Atacama
Large
Millimeter
Array

Front-End Sub-System for the 12 m-Antenna Array
Acceptance Verification Results

FEND-40.00.00.00-116-A-REP

Status: Released

2008-04-29

Prepared By: Name(s) and Signature(s)	Organization	Date
K. S. Saini G. A. Ediss M. McLeod J. Crabtree	NRAO NRAO NRAO NRAO	2008-04-29
Approved By FEIC Manager		
Name and Signature		
A. Perfetto	NRAO Antonio Perfetto Digitally signed by Antonio Perfetto DN: cn=Antonio Perfetto, o=NRAO, ou, email=aperfett@nrao.edu, c=US Date: 2008.04.29 16:49:39 -04'00'	
Approved By FE sub-system Engineer		
Name and Signature		
K. S. Saini Kamaljeet S Saini ALMA / FE IPT 2008.04.29 15:48:14 -04'00' H. Rudolf	NRAO ESO	
Approved By FE IPT		
Name and Signature		
J. Webber G. H. Tan	NRAO ESO	

Change Record

Version	Date	Affected Section(s)	Change request #	Reason/remarks
	2008-03-10			More results added/corrected.
	2008-03-11			Added cool-down, warm-up, and hold times. Corrected total power and in-band power. Added B6 & B9 Amplitude stability. Added B6 power variation and spurious.
	2008-03-13	all		Amplitude stability complete. Added B6 & B7 amplitude vs. tilt. Added sections at end for ICD and safety requirements. Added pol/sideband verification for B6 Checked all sections for accuracy to current status.
	2008-03-24	3.1.7, 6.10		Added spec lines to unlocked amplitude stability charts. Added B9 amplitude vs. tilt angle. Added verification of pol&sb outputs for bands 3, 7, and 9.
	2008-04-14	3.3.1.1,3.3.1.2, 3.3.1.3 3.3.1.5 and 3.3.2.6		Reanalysis of data
	2008-04-15	Several		Added footnotes to respond to questions submitted by Richard Hills.
	2008-04-29	Signature Block		Updated signature block

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Purpose

This document summarizes the results obtained during the acceptance verification of the ALMA Front End, Serial Number 001. All of the measurements, analysis and conclusions in this report are subject to change upon further work.

1.2 Scope

This document applies to the work-package for the Front End described by the statement of work in [RD5] and applies to all products 40.xx.xx.xx within the ALMA product tree [RD3] with the exception of 40.06.00.00 (Front end integrated calibration & widgets), 40.07.00.00 (Water Vapor Radiometer, 40.09.xx.xx (Front End specific test, construction and service equipment) and 40.90.xx.xx (Front End Design Reviews).

1.3 Applicable documents

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

Reference	*Document title*	*Document ID*
[AD1]	ALMA Environmental Specification	ALMA-80.05.02.00-001-B-SPE
[AD2]	ALMA System: Electromagnetic Compatibility (EMC) Requirements	ALMA-80.05.01.00-001-B-SPE
[AD3]	ICD between Antenna and Front-End	ALMA-34.00.00.00- 40.00.00.00-D-ICD
[AD4]	ICD between Front-End/WVR and Back End/LO & Time Reference	ALMA-40.07.00.00 -50.03.00.00-B-ICD
[AD5]	ICD between Front-End/IF and Back End/IF Down-converter	ALMA-40.08.00.00 -52.00.00.00-A-ICD
[AD6]	ICD between Front-End and Computing/Control software	ALMA-40.00.00.00 -70.35.25.00-A-ICD
[AD7]	ICD between Front-End/Compressor and Computing/Control software	ALMA-40.03.00.00 -70.35.25.00-A-ICD
[AD8]	ICD between Front-End/WVR and Computing/Control software	ALMA-40.07.00.00 -70.35.25.00-A-ICD
[AD9]	ALMA System: Electrical Design Requirements	ALMA-80.05.00.00-005-C-SPE
[AD10]	ALMA Power Quality (Compatibility Levels) Specification	ALMA-80.05.00.00-001-C-SPE
[AD11]	Standards for AC Plugs, Socket-outlets, and Couplers	ALMA-80.05.00.00-004-B-STD
[AD12]	ALMA System: General Safety Design Specification	ALMA-10.08.00.00-003-B-SPE
[AD13]	ALMA Project System-Level Technical Requirements	ALMA-80.04.00.00-005-B-SPE
[AD14]	ICD between Front End – Integrated Calibration & Widgets and Computing – Control Software	ALMA-40.06.00.00-70.35.25.00-A-ICD
[AD15]	ICD between Front End - power supply unit and Computing – control software	ALMA-40.04.01.00-70.35.25.00-A-ICD
[AD16]	ICD between Front End First Local Oscillator and Back End LO and Time Reference	ALMA-40.10.00.00-50.00.00.00-A-ICD

[AD17]	Front End Acceptance Test Plan	FEND-40.00.00.00-078-A-PLA
[AD18]	Compliance Matrix for FE Serial No 001	Under Preparation
[AD19]	Electromagnetic Compatibility Testing With Bands 3, 6, 7, and 9	FEND-40.02.00.00-003-A-REP
[AD20]	Thermal/Airflow measurements report.	find document
[AD21]	Relative humidity/condensation report.	find document
[AD22]	Cryostat Technical Specifications	FEND-40.03.00.00-002-B-SPE

Table 1

In the event of a conflict between one of the above referenced applicable documents and the contents of this document, the contents of this document shall be considered as a superseding requirement.

1.4 Reference documents

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

Reference	*Document title*	*Document ID*
[RD1]	ALMA Acronyms and Abbreviations	ALMA-80.02.00.00-004-A-LIS
[RD2]	ALMA Front-end Optics Design Report	FEND-40.02.00.00-035-B-REP
[RD3]	ALMA Product Tree	ALMA-80.03.00.00-001-N-LIS
[RD4]	ALMA Scientific Specifications and Requirements	ALMA-90.00.00.00-001-A-SPE
[RD5]	Front End – Statement of Work	FEND-40.00.00.00-036-A-SOW
[RD6]	Band 7 Cartridge Operation Manual	FEND-40.02.07.00-025-A-MAN

Table 2

1.5 Acronyms

A limited set of basic acronyms used in this document is given below. A complete set of acronyms used in the ALMA project can be found in reference [RD1].

ALMA	Atacama Large Millimeter Array
DSB	Double-SideBand
EMC	Electro-Magnetic Compatibility
FESS	Front-End Support Structure
FLOOG	First LO Offset Generator
FWHM	Full Width Half Maximum
HPBW	Half power beam width
ICD	Interface Control Document
LO	Local Oscillator
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
MTTS	Mean Time To Service
PDR	Preliminary Design Review
RF	Radio Frequency
RFI	Radio Frequency Interference
RMS	Root Mean Square
SSB	Single-SideBand
WVR	Water Vapour Radiometer
2SB	Dual Side Band separating

1.6 Verb Convention

"Shall" is used whenever a specification expresses a provision that is binding. The verbs "should" and "may" express non-mandatory provisions.
"Will" is used to express a declaration of purpose on the part of the design activity.

1.7 Requirements Numbering

The requirements within the present document are numbered according to the following code:

[FEND-40.00.00.00-XXXXX-YY / Z(ZZ)]

Where:

FEND-40.00.00.00 identifies the 'Front-End Sub-System' as based on [RD3];

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(ZZ) 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.

2 FUNCTIONAL REQUIREMENTS EVALUATED

2.1 Operation modes

It was verified that the ALMA Front-End can be placed in the following modes/states, as described below:

2.1.1 Operational

In this mode electrical power is applied to the ALMA Front-End with all active signal levels at nominal values. One frequency band cartridge is powered and operational while a maximum of two other cartridges are on stand-by (see section 3.1.3). See [AD19], a report of electromagnetic compatibility testing with simultaneous operation of cartridge bands.

2.1.2 Non-Operational

In this mode electrical power is not applied and signal levels are not at nominal values.

2.1.3 Stand-by

In this mode operational power is applied to a cartridge but signal levels are not at nominal values. The stand-by mode only applies to cartridges within the Front-End and not to the Front-End assembly as a whole.

2.1.4 Transport with the antenna or in the service vehicle

In this mode the Front-End is transported with the antenna on the antenna transport vehicle or in the Front-End service vehicle. This mode differs from the non-operational mode in the environmental operating conditions [AD1]. For this mode, the same specifications and requirements as for the non-operational mode apply, ***no verification with respect to compliance to this requirement was made.***

2.1.5 Storage

In this mode the ALMA Front-End is stored completely assembled. This mode differs from the non-operational mode in the environmental conditions and the lack of monitoring and control signals. For storage, the same specifications and requirements as for the non-operational mode apply; ***no verification with respect to compliance to this requirement was made.***

2.2 General

2.2.1 Pre-selection of observation bands

[FEND-40.00.00.00-00010-00 / R]

Specification to be verified: Means shall be provided for the application of nominal power and signals to the desired cartridge and the associated warm cartridge assembly. The local oscillator of the pre-selected cartridge does not need to be phase locked.

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

2.2.2 Mechanical tuning

[FEND-40.00.00.00-00020-00 / R]

Specification to be verified: The operation of the Front-End shall not require the use of mechanical tuners.

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

2.2.3 Standard parts

[FEND-40.00.00.00-00030-00 / R]

Specification to be verified: Standard, unmodified commercially available components shall be used where possible.

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

2.2.4 Cables and connectors

[FEND-40.00.00.00-00040-00 / IR]
Specification to be verified: All power cables and connectors shall comply with [AD10] and [AD11].

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

2.2.5 Solar observing and safety

[FEND-40.00.00.00-00050-00 / AT]
Specification to be verified: This specification applies only to the operational and non-operational modes. During solar observation no cartridges are required to be in the stand-by mode.
The application of 0.03 W/cm^2 of solar radiation shall not result in damage to a Front-End assembly. Provisions shall be taken to allow observations of the sun. The performance specifications for solar observation are TBD.

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

2.3 Frequency Coverage

This section only applies to the operational mode.

2.3.1 RF input port

[FEND-40.00.00.00-00060-00 / R]
Specification to be verified: The RF input frequency ranges shall comply with the following values:

Band	*Lower frequency*	*Upper frequency*
1	31.3 GHz	45 GHz
2	67 GHz	90 GHz
3	84 GHz	116 GHz
4	125 GHz	163 GHz
5	163 GHz	211 GHz
6	211 GHz	275 GHz
7	275 GHz	373 GHz
8	385 GHz	500 GHz
9	602 GHz	720 GHz
10	787 GHz	950 GHz

Table 3

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

2.3.2 LO input port

[FEND-40.00.00.00-00070-00 / R]

Specification to be verified: The first LO frequency ranges shall comply with the following values:

Band	*Lower frequency*	*Upper frequency*	*Mixing scheme*	*Remarks*
1	27.3 GHz	33 GHz	USB	
2	79 GHz	94 GHz	LSB	
3	92 GHz	108 GHz	2SB	
4	133 GHz	155 GHz	2SB	
5	171 GHz	203 GHz	2SB	
6	221 GHz	265 GHz	2SB	Band 6 uses a 2SB mixing scheme, but provides an IF at 4-12 GHz. All specifications met over 4.5-10 GHz, usable with slight degradation over the remainder of the 4-12 GHz range
7	283 GHz	365 GHz	2SB	
8	393 GHz	492 GHz	2SB	
9	610 GHz	712 GHz	DSB	This allows for a possible 2SB option.
10	795 GHz	942 GHz	DSB	This allows for a possible 2SB option.

Table 4

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

2.3.3 IF output port bandwidth and centre frequency

[FEND-40.00.00.00-00080-00 / R]

Specification to be verified: Each signal channel shall provide 8 GHz total IF bandwidth per polarisation using the following scheme

- 8 GHz bandwidth single-sideband (SSB), upper or lower sideband centred at 8.0 GHz
- 8 GHz bandwidth double-sideband (DSB), centred at 8.0 GHz
- 4 GHz bandwidth dual-sideband, (2SB) upper and lower sideband, centred between 6.0 GHz and 10 GHz. This shall be compatible with the LO tuning range of section 2.3.2.

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

3 PERFORMANCE REQUIREMENTS EVALUATED

3.1 General requirements

3.1.1 Front-End Noise Performance

[FEND-40.00.00.00-00090-00 / T]

This section only applies to the operational mode.

