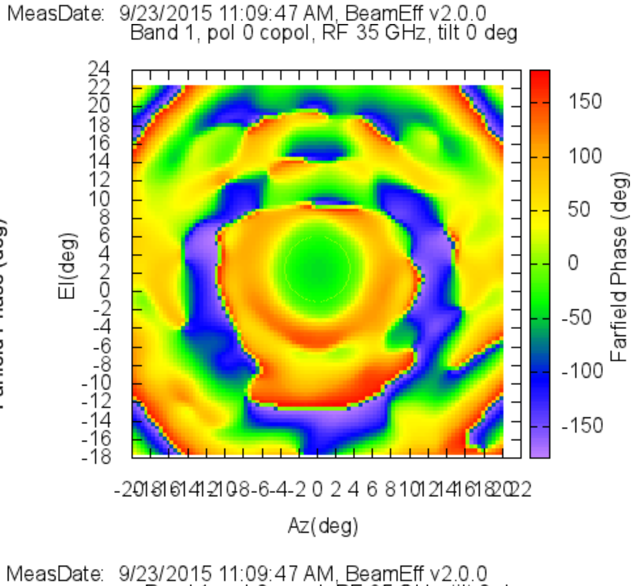
The 2.0.x plots were made using Gnuplot 4.2.6 on Windows. A newer version might be a bit better behaved about centering. Clearly some improvement is still needed in spacing the axis markers.

