Atacama
Large
Millimeter
Array

Band 3 Cartridge Acceptance Report

(Serial No 03)

FEND-40.02.03.00-133-A-REP

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Change Record

Version	Date	Affected Section(s)	Change Request #	Reason/Initiation/Remarks
A	2007-01-30	All		Initial document

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1 Introduction

1.1 Purpose

This document contains the data compiled during the verification of the performance of the Band 3 Cartridge Serial Number 3. The tests were performed according to the acceptance test plan [AD2]. The tests of the cartridge presented in this document were done using the HIA Cartridge Test Set, as described in [AD7] to which was added the NRAO Bias box Rev B and WCA3-5 [AD3].

1.2 Applicable Documents

Reference	Document Title	ALMA Doc. Number
[AD1]	Band 3 Cartridge – Technical Specifications	FEND-40.02.03.00-012-A-SPE
[AD2]	Band 3 Cartridge – Acceptance test Plan	FEND-40.02.03.00-082-A-PLA
[AD3]	First Local Oscillator Driver for Band 3 Acceptance Report SN 2	FEND-40.10.03.00-102-A-REP
[AD4]	ICD Band 3 cartridge – IF switch sub-system	FEND-40.02.03.00-40.08.01.00-A-ICD
[AD5]	Band 3 optics System Error Budget	SYSE-40.02.03.00.068-A-REP.xls
[AD6]	Band 3 Beam Pattern Measurements – Teleconference	FEND-40.02.03.00.083-A-MIN
[AD7]	Band 3 Cartridge – Experimental Procedures for Acceptance Tests	FEND-40.02.03.00-092-A-PRO
[AD8]	Cryostat Technical Specification	FEND-40.03.00.00-002-B-SPE
[AD9]	ICD Band 3 cartridge – Band 3 bias circuits	FEND-40.02.03.00-40.02.03.06-A-ICD
[AD10]	ICD Band 3 cartridge – Band 3 first LO	FEND-40.02.03.00-40.10.03.00-A-ICD
[AD11]	ICD between cartridges and warm cartridge assembly	FEND-40.02.00.00-40.11.00.00-A-ICD
[AD12]	ICD Band 3 cartridge – Cryostat	FEND-40.02.03.00-40.03.01.00-A-ICD
[AD13]	Measurement of the Band 3 Beam Pointing in the Test Cryostat	FEND-40 02 03 00-127-B-REP
[AD14]	Cryostat System Vacuum Component Test Procedure	FEND-40.03.00.00-038-A-PRO.doc
[AD15]	ALMA Environmental Specification	ALMA-80.05.02.00-001-B-SPE
[AD16]	ALMA System: Electromagnetic Compatibility Requirements	ALMA-80.05.01.00-001-A-SPE
[AD17]	First Local Oscillator for Band 3 Technical Specifications	FEND-40.10.03.00-001-A-SPE
[AD18]	Band 3 Preliminary Design Review - Volume I: Technical Documentation	FEND-40.90.00.00-001-A-REP

[AD19]	Band 3 Local Oscillator power adjustment for each channel 0 and 1	FEND-40.00.00.00-042-A-CRE
[AD20]	YIG and Gunn Based LO Systems Comparisons, Dindo and Derdall	HIA Band 3 Report
[AD21]	Specifications for Shocks and Vibrations Analysis and Testing	ALMA FE System Draft document
[AD22]	Mixer and IF amplifier Vibration Test Report	FEND-40.02.03.00-087-A-REP
[AD23]	Band 3 Shipping, Handling and Storage Procedures	FEND-40.02.03.00-074-A-REP
[AD24]	Thermo-Mechanical Design of the Band 3 Cartridge	FEND-40.02.03.00-008-A-REP
[AD25]	Change to Band 3 Vacuum Leak Rate Specification	FEND-40.02.03.00-094-A-CRE
[AD26]	ALMA Front End Reliability Analysis Interim Report	SYSE-80.11.00.00-004-A-REP
[AD27]	Band 3 Local Oscillator Noise Measurements	FEND-40.02.03.00-121-A-REP
[AD28]	Band 3 Cartridge Shock/Vibration Test Results	FEND-40.02.03.00-100-A-REP

1.3 Reference documents

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

Reference	Document Title	ALMA Doc. Number
[RD1]	ALMA Front-End Optics Conceptual Design Report	FEND-40.01.00.00-003-A-REP
[RD2]	ALMA Front-End Design Specifications & Requirements	FEND-40.00.00.00-001-A-SPE

1.4 Acronyms

A list of the acronyms used in this document is given below.

ALMA	Atacama Large Millimeter Array
CDR	Critical Design Review
DSB	Double side-band
EMC	Electromagnetic compatibility
FE	Front-End
FEIC	Front-End Integration Centre
HIA	Herzberg Institute of Astrophysics
ICD	Interface Control Document
IF	Intermediate Frequency
IPT	Integrated Product Team
LO	Local Oscillator
MTBF	Mean time between failures
NRAO	National Radio Astronomy Observatory
OMT	Orthomode transducer
PAI	Preliminary Acceptance In-house
PAS	Provisional Acceptance On-Site (at FEIC)
RF	Radio frequency
SIS	Superconductor-Insulator-Superconductor
SSB	Single side-band
2SB	Side-band separating

2 General requirements

2.1 Operation modes

The band 3 cartridge will be used in the following modes.

In normal operation conditions, the band 3 cartridge is either “operational” or in “stand-by”.

2.1.1 Operational

[FEND-40.02.03.00-00010-00 / I]

2.1.1.1 Requirements

This mode applies during normal observations with the Front-End sub-system. In this mode, all the specifications and requirements described in this document apply.

2.1.1.2 Compliance

The Band 3 cartridge complies with the ALMA operational mode.

2.1.2 Non-Operational

[FEND-40.02.03.00-00020-00 / I]

2.1.2.1 Requirements

This mode applies when the Band 3 cartridge is switched off. In this mode, the specifications and requirements, with the exception of section 4, apply.

2.1.2.2 Compliance

The Band 3 cartridge complies with the ALMA non-operational mode.

2.1.3 Stand-by

[FEND-40.02.03.00-00025-00 / I]

2.1.3.1 Requirements

This mode applies when operational power is applied to the Band 3 cartridge but signal levels are not at their nominal values. In this mode, the specifications and requirements, with the exception of section 4, apply.

2.1.3.2 Compliance

The Band 3 cartridge complies with the ALMA stand-by mode.

2.1.4 Transport with the antenna

[FEND-40.02.03.00-00030-00 / I]

2.1.4.1 Requirements

This mode applies when the Band 3 cartridge, integrated into the Front-End sub-system, is transported with the antenna on the antenna transport vehicle. In this mode, the specifications and requirements, with the exception of section 4, apply.

2.1.4.2 Compliance

The Band 3 cartridge complies with the ALMA transport with the antenna mode.

2.1.5 Transport in the service vehicle

[FEND-40.02.03.00-00040-00 / I]

2.1.5.1 Requirements

This mode applies when the Band 3 cartridge, integrated into the Front-End sub-system, is transported on the Front-End service vehicle. In this mode, the specifications and requirements, with the exception of section 4, apply.

2.1.5.2 Compliance

The Band 3 cartridge complies with the ALMA transport in the service vehicle mode.

2.2 Compatibility with the ALMA Front-End sub-system

[FEND-40.02.03.00-00050-00 / I]

2.2.1 Requirements

The Band 3 cartridge design shall be compatible with other parts of the ALMA Front-End sub-system, especially the receiver optics and cryostat. Details are given in the applicable ICDs.

2.2.2 Compliance

The applicable ICDs between Band 3 and ALMA FE subsystem [AD4], [AD9], [AD10], [AD11], [AD12] show the compliance.

2.3 Design for production

2.3.1 Technology

[FEND-40.02.03.00-00060-00 / R]

2.3.1.1 Requirements

The Band 3 cartridge design should use mature technologies whenever possible.

2.3.1.2 Compliance

All technologies using in the Band 3 cartridge, including the key technologies, i.e. SIS mixer and the InP transistors, are mature and have been in operation on telescopes.

2.3.2 Series production

[FEND-40.02.03.00-00070-00 / R]

2.3.2.1 Requirements

The Band 3 cartridge design should be compatible with low production and assembly costs. The design should be as simple as possible.

2.3.2.2 Compliance

Careful care was taken to make the cartridge design as simple as possible in a view for series production, yet without compromising performances [AD18].

2.3.3 Standard parts

[FEND-40.02.03.00-00080-00 / R]

2.3.3.1 Requirements

Standard, unmodified commercially available components, should be used whenever possible.

2.3.3.2 Compliance

As described in [AD18], commercially available components such as IF coupler or the isolator have been chosen for the Band 3 system. Also, un-modified standard WR10 waveguides are used for the RF and LO signals.

2.4 Mechanical tuning

[FEND-40.02.03.00-00090-00 / R]

2.4.1 Requirements

Operation of the band 3 cartridge shall not require the use of mechanical tuners.

2.4.2 Compliance

SIS mixers normally require mechanical tuners because of their narrow band operation or for tuning in single sideband. The Band 3 mixer unit has no mechanical tuners and consists of a wide band mixer chip, and as well the image rejection is provided by broadband waveguide couplers.

2.5 Metric dimensioning

[FEND-40.02.03.00-00110-00 / R]

2.5.1 Requirements

In general, metric dimensioning shall be used in the Band 3 cartridge. This includes items such as fasteners and tapped holes. However, the internal details of components may use imperial dimensioning and fasteners. Standard wave-guide flanges (using imperial dimensions) may be used.

2.5.2 Compliance

All dimensions in the Band 3 system are in metric.

3 Functional Requirements

3.1 Mixer type

[FEND-40.02.03.00-00120-00 / R]

3.1.1 Requirements

The Band 3 cartridge shall employ SIS mixers as the frequency-translating devices.

3.1.2 Compliance

There are four SIS mixers per cartridge.

3.2 Mixing scheme

[FEND-40.02.03.00-00130-00 / R]

3.2.1 Requirements

The band 3 mixers shall be of the sideband separating type, in which both upper and lower sidebands are available.

3.2.2 Compliance

The band 3 is of the sideband separating type providing simultaneously the upper and the lower sideband (2SB).

3.3 Frequency Coverage

(Note that this section applies to the operational mode operational mode.)

3.3.1 RF input port

[FEND-40.02.03.00-00140-00 / R]

3.3.1.1 Requirements

The RF input frequency range shall be from 84 GHz to 116 GHz.

3.3.1.2 Compliance

Standard RF input components such as waveguides are in WR10 (75 to 110 GHz) which can be extended to 116 GHz with no performance degradation. The other components such as the lens, feedhorn, orthomode transducer, RF coupler, and mixer are all designed for the 84 to 116 GHz band.

3.3.2 LO input port

[FEND-40.02.03.00-00150-00 / R]

3.3.2.1 Requirements

The LO input port frequency range shall be from 92 GHz to 108 GHz.

3.3.2.2 Compliance

The Band 3 LO covers the required frequency range.

3.3.3 IF output ports

[FEND-40.02.03.00-00160-00 / R]

3.3.3.1 Requirements

Each polarization shall provide 8 GHz of IF bandwidth. Each eight GHz of bandwidth shall be evenly split into upper and lower sidebands and these shall be centered at 6 GHz.

3.3.3.2 Compliance

For each polarization, the Band 3 cartridge has a sideband separating mixer (2SB) that has, for each channel, 4 GHz of bandwidth centered at 6 GHz. Since a 2SB can provide upper and lower sideband simultaneously, the 8 GHz bandwidth requirement is met.

3.4 Polarization States

[FEND-40.02.03.00-00170-00 / R]

3.4.1 Requirements

The cartridge shall receive two orthogonal polarizations, designated “polarization 0” and “polarization 1”, with each being converted to two separate IF outputs. The nominal polarization states shall be linear.

3.4.2 Compliance

The input circular polarization detected by the lens and feedhorn is split in two orthogonal polarizations by an orthomode transducer (OMT). The two outputs of the OMT are fed to the mixer units which in turn have two separate IF outputs.

4 Performance Requirements

4.1 Cartridge Noise-Temperature

4.1.1 Specification

[FEND-40.02.03.00-00180-00 / T]

The following Table 1 details the required noise temperature performance for the Band 3 cartridge. The cartridge noise performance is referenced to its quasi optical RF input port. The noise performance includes the contributions from the IF chain (up to the cartridge IF output connectors), cryostat vacuum window and IR filters (either as fabricated for the test cryostat, or standard issue ALMA windows and filters).

Table 1

Requirement	
T_{SSB} over 80% of the frequency. range	*T_{SSB} at any frequency within The RF band*
37	62

Remarks:

- The frequency ranges of the bands in Table 1 are specified in section 3.3.1 of this document.
- The required noise temperatures shall be met when averaging over the full IF band, (as defined in section 3.3.3). At no point within the IF bandwidth shall the noise-temperature exceed the average by more than 25% when measured in a bandwidth of not more than 100 MHz.
- The noise temperature shall be calculated from measurements according to the Rayleigh-Jeans law.
- SSB noise temperatures must be corrected for residual image response.
- The noise performance shall be measured for an operating temperature of 4 ± 0.25 K, measured at the mixer block.

4.1.2 Verification Method

Please refer to [AD7].

4.1.3 Test results

The following graphs were corrected for residual image response.
The temperature sensor readings of mixers were corrected for their inherent offsets.

As shown in Figure 1, the broadband noise of the cartridge does not meet the specification. Also, the narrow band noise does not meet the specification at LO=108 GHz, as shown in Figure 18. See section 9 for more details.

4.1.3.1 Broadband Noise Temperature Plot

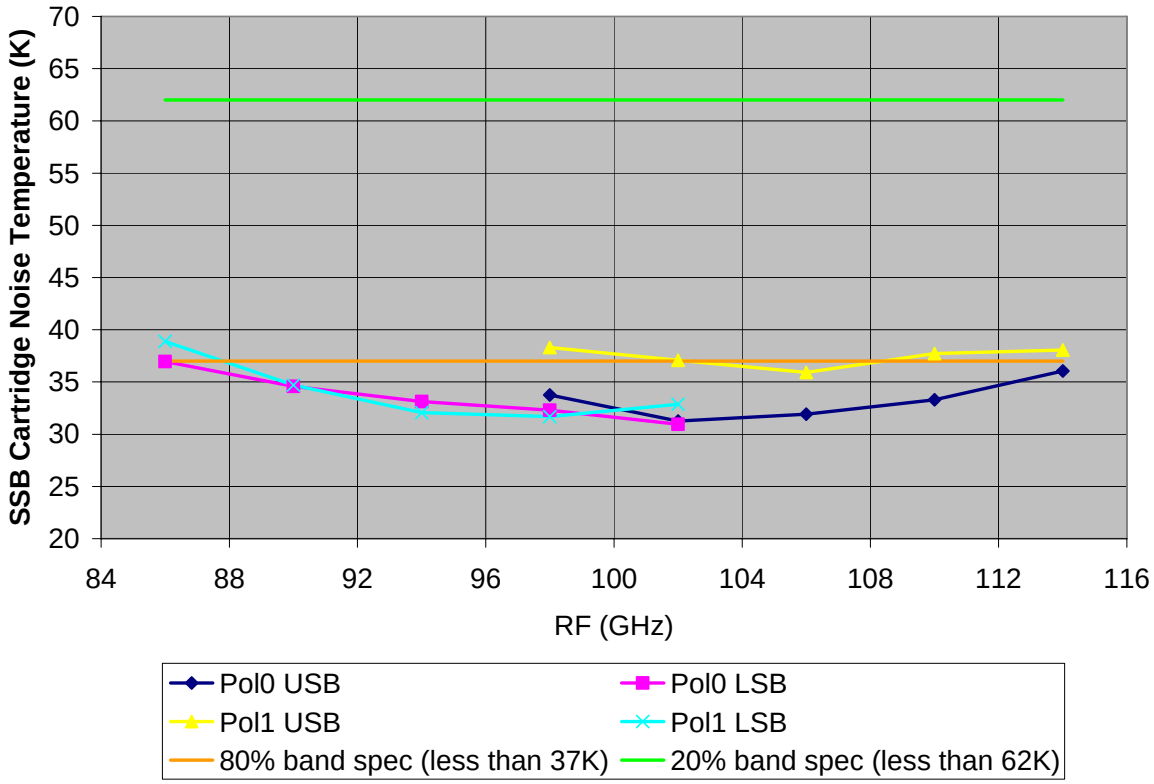
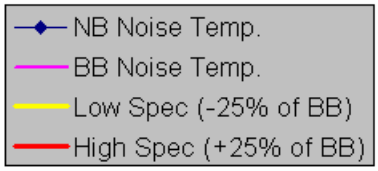


Figure 1

SSB cartridge noise temperature for the four channels plotted as function of the RF input frequency. Each point is corrected for the residual image response and is integrated over 4 GHz IF (broadband mode).

4.1.3.2 92 GHz – Narrowband & Broadband Noise Temperature Plots (corrected for residual image response)

Legend:



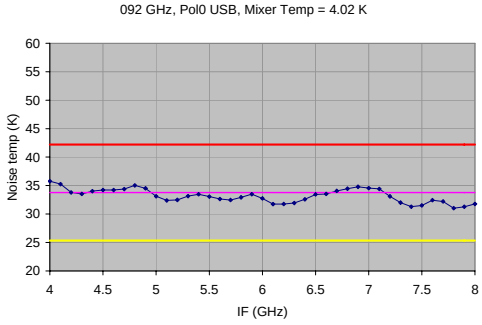


Figure 2

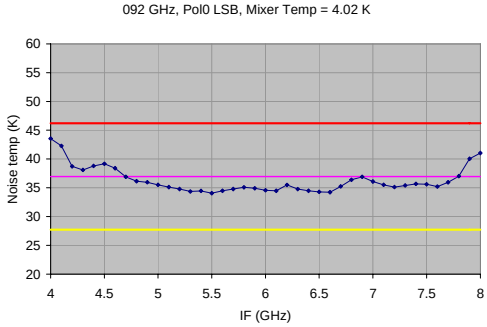


Figure 3

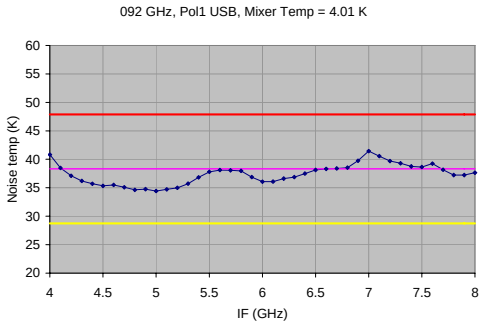


Figure 4

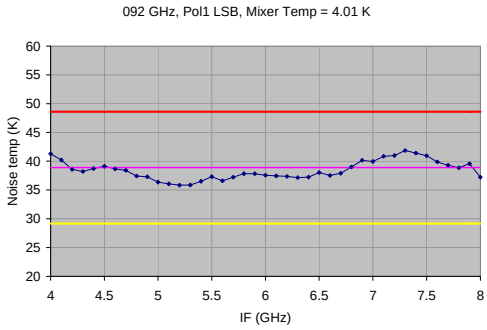


Figure 5

4.1.3.3 92 GHz – Broadband Noise Temperature

Table 2

Freq (GHz)	Pol0 USB (K)	Pol0 LSB (K)	Pol1 USB (K)	Pol1 LSB (K)
92	33.8	37.0	38.3	38.9

4.1.3.4 96 GHz – Narrowband & Broadband Noise Temperature Plots

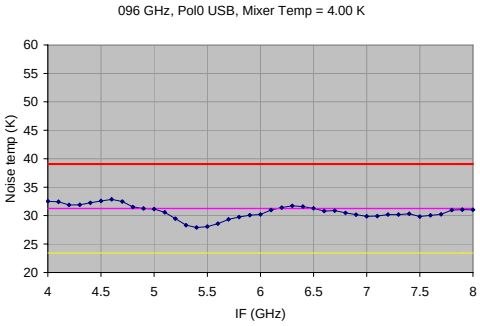
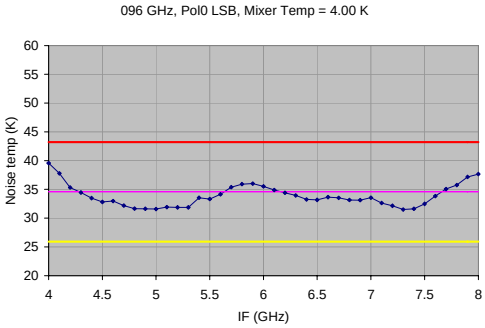


Figure 6



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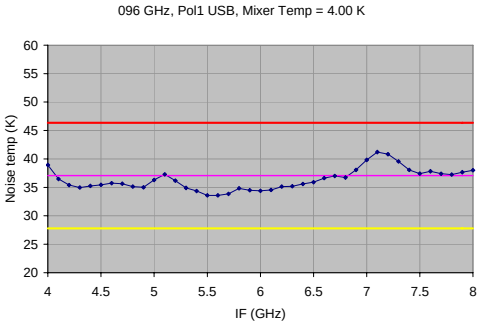


Figure 8

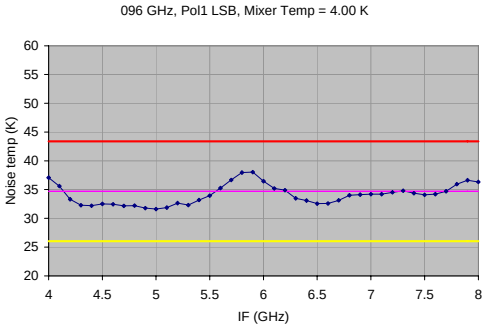


Figure 9

4.1.3.5 96 GHz – Broadband Noise Temperature

Table 3

Freq (GHz)	Pol0 USB (K)	Pol0 LSB (K)	Pol1 USB (K)	Pol1 LSB (K)
96	31.3	34.6	37.1	34.7