Specification to be verified: The following table indicates the required noise temperature performance of the ALMA Front-End. The noise performance includes all contributions from warm optics, cryostat windows, and IR filters. It shall include all noise contributions through to the Front-End assembly IF output ports.
The cartridge noise temperature shall not exceed the values as follows:

Specifications for maximum receiver noise temperatures

Band	***SSB***		***DSB***		***Requirement Number***
	T_{SSB} over 80% of the RF band	***T_{SSB} at any RF frequency***	***T_{DSB} over 80% of the RF band***	***T_{DSB} at any RF frequency***	
1	17 K	26 K	NA	NA	[FEND-40.00.00.00-00810-00 / T]
2	30 K	47 K	NA	NA	[FEND-40.00.00.00-00820-00 / T]
3	37 K	60 K	NA	NA	[FEND-40.00.00.00-00830-00 / T]
4	51 K	82 K	NA	NA	[FEND-40.00.00.00-00840-00 / T]
5	65 K	105 K	NA	NA	[FEND-40.00.00.00-00850-00 / T]
6	83 K	136 K	NA	NA	[FEND-40.00.00.00-00860-00 / T]
7	147 K	219 K	NA	NA	[FEND-40.00.00.00-00870-00 / T]
8	196 K	292 K	NA	NA	[FEND-40.00.00.00-00880-00 / T]
9	NA	NA	175 K	261 K	[FEND-40.00.00.00-00890-00 / T]
10	NA	NA	230 K	344 K	[FEND-40.00.00.00-00900-00 / T]

Table 5

Results:

Band 3

The band 3 noise temperature results given here use data measured at the North American FEIC. The band 3 warm optics were installed and aligned for these measurements. They are corrected for image-band suppression using data provided by the band 3 cartridge group. Additionally, an intermediate version of the mixer bias algorithm was used. The band 3 cartridge group has since provided an optimization routine which may give better results.

The noise temperature measured here is worse than that provided by the band 3 cartridge group because these measurements include the warm optics and there is a thicker cryostat window (corresponding to the final window design.) The noise issues were widely discussed at the band 3 CDR. A change request seeking a relaxation of the specs is pending.

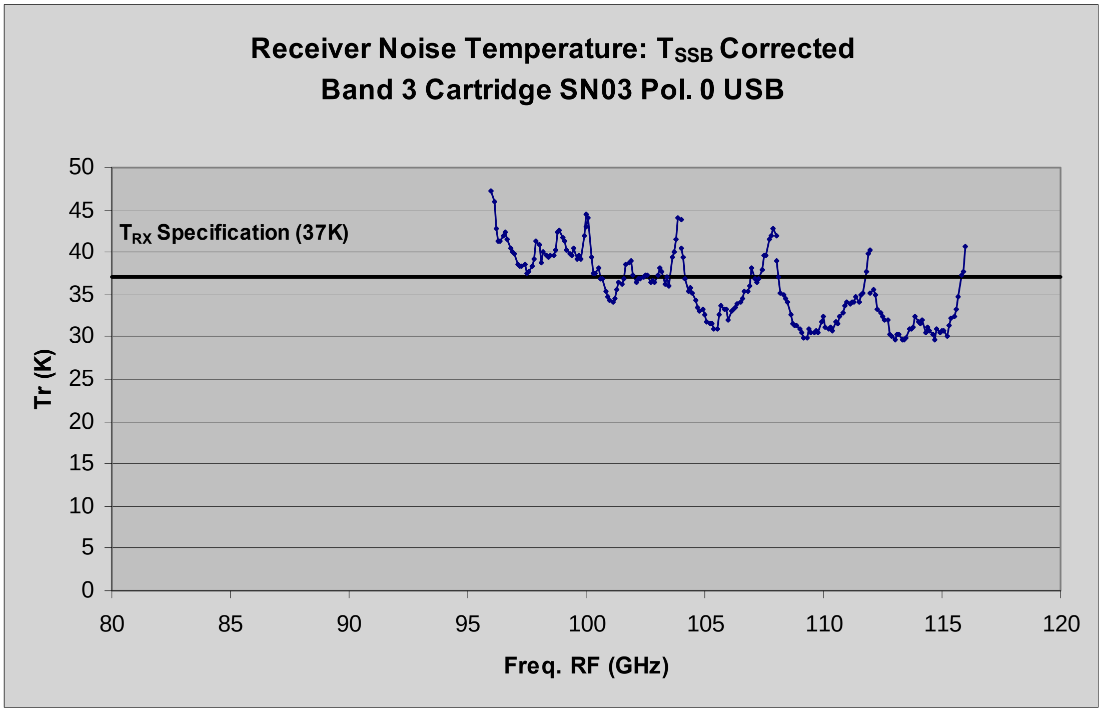


Figure 1 - Band 3 Pol.0 USB noise temperature

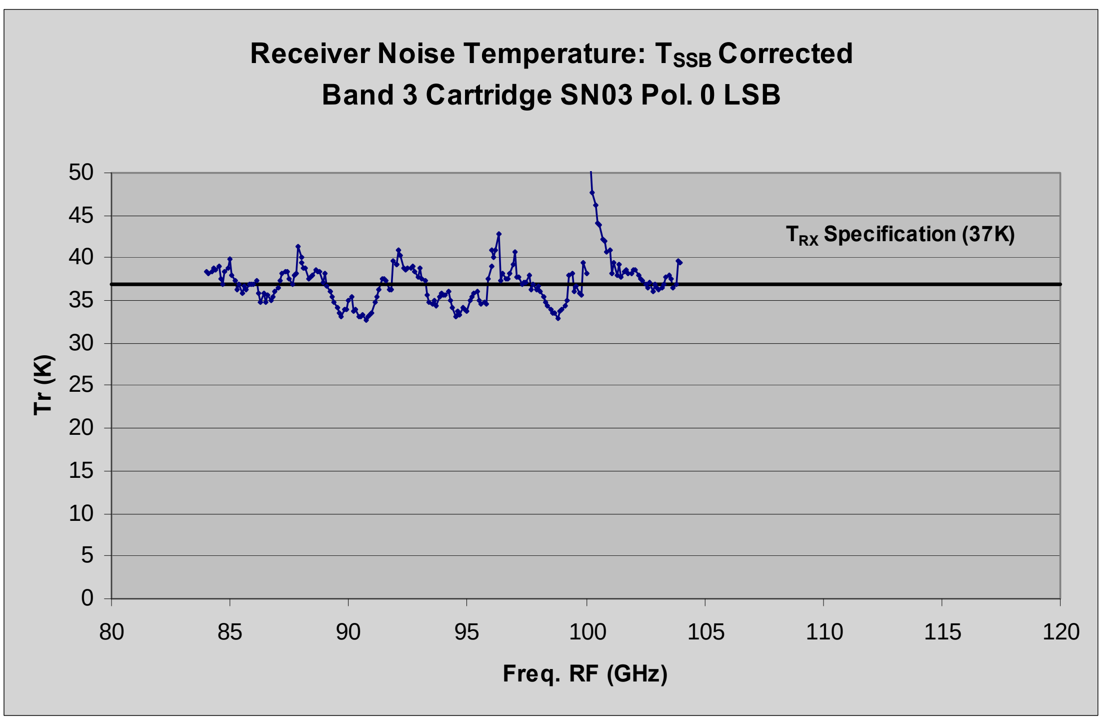


Figure 2 - Band 3 Pol.0 LSB noise temperature

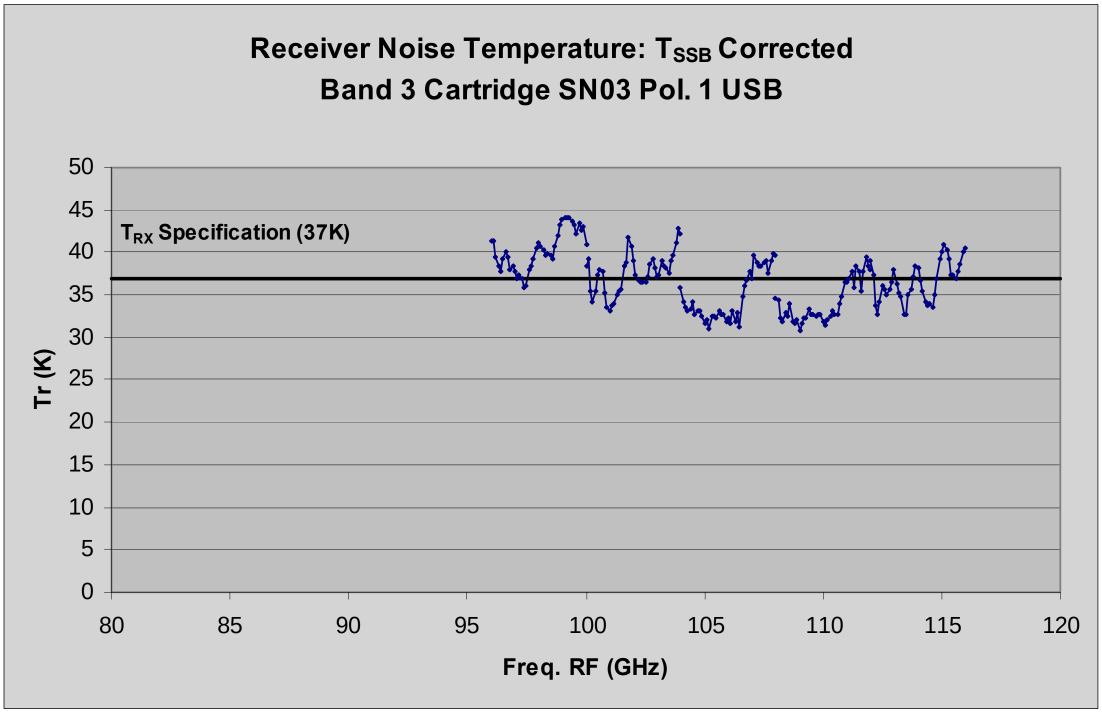


Figure 3 - Band 3 Pol.1 USB noise temperature

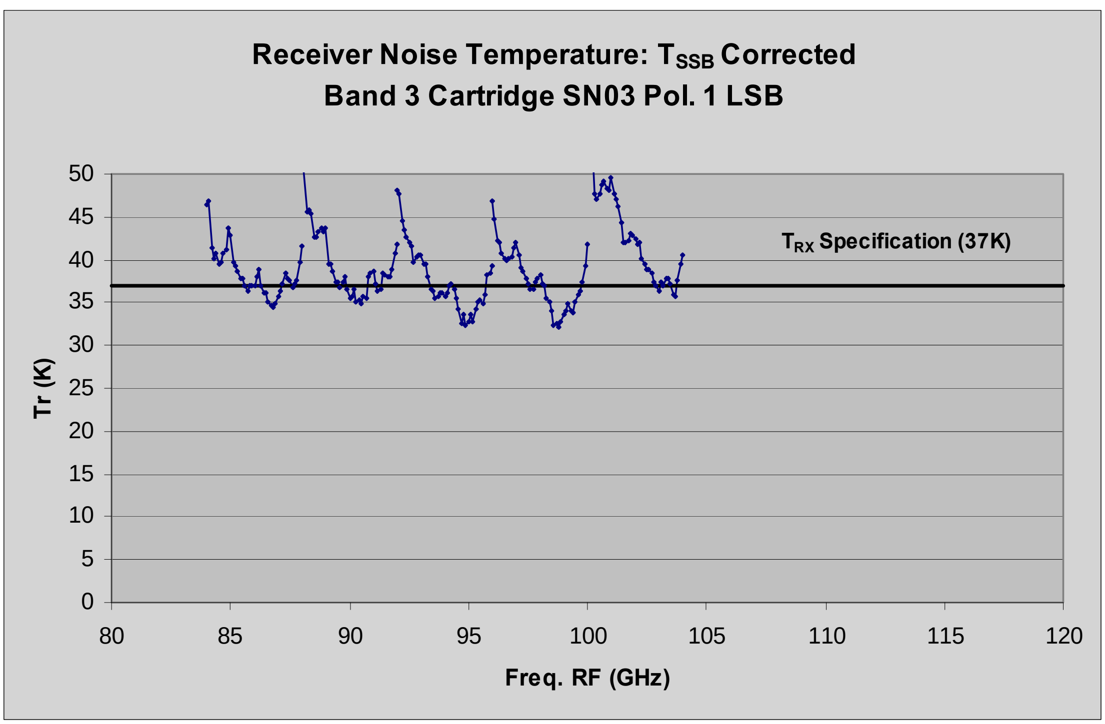


Figure 4 - Band 3 Pol.1 LSB noise temperature

Band 6

The band 6 noise temperature results given here use data measured at the North American FEIC. They are corrected for image-band suppression using data provided by the band 6 cartridge group.