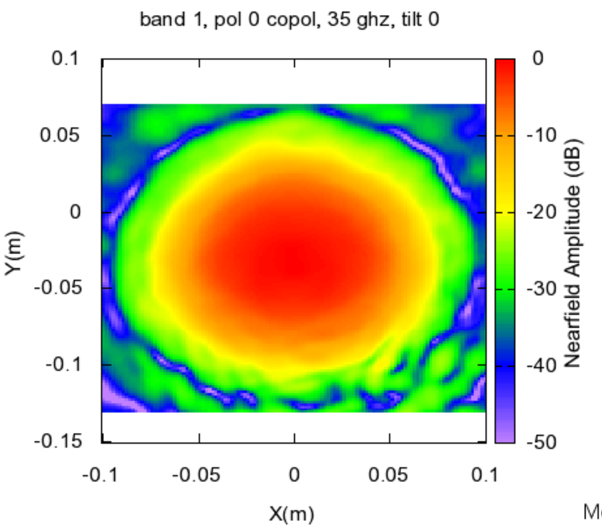
4.8.1 Data set Band1-SN03-RF35

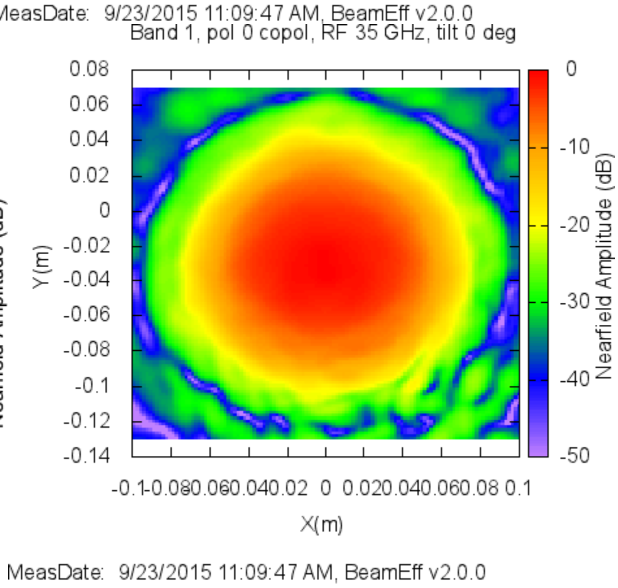


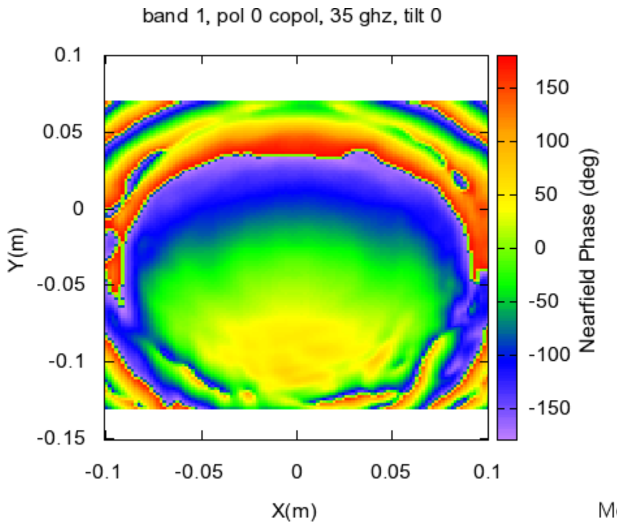


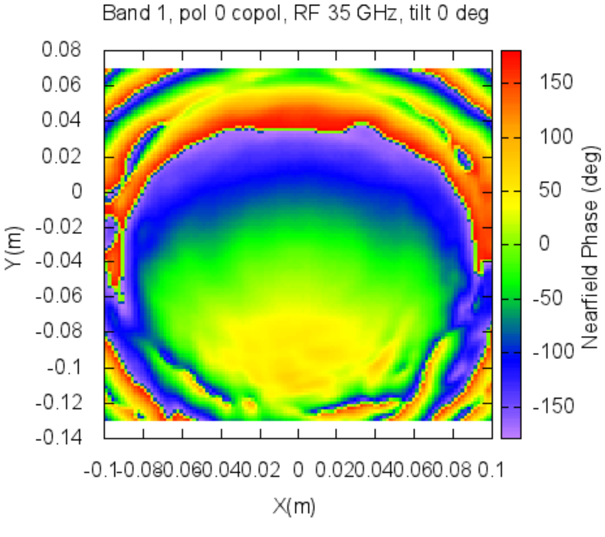


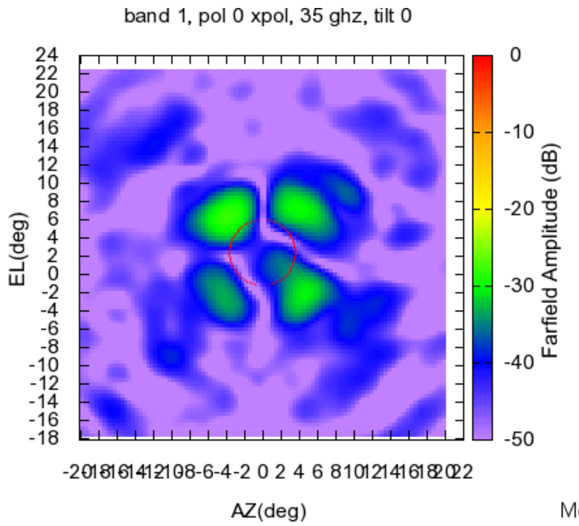


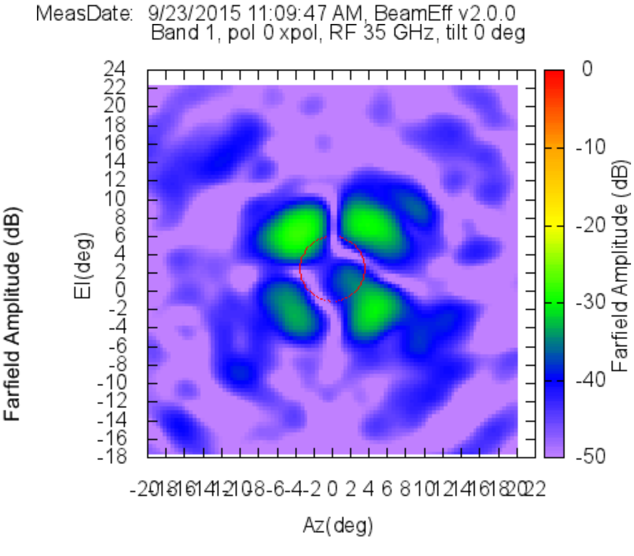


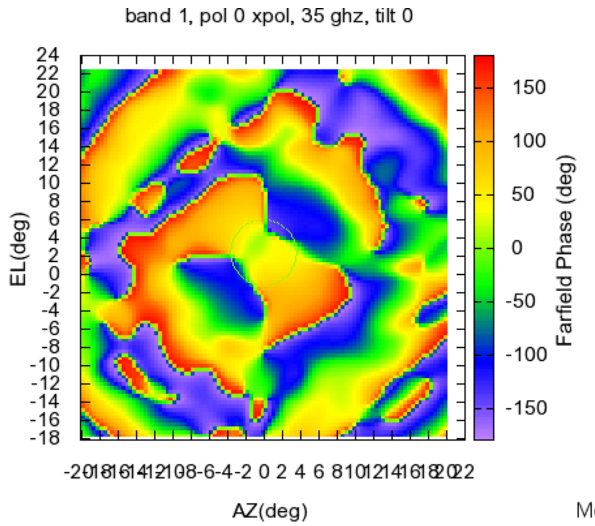


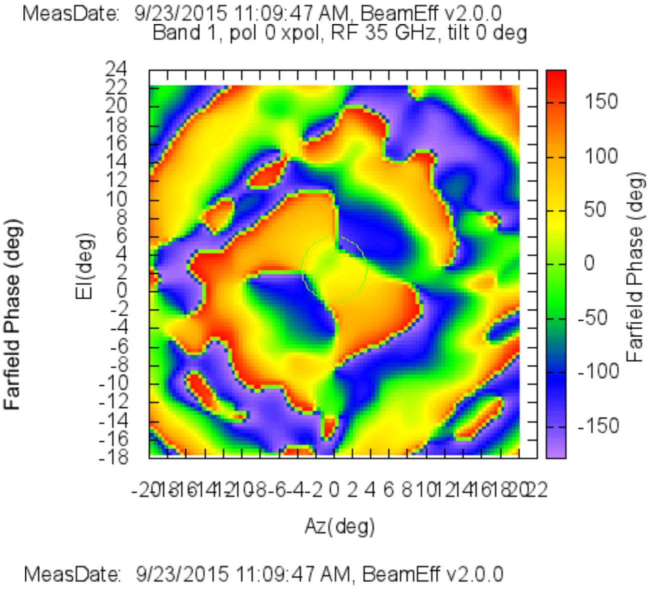

band 1, pol 0 copol, 35 ghz, tilt 0
Y(m)
X(m)
Nearfield Phase (deg)

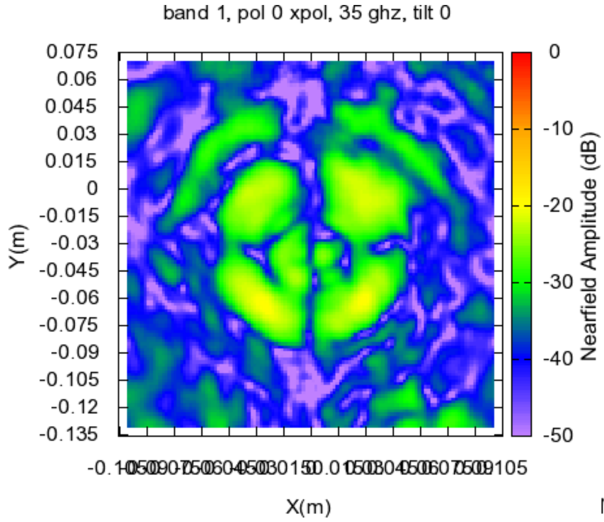

Band 1, pol 0 copol, RF 35 GHz, tilt 0 deg
Y(m)
X(m)
Nearfield Phase (deg)
MeasDate: 9/23/2015 11:09:47 AM, BeamEff v2.0.0

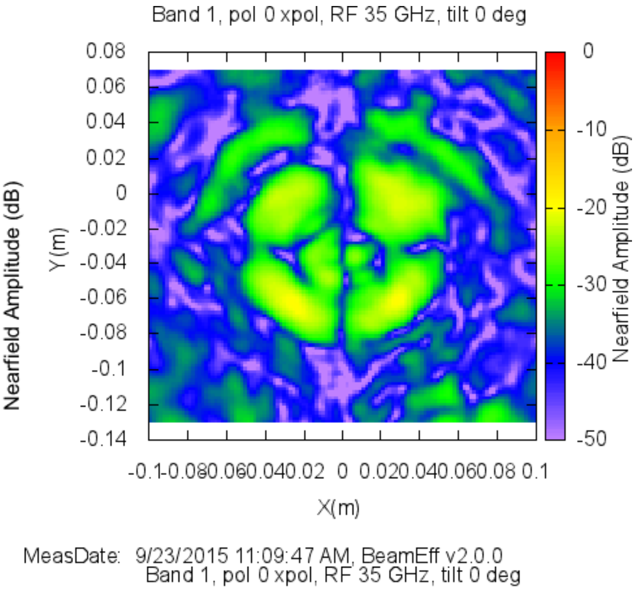

band 1, pol 0 xpol, 35 ghz, tilt 0
EL(deg)
AZ(deg)
Farfield Amplitude (dB)

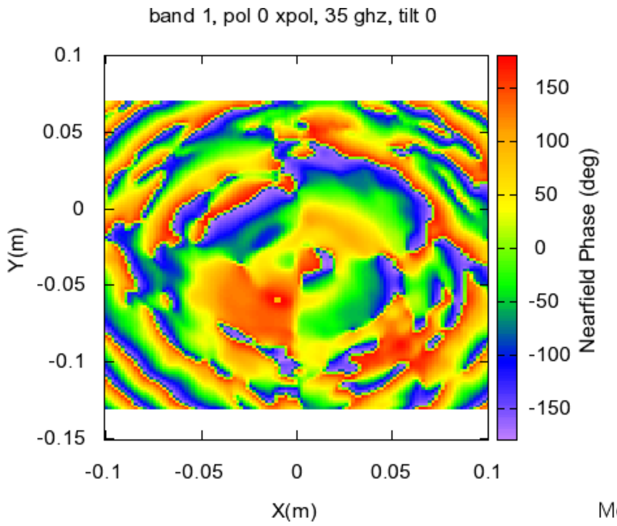

Band 1, pol 0 xpol, RF 35 GHz, tilt 0 deg
El(deg)
Az(deg)
Farfield Amplitude (dB)
MeasDate: 9/23/2015 11:09:47 AM, BeamEff v2.0.0

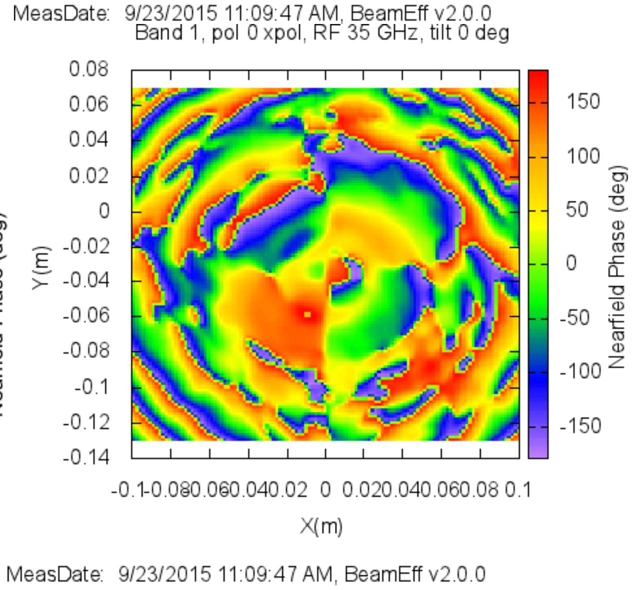

band 1, pol 0 xpol, 35 ghz, tilt 0
EL(deg)
AZ(deg)
Farfield Phase (deg)


Band 1, pol 0 xpol, RF 35 GHz, tilt 0 deg
El(deg)
Az(deg)
Farfield Phase (deg)
MeasDate: 9/23/2015 11:09:47 AM, BeamEff v2.0.0

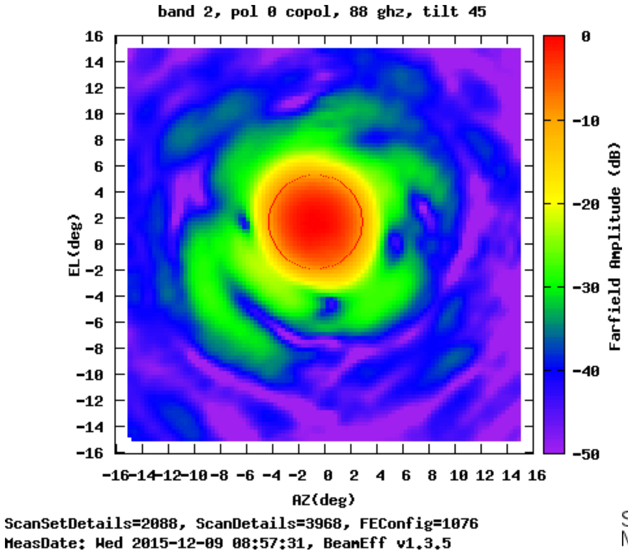

band 1, pol 0 xpol, 35 ghz, tilt 0
Y(m)
X(m)
Nearfield Amplitude (dB)