4.1.3.6 100 GHz – Narrowband & Broadband Noise Temperature Plots

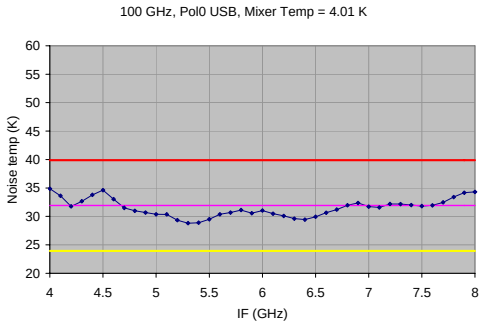


Figure 10

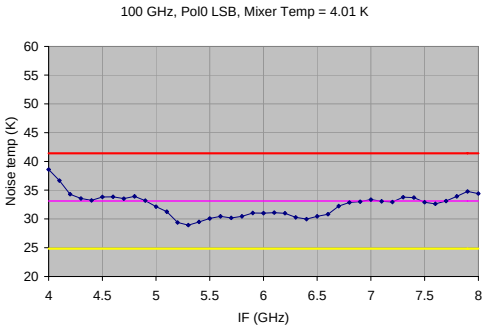


Figure 11

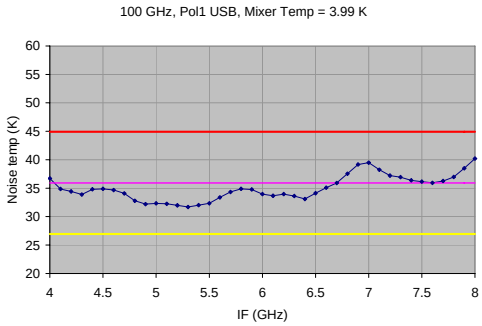


Figure 12

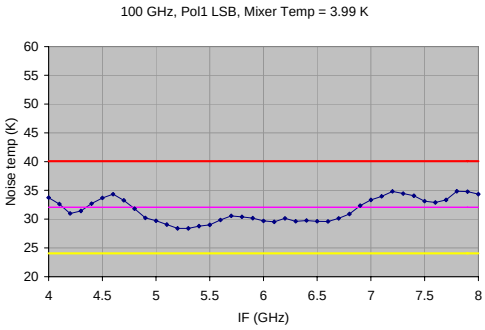


Figure 13

4.1.3.7 100 GHz – Broadband Noise Temperature

Table 4

Freq (GHz)	Pol0 USB (K)	Pol0 LSB (K)	Pol1 USB (K)	Pol1 LSB (K)
100	31.9	33.1	35.9	32.1

4.1.3.8 104 GHz – Narrowband & Broadband Noise Temperature Plots

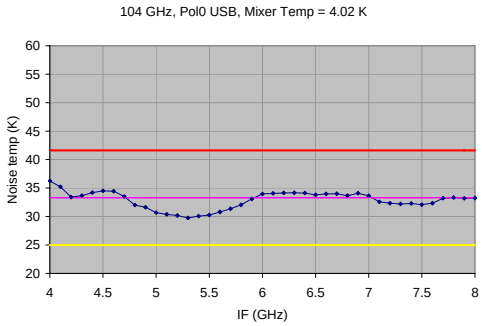


Figure 14

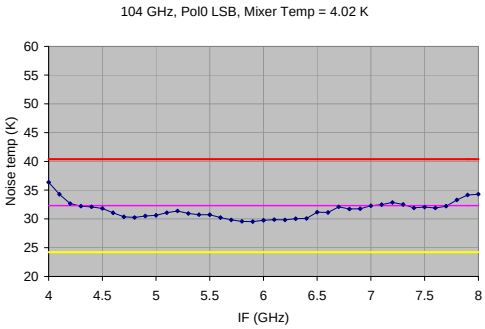


Figure 15

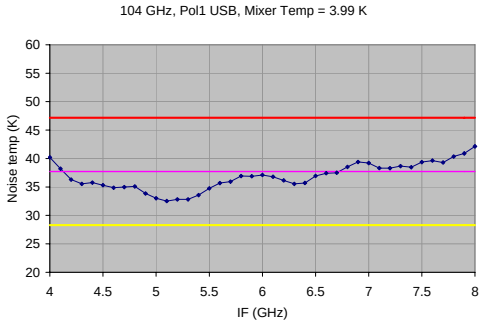


Figure 16

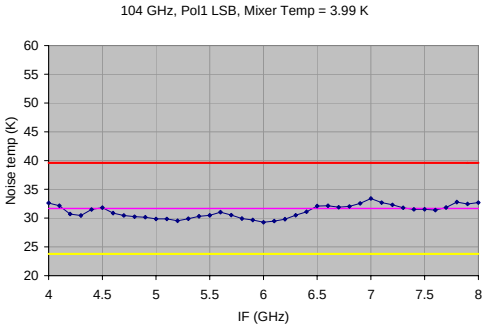


Figure 17

4.1.3.9 104 GHz – Broadband Noise Temperature

Table 5

Freq (GHz)	Pol0 USB (K)	Pol0 LSB (K)	Pol1 USB (K)	Pol1 LSB (K)
104	33.3	32.3	37.7	31.7

4.1.3.10 108 GHz – Narrowband & Broadband Noise Temperature Plots

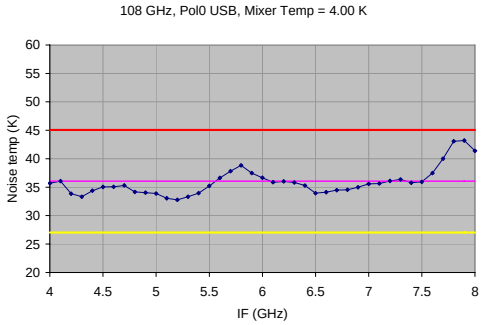


Figure 18

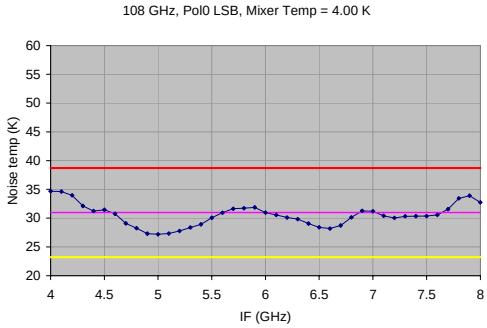
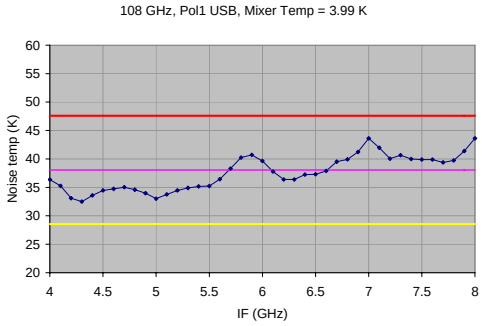


Figure 19



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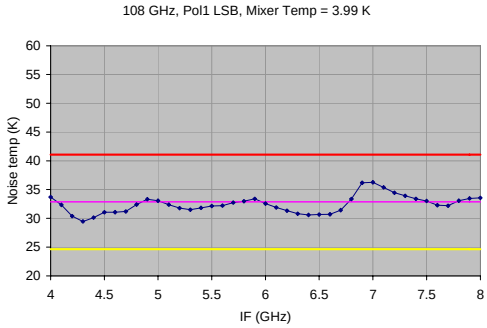


Figure 21

4.1.3.11 108 GHz – Broadband Noise Temperature

Table 6

Freq (GHz)	Pol0 USB (K)	Pol0 LSB (K)	Pol1 USB (K)	Pol1 LSB (K)
108	36.0	31.0	38.1	32.9

4.2 Image band suppression and sideband mismatch

4.2.1 Specification

[FEND-40.02.03.00-00190-00 / T]

The image-band suppression shall be 10 dB or better across the full IF band.

4.2.2 Verification Method

Please refer to [AD7].

4.2.3 Test results

4.2.3.1 92 GHz

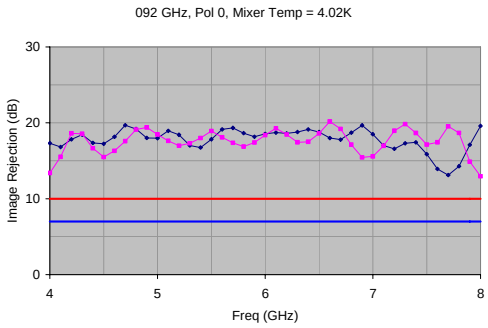


Figure 22

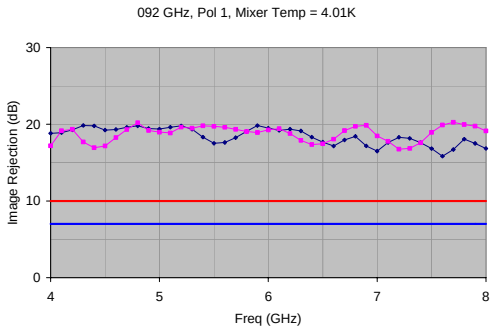


Figure 23

4.2.3.2 96 GHz

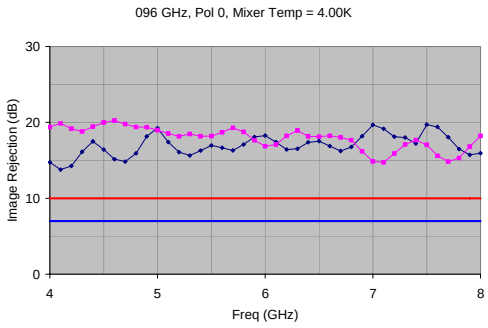


Figure 24

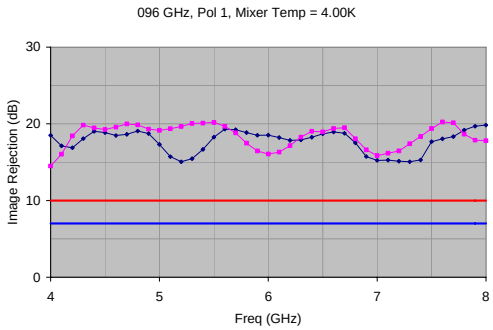


Figure 25

4.2.3.3 100 GHz

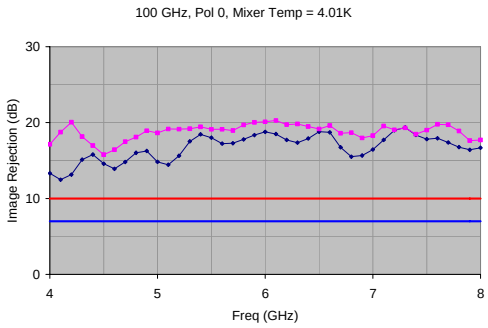


Figure 26

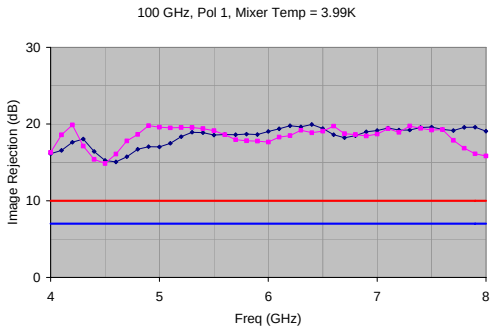


Figure 27

4.2.3.4 104 GHz

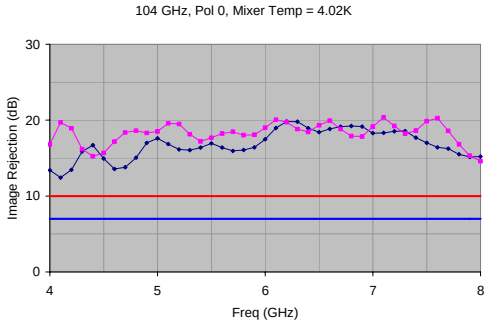


Figure 28

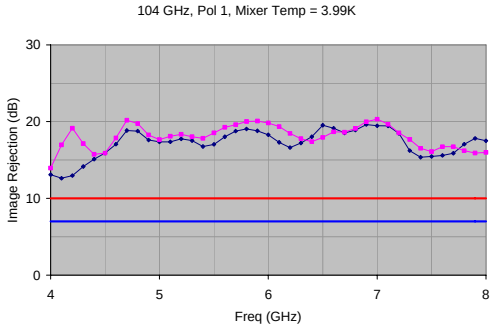


Figure 29

4.2.3.5 108 GHz

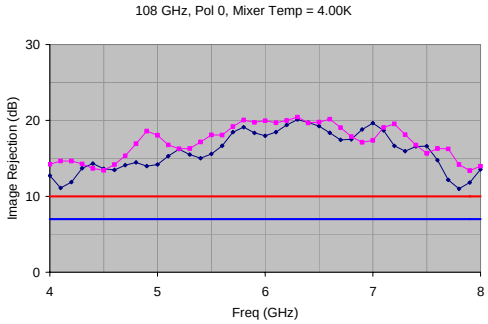


Figure 30

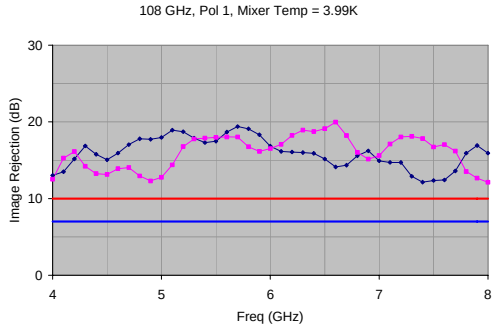


Figure 31

4.2.3.6 Summary

LO Freq (GHz)	Pass (% of IF bandwidth)							
	Pol 0 R-usb		Pol 0 R-lsb		Pol 1 R-usb		Pol 1 R-lsb	
	Better than 10 dB	Better than 7 dB	Better than 10 dB	Better than 7 dB	Better than 10 dB	Better than 7 dB	Better than 10 dB	Better than 7 dB
92	100	100	100	100	100	100	100	100
96	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100
104	100	100	100	100	100	100	100	100
108	100	100	100	100	100	100	100	100

4.3 Cartridge IF power

The Band 3 cartridge IF signals at the output IF connectors shall have the following specifications. These specifications are valid for all four IF outputs.

Table 7: Specifications of the IF electronic interface

4 - 8 GHz IF	
Minimum Frequency	4 GHz
Maximum Frequency	8 GHz
Maximum Total Power @ 4-8 GHz	-25 dBm
Maximum Total Power @ 10 MHz – 18 GHz	-20 dBm
Minimum Total Power @ 4-8 GHz	-40 dBm
Maximum Spectral Power @ 4-8 GHz	-61 dBm/MHz
Minimum Spectral Power @ 4-8 GHz	-74 dBm/MHz
Gain Slope	6 dB peak to peak across the whole IF band measured in a 100MHz resolution
Ripple	4 dB peak to peak in any 2 GHz portion of the IF band measured in a 100MHz resolution
VSWR	≤ 1.4 on both sides of the interface
Impedance	50 Ω

4.3.1 IF output power

4.3.1.1 Specification

[FEND-40.02.03.00-00200-00 / T]

With a 300 K load at the RF input of the cartridge, the output power for each of the cartridge IF outputs shall comply with the requirements described in [AD4].

Remarks:

These power levels must be measured at the IF outputs of the warm cartridge assembly that houses the second-stage IF amplifier and the first local oscillator chain.

4.3.1.2 Verification Method

Please refer to [AD7].

4.3.1.3 Test results

Table 8

Total in-band power

			Total In-band Power (dBm)			
Freq (GHz)	Min Spec (dBm)	Max Spec (dBm)	Pol0 USB	Pol0 LSB	Pol1 USB	Pol1 LSB
92	-32	-22	-25.2	-26.7	-27.9	-24.5
96	-32	-22	-24.2	-26.1	-27.5	-23.9
100	-32	-22	-24.2	-25.9	-27.5	-23.7
104	-32	-22	-24.3	-25.7	-27.9	-24.3
108	-32	-22	-24.4	-25.6	-27.9	-24.1

Table 9

Total power

			Total Power (dBm)			
Freq (GHz)	Min Spec (dBm)	Max Spec (dBm)	Pol0 USB	Pol0 LSB	Pol1 USB	Pol1 LSB
92	N/A	-20	-23.8	-24.9	-25.9	-22.8
96	N/A	-20	-22.9	-24.4	-25.7	-22.4
100	N/A	-20	-22.9	-24.3	-25.7	-22.2
104	N/A	-20	-22.9	-24.0	-25.5	-22.8
108	N/A	-20	-23.1	-23.9	-26.1	-22.6

4.3.2 IF spectral power density

4.3.2.1 Specification

[FEND-40.02.03.00-00200-00 / T]

With a 300 K load at the RF input of the cartridge, the output power for each of the cartridge IF outputs shall comply with the requirements described in [AD4].

Remarks:

These power levels must be measured at the IF outputs of the warm cartridge assembly that houses the second-stage IF amplifier and the first local oscillator chain.

4.3.2.2 Verification Method

Please refer to [AD7].

4.3.2.3 Test results

Table 10

Max Spectral Density

	Max Spectral Density (dBm/MHz)				
Freq (GHz)	Max Spec	Pol0 USB	Pol0 LSB	Pol1 USB	Pol1 LSB
92	-61	-57.8	-59.2	-60.5	-57.7
96	-61	-57.7	-59.7	-60.6	-57.2
100	-61	-57.8	-59.3	-60.9	-56.9
104	-61	-57.8	-59.0	-60.6	-56.4
108	-61	-57.8	-58.9	-61.2	-57.5

Note that the specification for the maximum spectral density needs to be updated as the maximum in band power level was increase to -22 dBm.

Table 11

Min Spectral Density

	Min Spectral Density (dBm/MHz)				
Freq (GHz)	Min Spec	Pol0 USB	Pol0 LSB	Pol1 USB	Pol1 LSB
92	-74	-61.2	-62.6	-64.6	-61.6
96	-74	-61.3	-62.6	-64.3	-61.1
100	-74	-61.6	-62.8	-64.2	-60.8
104	-74	-61.7	-62.6	-64.0	-60.6
108	-74	-62.3	-62.3	-64.2	-61.0