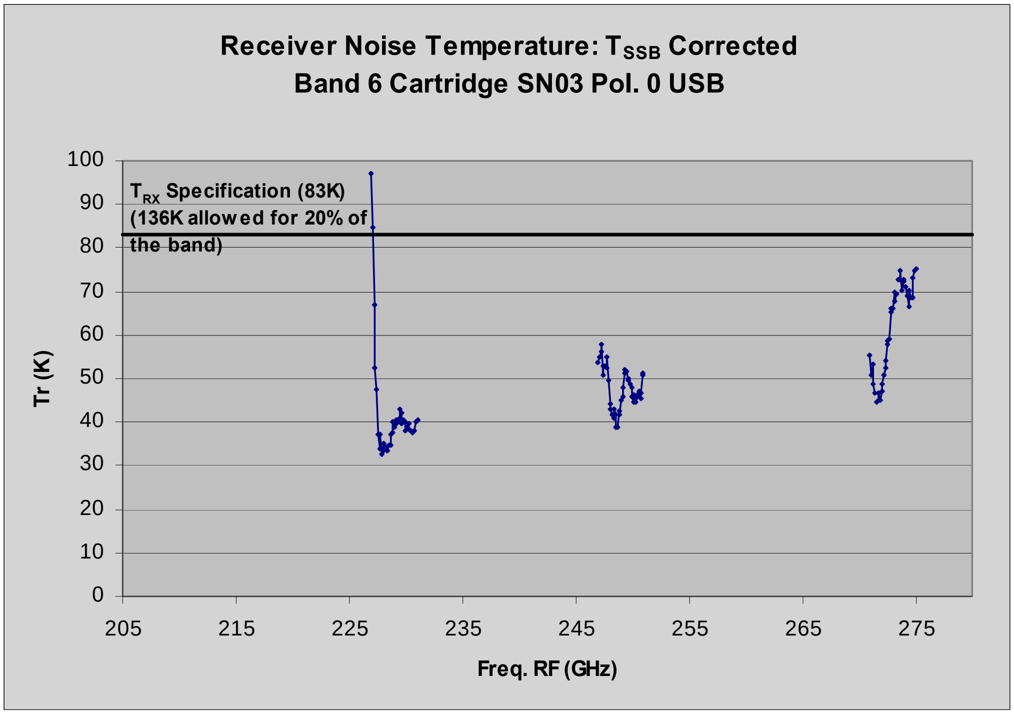


Figure 5 - Band 6 Pol.0 USB noise temperature[1]

[1] The cartridge group measurements also had this anomaly, but this was not explored further. Similar problem with another WCA (in conjunction with another cartridge) was confirmed to be a WCA noise problem at the band edge using the LO groups' noise screening setup. However in this case the excess noise is seen only on one polarization.

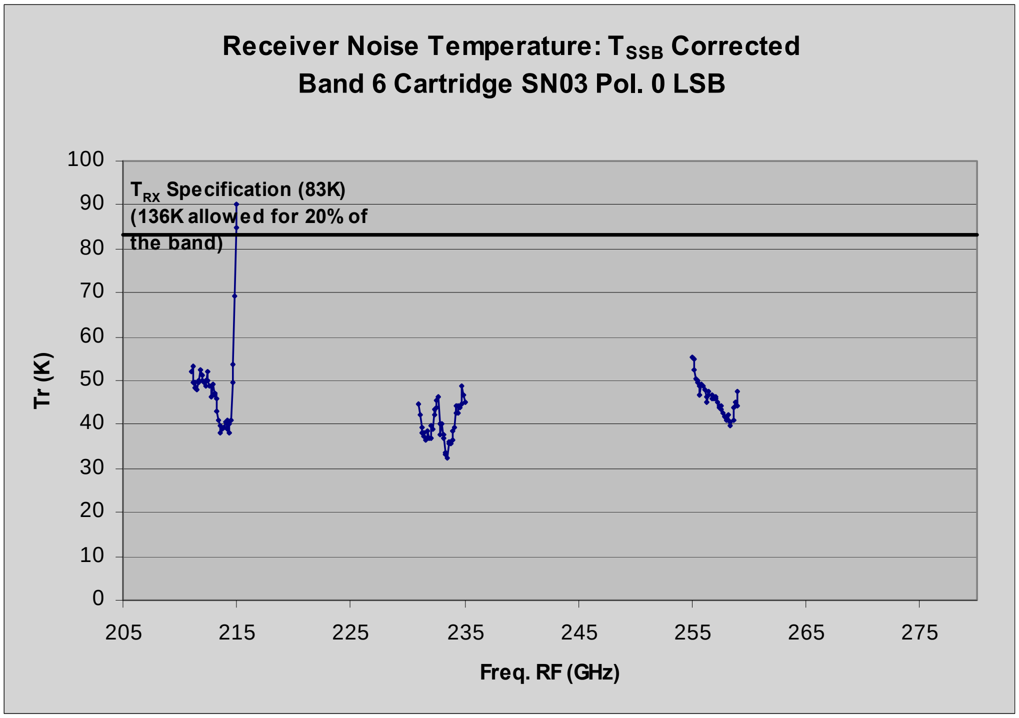


Figure 6 - Band 6 Pol.0 LSB noise temperature

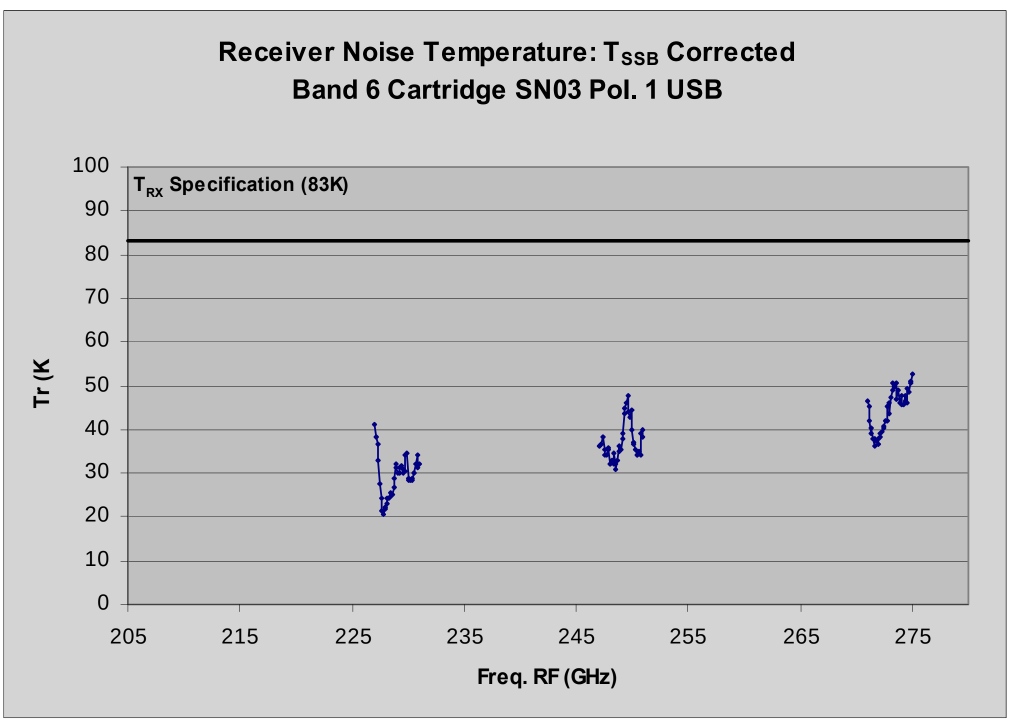


Figure 7 - Band 6 Pol.1 USB noise temperature

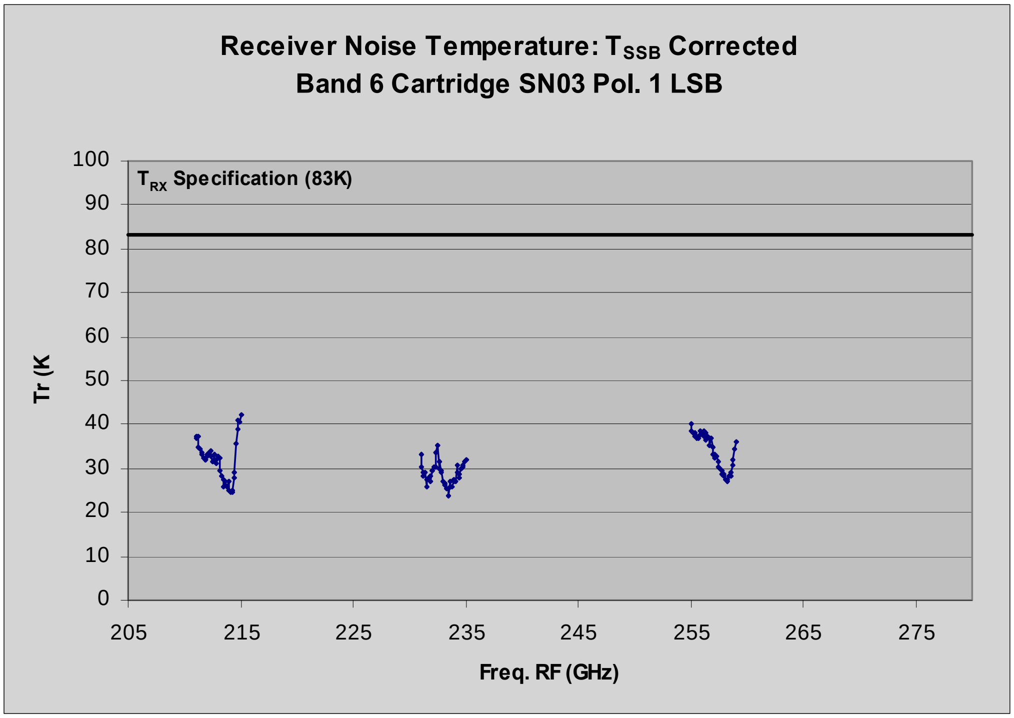


Figure 8 - Band 6 Pol.1 LSB noise temperature

Band 7

The band 7 noise temperature results here are from measurements taken at the North American FEIC; however they are corrected for image-band suppression using typical/average values from the band 7 cartridge acceptance report (13 dB for pol.0, 15 dB for pol.1) We await delivery of the actual image-band suppression data for this cartridge.

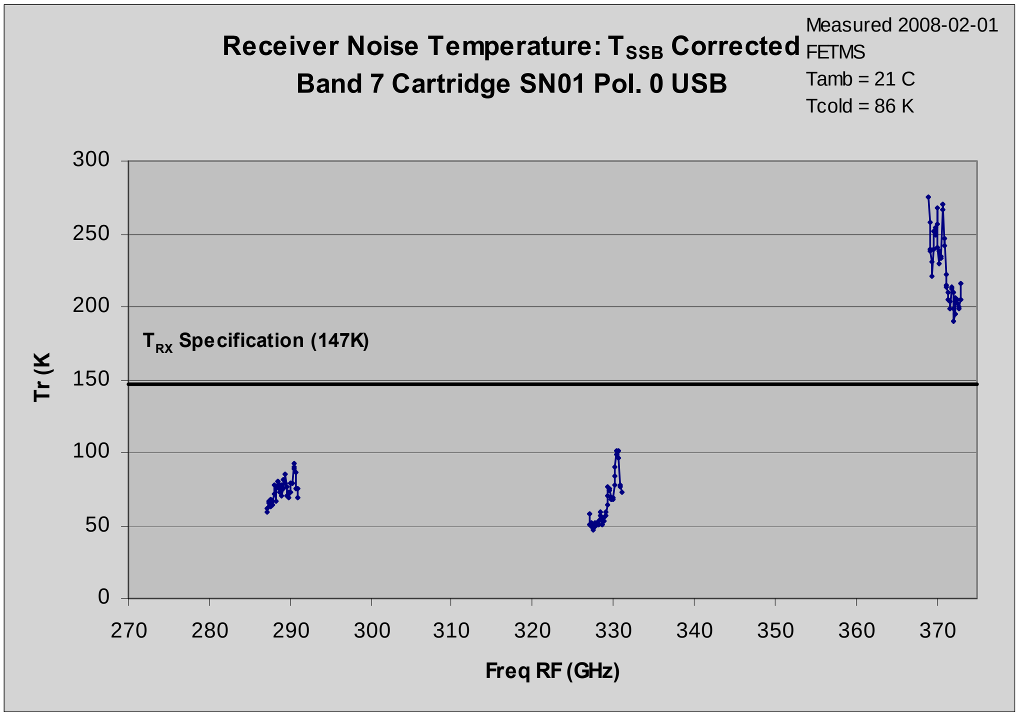


Figure 9 - Band 7 Pol.0 USB noise temperature[2]

[2] For a good while it was thought (on the basis of noise measurements at middle frequency) that the FEIC Band 7 cartridge measurements were consistent with the cartridge groups' measurements. However, while taking the final PAI data it was discovered not to be true and an excess noise was seen at the high end of the band. But there was no time for a follow up. Note that for the FEIC measurements, the mixer is cooler than it was during the cartridge groups' testing. Also the measurements were made with the operating parameters provided by the cartridge group at 4 K without further optimization. From the un pumped IV curves, however, there was no indication of Josephson currents.