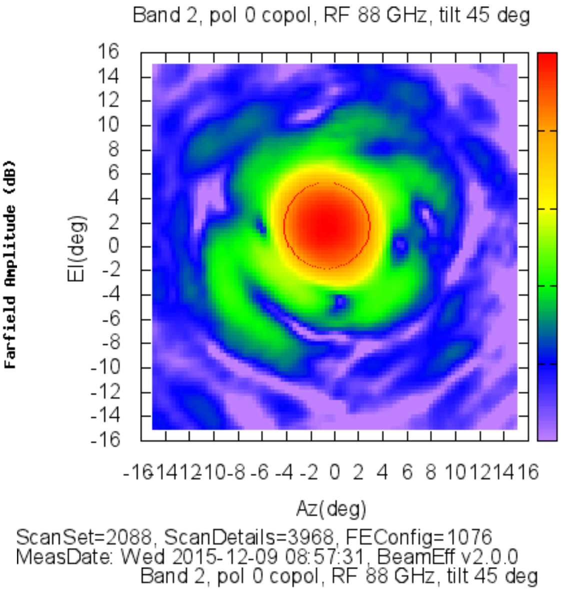

Band 1, pol 0 xpol, RF 35 GHz, tilt 0 deg
Y(m)
X(m)
Nearfield Amplitude (dB)
MeasDate: 9/23/2015 11:09:47 AM, BeamEff v2.0.0

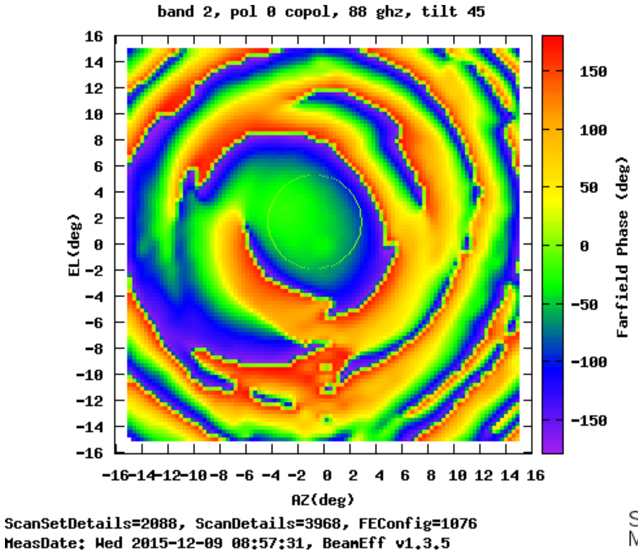

band 1, pol 0 xpol, 35 ghz, tilt 0
Y(m)
X(m)
Nearfield Phase (deg)

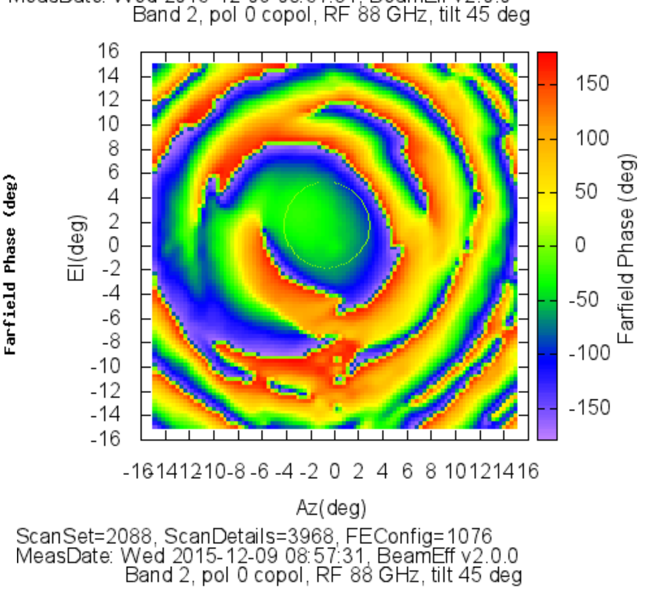

Band 1, pol 0 xpol, RF 35 GHz, tilt 0 deg
Y(m)
X(m)
Nearfield Phase (deg)
MeasDate: 9/23/2015 11:09:47 AM, BeamEff v2.0.0