IF spectral power at 92 GHz

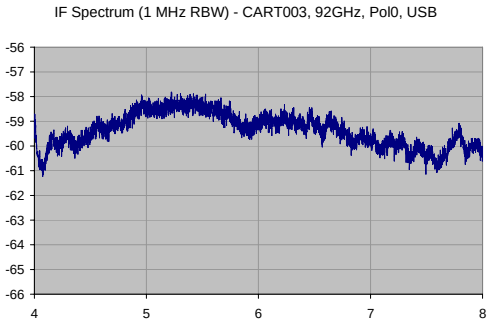


Figure 32

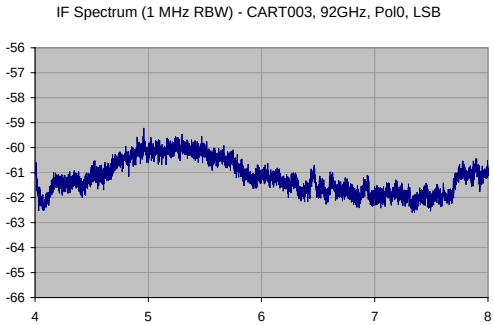


Figure 33

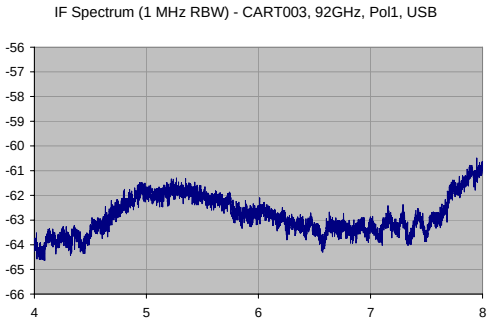


Figure 34

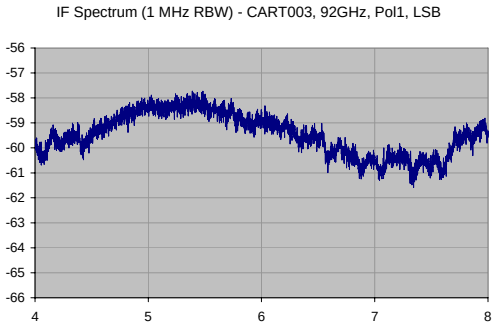


Figure 35

IF spectral power at 96 GHz

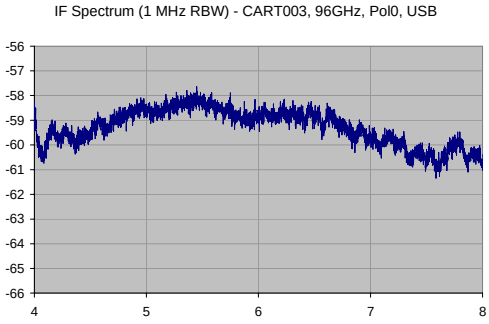


Figure 36

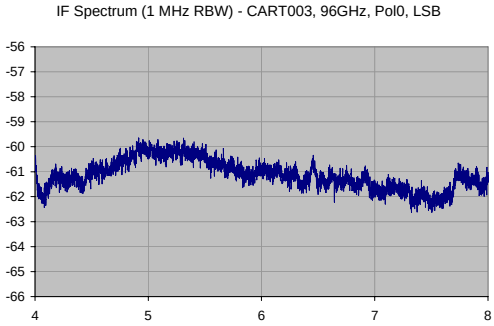


Figure 37

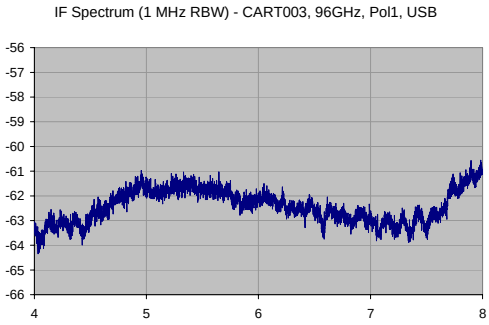


Figure 38

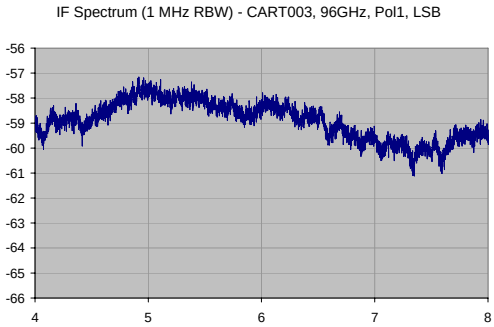


Figure 39

IF spectral power at 100 GHz

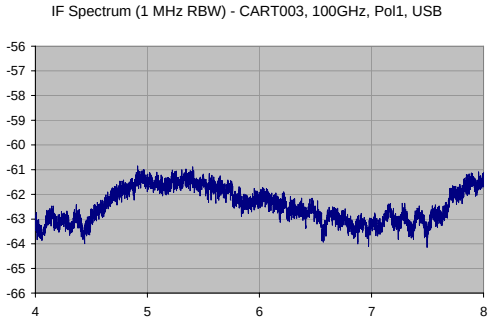


Figure 40

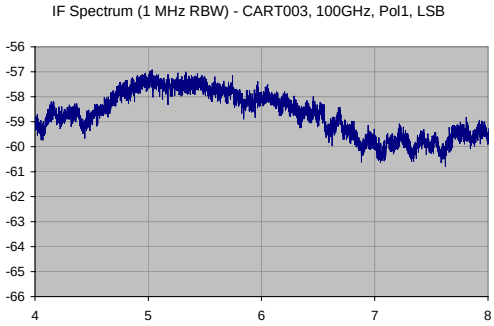


Figure 41

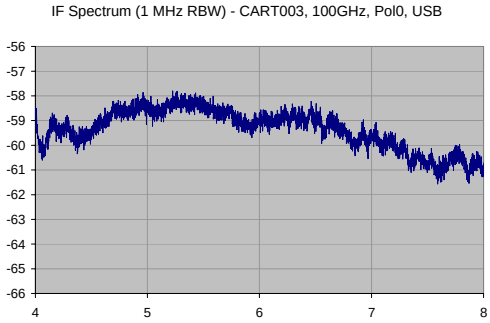


Figure 42

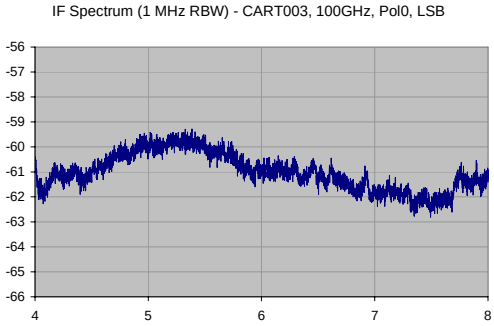


Figure 43

IF spectral power at 104 GHz

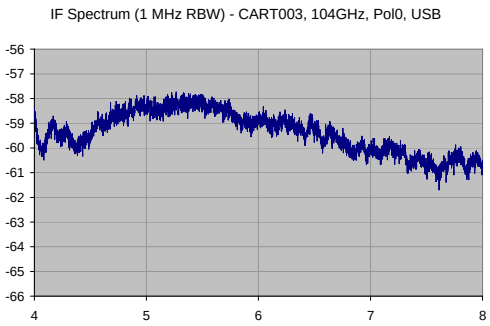


Figure 44

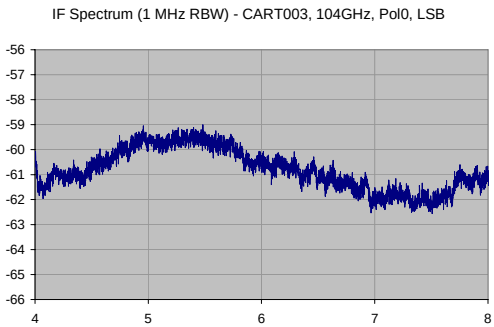


Figure 45

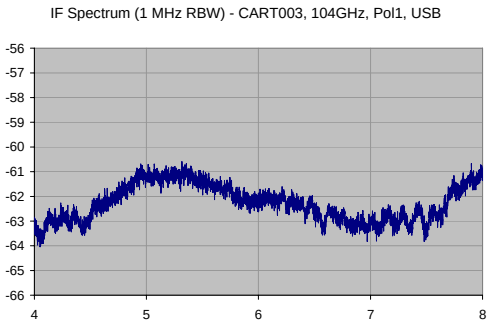


Figure 46

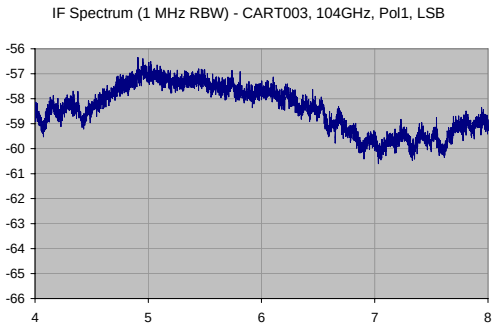


Figure 47

IF spectral power at 108 GHz

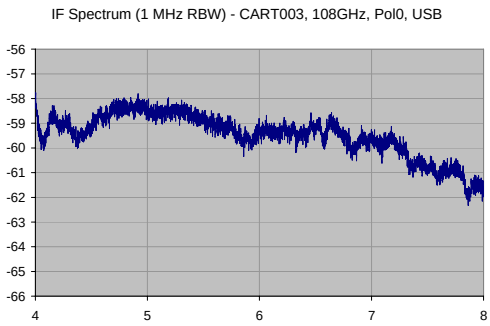


Figure 48

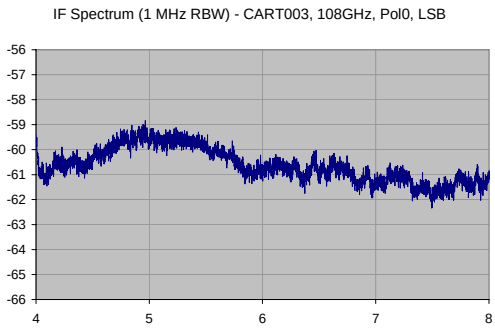


Figure 49

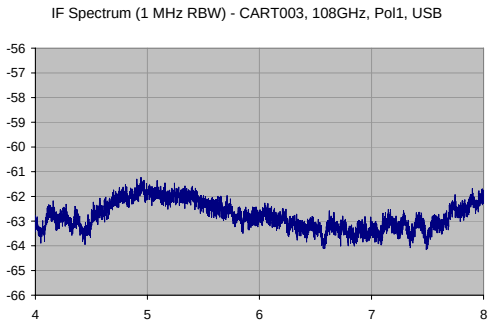


Figure 50

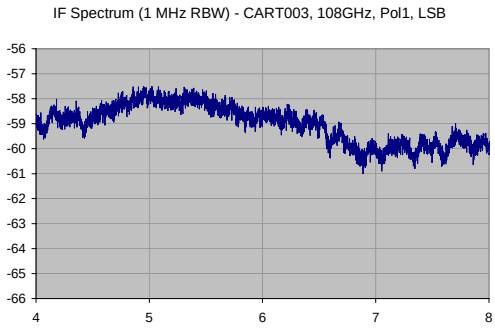


Figure 51

4.3.3 IF power variations

4.3.3.1 Specification

[FEND-40.02.03.00-00210-00 / T]

Within the IF band (as specified in section 3.3.3), variations from the average IF power must be as described in [AD4].

4.3.3.2 Verification Method

Please refer to [AD7].

4.3.3.3 Test Results

Table 12

Max 2 GHz sub-band IF power variation

	Sub-band pk-pk (dB)				
Freq (GHz)	Max Spec (dB)	Pol0 USB	Pol0 LSB	Pol1 USB	Pol1 LSB
92	4.0	2.1	2.0	2.5	2.5
96	4.0	2.3	1.7	2.1	2.0
100	4.0	2.4	2.2	1.9	2.6
104	4.0	2.6	2.5	2.1	2.8
108	4.0	2.5	1.8	1.7	2.4

Table 13

Max Full IF band power variation

	Full-band pk-pk (dB)				
Freq (GHz)	Max Spec	Pol0 USB	Pol0 LSB	Pol1 USB	Pol1 LSB
92	6.0	2.3	2.0	3.0	2.5
96	6.0	2.4	2.0	2.4	2.5
100	6.0	2.7	2.4	1.9	2.8
104	6.0	2.7	2.6	2.1	2.9
108	6.0	3.3	2.2	1.7	2.4

4.3.3.3.1 92 GHz

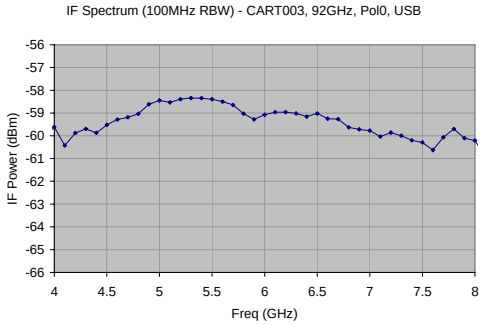


Figure 52

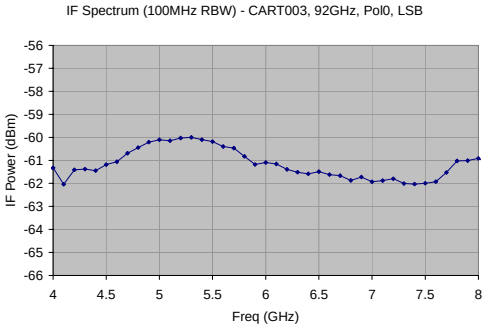


Figure 53

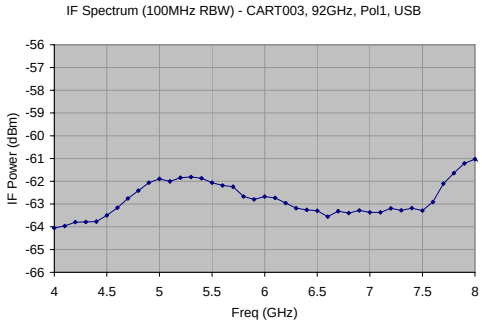


Figure 54

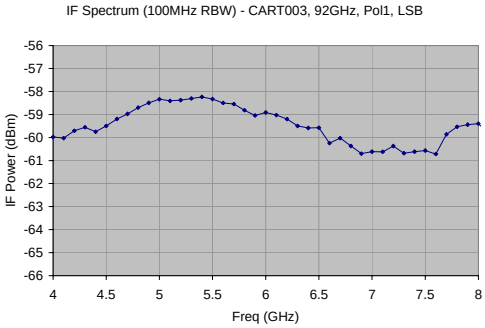


Figure 55

4.3.3.3.2 96 GHz

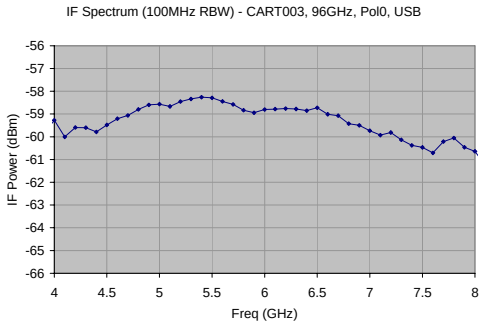


Figure 56

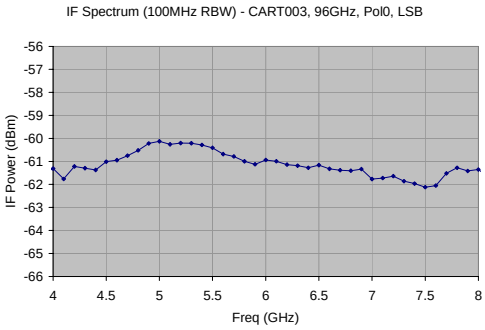


Figure 57

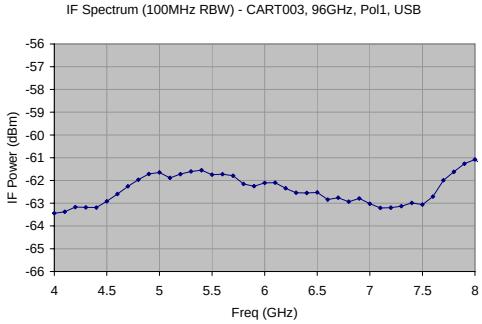


Figure 58

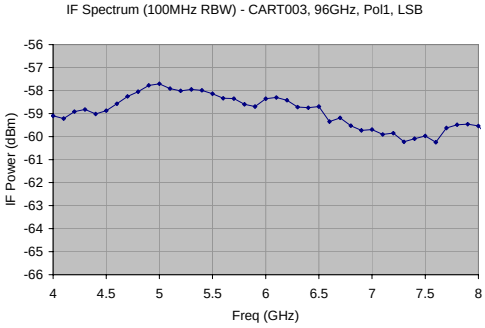


Figure 59

4.3.3.3.3 100 GHz

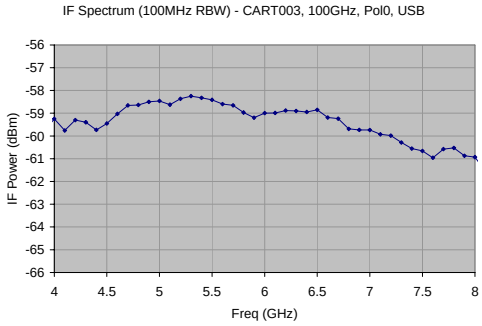


Figure 60

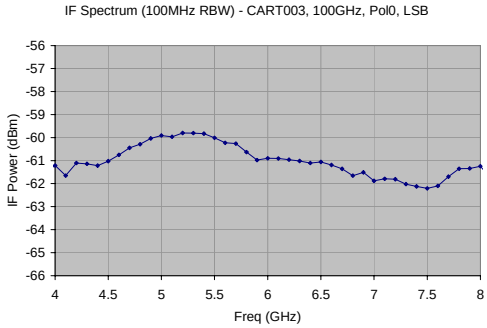


Figure 61

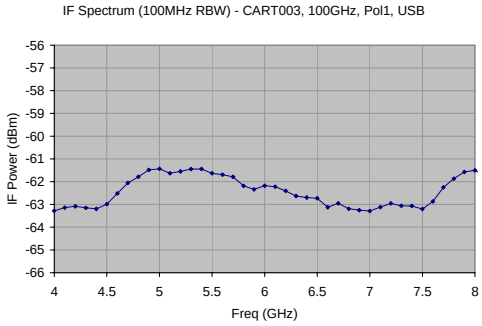


Figure 62

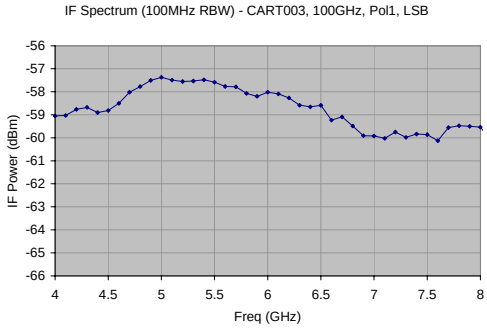


Figure 63

4.3.3.3.4 104 GHz

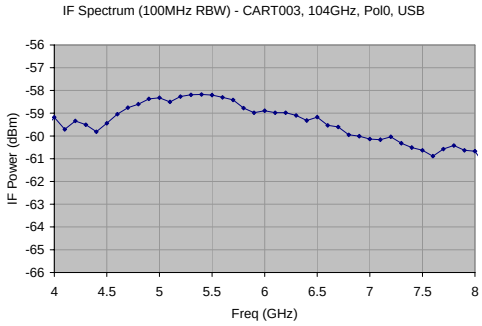


Figure 64

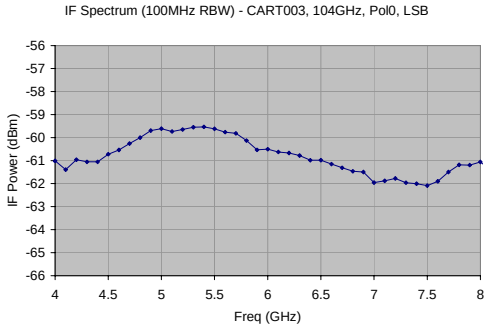


Figure 65

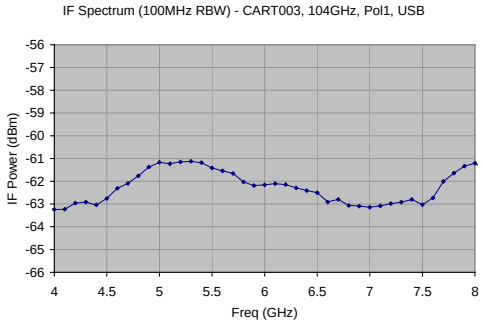


Figure 66

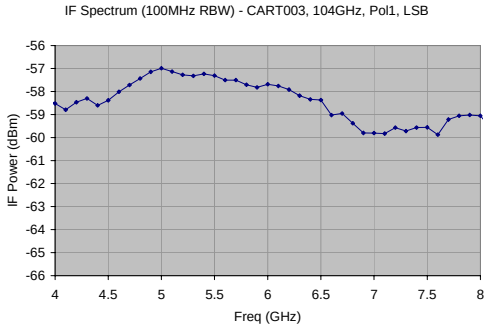


Figure 67

4.3.3.3.5 108 GHz

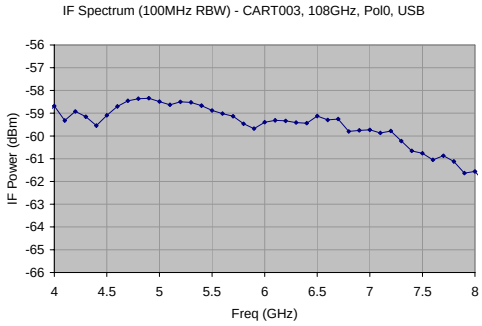


Figure 68

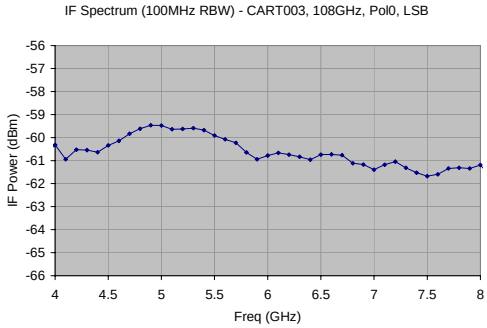


Figure 69

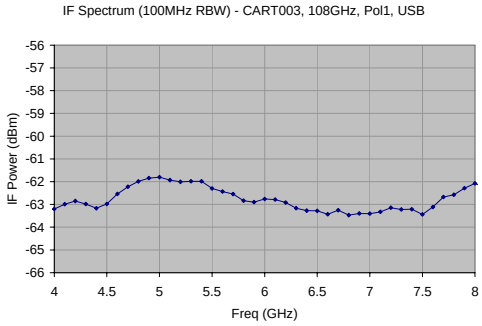


Figure 70

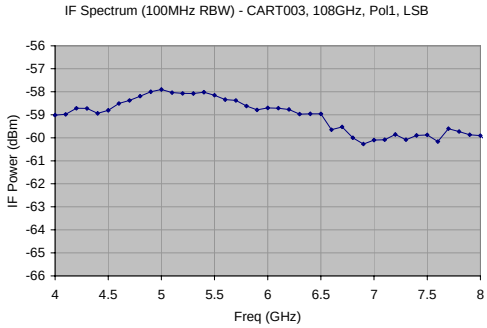


Figure 71

4.3.4 VSWR

4.3.4.1 Specification

The VSWR at the four IF ports of the Band 3 cartridge must be less or equal to 1.4.

4.3.4.2 Verification Method

Please refer to [AD7].

The maximum output VSWR is displayed in Table 14 hereafter.

4.3.4.3 Test Results

Table 14

	Maximum VSWR at the output of Warm Cartridge Assembly	Specification
Pol0 USB	1.2	≤ 1.4
Pol0 LSB	1.3	≤ 1.4
Pol1 USB	1.2	≤ 1.4
Pol1 LSB	1.1	≤ 1.4

4.3.5 Gain matching amongst Band 3 cartridges

[FEND-40.02.03.00-00220-00 / T]

When comparing the IF pass-band characteristics of any two Band 3 cartridges, the difference in the exponential slope in any 2 GHz portion of the IF band shall not exceed 3 dB.

Not tested.

4.4 Gain compression

4.4.1 Specification

[FEND-40.02.03.00-00230-00 / T]

The large signal gain compression caused by the exchange of RF load temperatures of 77 and 300K must be less than 5 %.

4.4.2 Verification Method

The technique is described in [AD7].

4.4.3 Test results

Table 15

	Gain Compression (%)			
Freq (GHz)	Pol0 USB	Pol0 LSB	Pol1 USB	Pol1 LSB
92	3.1	3.0	2.1	2.7
100	1.6	2.3	2.4	2.6
108	1.5	1.8	0.6	0.9

4.5 Amplitude stability

4.5.1 Specification

[FEND-40.02.03.00-00240-00 / T]

The IF amplitude stability, measured at the IF output connectors of the warm cartridge assembly that houses the second-stage IF amplifier and the local oscillator chain, shall comply with the following requirements:

- The Allan variance, σ2(2, T, 0.9*T), of the IF output power in the IF band (specified in sections 4.3.1 and 3.3.3) must be less than 4.0 10-7 for timescales between 0.1 and one second (ALMA Spec 1) and 8.0 10-5 at 100 seconds (ALMA Spec 2).
- The Allan variance of the difference of the output IF powers of the two polarization channels (differential polarization variance) shall be less than 5.5 10-7 for T in the range from 0.1 to 1.0 second (ALMA Spec 1) and 1.1 10-4 at 100 seconds (ALMA Spec 2).

Note that this amplitude stability must be achieved when using the first local oscillator chain as supplied by the ALMA project.

4.5.2 Verification Method

Please refer to [AD7].