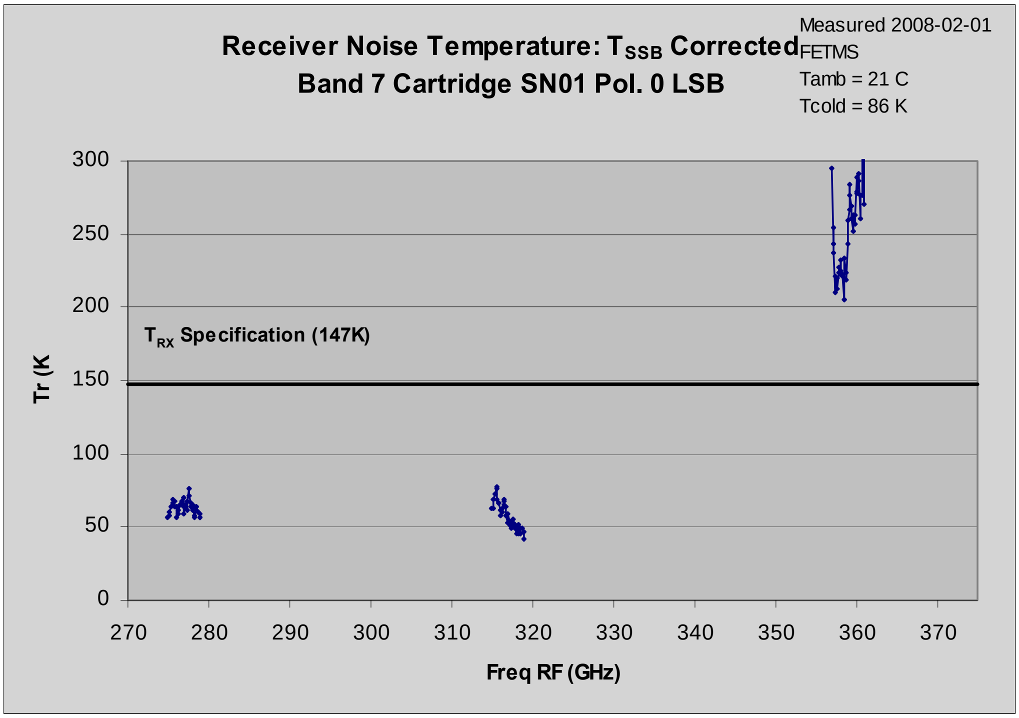


Figure 10 - Band 7 Pol.0 LSB noise temperature

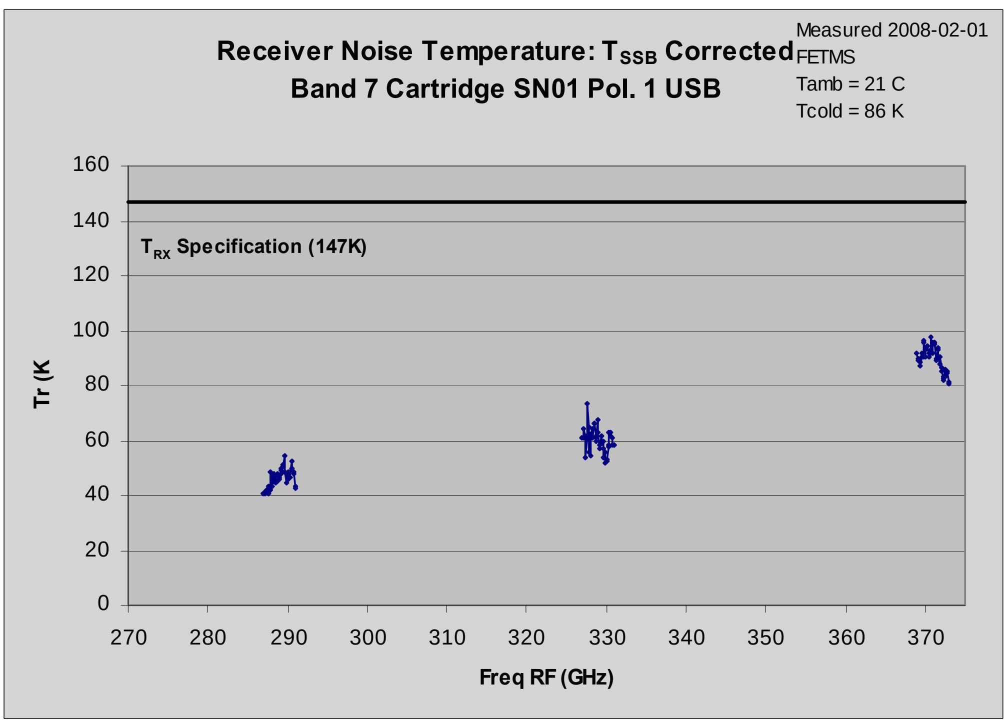


Figure 11 - Band 7 Pol.1 USB noise temperature

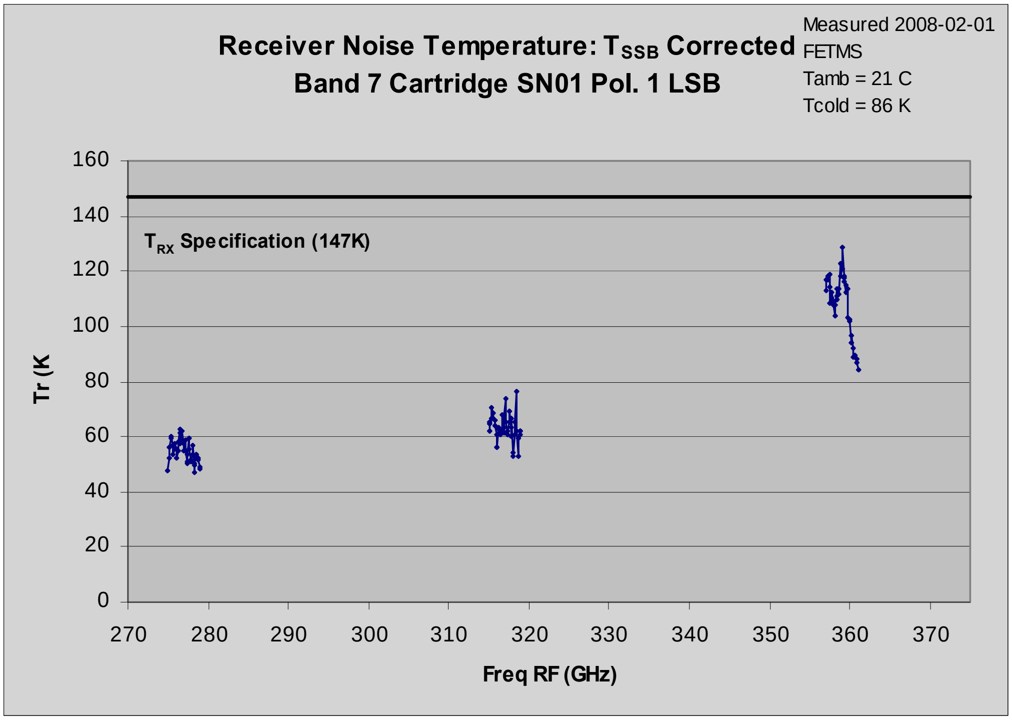


Figure 12 - Band 7 Pol.1 LSB noise temperature

Figure 13 gives the results of further investigation into the elevate noise temperature at higher LO frequencies: The receiver was measured using a cold load dipped in liquid nitrogen and a similar cone at ambient temperature. A selection of LO frequencies were measured with the YIG filter left fixed at 6 GHz in the IF.

The band 7 cartridge operating manual [RD6] only provides optimization instructions for minimizing the mixers' Josephson current. When we measured the I-V curve of the mixers when operating at the frequencies with high noise temperature, no Josephson current spikes were evident.

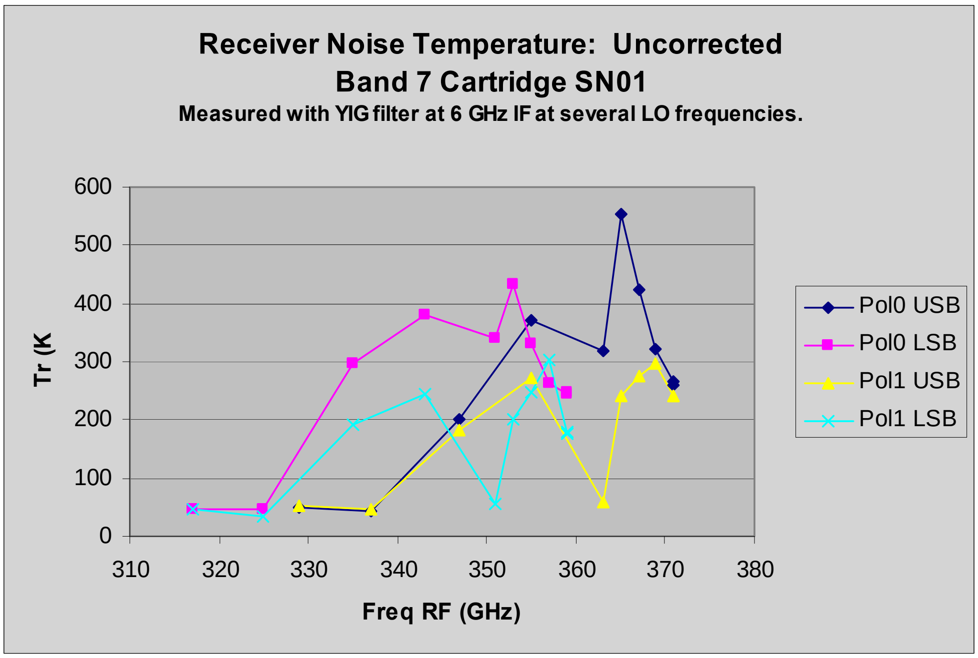


Figure 13 - Band 7 noise temperature – further investigation

Band 9

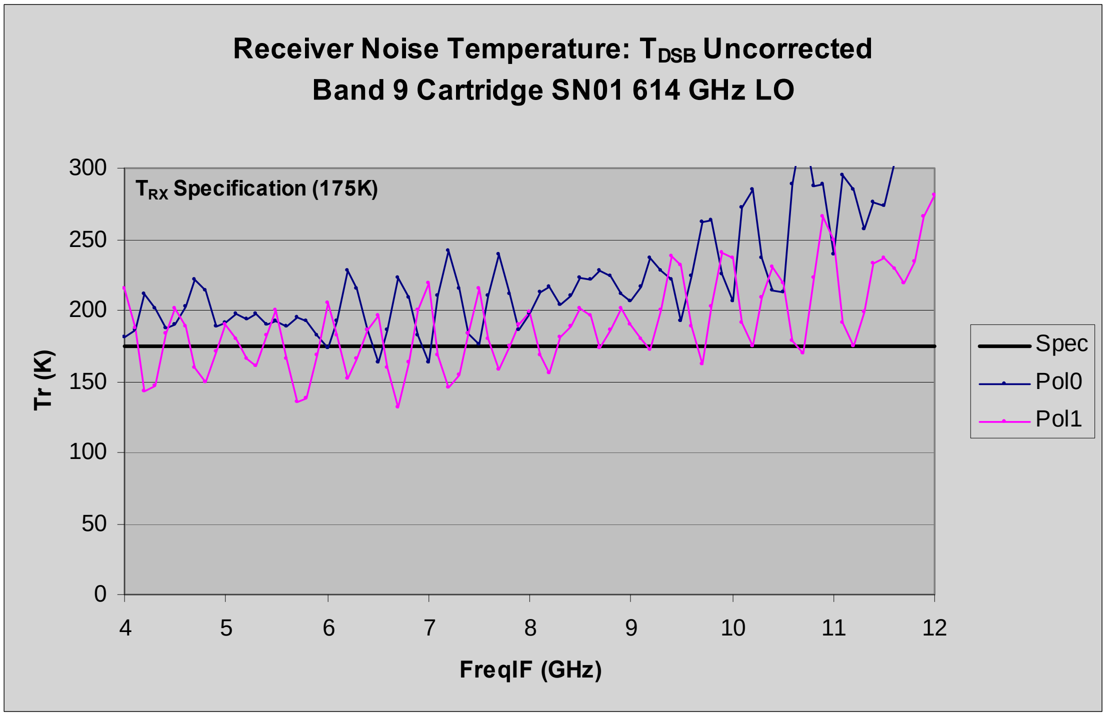


Figure 14 - Band 9 noise temperature at 614 GHz LO.[3]

[3] The ripple could be explained by a possible mismatch problem at the low frequency end, where the mixer match could be deteriorating.