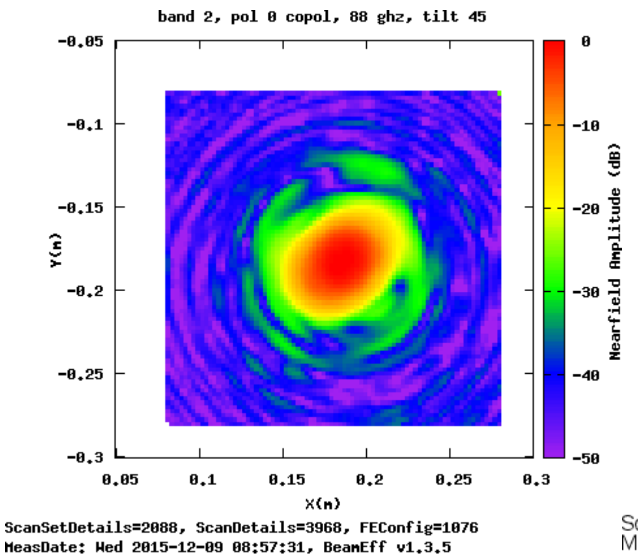
4.8.2 Data set Band2-TDH18144-RF88

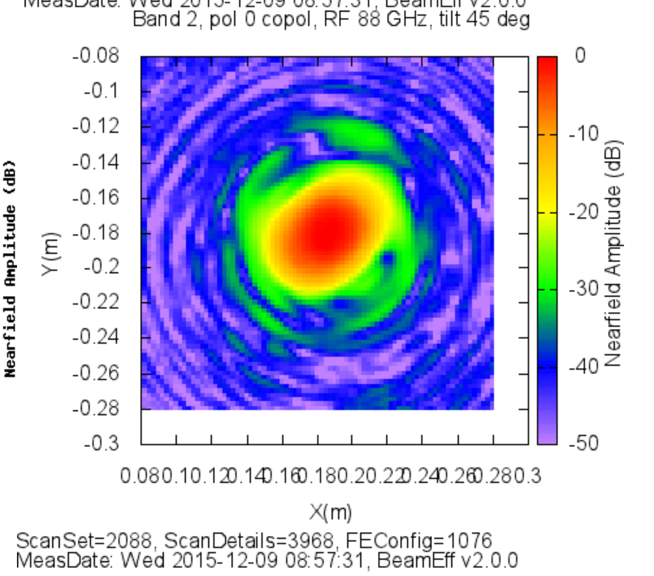


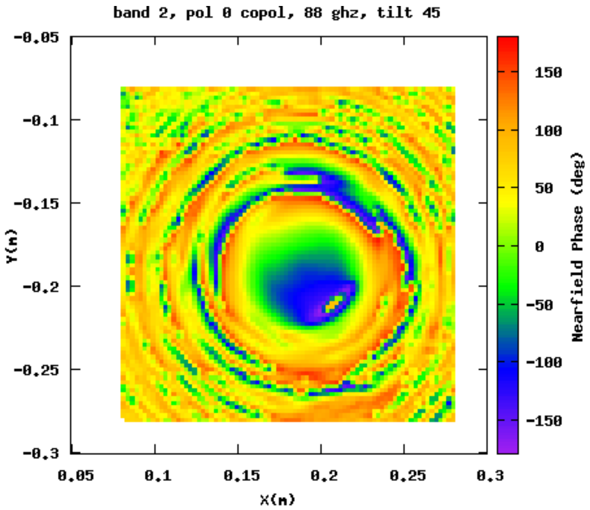




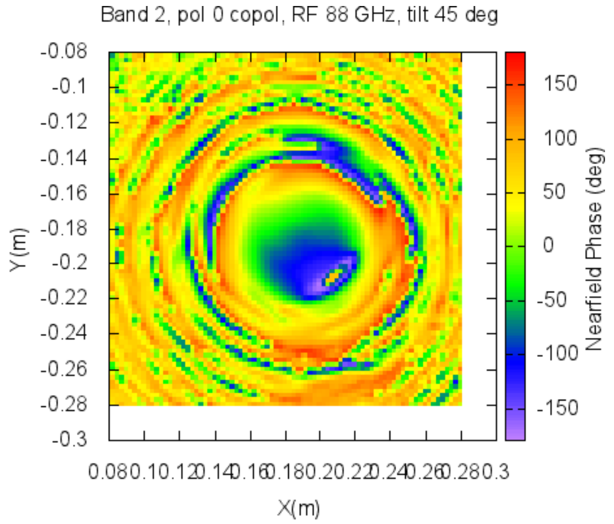




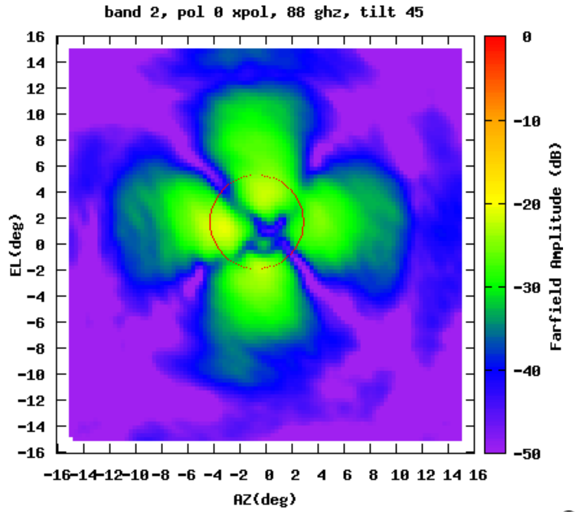




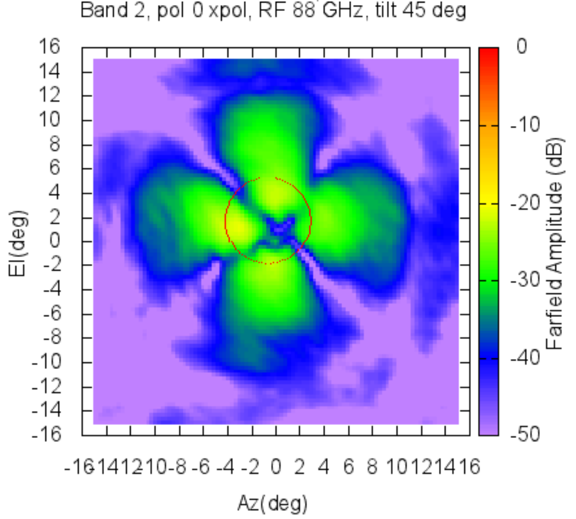
ScanSetDetails=2088, ScanDetails=3968, FEConfig=1076
MeasDate: Wed 2015-12-09 08:57:31, BeamEff v1.3.5



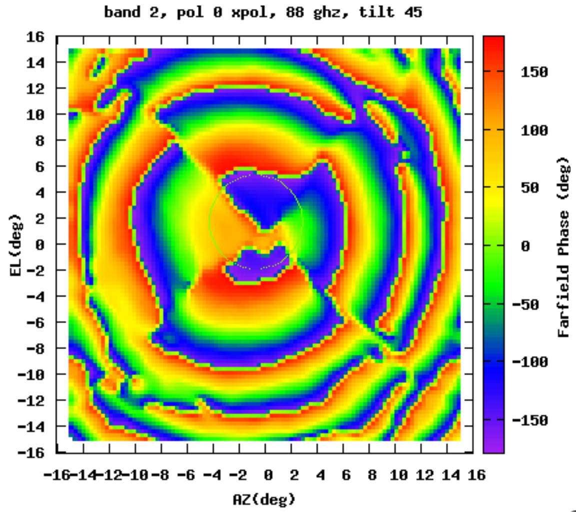
ScanSet=2088, ScanDetails=3968, FEConfig=1076
MeasDate: Wed 2015-12-09 08:57:31, BeamEff v2.0.0



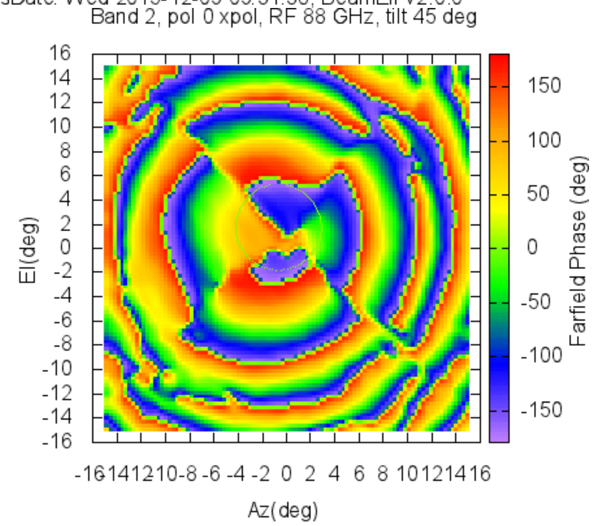
ScanSetDetails=2088, ScanDetails=3970, FEConfig=1076
MeasDate: Wed 2015-12-09 09:31:38, BeamEff v1.3.5



ScanSet=2088, ScanDetails=3970, FEConfig=1076
MeasDate: Wed 2015-12-09 09:31:38, BeamEff v2.0.0



ScanSetDetails=2088, ScanDetails=3970, FEConfig=1076
MeasDate: Wed 2015-12-09 09:31:38, BeamEff v1.3.5



ScanSet=2088, ScanDetails=3970, FEConfig=1076
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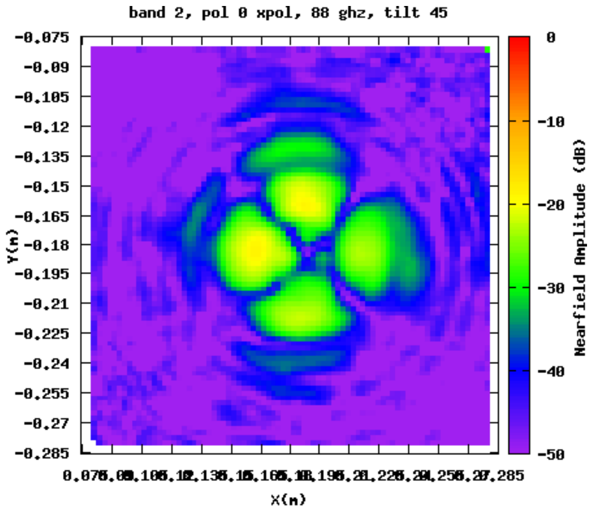
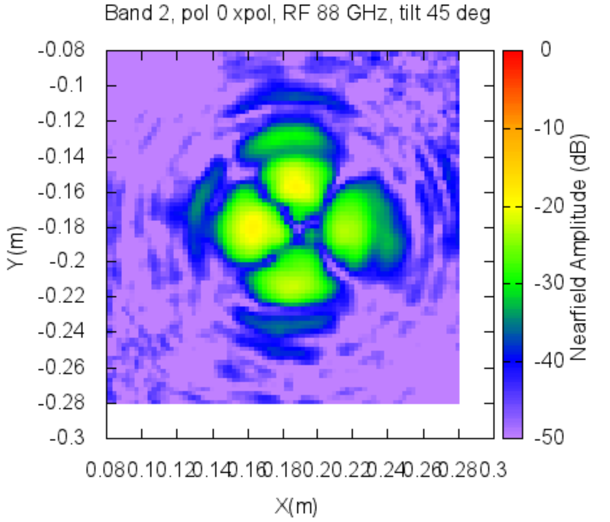


ScanSetDetails=2088, ScanDetails=3970, FEConfig=1076
MeasDate: Wed 2015-12-09 09:31:38, BeamEff v1.3.5



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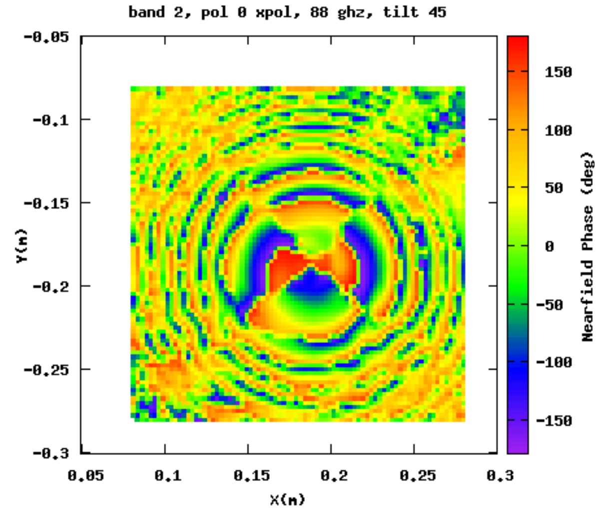