4.5.3 Test results

4.5.3.1 Single Channel – 92, 100, & 108 GHz

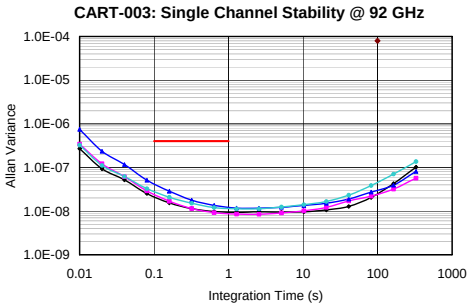


Figure 72

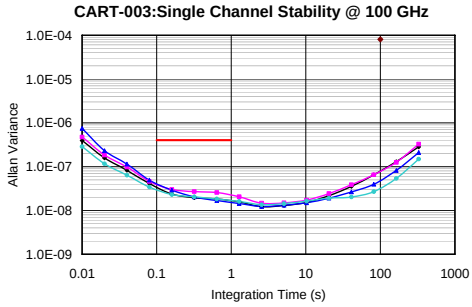


Figure 73

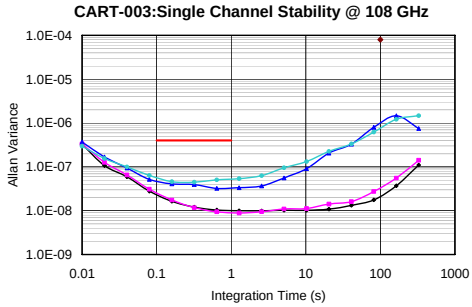


Figure 74

4.6 Signal path phase stability

4.6.1 Specification

[FEND-40.02.03.00-00250-00 / T]

For all frequencies within the IF pass-band the signal path transfer function shall maintain a phase stability of better than 0.25 degrees. This delay drift refers to a two-point Allan Standard Deviation with fixed averaging time of 10 s and for intervals between 20 and 300 s. The signal path shall include all components between the RF window and the IF outputs of the warm assembly that houses the second-stage amplifier and the local oscillator chain. The required phase stability excludes any contribution from the local oscillator chain. The phase stability must be maintained as the gravity vector is varied within a solid angle of three degrees.

4.6.2 Verification Method

Please refer to [AD7].

4.6.3 Test results

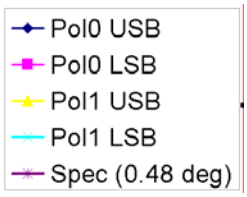
The cartridge was tested at 3 LO frequencies – 92, 100, and 108 GHz.
Please note that the following graphs show the phase drift of the entire system and does not de-embed the contribution of the LO, and the two amplifiers (used in the test setup). The LO phase drift specification is 12.5 fs [AD17], which corresponds to 0.41 deg at 92 GHz which is the worst case (lowest LO frequency). Therefore, the specification for the cartridge + LO system, as tested at HIA is;

$$Band3System = \sqrt{(Band3cartridge)^2 + (Band3LO)^2} = 0.48\,\text{deg}$$

The test instrumentation, such as the two room temperature amplifiers are not de-embedded, therefore, the measurements provide an upper limit of the Band 3 cartridge phase drift.

Phase plots at 92 GHz

Legend:



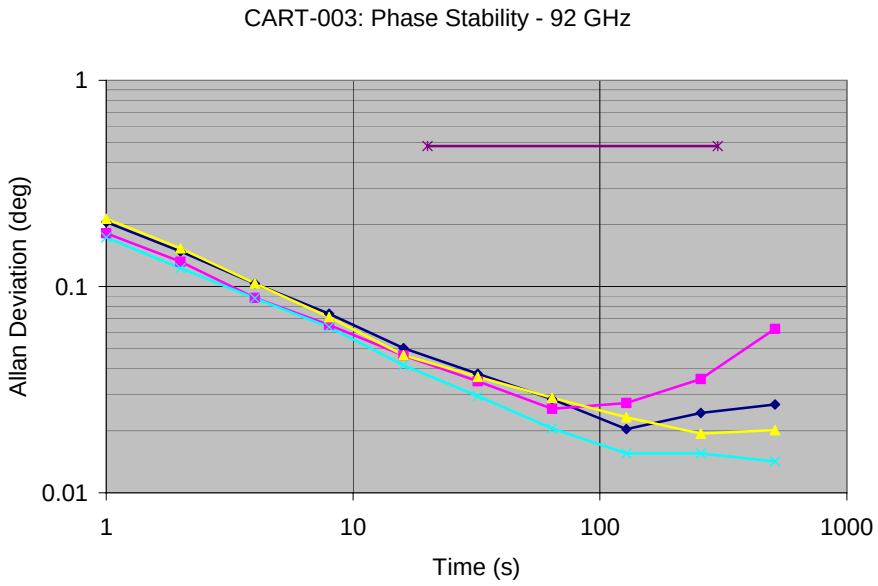


Figure 75

Phase at 100 GHz

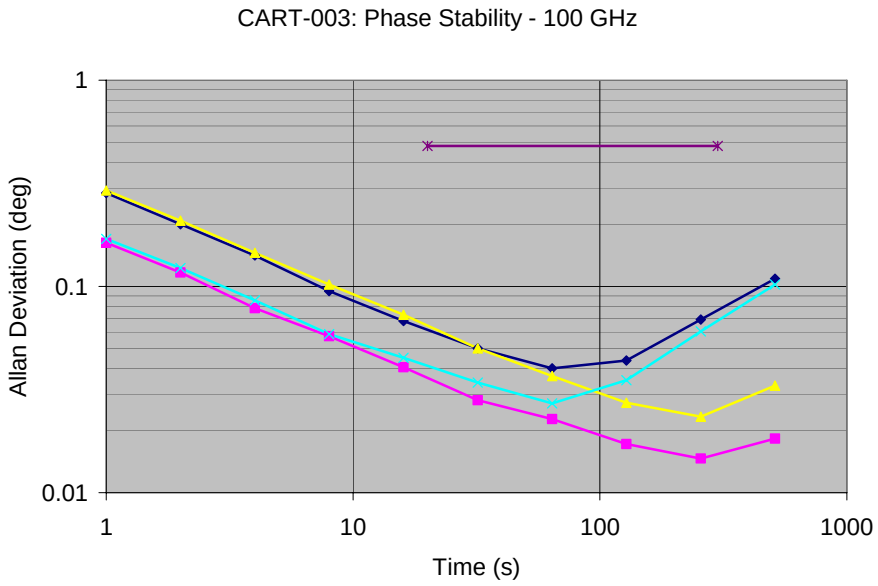


Figure 76

Phase at 108 GHz

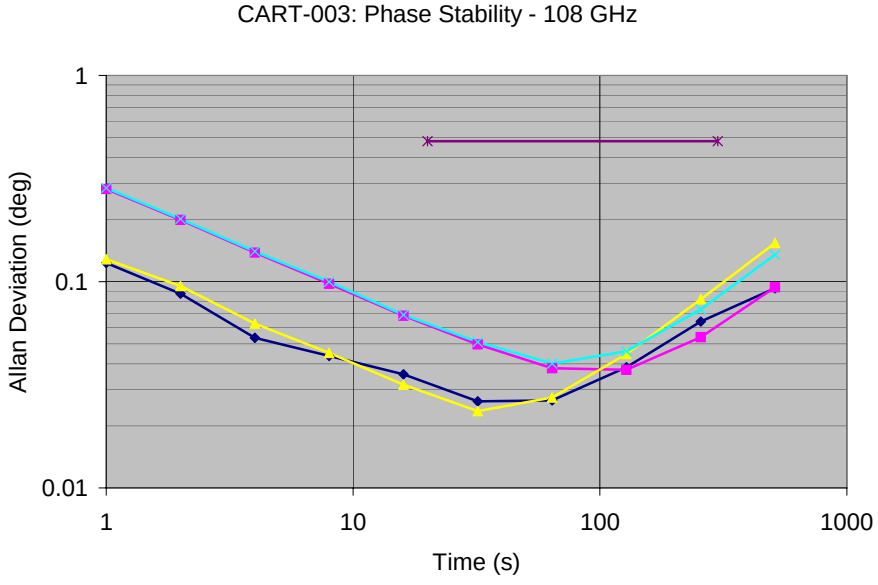


Figure 77

4.7 Optics

4.7.1 Beam Scan

4.7.1.1 Specification

[FEND-40.02.03.00-082-00-A-PLA]

The objective of this experiment is to verify the design of the cold optics including horn, lens, IR filters, and window. The side-lobes of the amplitude must be below 20dB. The shape of the beam shall also be qualified.

4.7.1.2 Verification Method

The experiment described below is using the recently acquired beam scanner. This set up is a first step towards a full Near Field Scan System as it only allows the amplitude to be measured accurately. Without the phase information amplitude scans taken at a distance of 45 Cm from the feedhorn, which is assumed to be in the far-field were acquired. The scans allow the verification of the sidelobe levels to be below 20 dB levels. New hardware has been ordered to provide a phase and amplitude scan at a later date.

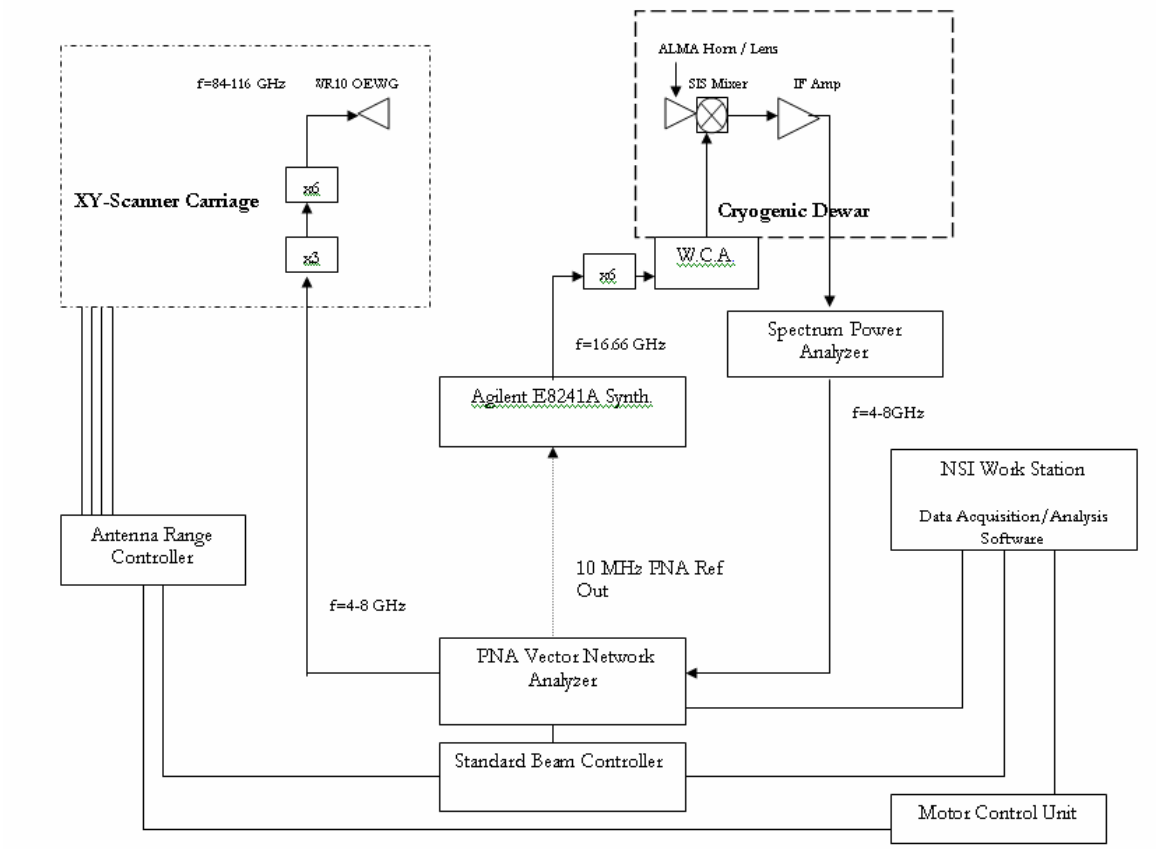


Figure 1: Block Diagram of Proposed ALMA Band 3 Beam Pattern Measurement System Using VNA

An Agilent PNA vector network analyzer, and a planar near field antenna range provided by Near Field Systems were used to measure the amplitude of the radiation pattern of the Band 3 feed horn. The test setup is shown above in Figure 1. The Band 3 RF frequencies were produced by up-converting the PNA's output frequency (operating at the Band 3 4-8 GHz IF) by a factor of 18x. Phase measurements were not stable using this configuration because of inherent drift between the two signal sources required for transmission and reception.

The scanner was placed at a distance of 45 cm along the transmission axis from the band 3 horn aperture. This distance, along with scan center, vertical and horizontal alignment was determined by a FARO arm (3 D coordinate measurement probe) with an accuracy of 1 cm. Polarization alignment was accomplished by locating a power minimum for a range of cross polar angular values. This had an approximate accuracy of 1 degree.

A span area 36.858 cm x 36.858 cm was sampled at intervals spaced 6.95 mm apart for each scan. This represents an approximate angular range of +/- 20 degrees off of the beam center axis. Amplitude readings were normalized to the on axis, co polar power level taken before

the scan. Cross Polar plots were generated by rotating the probe by 90 degrees and were normalized to the original, co-polar, on-axis reading.

4.7.1.3 Test results

RF=87.2 GHz (92GHz LO, Pol0 LSB)

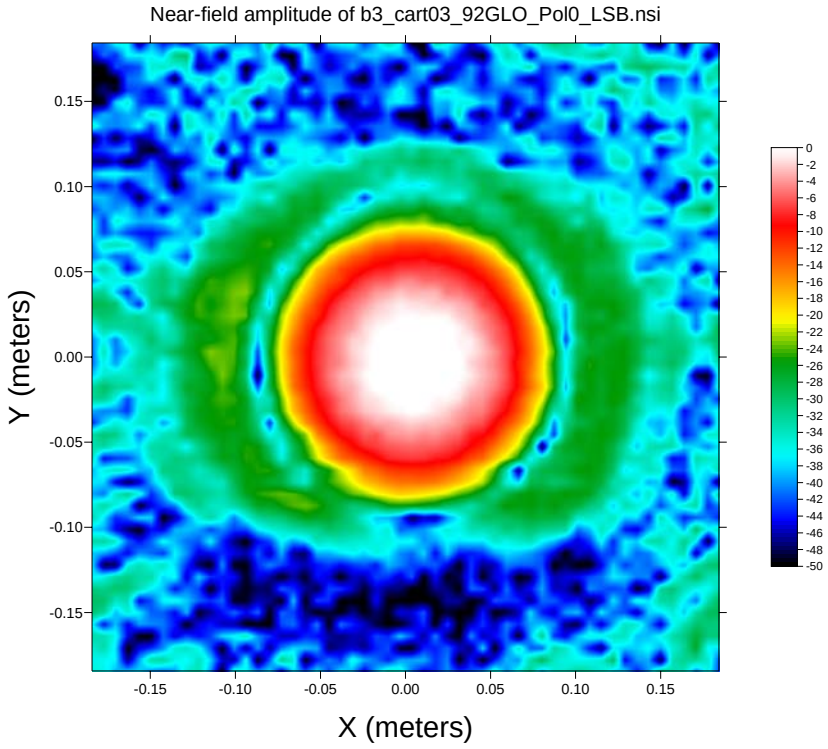


Figure 78 - CoPol

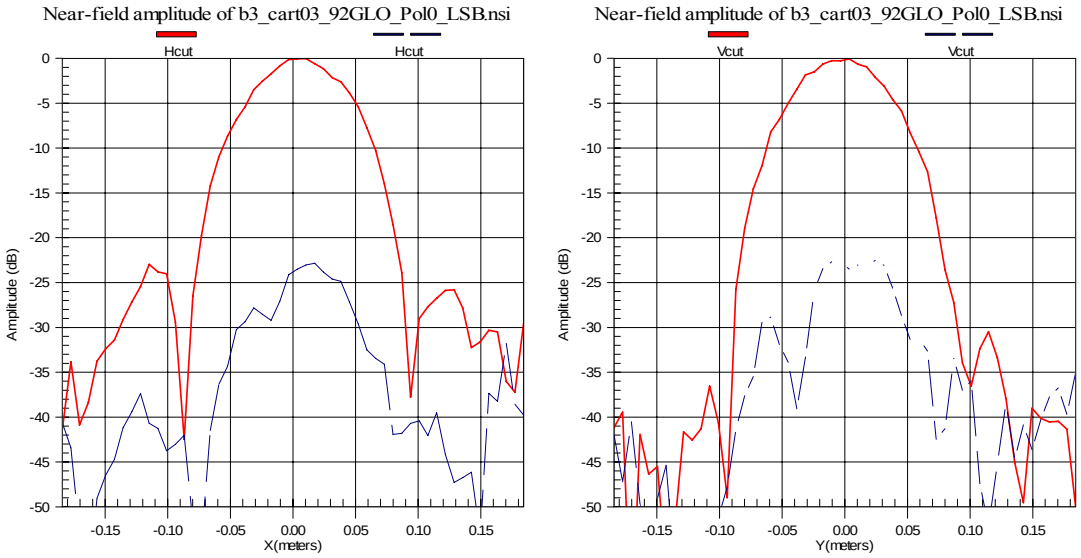


Figure 79 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol (dashed blue)

RF=97.4 GHz (92 GHz LO, Pol0, USB)

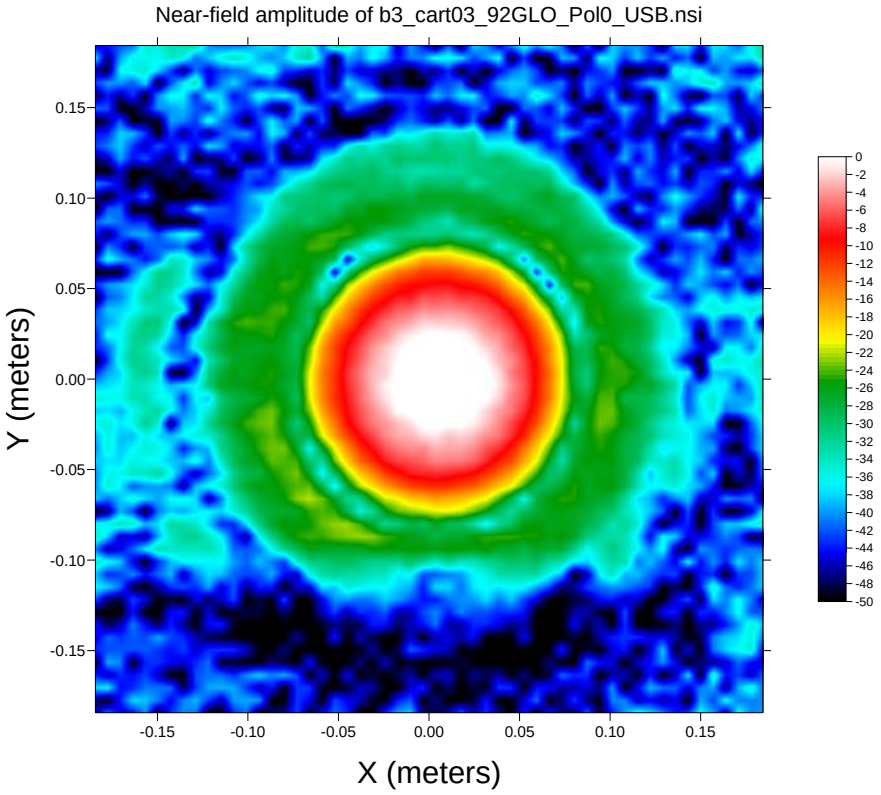


Figure 80 - CoPol

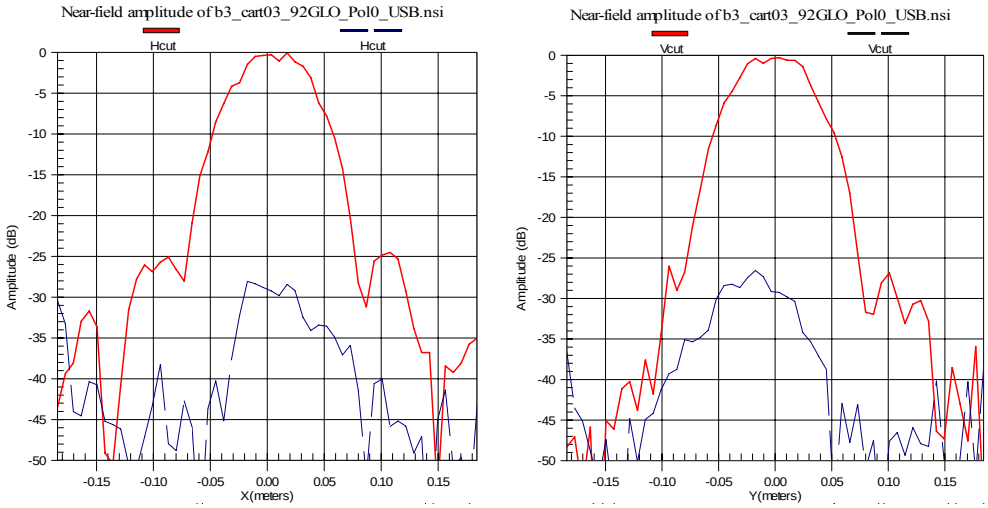


Figure 81 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol (dashed blue)

RF=91.0 GHz (96 GHz LO, Pol0, LSB)