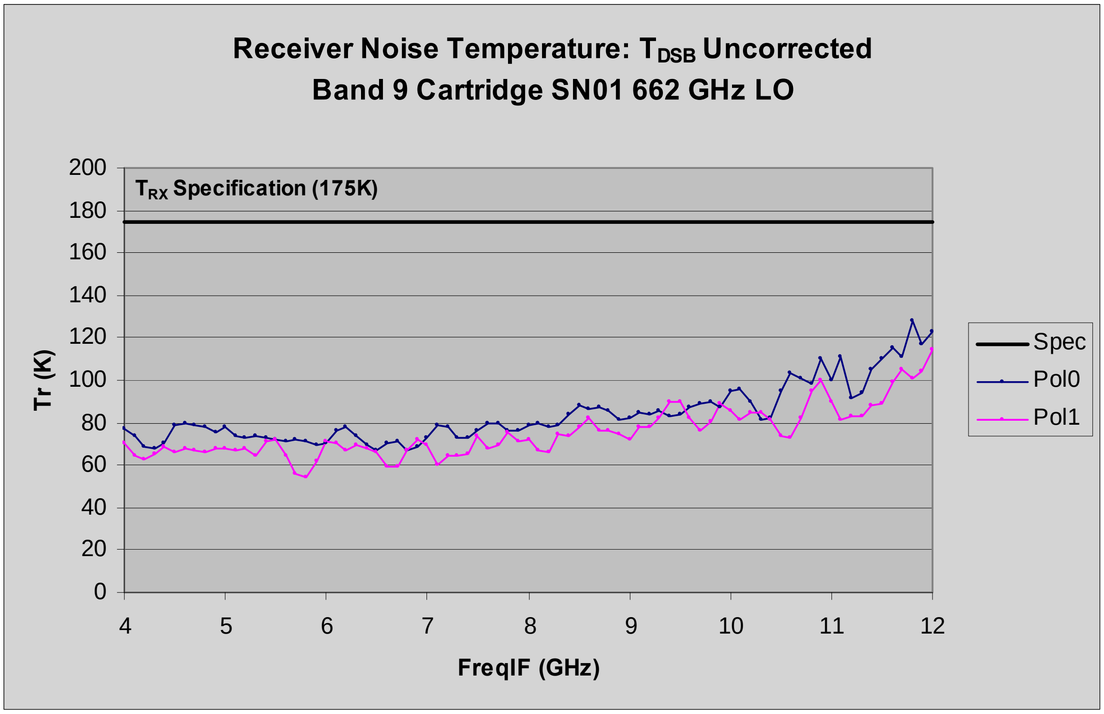


Figure 15 - Band 9 noise temperature at 662 GHz LO.

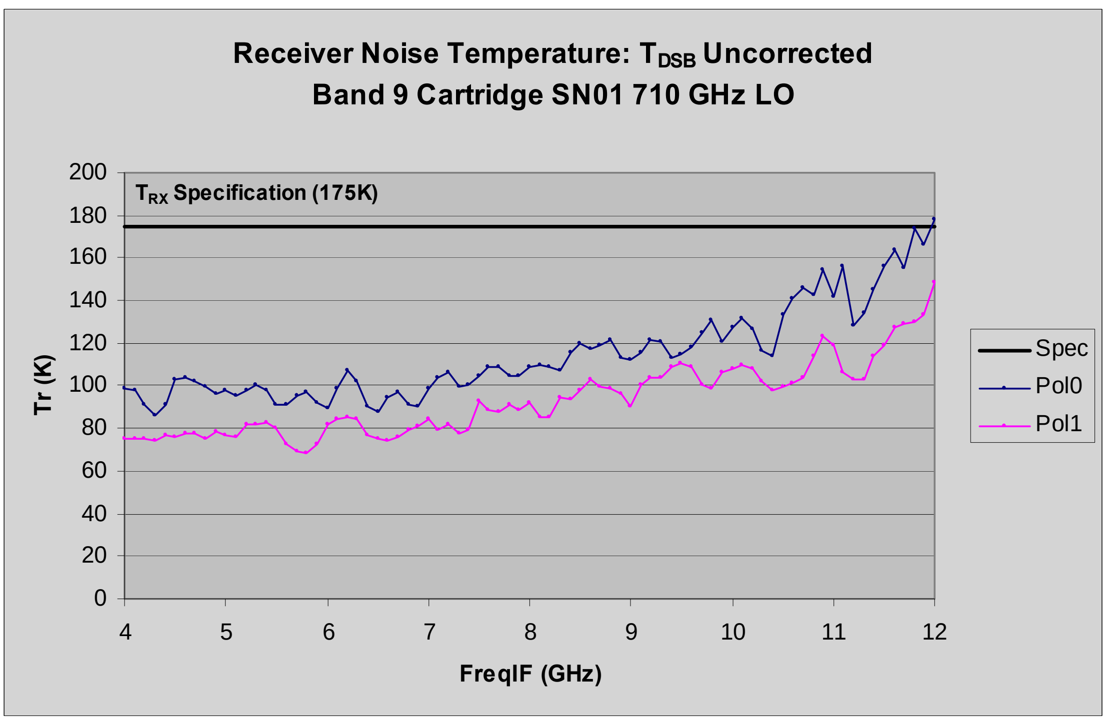


Figure 16 - Band 9 noise temperature at 710 GHz LO.

3.1.2 Image Band Suppression / sideband mismatch

[FEND-40.00.00.00-00100-00 / T]
This section only applies to the operational mode.

Specification to be verified: For a SSB or 2SB mixing scheme the image band suppression (for any LO frequency) shall be ≥ 10 dB over 90% of IF frequency range. Image-band suppression (for any LO frequency) shall be > 7 dB over entire IF frequency range

For all receiver bands using the DSB mixing scheme the side-band ratio shall be less than 3 dB averaged across all IF frequencies. This with the exception of that for the ALMA Band 9 the side-band ratio shall be 3 dB or better across 80% of the combined IF and LO frequency ranges specified under sections 3.3.1 and 3.3.2.

Results:

Not measured. Cold cartridges were verified to meet image suppression/sideband mismatch specifications by the cartridge manufacturers. The image rejection data provided by the cartridge manufacturers were used to correct noise temperature measurements given in this report.

3.1.3 Spurious response of the Front-End[4]

[FEND-40.00.00.00-00120-00 / T]

Specification to be verified: At any LO frequency (within the specified range of a band) the IF power due to incoherent spurious signals shall be at least 10 dB below the nominal noise power in any 2 GHz bandwidth. Spurious signals shall occupy less than 0.1% of the nominal IF bandwidth.

The level of any spurious (coherent or incoherent) LO CW signals shall be < -40 dBc over the frequency range from 500 Hz to 12 GHz offset from the carrier signal.

This applies to both interference between cartridges as well as interference between the cartridges and the water vapour radiometer. The later was not verified.

The IF band as specified in section 2.3.3 shall not contain any coherent or incoherent self generated spurious signals larger than -40 dB per 1 MHz (TBC) relative to the receiver noise spectral density at the IF output.

Results:

For all cartridge bands, the frequency resolution is 30 MHz (YIG filter bandwidth.) Shown are the P_{HOT} vs IF results, having been calibrated for the gain slope of the IF processor.

Band 3

[4] The measurements in this section are necessary but not sufficient proof that the spurious specifications are met. At the TRR it was agreed that verification with respect to this specification could be omitted.