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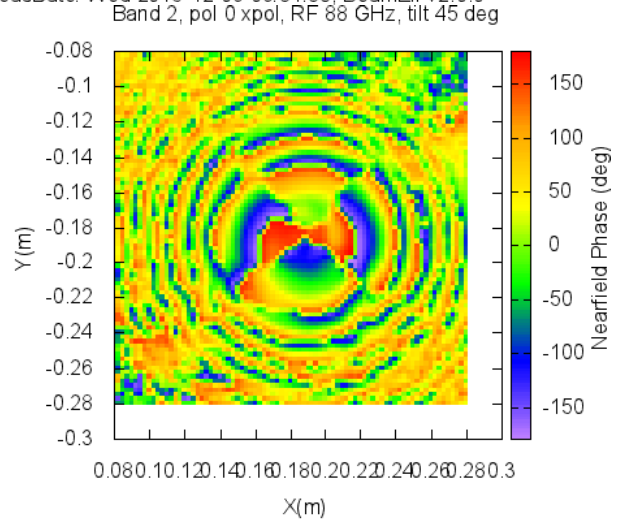
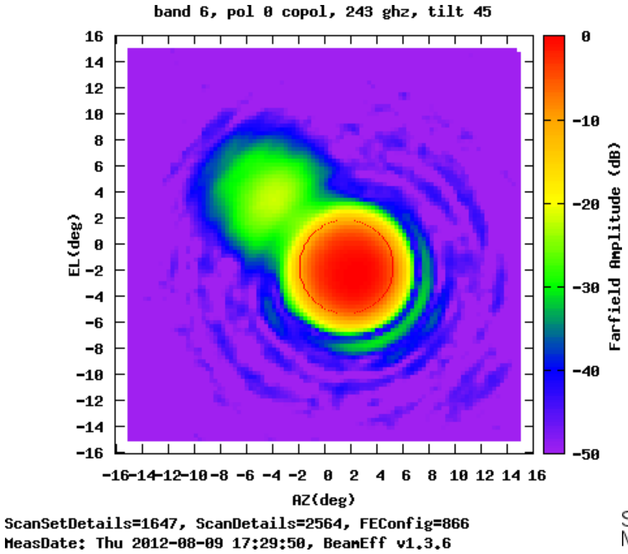
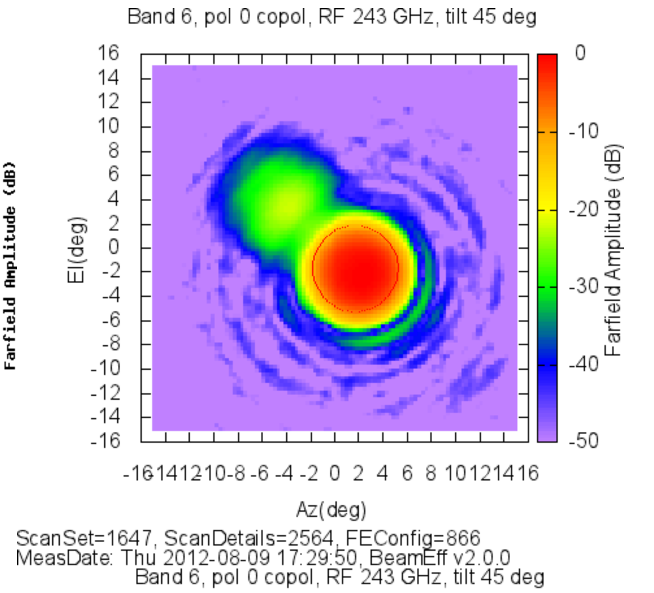
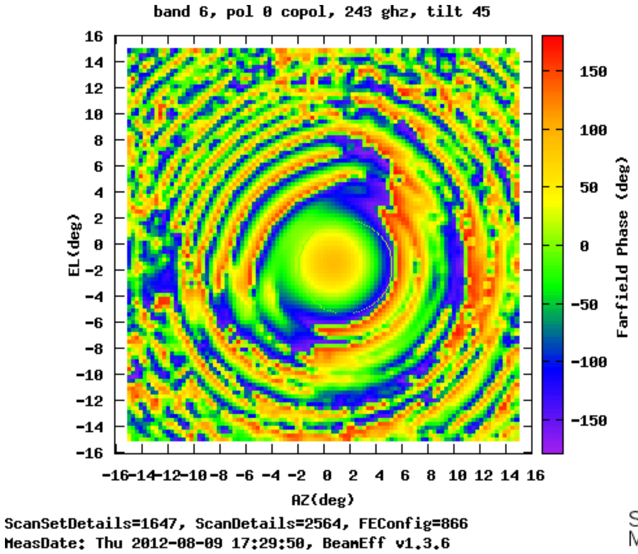


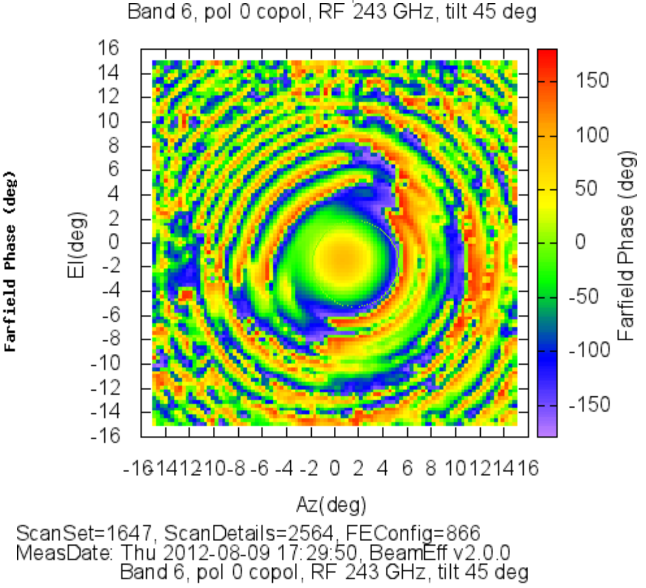
ScanSet=2088, ScanDetails=3970, FEConfig=1076
MeasDate: Wed 2015-12-09 09:31:38, BeamEff v2.0.0