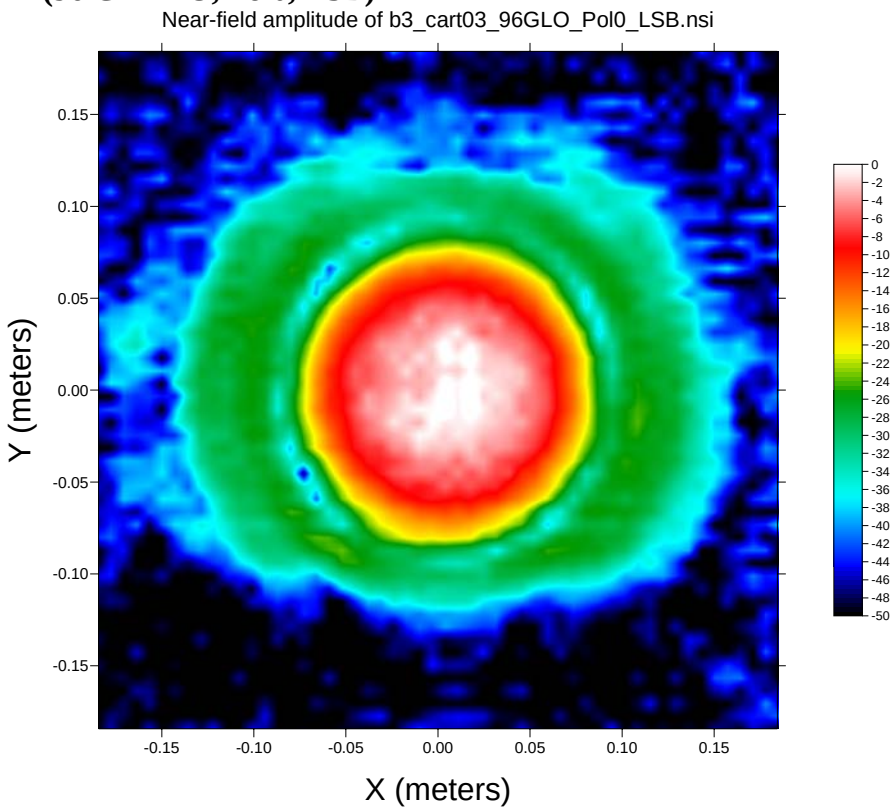


Figure 82 - CoPol

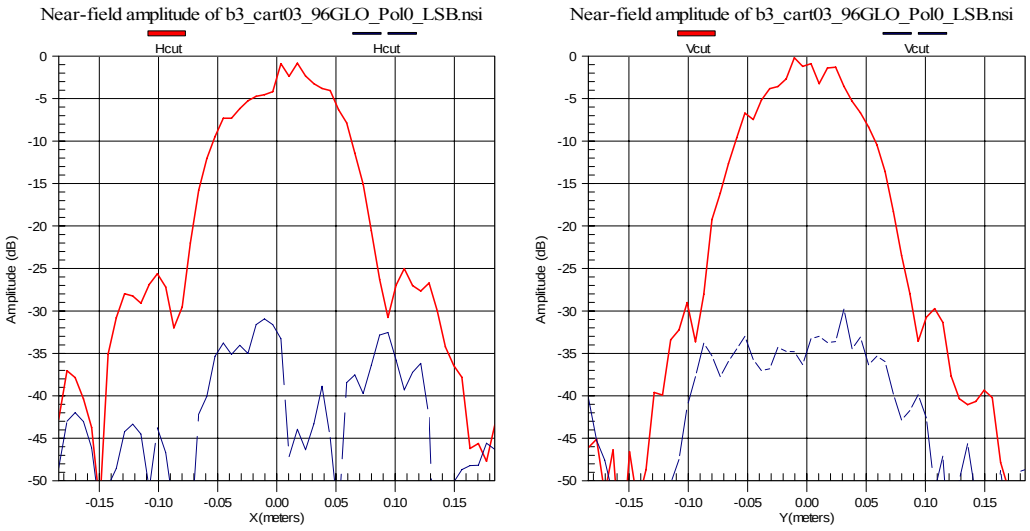


Figure 83 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol (dashed blue)

RF=101.7 GHz (96GHz LO, Pol0, USB)

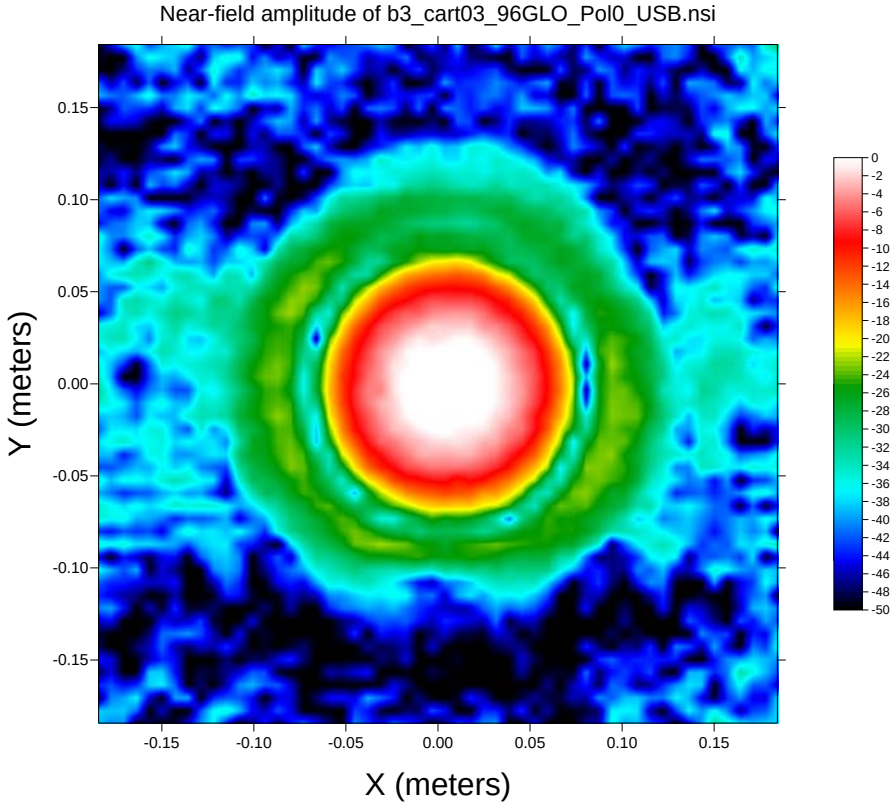


Figure 84 - CoPol

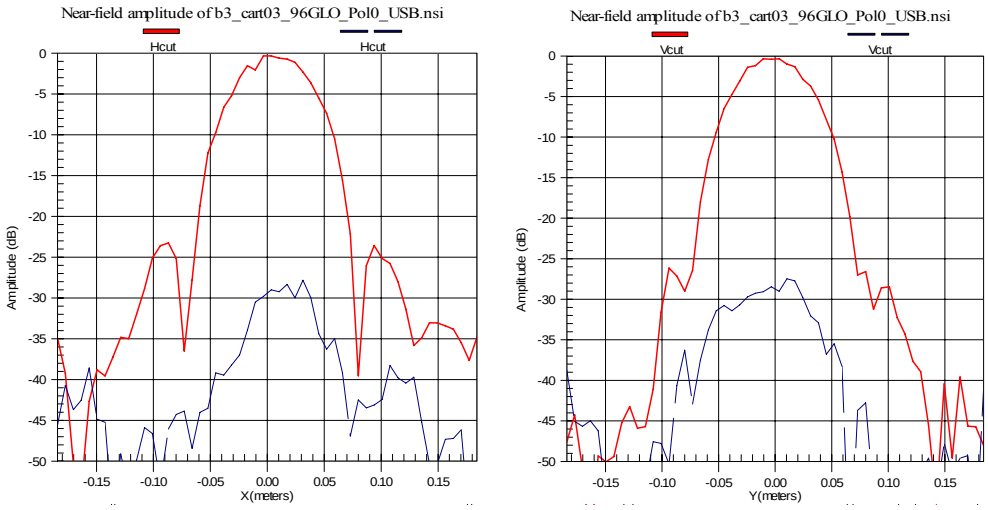


Figure 85 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol (dashed blue)

RF=94.8 GHz (100GHz LO, Pol0, LSB)

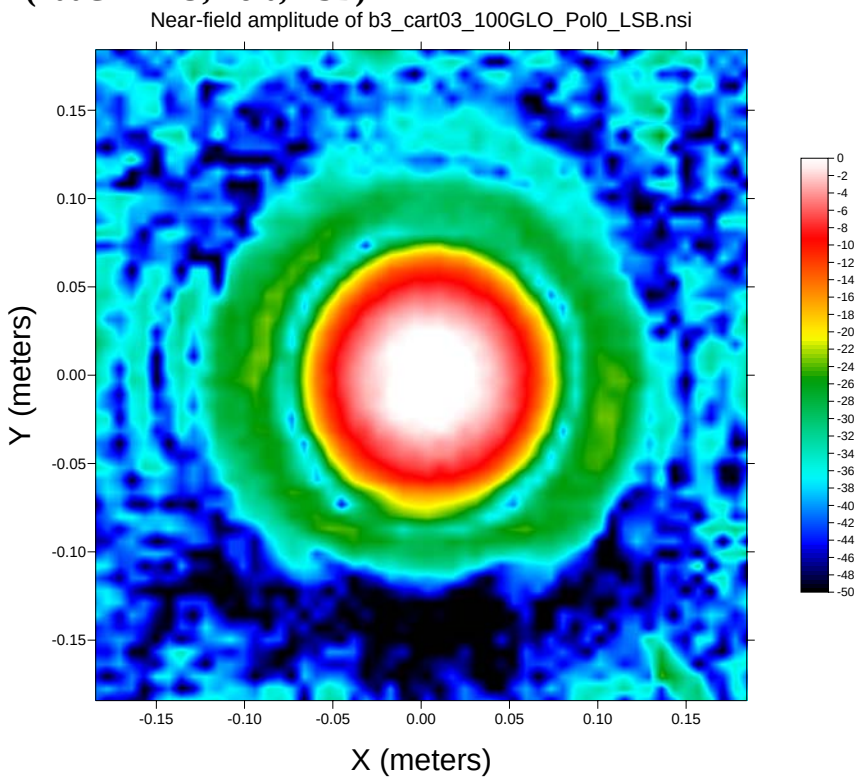


Figure 86 - CoPol

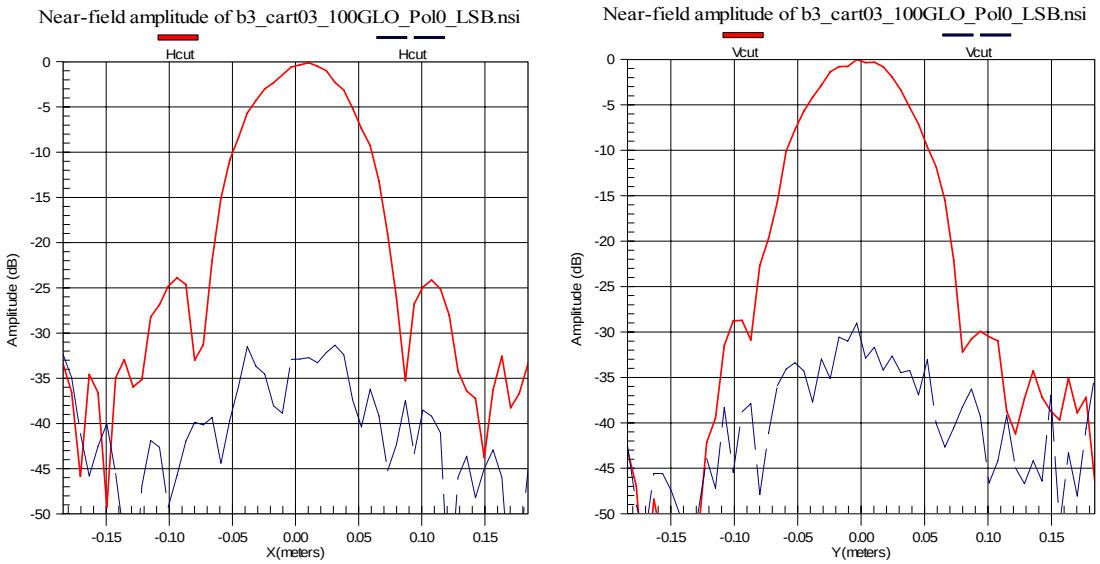


Figure 87 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol (dashed blue)

RF=105.9 GHz (100GHz LO, Pol0, USB)

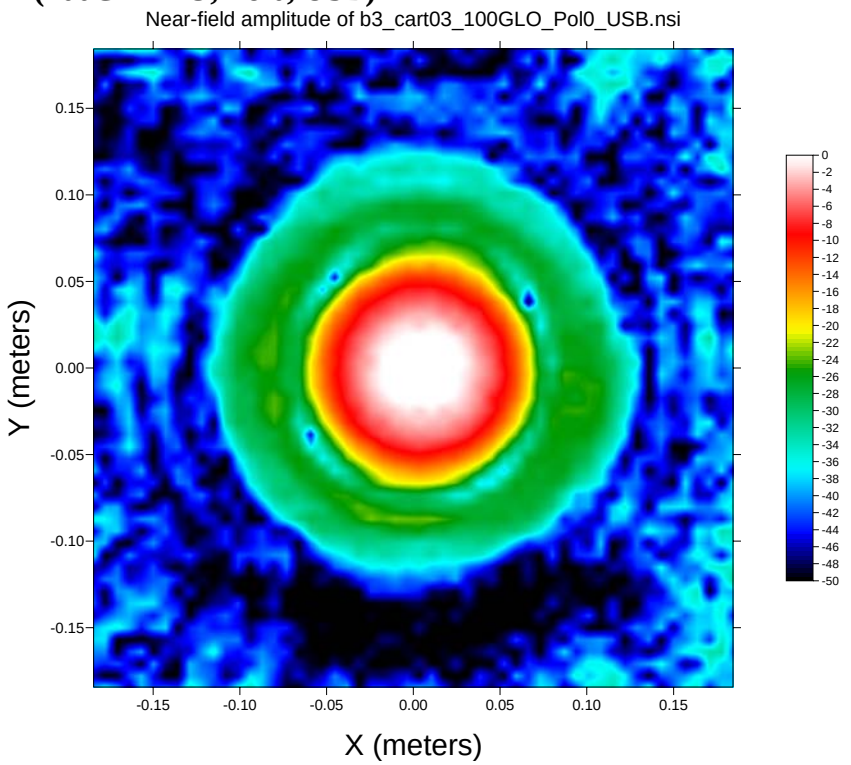


Figure 88 - CoPol

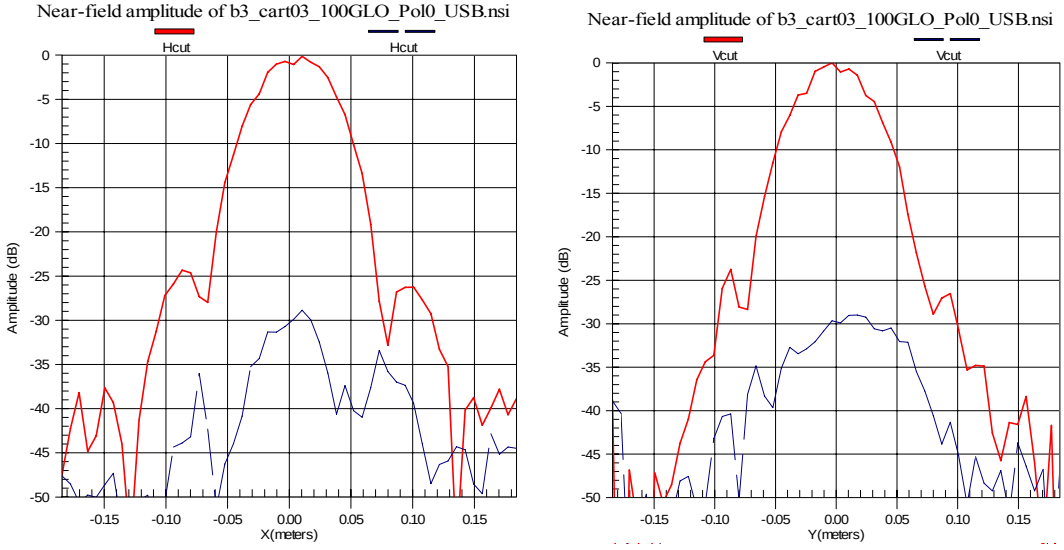


Figure 89 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol (dashed blue)

RF=98.6 GHz (104GHz LO, Pol0, LSB)

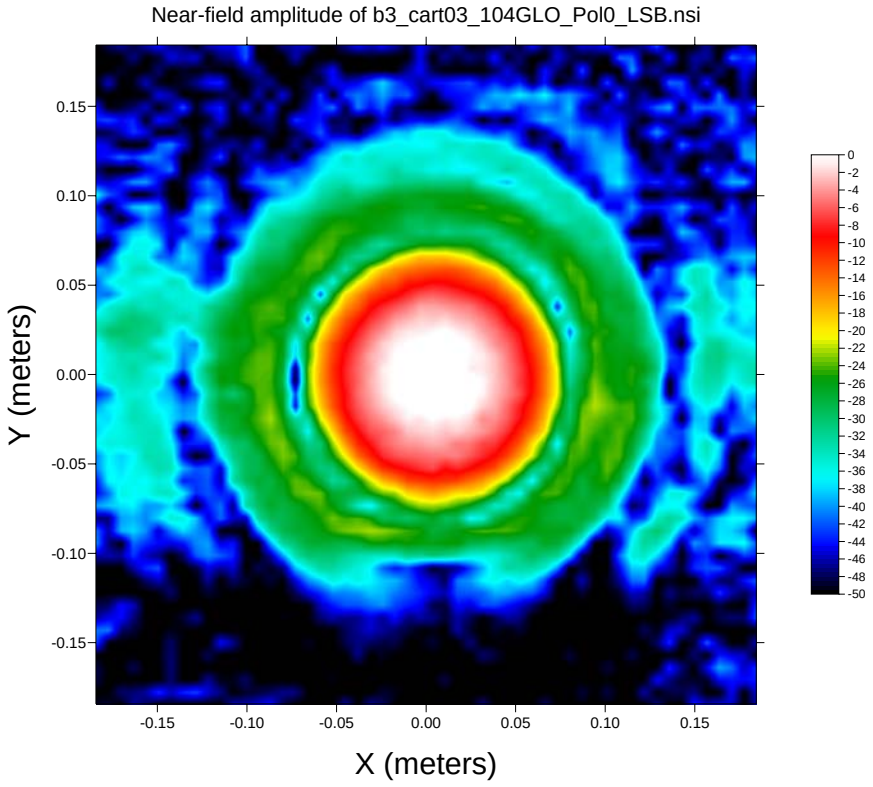


Figure 90 - CoPol

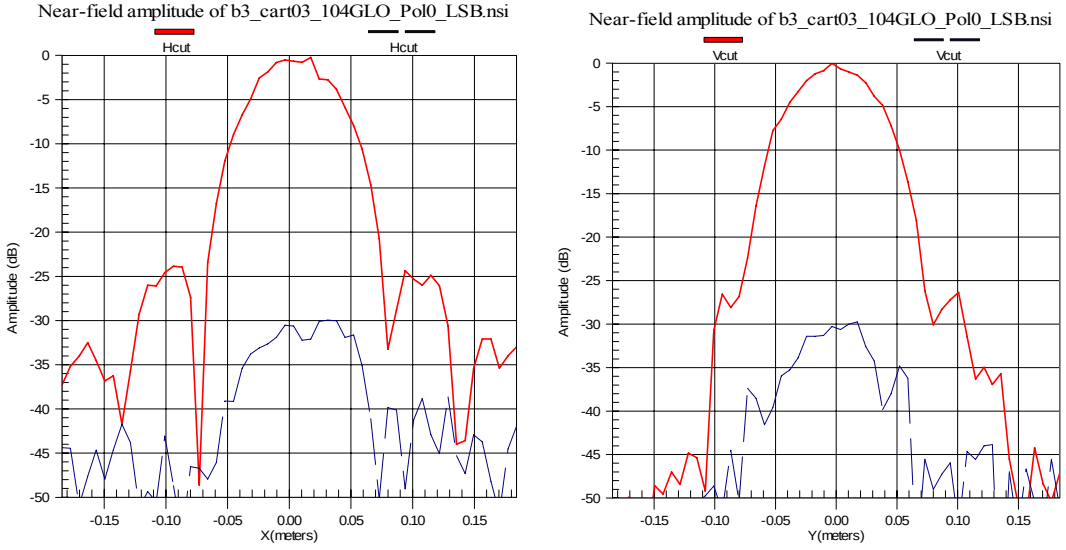


Figure 91 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol (dashed blue)

RF=110.1 GHz (104GHz LO, Pol0, USB)

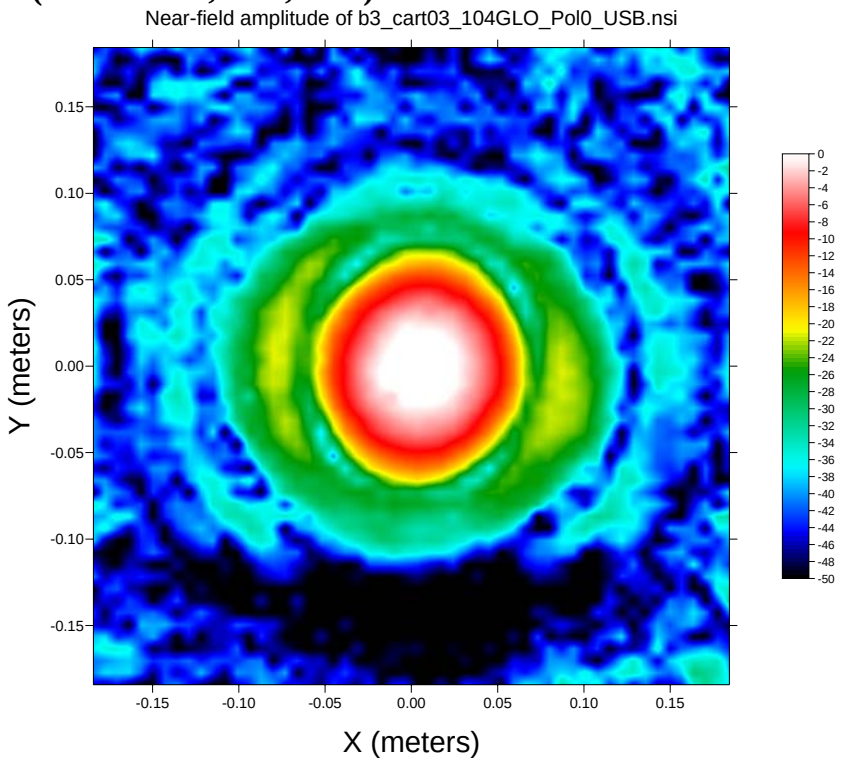


Figure 92 - CoPol

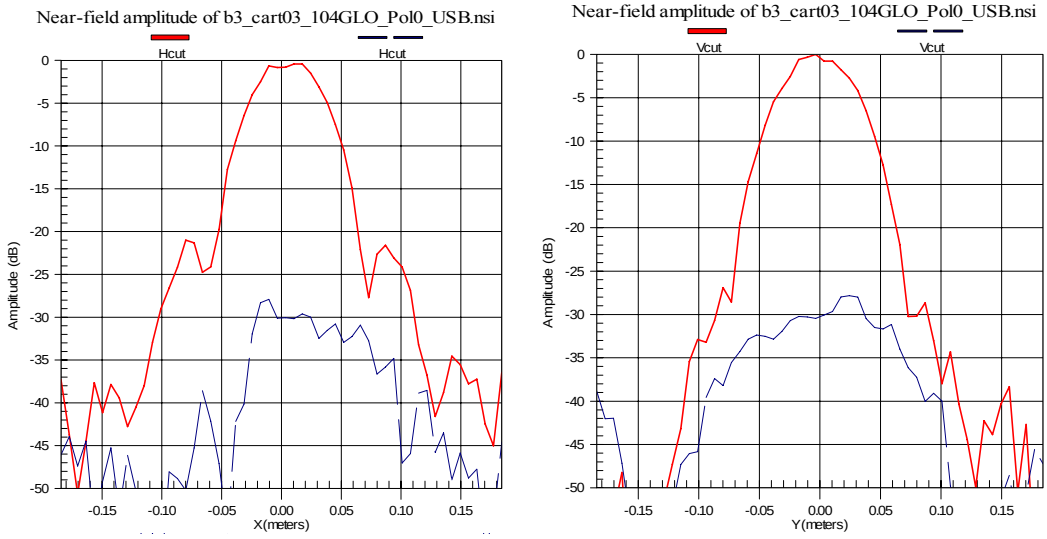


Figure 93 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol (dashed blue)