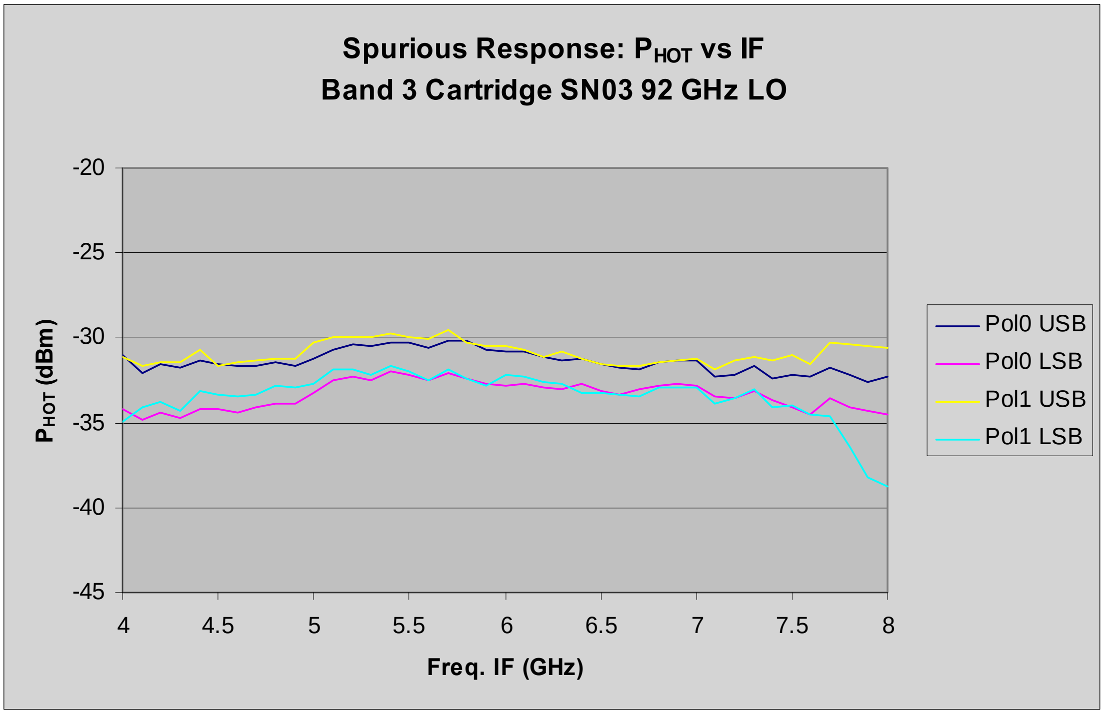


Figure 17 - Band 3 spurious 92 GHz LO

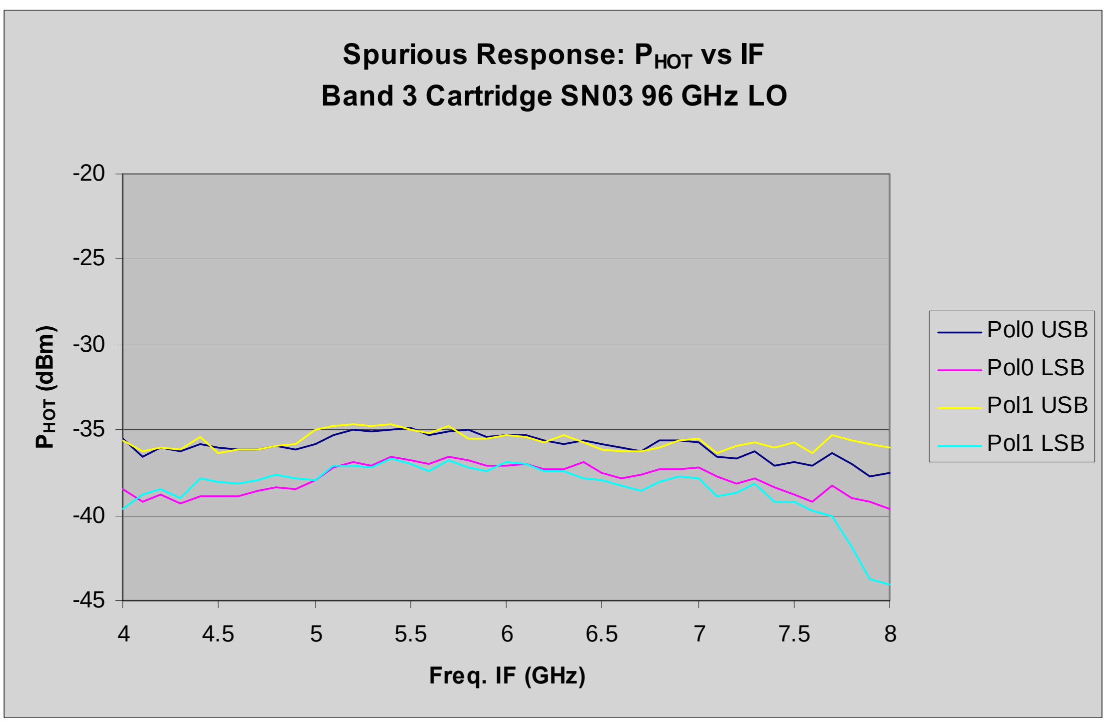


Figure 18 - Band 3 spurious 96 GHz LO

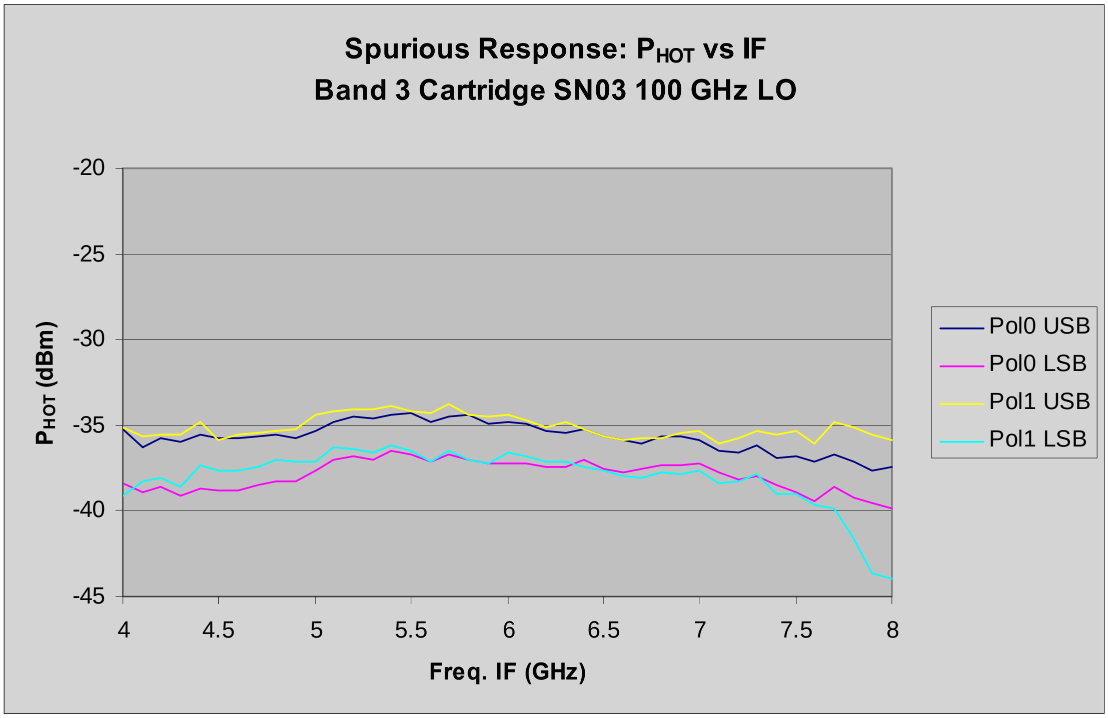


Figure 19 - Band 3 spurious 100 GHz LO

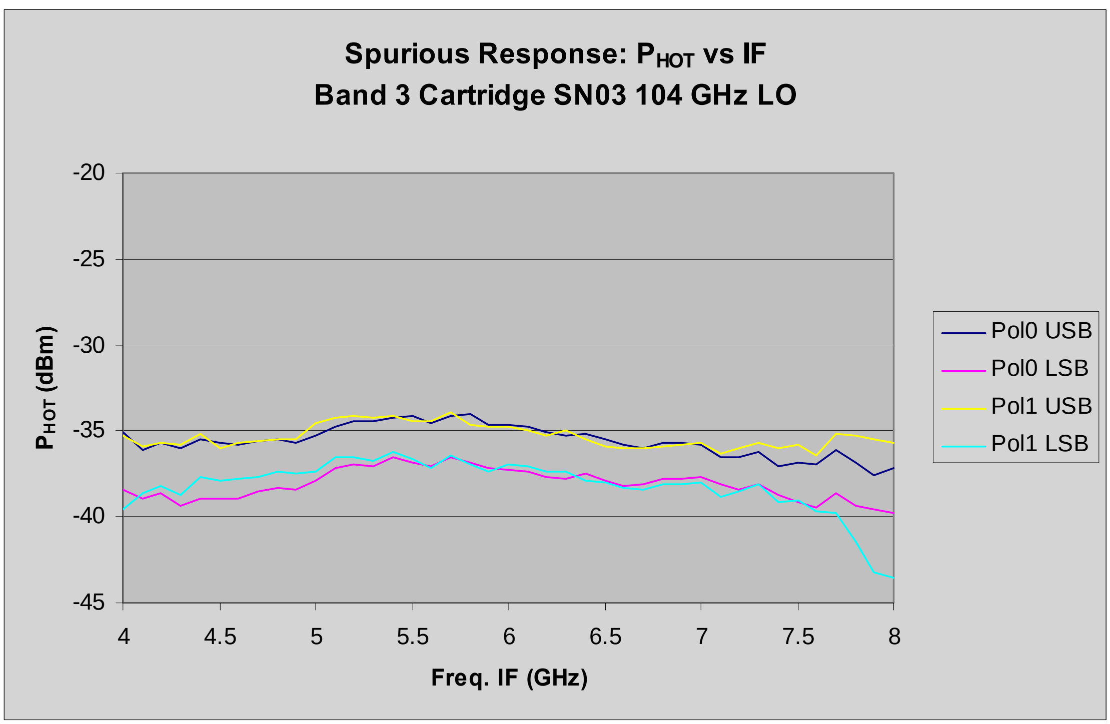


Figure 20 - Band 3 spurious 104 GHz LO

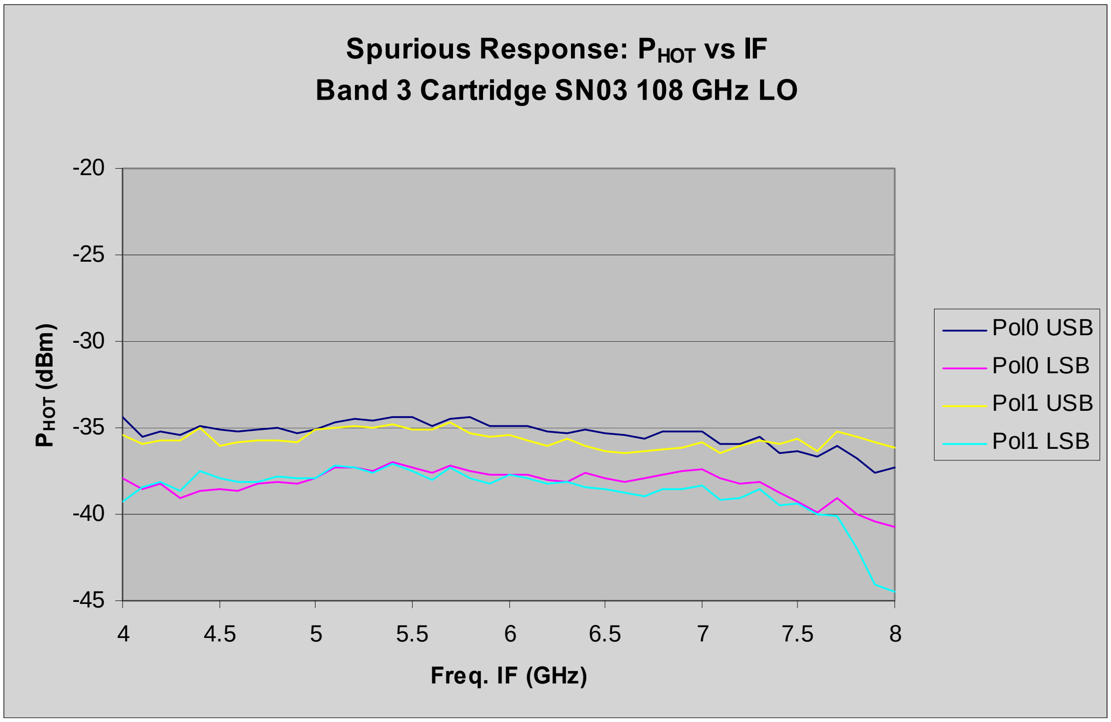


Figure 21 - Band 3 spurious 108 GHz LO

Band 6

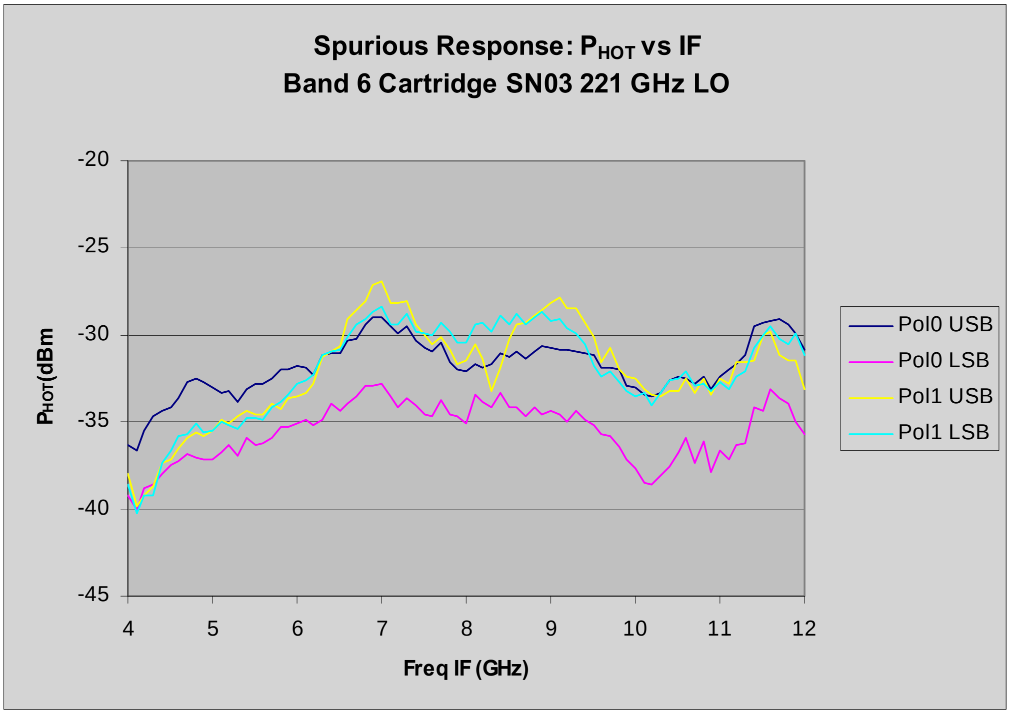


Figure 22 - Band 6 spurious 221 GHz LO

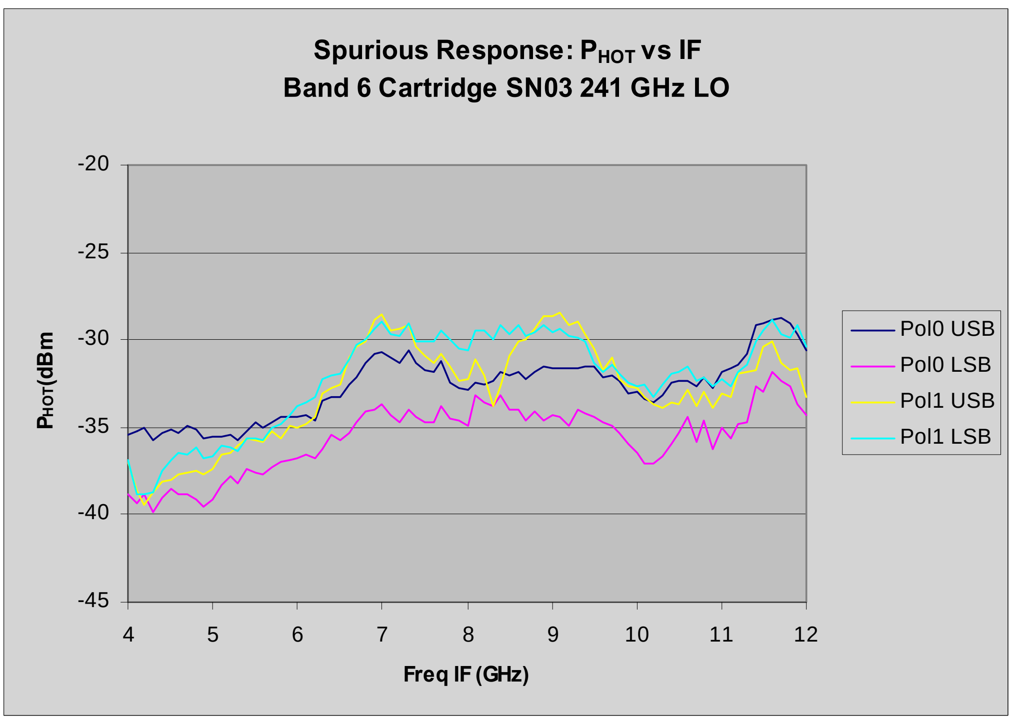


Figure 23 - Band 6 spurious 241 GHz LO

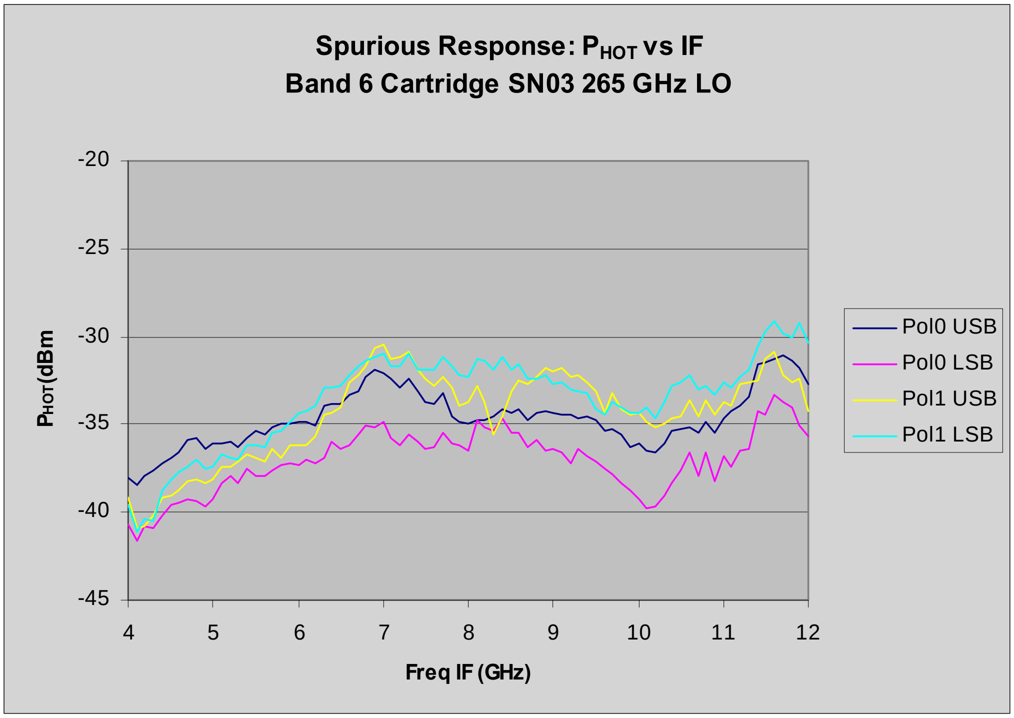


Figure 24 - Band 6 spurious 265 GHz LO

Band 7

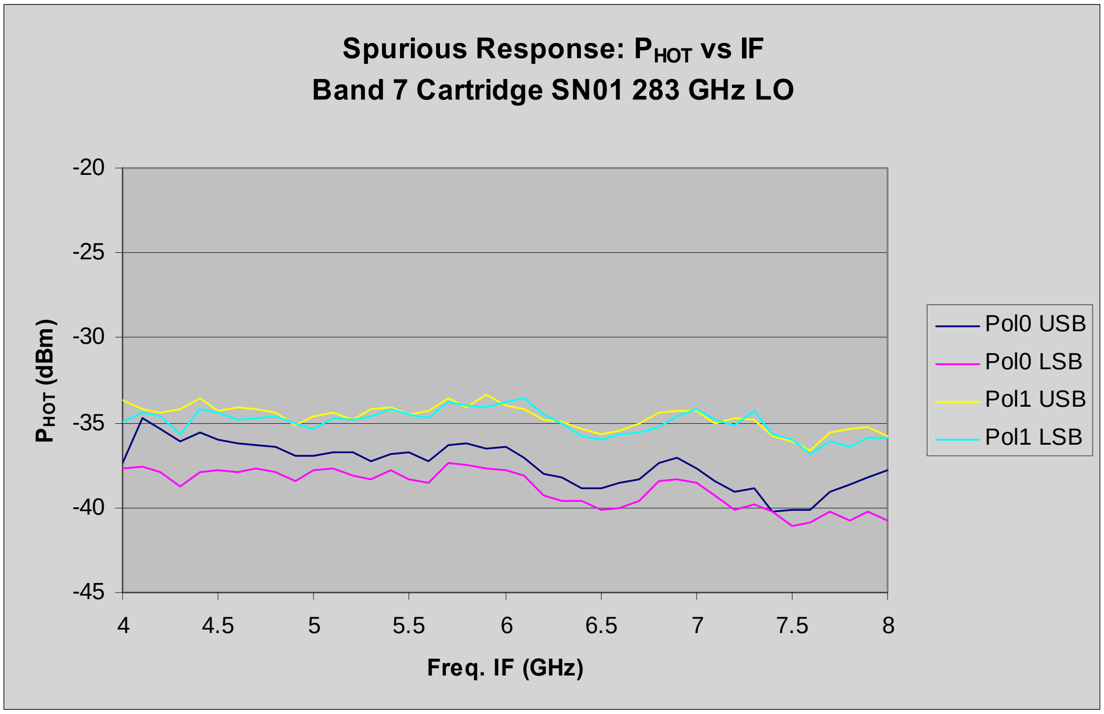


Figure 25 - Band 7 spurious 283 GHz LO

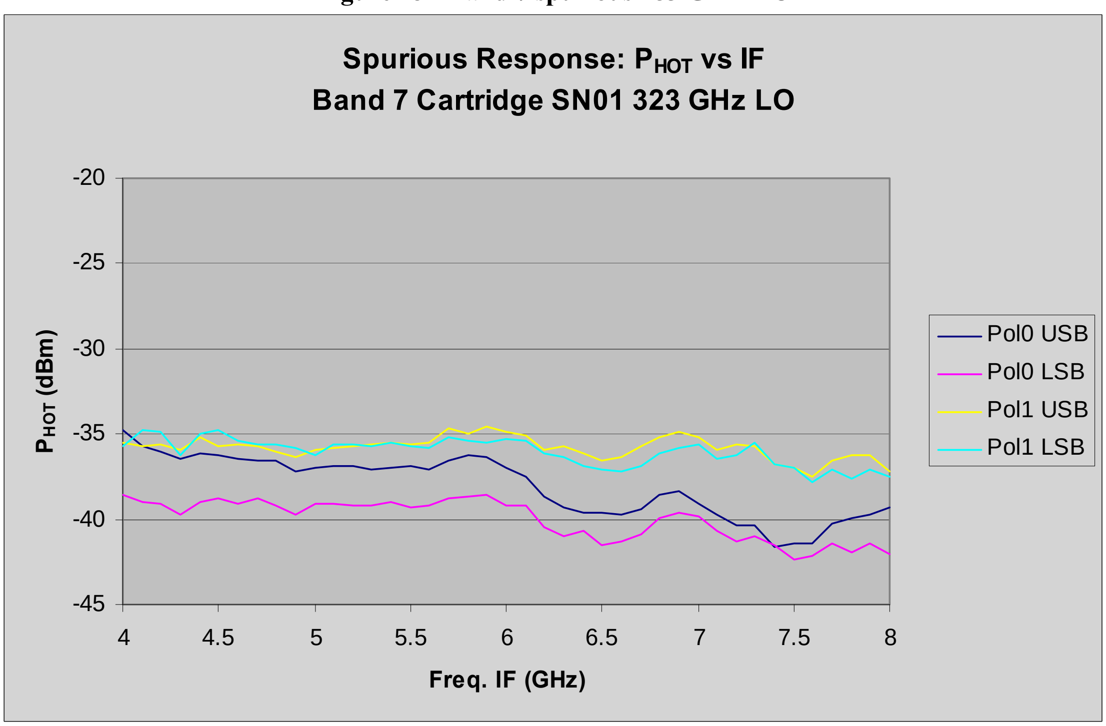


Figure 26 - Band 7 spurious 323 GHz LO

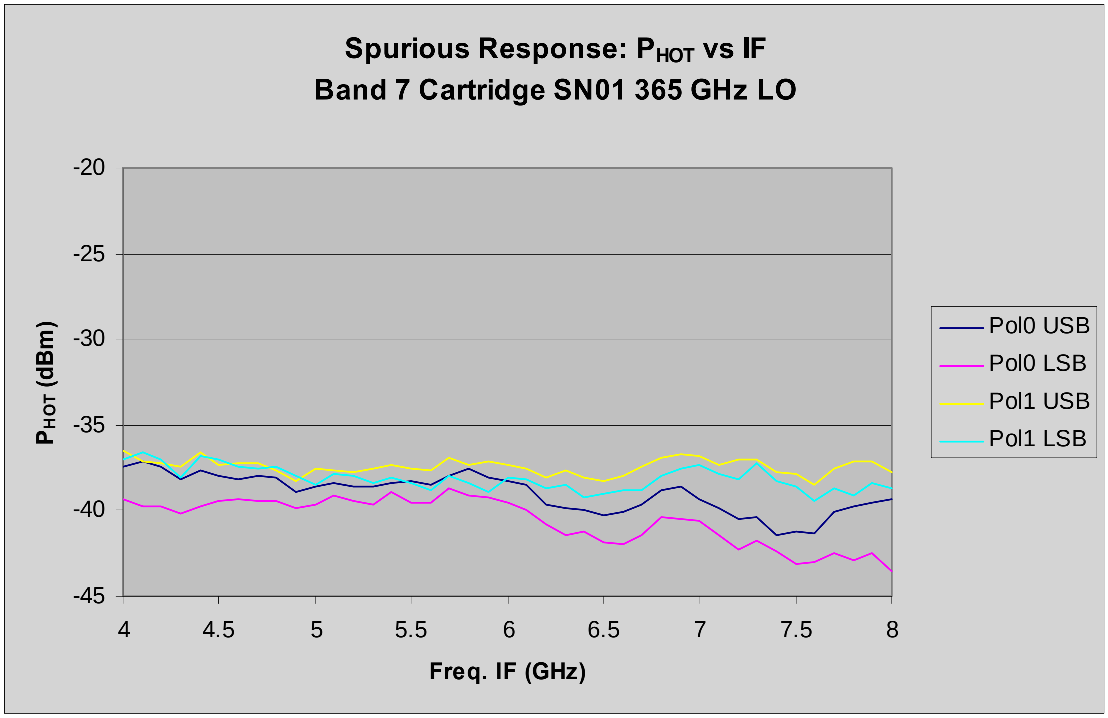


Figure 27 - Band 7 spurious 365 GHz LO

Band 9

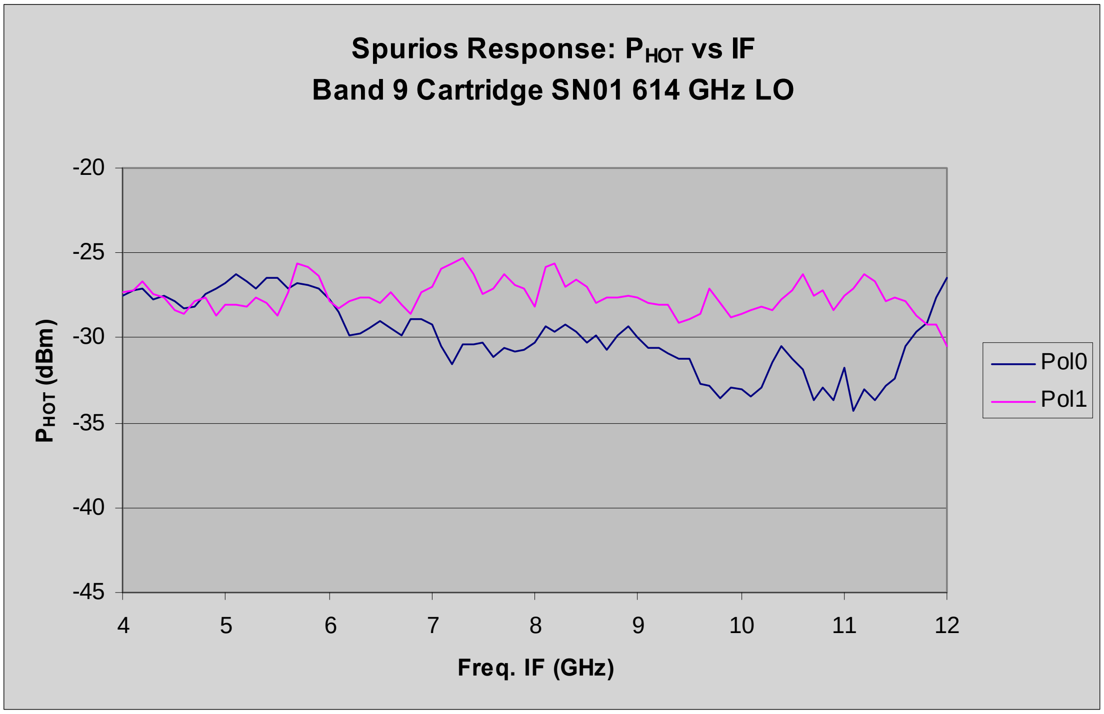


Figure 28 - Band 9 spurious 614 GHz LO

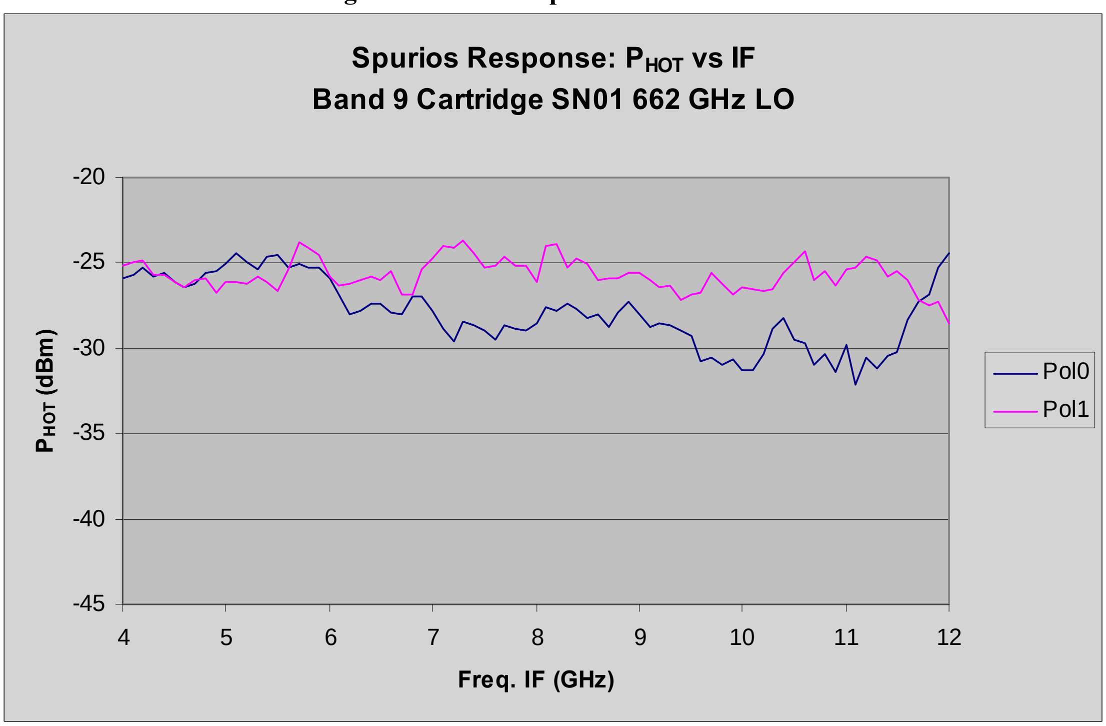


Figure 29 - Band 9 spurious 662 GHz LO

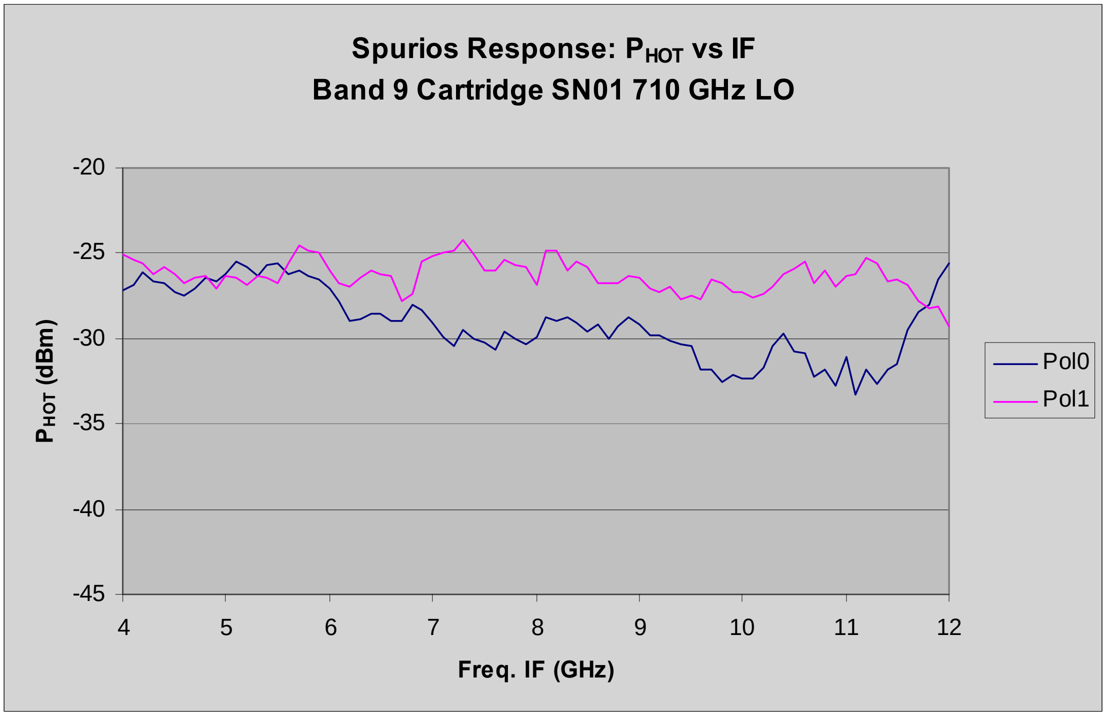


Figure 30 - Band 9 spurious 710 GHz LO

3.1.4 Saturation

[FEND-40.00.00.00-00130-00 / AT]
This section only applies to the operational mode.

Specification to be verified: The large signal gain compression resulting from an RF load of 100°C shall be less than 5%.

Result:

Not Measured. Gain compression including warm IF amplifiers was verified by the cartridge manufacturers to meet the specification. The other active component is the IF Switch, which was independently tested and found to be a negligible contributor to gain compression at the IF levels provided by the cartridges.

3.1.5 IF output power

[FEND-40.00.00.00-00140-00 / AT]
This section only applies to the operational mode.

Specification to be verified: For load temperature between 10 and 800 K at the RF input of the cartridge, the IF output power of the Front-End (measured at the Front-End IF outputs) shall comply with the following requirements:

- Total power in the IF frequency range specified in section 2.3.3: -31 dBm to -18 dBm