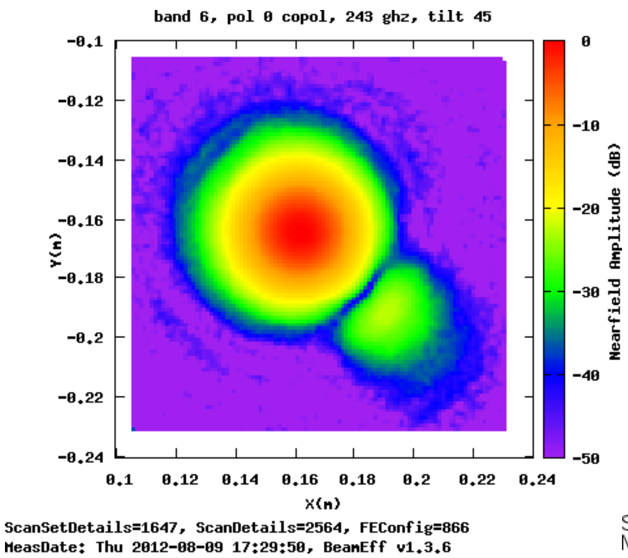
4.8.3 Data set Band6-TDH14050-RF243

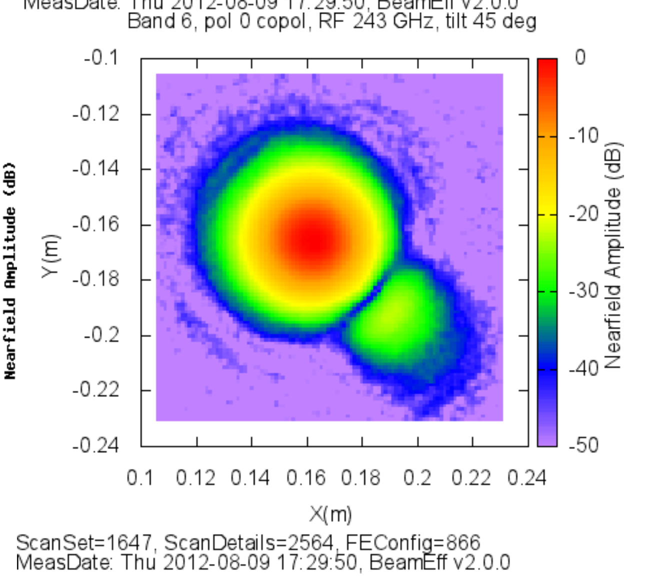


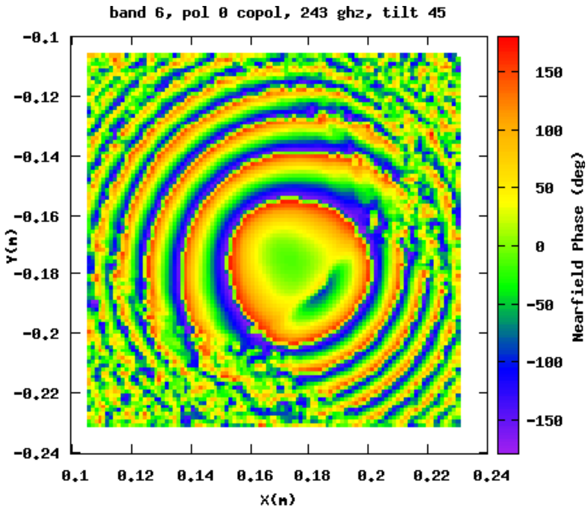




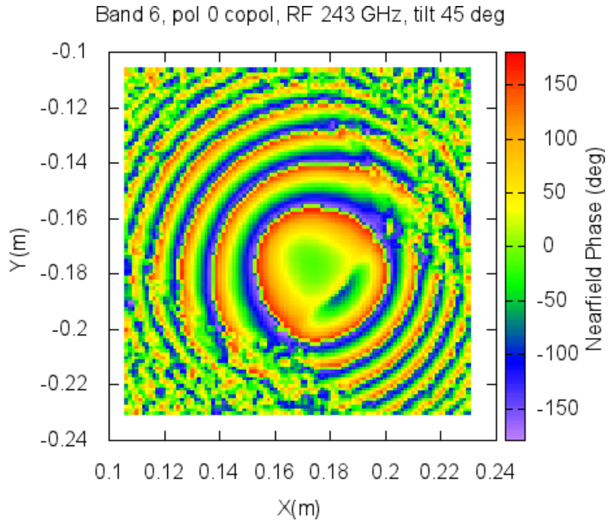








ScanSetDetails=1647, ScanDetails=2564, FEConfig=866
MeasDate: Thu 2012-08-09 17:29:50, BeamEff v1.3.6



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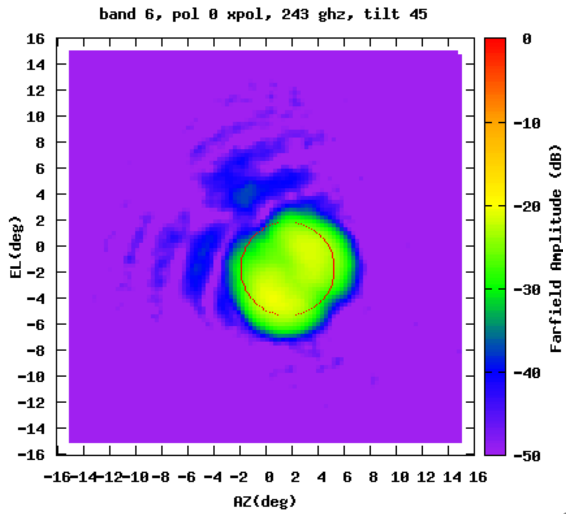
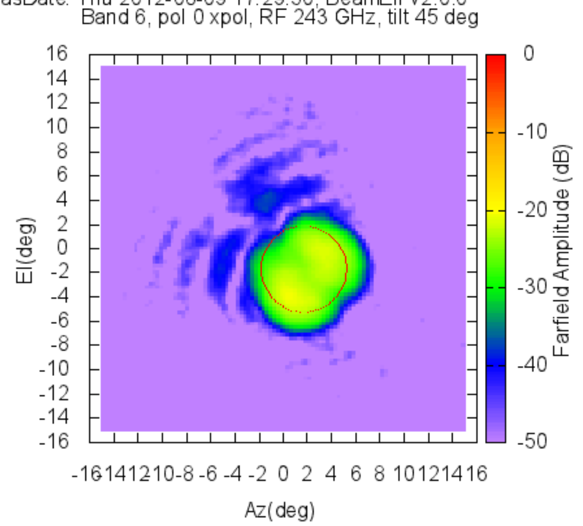


ScanSetDetails=1647, ScanDetails=2566, FEConfig=866
MeasDate: Thu 2012-08-09 18:24:19, BeamEff v1.3.6



ScanSet=1647, ScanDetails=2566, FEConfig=866
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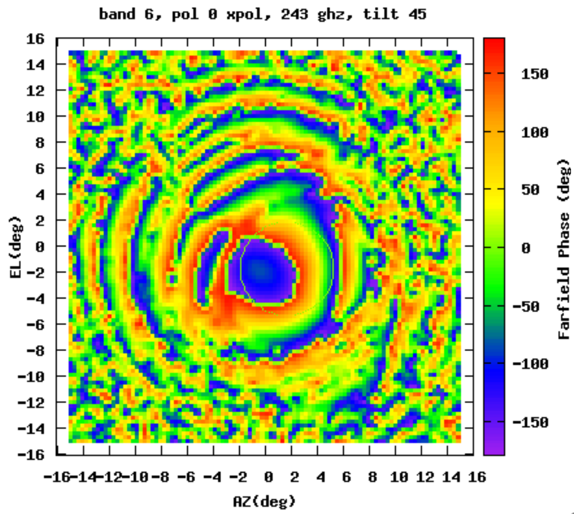

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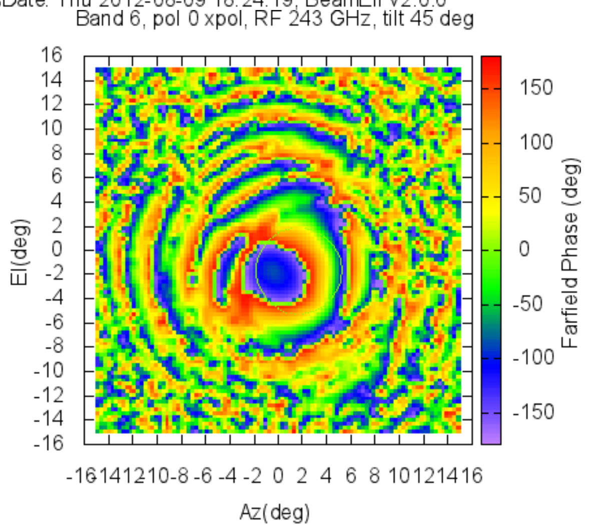
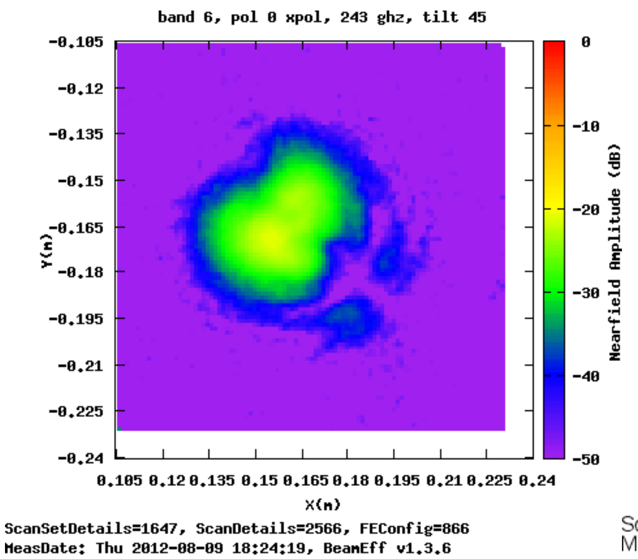
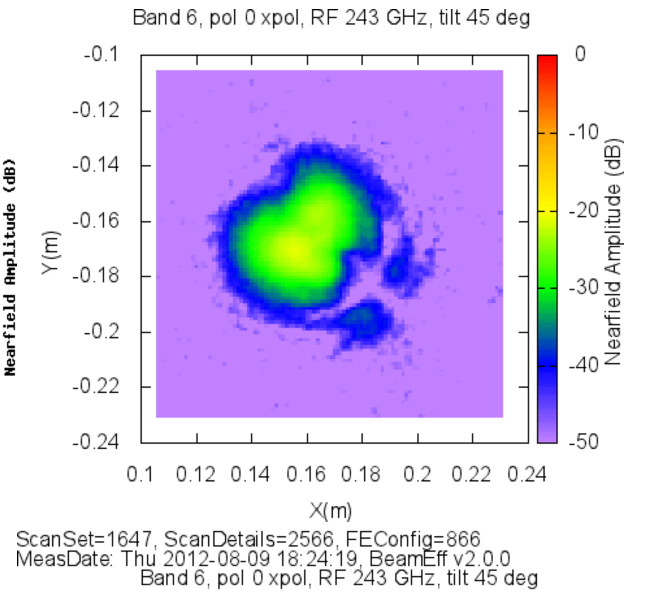
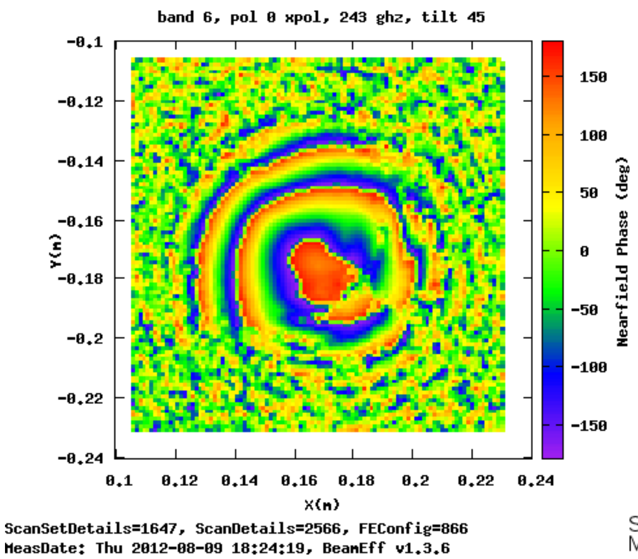
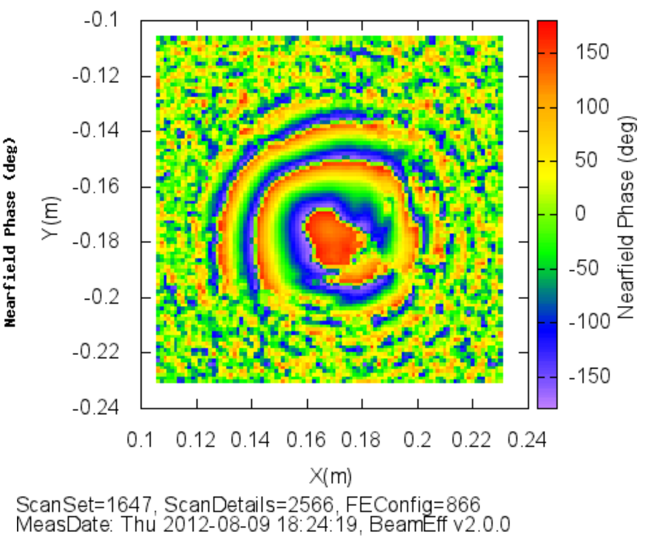