RF=102.3 GHz (108GHz LO, Pol0, LSB)

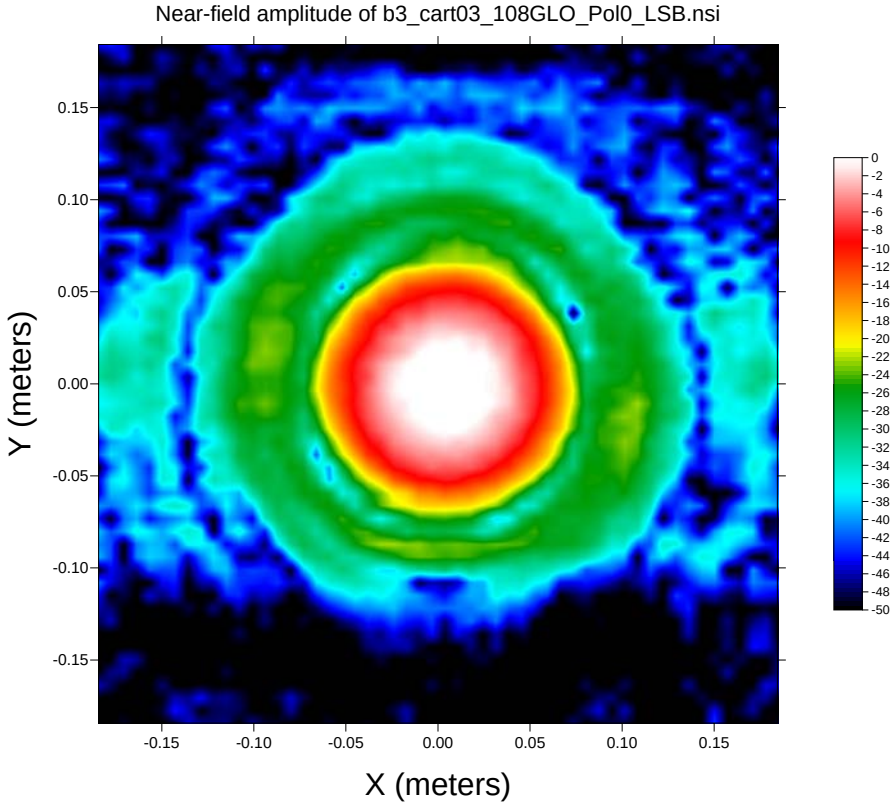


Figure 94 - CoPol

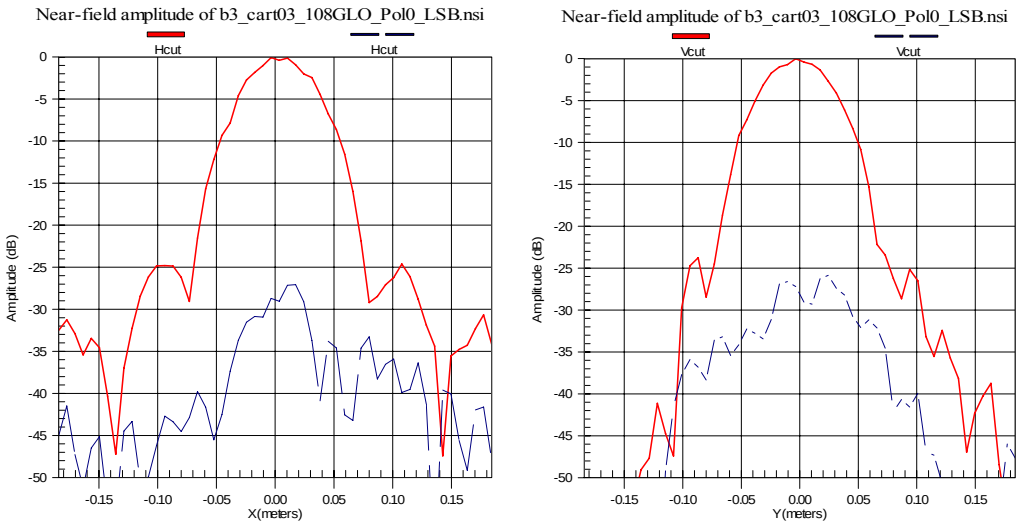


Figure 95 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol (dashed blue)

RF=114.4 GHz (108GHz LO, Pol0, USB)

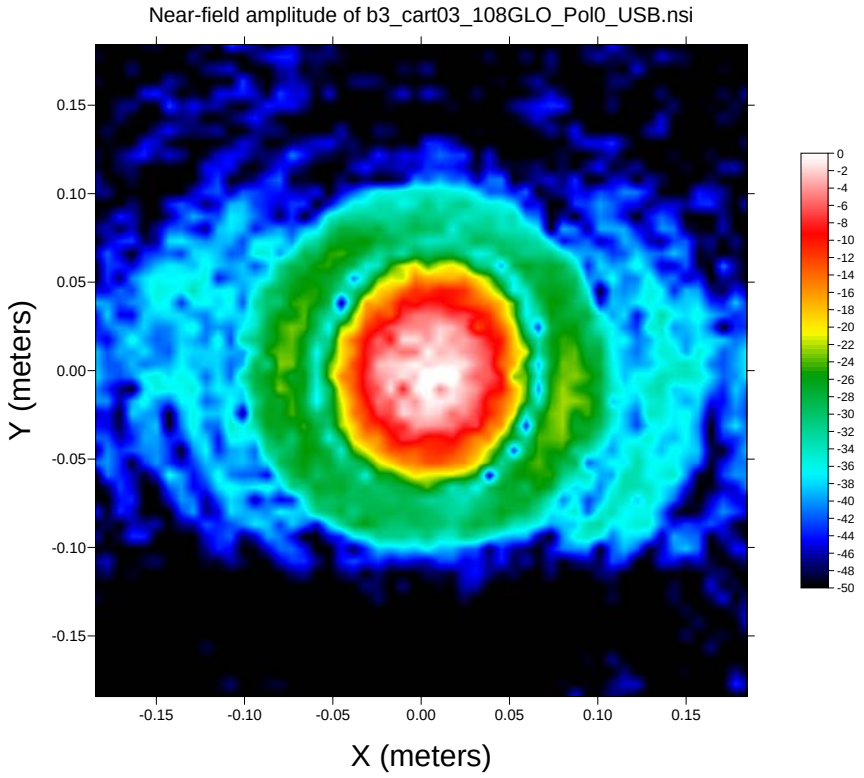


Figure 96 - CoPol

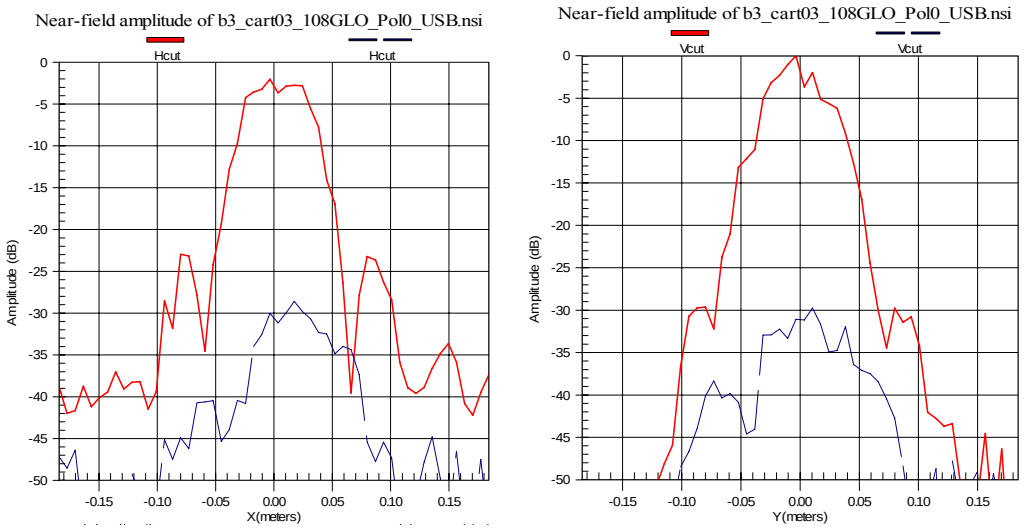


Figure 97 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol (dashed blue)

4.7.2 RF beam efficiency

4.7.2.1 Specification

[FEND-40.02.03.00-00260-00 / T]

The Band 3 feedhorn and lens shall be fabricated and positioned in accordance with the designs detailed in the ALMA Front-End optics report [RD1].

4.7.2.2 Verification Method

Please refer to [AD7].

4.7.2.3 Test results

At HIA

Measurement of the horn position with respect to the 4 K plate, at room temperature

To be within the adjustment range of the warm optics assembly, the cartridge cold optics assembly must be positioned according to the locations and tolerances given in Table 16 below. These specifications are taken from [AD5], and are relative to the cartridge coordinate system located at the 4 K plate. Therefore, these are in addition to the allowable location tolerances of the 4 K plate itself. Positions are measured from the apex of the lens, and angles are measured from the optical axis of the feedhorn.. The position of the feedhorn is measured at room temperature with a dial gauge system.

Table 16: Cold optics static alignment specs and measurements

Spec description	Spec	± Tol.	Measured position error	Units
Lens X location	-4.2	0.5	-0.356	mm
Lens Y location	23.9	0.5	0.102	mm
Lens Z location	228.5	0.5	0.381	mm
Horn axis tilt	0.0	3.0	2.117	mrad

A report on the beam alignment measured was issued [AD13]. These measurements need to be confirmed in the FEIC with the ALMA Cryostat.

4.7.3 Polarization alignment

4.7.3.1 Specification

[FEND-40.02.03.00-00270-00 / T]

At the RF input of the cartridge the E vector of polarization channel 0 must be aligned with the radial direction of the cryostat. Channel 1 shall be orthogonal to channel 0.

4.7.3.2 Verification Method

Please refer to [AD7].

4.7.3.3 Test results

Although tests are planned at the FEIC, from the design, see [AD18], the cartridge complies with this requirement.

4.7.4 Polarization alignment accuracy

4.7.4.1 Specification

[FEND-40.02.03.00-00280-00 / T]

At the RF input of the cartridge the alignment between the orientation of the E vector of either of the polarization channels and the ideal polarization alignment (as specified in 4.7.3) must be better than two degrees.

4.7.4.2 Verification Method

Please refer to [AD7].

4.7.4.3 Test results

Although tests are planned at the FEIC, from the design ([AD24] and [AD12]) the cartridge complies with this requirement.

4.7.5 Cross-Polarization

4.7.5.1 Specification

[FEND-40.02.03.00-00290-00 / T]

At any frequency within the RF tuning range and for either of the two polarization channels, the cross-polarized signal shall be at least 20 dB below the co-polar signal.

4.7.5.2 Verification Method

Please refer to section 4.7.1.2

4.7.5.3 Test results

RF=87.2 GHz (92GHz, Pol0 LSB)

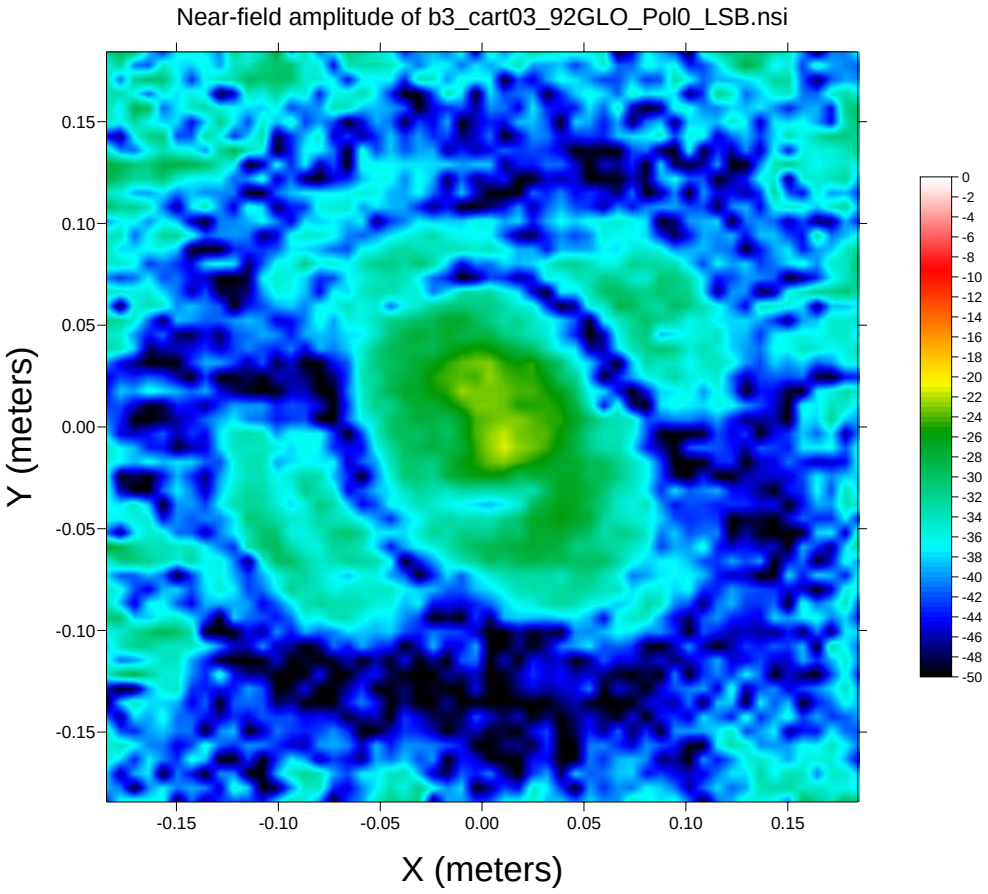


Figure 98 - CoPol

Please refer to horizontal and vertical cuts shown in Figure 79 – Horizontal Cut (left) & Vertical Cut (right) of CoPol (solid red) & CrossPol to quantify the above result.

RF=97.4 GHz (92 GHz Lo, Pol0, USB)

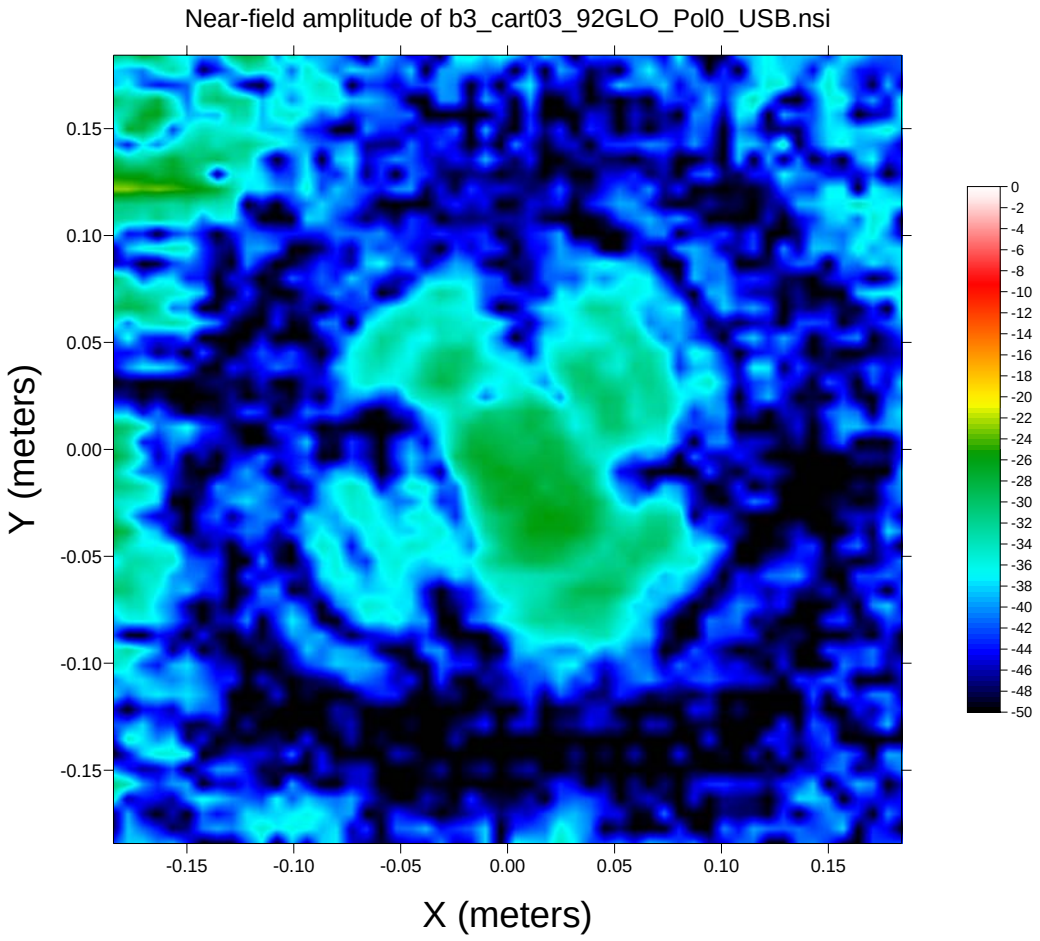


Figure 99 - CrossPol

Please refer to horizontal and vertical cuts shown in Figure 81 – to quantify the above result.

RF=91.0 GHz (96 GHz LO, Pol0, LSB)

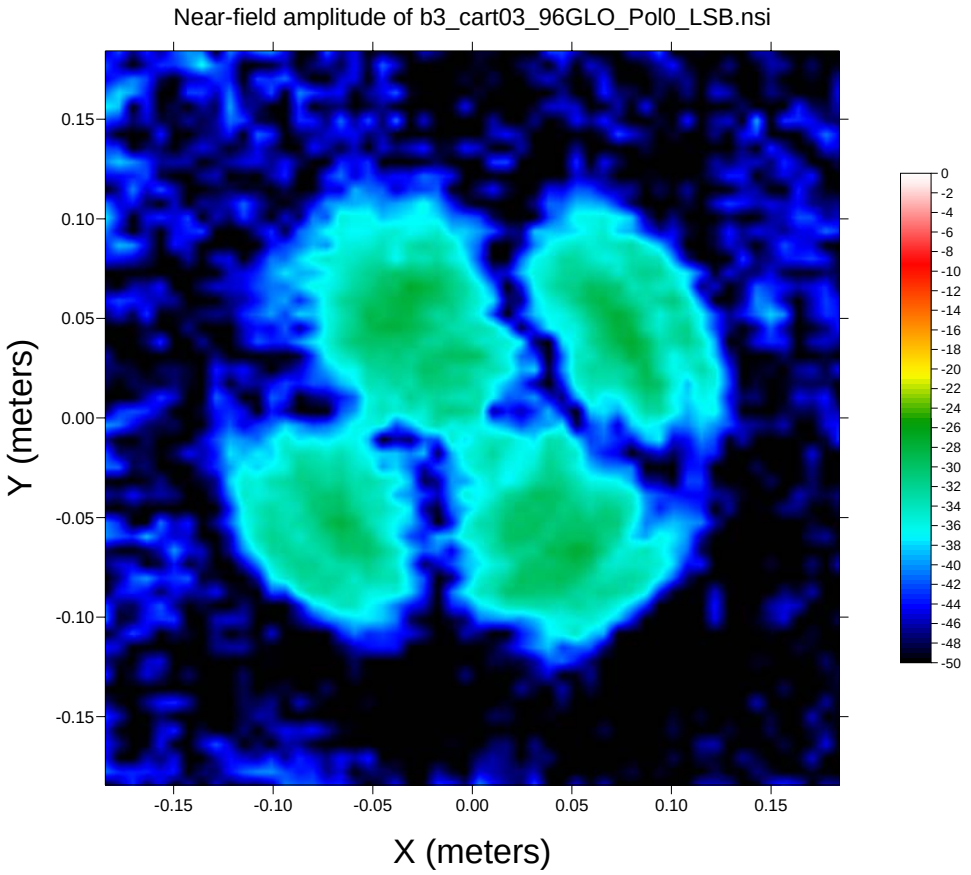


Figure 100 - CrossPol

Please refer to horizontal and vertical cuts shown in Figure 83 – to quantify the above result.