- Total power in the frequency range 10 MHz to 18 GHz: < -12 dBm (SSB, DSB)

- Total power in the frequency range 10 MHz to 18 GHz: < -15 dBm (2SB)

Result:

First the gain/loss of the cables and IF processor were calibrated by comparing a power meter and sensor attached directly to the FE IF outputs with power meters in the test system, after the IF processor. With the IF Processor's lowpass filter at 8 or 12 GHz switched out, 46 dB of attenuation in the IF processor was sufficient to obtain the same levels at either location. Then we measured the total and in-band power, with the FE IF Switch providing zero or 15 dB of attenuation. The following tables give the results.

In the tables for all bands the P_{300} values are measured whereas the P_{10} and the P_{800} values given in brackets are calculated from the P_{300} values.

Band 3

	Total Power (dBm) at IF Switch Attenuation:		In-band Power (dBm) at IF Switch Attenuation:	
	0 dB	15 dB	0 dB	15 dB
Pol0 USB	P_{300} = -12.19 (P_{10} = -20.75)	P_{300} = -27.41 (P_{800} = -23.46)	P_{300} = -12.72 (P_{10} = -21.28)	P_{300} = -27.93 (P_{800} = -23.98)
Pol0 LSB	P_{300} = -12.56 (P_{10} = -21.12)	P_{300} = -27.82 (P_{800} = -23.87)	P_{300} = -13.04 (P_{10} = -21.60)	P_{300} = -28.22 (P_{800} = -24.27)
Pol1 USB	P_{300} = -13.59 (P_{10} = -22.15)	P_{300} = -28.88 (P_{800} = -24.93)	P_{300} = -14.20 (P_{10} = -22.76)	P_{300} = -29.47 (P_{800} = -25.52)
Pol1 LSB	P_{300} = -11.94 (P_{10} = -20.50)	P_{300} = -27.24 (P_{800} = -23.29)	P_{300} = -12.71 (P_{10} = -21.27)	P_{300} = -27.99 (P_{800} = 24.04-)

Table 6 - Band 3 Total and In-Band power at 100 GHz LO

Band 6

	Total Power (dBm) at IF Switch Attenuation:		In-band Power (dBm) at IF Switch Attenuation:	
	0 dB	15 dB	0 dB	15 dB
Pol0 USB	P_{300} = -13.40 (P_{10} = -19.55)	P_{300} = -28.28 (P_{800} = -24.65)	P_{300} = -13.99 (P_{10} = -20.14)	P_{300} = -28.87 (P_{800} = -25.24)
Pol0 LSB	P_{300} = -12.84 (P_{10} = -18.99)	P_{300} = -27.75 (P_{800} = -24.12)	P_{300} = -13.94 (P_{10} = -20.09)	P_{300} = -28.81 (P_{800} = -25.18)
Pol1 USB	P_{300} = -11.82 (P_{10} = -17.97)	P_{300} = -27.00 (P_{800} = -23.37)	P_{300} = -12.60 (P_{10} = -18.75)	P_{300} = -27.74 (P_{800} = -24.11)