ScanSet=1647, ScanDetails=2566, FEConfig=866
MeasDate: Thu 2012-08-09 18:24:19, BeamEff v2.0.0





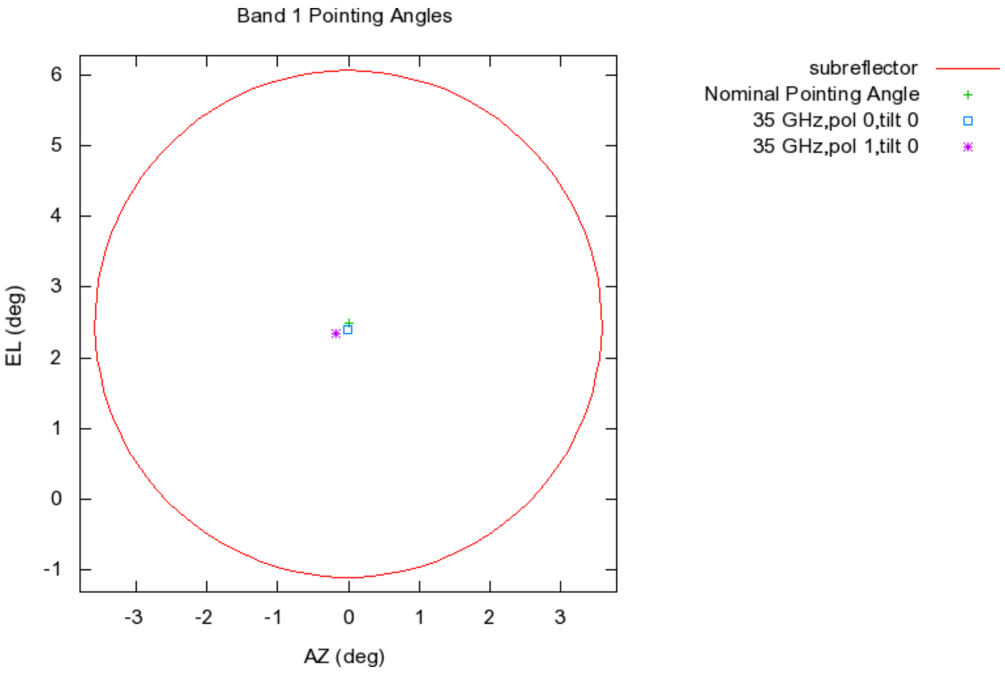


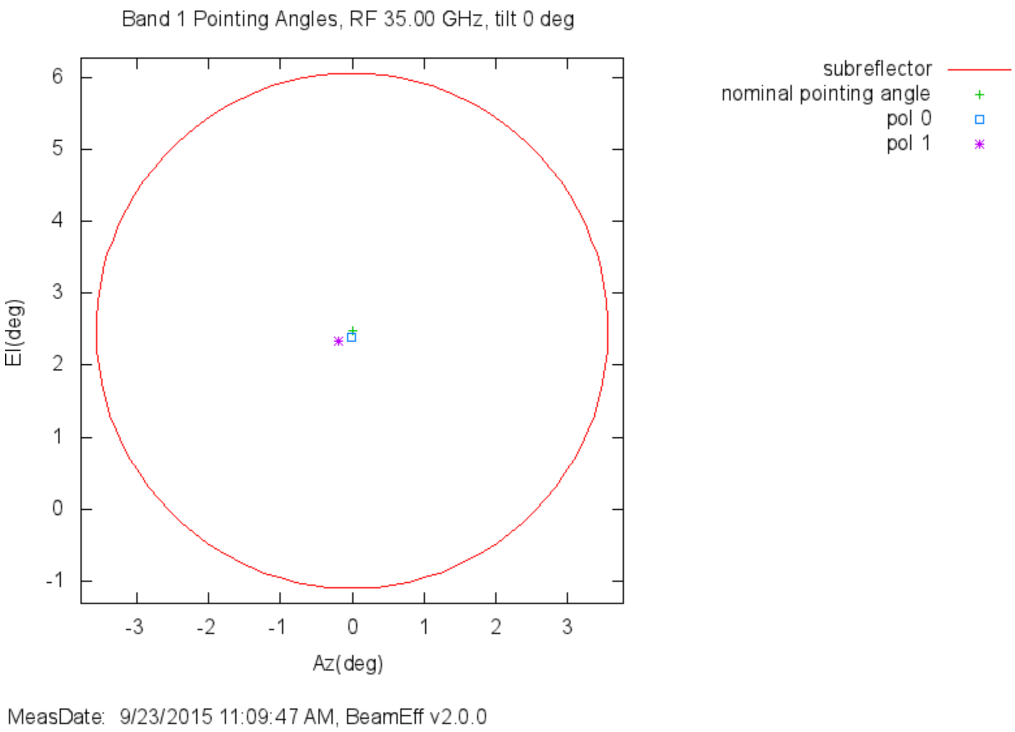


4.9 Pointing angle plots

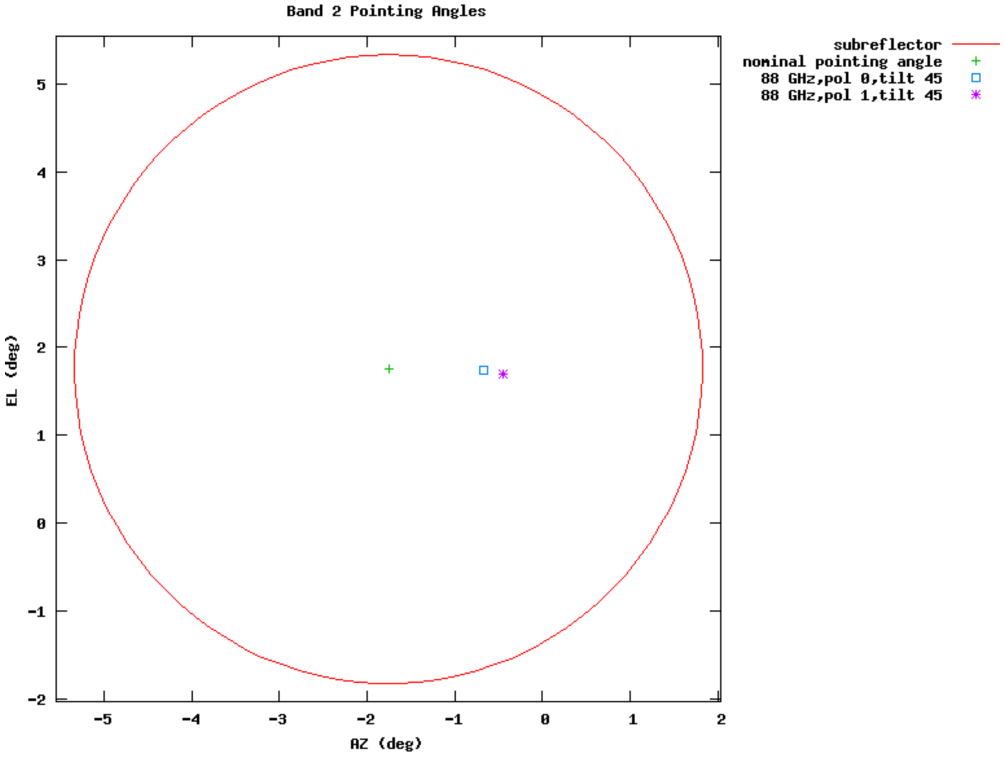
The 1.x pointing angle plots are above. The 2.0.x plots are below.