RF=101.7 GHz (96GHz LO, Pol0, USB)

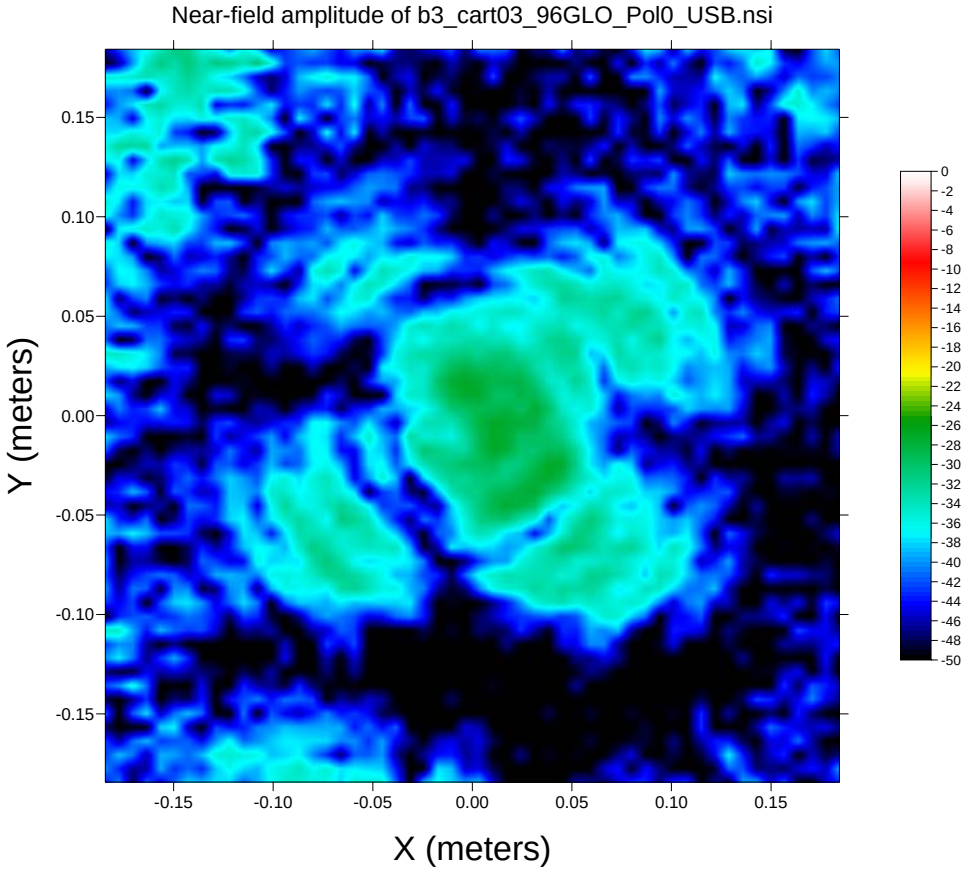


Figure 101 - CrossPol

Please refer to horizontal and vertical cuts shown in Figure 85 – to quantify the above result.

RF=94.8 GHz (100GHz LO, Pol0, LSB)

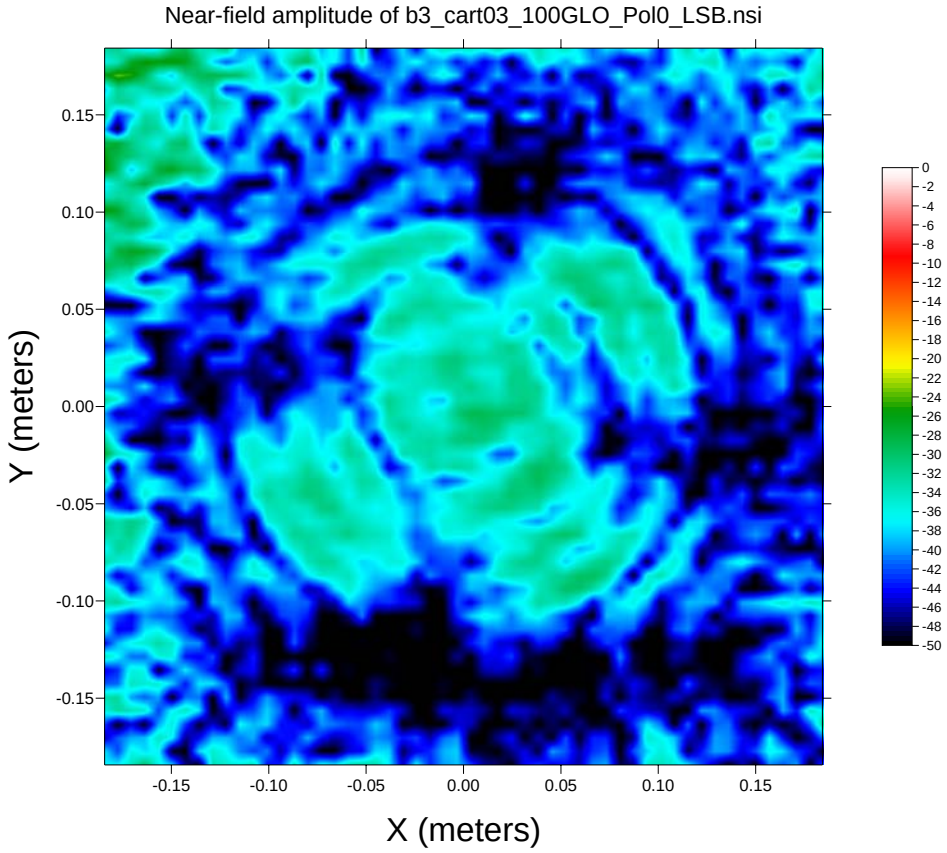


Figure 102 - CrossPol

Please refer to horizontal and vertical cuts shown in Figure 87 – to quantify the above result.

RF=105.9 GHz (100GHz LO, Pol0, USB)

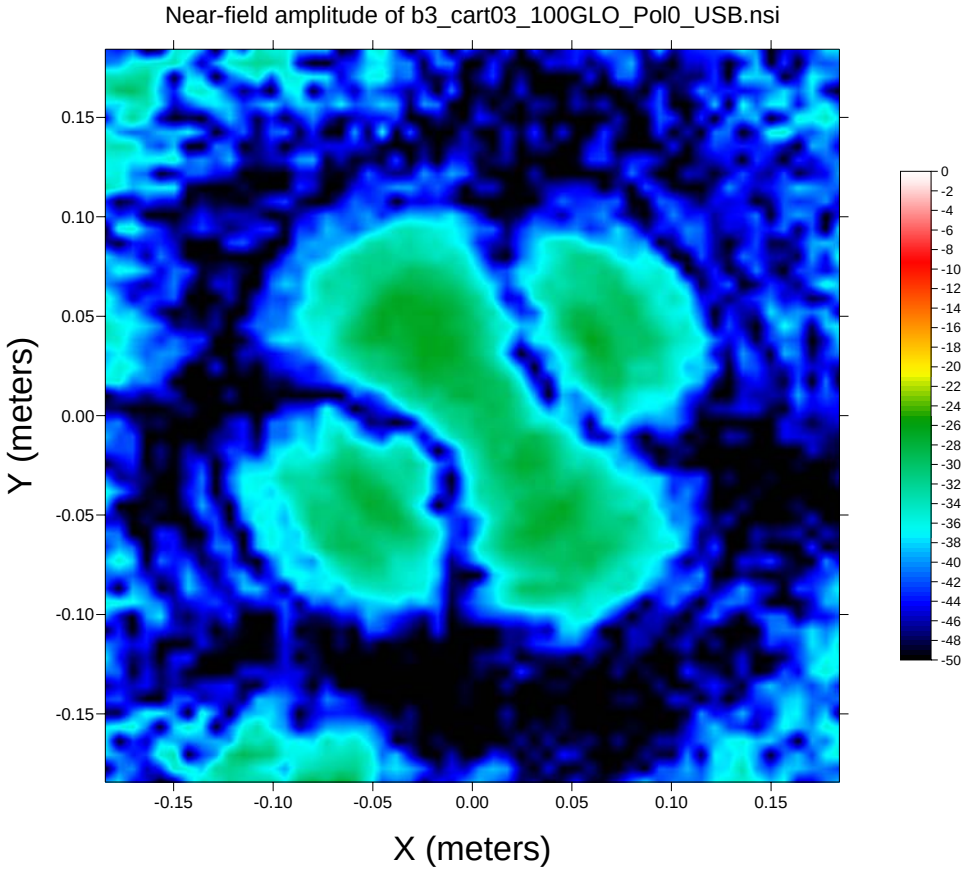


Figure 103 - CrossPol

Please refer to horizontal and vertical cuts shown in Figure 89 – to quantify the above result.

RF=98.6 GHz (104GHz LO, Pol0, LSB)

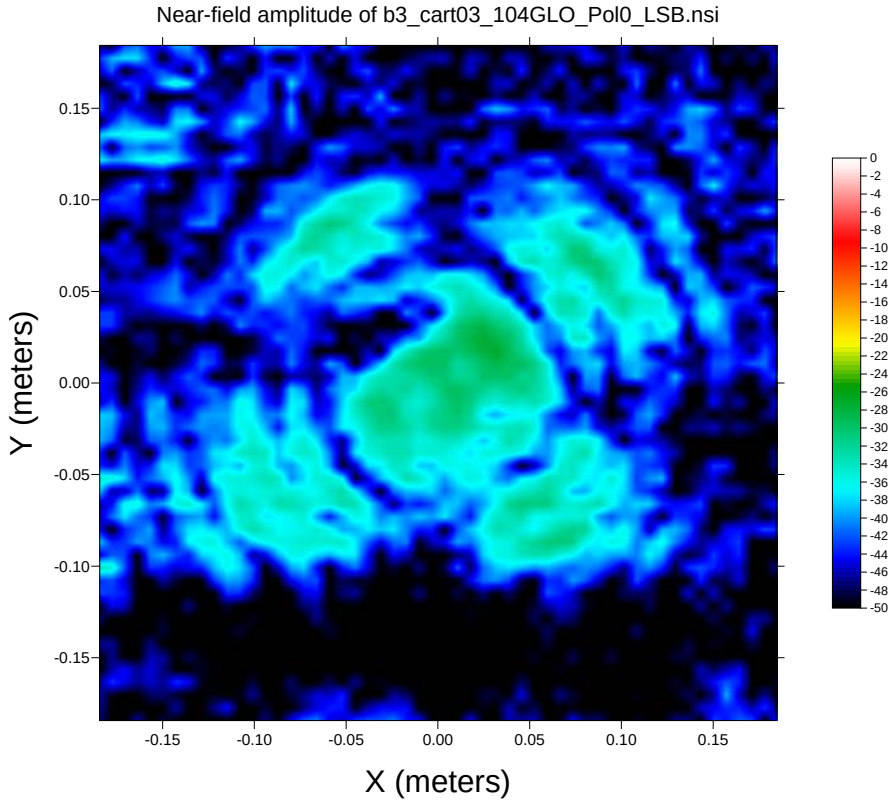


Figure 104 - CrossPol

Please refer to horizontal and vertical cuts shown in Figure 91 – to quantify the above result.

RF=110.1 GHz (104GHz LO, Pol0, USB)

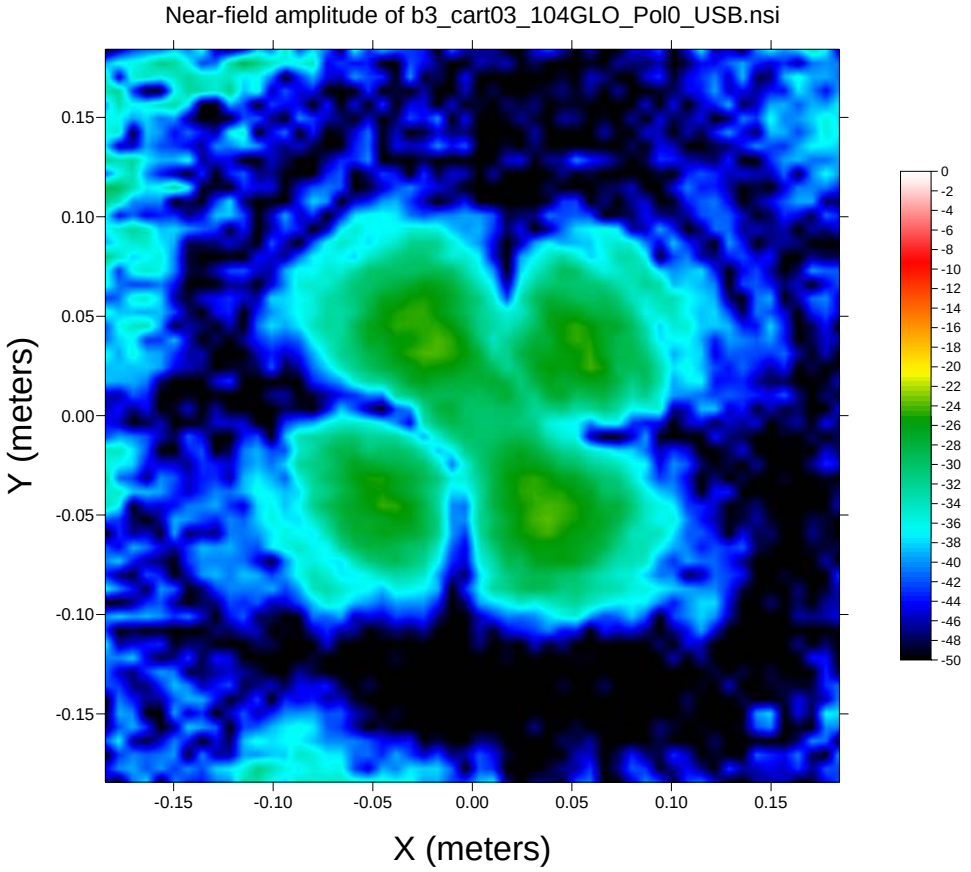


Figure 105 - CrossPol

Please refer to horizontal and vertical cuts shown in Figure 93 – to quantify the above result.

RF=102.3 GHz (108GHz LO, Pol0, LSB)

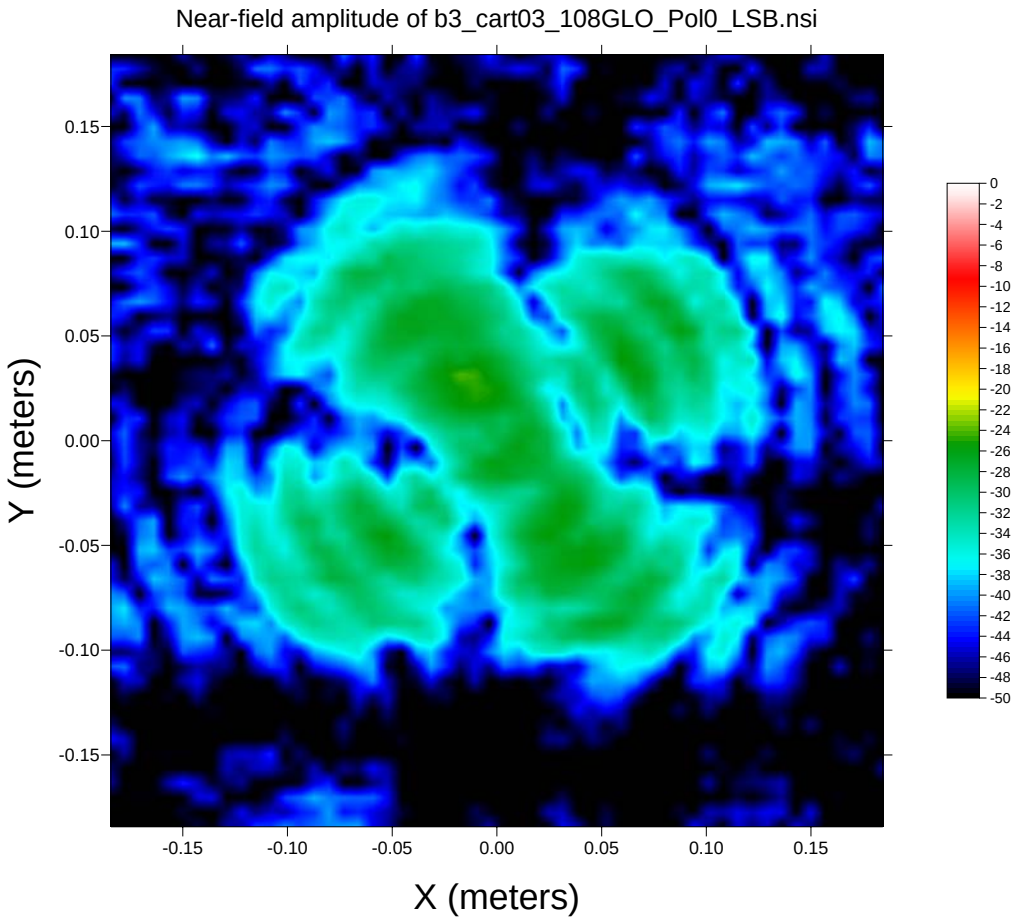


Figure 106 - CrossPol

Please refer to horizontal and vertical cuts shown in Figure 95 – to quantify the above result.

RF=114.4 GHz (108GHz LO, Pol0, USB)

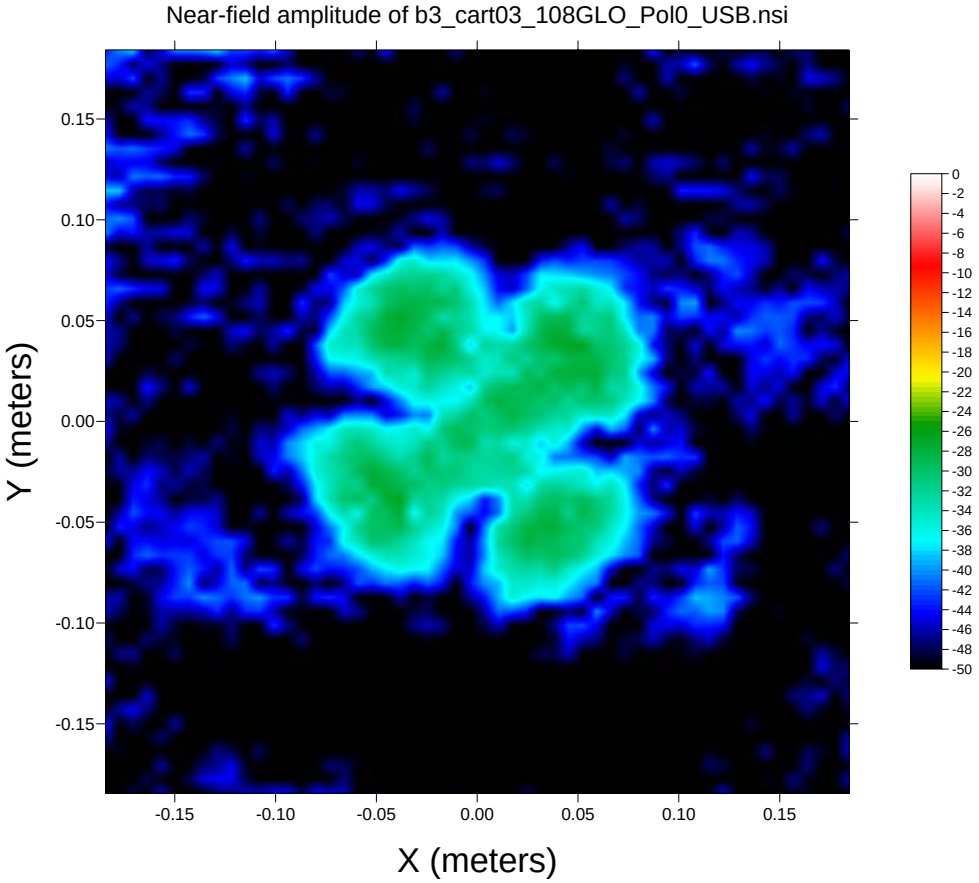


Figure 107 - CrossPol

Please refer to horizontal and vertical cuts shown in Figure 97 – to quantify the above result.

4.8 Stabilization time

4.8.1 Stabilization time from non-operational mode

[FEND-40.02.03.00-00300-00 / T]

4.8.1.1 Requirements

The transition from the non-operational to the operational mode shall take no more than 15 minutes.

4.8.1.2 Compliance

A report will be issued at the Band 3 CDR.

4.8.2 Stabilization time from stand-by mode

[FEND-40.02.03.00-00305-00 / T]

4.8.2.1 Requirements

The transition from the stand-by mode to the operational mode shall take no more than 1.5 seconds.

4.8.2.2 Compliance

A report will be issued at the Band 3 CDR.

5 Mechanical and Electrical Requirements

5.1 Mass

5.1.1 Requirements

The total mass of components added to the unmodified cartridge body shall be less than 2.0 kg. Where material is removed (through machining) from the cartridge body thermal stages, the mass of this material can be added to the total allowance.

Table 17: Breakdown of mass allowance

	Spec (kg)
Mass of unmodified body	5.7
Additional allowance	2.0 (max)
Total mass allowance	7.7 (max)

5.1.2 Compliance

The mass of the Band 3 cartridge is 7.2 kg [AD24]. The centre of mass of the Band 3 cartridge will be positioned as follows with respect to the cryostat coordinate system:

Table 18: Location of centre of mass

X =	58 mm	± 10 mm
Y =	-330 mm	± 10 mm
Z =	-128 mm	± 20 mm

The results of the CAD solid-model centre of mass analysis are as follows:

Table 19

Coordinate	Required position (mm)	Tolerance (mm)	Results (mm)
X =	58	± 10	58.7
Y =	-330	± 10	-330.2
Z =	-128	± 20	-129.1

5.2 Eigen frequency

[FEND-40.02.03.00-00320-00 / A,R]

5.2.1 Requirements

The band 3 cartridge shall have a first Eigen-frequency of 70 Hz or greater.

5.2.2 Compliance

Here is a summary of the Band 3 Eigen frequencies:

Table 20

Vibration mode	Eigen-freq. (Hz)	Description of mode shape
Mode #1	= 78.8	Bending about Y axis
Mode #2	= 93.1	Bending about X axis + shear in Y axis
Mode #3	= 253.3	Shear in X axis

The results are presented in more details in [AD24].

5.3 Volume

[FEND-40.02.03.00-00330-00 / I]

5.3.1 Requirements

The cartridge components which are located inside the vacuum chamber shall be contained within a volume defined by the union of two cylinders.

The first cylinder is ∅140 x 475 mm tall. It is concentric with the mounting interface on the bottom of the cryostat (X, Y) = (58.2, -329.0) and is flush with the plane of the interface between the cartridge and cryostat (Z = -573.0).

The second cylinder is ∅45 x 510 mm tall. It is concentric with the vacuum window on the top of the cryostat (X, Y) = (54.0, -306.0) and is also flush with the plane of the interface between the cartridge and cryostat (Z = -573.0).

5.3.2 Compliance

All Band 3 components are contained within the abovementioned volume. Using this volume, here is nominally 6 mm of clearance in the Z direction between the top of the second cylinder, and the lower surface of the 15 K IR filter, when the cryostat is at ambient vacuum and temperature conditions. When cold, the apex of the lens will deflect approximately 1.5 mm, in the –Z direction, due to thermal contraction of the cartridge.