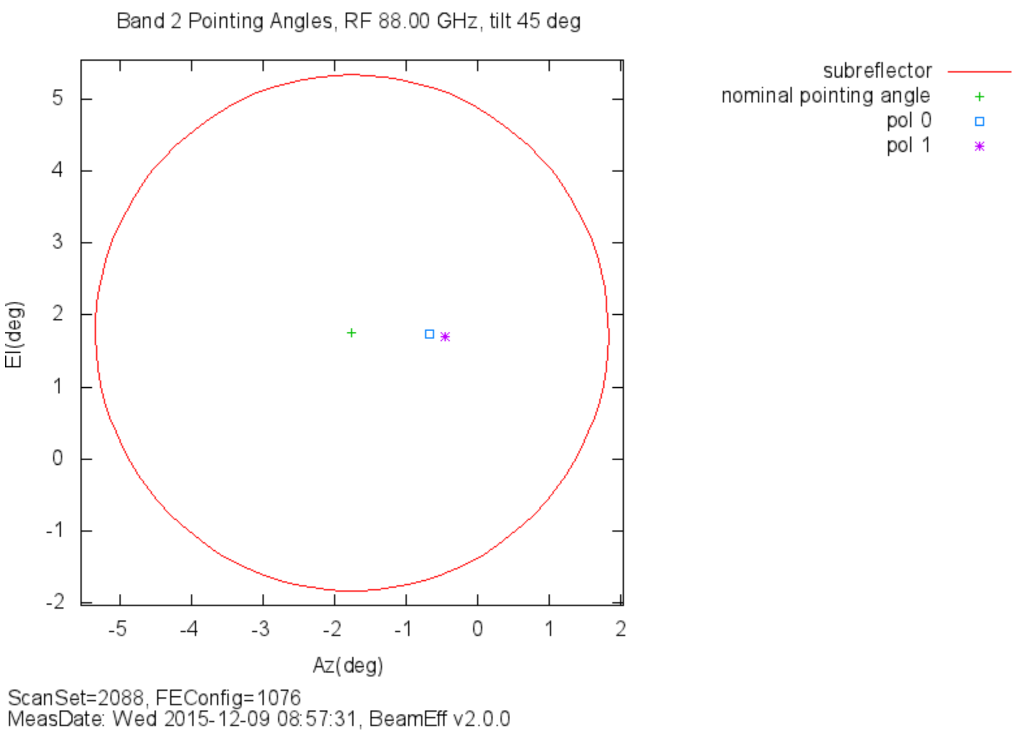
4.9.1 Data set Band1-SN03-RF35



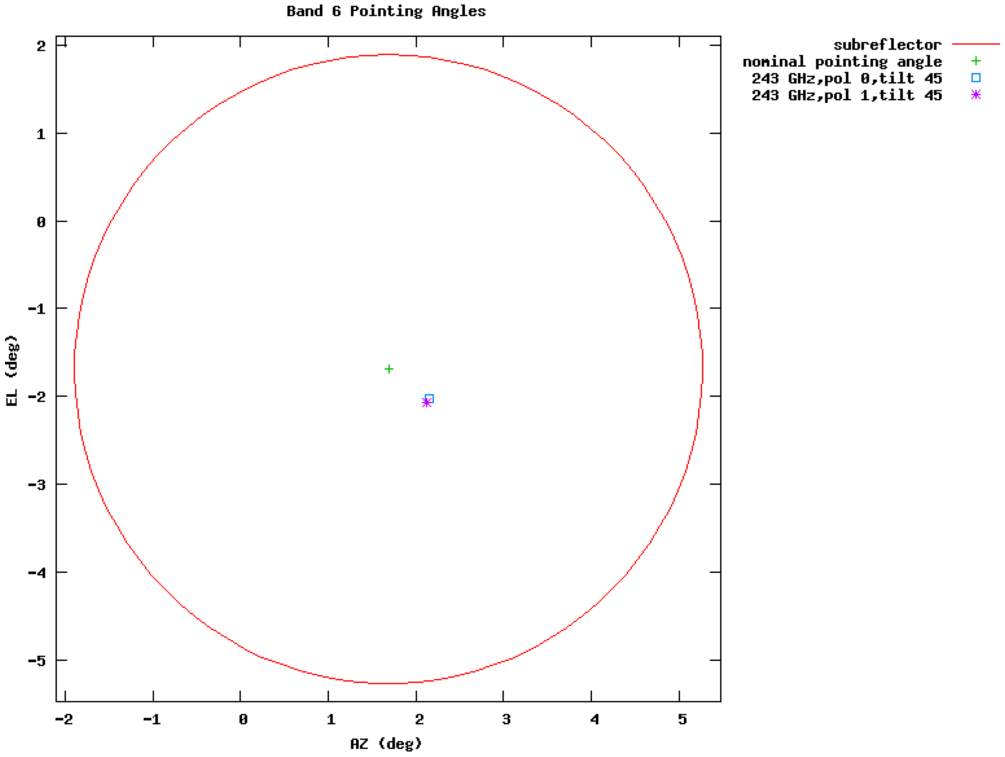


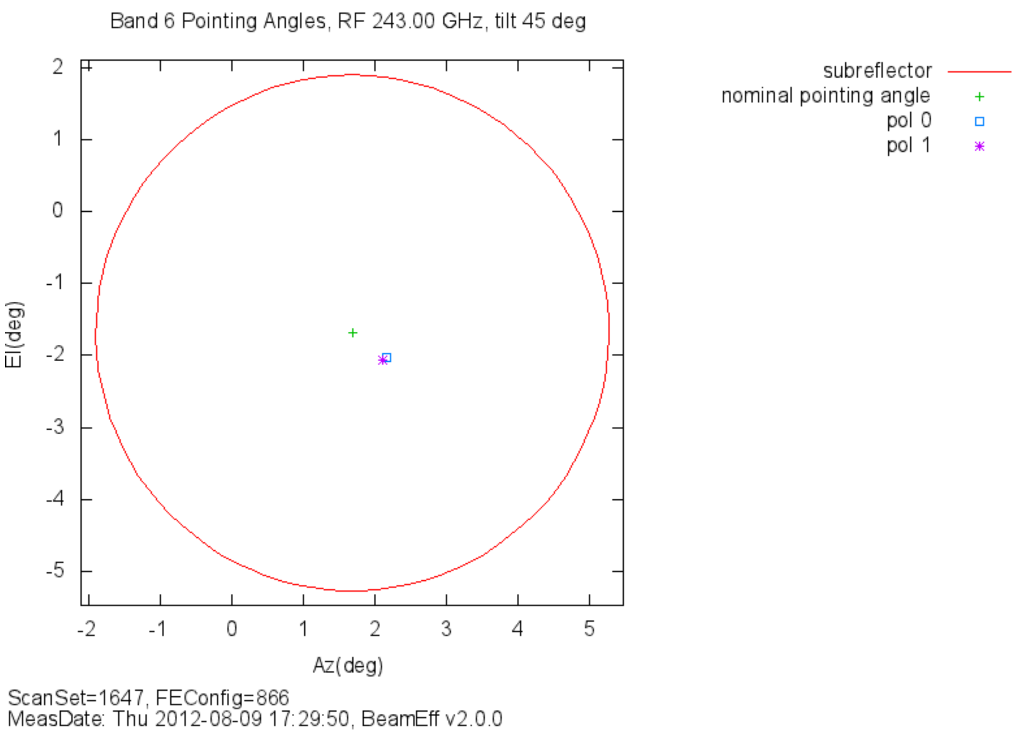
4.9.2 Data set Band2-TDH18144-RF88





4.9.3 Data set Band6-TDH14050-RF243





4.10 Dual-Z scan sets

No data yet. Plan is to figure out how to split out the two Z scans from the band 1 data and reprocess it so that BeamEff combines the dual Z scans. In [RD4], A. Baryshev notes that when NSI2000 combines the dual-Z beams it uses average (a1+a2)/2 instead of (a1+i*a2)/2 or (a1-i*a2)/2 depending on the sideband used in detection. The dual-Z algorithm in BeamEff, both 1.x and 2.0.x simply finds the correction having the greater magnitude rather than using the "sb" input variable as it probably should.