5.4 Orientation

[FEND-40.02.03.00-00340-00 / A,R,T]

5.4.1 Requirements

The cartridge shall meet all performance requirements over a range of gravity vectors from 0 to 90 degrees. This rotation occurs about the axis of the antenna elevation-bearing.

5.4.2 Compliance

An investigation of the cartridge structure using Finite Element Analysis (see [AD24]) shows that upon tilting the cartridge tilt will not affect its performance. The testing at different elevations will be performed when the cartridge is integrated to the FE cryostat at the FEIC.

5.5 Thermal Load

[FEND-40.02.03.00-00350-00 / A]

5.5.1 Requirements

The thermal interface between the cryostat and Band 3 cartridge is specified in [AD8], and is repeated in Table 21 below for completeness. Passive heat loads refer to conduction along the wiring, coax cables and waveguides. This heat load is present at all times. Active heat loads refer to the power dissipation from the four IF amplifiers, and is only present when the amplifiers are operating.

Table 21: Summary of thermal interface specifications

	Temperature range	Temp stability (1 min or less)	Passive heat load	Passive + Active heat load
300 K interface plate	(TBD)	(N/A)	(TBD)	(N/A)
90 K thermal stage	70 – 130 K	100 mK	350 mW	400 mW
15 K thermal stage	10 – 18 K	50 mK	95 mW	162 mW
4 K thermal stage	4 K (max)	2 mK	5 mW	41 mW

5.5.2 Compliance

Here is a summary of the Band 3 heat loads. These are calculated values.

Table 22

	Passive heat load	Passive + Active heat load
90 K thermal stage	349 mW	353 mW
15 K thermal stage	59 mW	61 mW
4 K thermal stage	2 mW	39 mW

A more detailed description of the heat loads is presented in [AD24].

5.6 Bias requirements

[FEND-40.02.03.00-00360-00 / R]

5.6.1 Requirements

Details can be found in the applicable Interface Control Document [AD9].

5.6.2 Compliance

The ICD has been finalized and all Band 3 components comply with the bias requirements.

5.7 Connectors and RF ports

5.7.1 RF input port interface

[FEND-40.02.03.00-00370-00 / R]

The RF input port of the cartridge shall comply with the requirements as described in section 4.2.3. of [RD2].

5.7.2 LO input port interface

[FEND-40.02.03.00-00380-00 / R, I]

5.7.2.1 Requirements

The mixer LO input ports shall be rectangular waveguides.
Details can be found in the applicable Interface Control Document [AD11].

5.7.2.2 Compliance

The ICD has been finalized and both Band 3 input waveguides comply with the requirement.

5.7.3 IF output port interface

[FEND-40.02.03.00-00390-00 / R, I]

5.7.3.1 Requirements

All IF output ports shall be coaxial, details can be found in the applicable Interface Control Document [AD4].

5.7.3.2 Compliance

The ICD has been finalized and the four Band 3 output IF connectors comply with the requirement.

5.7.4 Bias connectors

[FEND-40.02.03.00-00400-00 / R, I]

5.7.4.1 Requirements

Details for the bias connector (s) can be found in the applicable Interface Control Document [AD9].

5.7.4.2 Compliance

The ICD has been finalized and the Band 3 DC connector complies with the requirement.

6 Operating Requirements

6.1 Local Oscillator

The requirements for the local oscillators have been addressed in [AD3].

6.1.1 LO input port

[FEND-40.02.03.00-00420-00 / T]

6.1.1.1 Requirement

The LO frequency range of the local-oscillator signal is 92 GHz to 108 GHz.

6.1.1.2 Compliance

The LO unit complies. See [AD3].

6.1.2 LO power requirement

[FEND-40.02.03.00-00430-00 / A,T]

6.1.2.1 Requirement

For further details see [AD5].
The requirements in [AD10] have been updated by the change request [AD19], as follows; +2 dBm (2 mW) to +9 dBm (8 mW) adjustable in 0.2 dB steps or less. Each channel shall have independent output power level control.

6.1.2.2 Compliance

The LO unit SN WCA3-3 complies.

6.1.3 LO sideband and phase noise

[FEND-40.02.03.00-00440-00 / T]

6.1.3.1 Requirement

The sideband noise on the output signal of the Band 3 first local oscillator shall not exceed 10K/μW of power absorbed in the SIS device(s).

6.1.3.2 Compliance

As detailed in [AD27], the WCA does not meet the noise specification.

6.1.4 LO amplitude stability

[FEND-40.02.03.00-00450-00 / T]

6.1.4.1 Requirement

Allan variance of output power, $\sigma 2(2, T, 0.9*T)$, should be less than $9 \times 10\text{-}8$ from 0.1 to 1 second.

6.1.4.2 Compliance

LO unit SN2 complies. See [AD3].

6.2 Thermal Environment

[FEND-40.02.03.00-00460-00 / T]

6.2.1 Requirement

(Note that this subsection only applies to the operational mode.)
The cartridge shall meet its performance requirements in a thermal environment detailed in [AD12].

See Table 21 of this document for the thermal interface between band 3 and the FE cryostat.

An operating cartridge must be able to withstand an increase in temperature to ambient (20^{o} C) without damage.

6.2.2 Compliance

The cartridge performance tests were all done under the required thermal environment, that is the three cryogenic stages were all temperature controlled within the specified range.
The thermal environment of the cartridge in the FE cryostat will be verified when integrated at the FEIC.

6.3 Vacuum conditions

[FEND-40.02.03.00-00470-00 /R]

6.3.1 Requirement

The 300 K vacuum interface plate contains ten O-ring seals. To maintain vacuum integrity of the cryostat, these seals shall have a combined maximum helium gas leak rate of 1.0e-7 mbar-l/s, measured after 20 minutes of exposure according to the procedure described in [AD14].

6.3.2 Compliance

The leak rate of the 300 K vacuum interface is 1.92e-6 mbar-l/s measured after 20 minutes of He gas exposure. A waiver will be requested for this non-compliance.

6.4 Environmental operating conditions

6.4.1 Vibration

[FEND-40.02.03.00-00480-00 /R,T]

6.4.1.1 Requirement

The band 3 cartridge must survive vibration levels as specified in Appendix 1 of [AD15]; the vertical direction being defined as perpendicular to the cartridge baseplate.

6.4.1.2 Compliance

This analysis will be presented for the CDR.

6.4.2 Acceleration

[FEND-40.02.03.00-00490-00 / R,T]

6.4.2.1 Requirement

The band 3 cartridge must survive the following accelerations:

- 3 g shock load in the vertical direction
- 2 g shock load in the horizontal direction

The vertical direction being defined as perpendicular to the cartridge baseplate.

6.4.2.2 Compliance

A drop test of the cartridge within its container showed that the cartridge can survive at least 15 g (see [AD28]). More importantly, the amplifier and mixers have been subject to shocks up to 20g and no performance changes were noticed after the shocks. For more details, please refer to [AD22].

6.5 Storage and shipping conditions

[FEND-40.02.03.00-00500-00 / R]

6.5.1 Requirement

(Note that this section only applies to the storage mode)
The band 3 cartridge must comply with [AD15].

6.5.2 Compliance

A shipping container was designed to meet the shipping conditions specified in [AD15]. For more details on the shipping container design, please see [AD23].

6.6 Electro-Magnetic Compatibility

[FEND-40.02.03.00-00510-00 / T]

6.6.1 Requirement

The band 3 cartridge must comply with [AD20].

6.6.2 Compliance

The compliance will be verified at the FEIC.

6.7 Monitoring and control

(Note that this section does not apply to the storage mode.)

6.7.1 Mixer voltages and currents

[FEND-40.02.03.00-00520-00 / R]

6.7.1.1 Requirement

The mixer voltages and currents must be monitored as stated in [AD9].

6.7.1.2 Compliance

The cartridge wiring allows the monitoring of the mixer voltages and currents.

6.7.2 Magnet currents

[FEND-40.02.03.00-00530-00 / R]

6.7.2.1 Requirement

If required by the mixer design, the currents flowing in the suppression magnet must be monitored, see [AD9].

6.7.2.2 Compliance

No magnet required.

6.7.3 Temperature

[FEND-40.02.03.00-00540-00 / R]

6.7.3.1 Requirement

Temperature sensors must be provided at critical points of all temperature stages; see [AD9].

6.7.3.2 Compliance

Five temperature sensors are attached to the Band 3 cartridge, as follows;
110K stage, 15 K stage, 4 K stage, 2SB mixer unit POL1, 2SB mixer unit POL0.

6.7.4 Removal of trapped flux

[FEND-40.02.03.00-00550-00 / R]

6.7.4.1 Requirement

Means shall be provided to remove flux trapped in the SIS junctions.

6.7.4.2 Compliance

Trapped flux is a concern when operating at higher frequencies, when the AC Josephson oscillations are interfering with the optimum bias point. It is not the case for Band 3, therefore the requirement is not applicable.

7 Reliability Requirements

7.1 Continuous operation

[FEND-40.02.03.00-00560-00 / R]

7.1.1 Requirement

The cartridge shall be designed for continuous use. It shall not require any periodic maintenance.

7.1.2 Compliance

The cartridge is designed for continuous use with no maintenance required.

7.2 Mean time to failure

[FEND-40.02.03.00-00570-00 / A]

7.2.1 Requirement

The MTBF of the cartridge shall exceed 20 years.

7.2.2 Compliance

The analysis of the MTBF for cryogenic component is not standard. Therefore, statistics must be generated for the Band 3 critical components such as the mixers, amplifiers, cables and connectors. Thermal cycle tests of components and an analysis will be provided for the CDR. Please see [AD26] for an initial analysis of the FE system.

7.3 Lifetime

[FEND-40.02.03.00-00580-00 / R]

7.3.1 Requirement

The Band 3 cartridge shall have a minimum lifetime of 15 years.

7.3.2 Compliance

The cartridge has been designed to have a greater than 15 year lifetime. An analysis will be presented at CDR.

8 Compliance Matrix

The requirements, taken directly from [AD2], are numbered according to the following code:
[FEND-40.02.03.00-XXXXX-YY / Z]
Where:
FEND-40.02.03.00 identifies the 'Front End – Band 3 Cartridge Technical Specifications' as in [AD1];
XXXXX is a consecutive number 00010, 00020, … (the nine intermediate numbers remaining available for future revisions of this document);
YY describes the requirement revision. It starts with 00 and is incremented by one with every requirement revision;
Z describes the requirement verification method(s), where T stands for Test, I for Inspection, R for Review of design and A for Analysis. Multiple verification methods are allowed.
For verification by test, the testing method is described in [AD7] and the test results will be reported in the acceptance report for that particular unit.
For verification by review/analysis of design, compliance will be verified in a design report currently under preparation and scheduled to be available at the CDR.

Serial No	Item	Specification No	Result of compliance tests / inspection/ review / analysis	Notes
1	**General Requirements**			
1.1	Operation modes			
1.1.1	Operational	FEND-40.02.03.00-00010-00/I	Compliant	
1.1.2	Non-operational	FEND-40.02.03.00-00020-00/I	Compliant	
1.1.3	Stand-by	FEND-40.02.03.00-00025-00/I	Compliant	
1.1.4	Transport with the antenna	FEND-40.02.03.00-00030-00/I	Compliant	
1.1.5	Transport in the service vehicle	FEND-40.02.03.00-00040-00/I	Compliant	
1.2	Compatibility with the ALMA front-end sub-system	FEND-40.02.03.00-00050-00/I	Compliant	

Serial No	Item	Specification No	Result of compliance tests / inspection/ review / analysis	Notes
1.3	Design for production			
1.3.1	Technology	FEND-40.02.03.00-00060-00/R	Compliant	
1.3.2	Series production	FEND-40.02.03.00-00070-00/R	Compliant	
1.3.3	Standard parts	FEND-40.02.03.00-00080-00/R	Compliant	
1.4	Mechanical tuning	FEND-40.02.03.00-00090-00/R	Compliant	
1.5	Metric dimensioning	FEND-40.02.03.00-00110-00/R	Compliant	
2	**Functional Requirements**			
2.1	Mixer type	FEND-40.02.03.00-00120-00/R	Compliant	
2.2	Mixing scheme	FEND-40.02.03.00-00130-00/R	Compliant	
2.3	Frequency coverage			
2.3.1	RF input port	FEND-40.02.03.00-00140-00/R	Compliant	
2.3.2	LO input port	FEND-40.02.03.00-00150-00/R	Compliant	
2.3.3	IF output ports	FEND-40.02.03.00-00160-00/R	Compliant	
2.4	Polarization state	FEND-40.02.03.00-00170-00/R	Compliant	
3	**Performance Requirements**			
3.1	Cartridge noise temperature	FEND-40.02.03.00-00180-00/T	Not compliant	See acceptance discrepancy report
3.2	Image band suppression or sideband mismatch	FEND-40.02.03.00-00190-00/T	Compliant	
3.3	Cartridge IF power			
3.3.1	IF output power	FEND-40.02.03.00-00200-00/T	Compliant	
3.3.2	IF power variations	FEND-40.02.03.00-00210-00/T	Compliant	
3.3.3	Gain matching amongst Band 3 cartridges	FEND-40.02.03.00-00220-00 / T	Not tested.	
3.4	Gain compression	FEND-40.02.03.00-00230-00/T	Compliant	
3.5	Amplitude stability	FEND-40.02.03.00-00240-00/T	Compliant	
3.6	Signal path phase stability	FEND-40.02.03.00-00250-00/T	Compliant	

Serial No	Item	Specification No	Result of compliance tests / inspection/ review / analysis	Notes
3.7	Optics			
3.7.1	RF beam efficiency	FEND-40.02.03.00-00260-00/T	Not yet tested	See acceptance discrepancy report
3.7.2	Polarization alignment	FEND-40.02.03.00-00270-00/T	Not yet tested	See acceptance discrepancy report
3.7.3	Polarization alignment accuracy	FEND-40.02.03.00-00280-00/T	Not yet tested	See acceptance discrepancy report
3.7.4	Cross-polarization	FEND-40.02.03.00-00290-00/T	Compliant	
3.8	Stabilization time			
3.8.1	From non-operational mode	FEND-40.02.03.00-00300-00/T	Compliant by design but needs to be verified	Will be verified at the integration centre
3.8.2	From stand-by mode	FEND-40.02.03.00-00305-00/T	Compliant by design but needs to be verified	Will be verified at the integration centre
3.9	Spurious response	FEND-40.00.00.00-00120-00/T	Compliant	See IF output power tests – section 4.3.1
4	**Mechanical and Electrical Requirements**			
4.1	Mass	FEND-40.02.03.00-00310-00/T	Compliant	
4.2	Eigen-frequency	FEND-40.02.03.00-00320-00/A, R	Compliant	
4.3	Volume	FEND-40.02.03.00-00330-00/I	Compliant	
4.4	Orientation	FEND-40.02.03.00-00340-00/A, R, T	Compliant by design but needs to be tested at the FEIC	See acceptance discrepancy report
4.5	Thermal load	FEND-40.02.03.00-00350-00/A	Compliant	
4.6	Bias requirements	FEND-40.02.03.00-00360-00/R	Compliant	
4.7	Connectors and RF ports			
4.7.1	RF input port interface	FEND-40.02.03.00-00370-00/R	Compliant	
4.7.2	LO input port interface	FEND-40.02.03.00-00380-00/R, I	Compliant	
4.7.3	IF output port interface	FEND-40.02.03.00-00390-00/R, I	Compliant	
4.7.4	Bias connectors	FEND-40.02.03.00-00400-00/R, I	Compliant	

Serial No	Item	Specification No	Result of compliance tests / inspection/ review / analysis	Notes
5	**Operating Requirements**			
5.1	Local oscillator			
5.1.1	LO input port	FEND-40.02.03.00-00420-00/T	Compliant	
5.1.2	LO power requirement	FEND-40.02.03.00-00430-00/T	Compliant	
5.1.3	LO sideband and phase noise	FEND-40.02.03.00-00440-00/T	Compliant	
5.1.4	LO amplitude stability	FEND-40.02.03.00-00450-00/T	Compliant	
5.1.5	LO phase stability	FEND-40.00.00.00-00600-00/T	Compliant	
5.1.6	LO frequency switching	FEND-40.00.00.00-00530-00/T to FEND-40.00.00.00-00590-00/T	Compliant by design but needs to be tested	
5.1.7	LO phase switching	FEND-40.00.00.00-00630-00/T	Compliant by design but needs to be tested	
5.2	Thermal environment	FEND-40.02.03.00-00460-00/T	Compliant	
5.3	Vacuum conditions	FEND-40.02.03.00-00470-00/R	Not compliant	See acceptance discrepancy report
5.4	Environmental operating conditions		Compliant	
5.4.1	Vibration	FEND-40.02.03.00-00480-00/R, T	Compliant	
5.4.2	Acceleration	FEND-40.02.03.00-00490-00/R, T	Compliant	
5.5	Storage/shipping conditions	FEND-40.02.03.00-00500-00/R	Compliant	
5.6	Electromagnetic compatibility	FEND-40.02.03.00-00510-00/T	Not tested yet	See acceptance discrepancy report
5.8	Monitor and control			
5.8.1	Mixer voltage and current	FEND-40.02.03.00-00520-00/R	Compliant	
5.8.2	Magnet current	FEND-40.02.03.00-00530-00/R	Compliant	
5.8.3	Temperature	FEND-40.02.03.00-00540-00/R	Compliant	
5.8.4	Removal of trapped flux	FEND-40.02.03.00-00550-00/R	Compliant	

Serial No	Item	Specification No	Result of compliance tests / inspection/ review / analysis	Notes
6	**Reliability Requirements**			
6.1	Continuous operation	FEND-40.02.03.00-00560-00/R	Compliant	
6.2	Mean time between failure	FEND-40.02.03.00-00570-00/A	Analysis not complete	
6.3	Lifetime	FEND-40.02.03.00-00580-00/R	Not analyzed yet	

Note on (PAI) Optics verification by the cartridge manufacturer: **(TBC)**

Scope of the Measurement – The objective of this measurement is to verify the design of the Band 3 cold optics including horn, lens, IR filters and window. The side-lobes of the amplitude must be below 20 dB. The shape of the beam shall also be qualified.

This shall be done by a 2D XY scan of the beam emanating from the Band 3 Cartridge Test Cryostat. The setup shall include the horn, lens, 12K IR filter, 100K IR filter and vacuum window. A Far Field Measurement shall be made at 1 m distance from the horn.

For the **first cartridge,** the following measurements shall be made at LO frequencies 92, 96, 100, 104 and 108 GHz at one tilt (cartridge vertical). For **other cartridges**, measurements shall be made at representative frequencies for low, middle and high end of the RF band (example LO frequencies of 96, 100 and 108 GHz) at one tilt (cartridge vertical).

Co-polar and cross-polar measurements at a fixed distance from the cryostat window (1 m). 2D relative (to the on-axis power) amplitude plots shall be generated. Angles and distances shall be properly referenced to the cartridge co-ordinate system. For further details see [AD9].

9 Acceptance Discrepancy Report

The following is a punch-list of non-compliant specifications along with comments regarding the remedies and their time frame of execution.

Serial No	Item	Specification No	Result of compliance tests / inspection/ review / analysis	Remedy, along with comments on the time-frame of execution
1.	Cartridge noise temperature	FEND-40.02.03.00-00180-00/T	The broadband noise is exceeding the specification at one frequency. See FEND-40.02.03.00-134-A-RFW	A CRE has been submitted FEND-40.02.03.00-131-A-CRE
2.	RF Beam efficiency	FEND-40.02.03.00-00260-00/T	Not yet tested	To be tested PAS at the FEIC To complete the amplitude scan, a phase measurement will be provided in order to calculate a true far field beam pattern. Harwar for this test is on order.
3.	Polarization alignment	FEND-40.02.03.00-00270-00/T	Not yet tested	To be tested PAS at the FEIC
4.	Polarization alignment accuracy	FEND-40.02.03.00-00280-00/T	Not yet tested	To be tested PAS at the FEIC
5.	Orientation	FEND-40.02.03.00-00340-00/A, R, T	Compliant by design but needs to be tested at the FEIC.	To be tested PAS at the FEIC
6.	Stabilization time from non-operational mode And from standby mode	FEND-40.02.03.00-00300-00/T	Compliant by design but needs to be verified.	Test data to be presented at Band 3 CDR

Serial No	Item	Specification No	Result of compliance tests / inspection/ review / analysis	Remedy, along with comments on the time-frame of execution
7.	Stabilization time from standby mode	FEND-40.02.03.00-00305-00/T	Compliant by design but needs to be verified.	This is an LO related item. This compliance will be verified at the integration centre when the cartridge is run within the FE system. The mixers and the amplifiers will be operational in standby mode. Therefore, this requirement does not affect the Band 3 cartridge. A report will be presentated at the Band 3 CDR.
8.	Orientation	FEND-40.02.03.00-00340-00/A, R, T	Compliant by design but needs to be tested at the FEIC.	This compliance will be verified once the Band 3 cartridge is integrated to the FE cryostat at the FEIC.
9.	LO frequency switching	FEND-40.00.00.00-00530-00/T to FEND-40.00.00.00-00590-00/T	Compliant by design but needs to be tested.	This is an LO related item. See [AD3]. Experimental verification to be done at the FEIC.
10.	LO phase switching	FEND-40.00.00.00-00630-00/T	Compliant by design but needs to be tested.	This is an LO related item. See [AD3]. Experimental verification to be done at the FEIC.
11.	Vacuum conditions	FEND-40.02.03.00-00470-00/R	Non compliant	With the present design, namely with the 'o' rings, the leak rate cannot be reduced to meet the specification. A change request has been issued [AD25].
12.	Electromagnetic compatibility	FEND-40.02.03.00-00510-00/T	Not tested yet.	Tests will be performed on one cartridge at the FEIC when the cartridge is integrated to the FE cryostat, PAS.
13.	Mean time between failure	FEND-40.02.03.00-00570-00/A	Analysis not complete	A number of tests (thermal cycle) of mixers and amplifiers must be done for performing a full analysis of the cold cartridge MTBF. Results will be presented at the CDR. See [AD26] for a first analysis.

14.	Lifetime	FEND-40.02.03.00-00580-00/R	Not analyzed yet	The cartridge was designed to have a lifetime longer than 15 years. An analysis will be presented at the CDR.