Pol1 LSB	P_{300} = -10.54 (P_{10} = -16.69)	P_{300} = -25.66 (P_{800} = -22.03)	P_{300} = -11.43 (P_{10} = -17.58)	P_{300} = -26.53 (P_{800} = -22.90)

Table 7 - Band 6 Total and In-Band power at 241 GHz LO

Band 7

	Total Power (dBm) at IF Switch Attenuation:		In-band Power (dBm) at IF Switch Attenuation:	
	0 dB	15 dB	0 dB	15 dB
Pol0 USB	P_{300} = -18.30 (P_{10} = -22.84)	P_{300} = -33.24 (P_{800} = -29.98)	P_{300} = -18.26 (P_{10} = -22.80)	P_{300} = -33.23 (P_{800} = -29.97)
Pol0 LSB	P_{300} = -19.27 (P_{10} = -23.81)	P_{300} = -34.13 (P_{800} = -30.87)	P_{300} = -19.00 (P_{10} = -23.54)	P_{300} = -34.00 (P_{800} = -30.74)
Pol1 USB	P_{300} = -15.74 (P_{10} = -20.28)	P_{300} = -31.00 (P_{800} = -27.74)	P_{300} = -17.72 (P_{10} = -22.26)	P_{300} = -32.90 (P_{800} = -29.64)
Pol1 LSB	P_{300} = -15.80 (P_{10} = -20.34)	P_{300} = -30.92 (P_{800} = -27.66)	P_{300} = -17.90 (P_{10} = -22.44)	P_{300} = -32.96 (P_{800} = -29.70)

Table 8 - Band 7 Total and In-Band power at 323 GHz LO

Band 9

	Total Power (dBm) at IF Switch Attenuation:		In-band Power (dBm) at IF Switch Attenuation:	
	0 dB	15 dB	0 dB	15 dB
Pol0	P_{300} = -16.90 (P_{10} = -21.00)	P_{300} = -31.70 (P_{800} = -28.58)	P_{300} = -17.40 (P_{10} = -21.50)	P_{300} = -32.21 (P_{800} = -29.09)
Pol1	P_{300} = -15.75 (P_{10} = -19.85)	P_{300} = -30.75 (P_{800} = -27.63)	P_{300} = -16.25 (P_{10} = -20.35)	P_{300} = -31.26 (P_{800} = -28.14)

Table 9 - Band 9 Total and In-Band power at 662 GHz LO

3.1.6 IF power variations

[FEND-40.00.00.00-00150-00 / A, T]

Specification to be verified: Within the IF band, variations from the average IF power over the whole IF band, specified in section 2.3.3, shall be less than:

- 1.35 dB (TBC) peak-to-peak in any 31 MHz portion of the IF band specified in section 2.3.3 (not verified, see [AD17].)
- 6 dB (7 dB for Band 9 only) peak-to-peak in any 2 GHz portion of the IF band specified in section 2.3.3
- 10 dB (11 dB for Band 9 only) peak-to-peak across the complete IF band specified in section 2.3.3

Result:

Band 3

	Full IF-band power variation (dB peak-to-peak) Spec = max 10 dB			
LO Frequency (GHz)	Pol0 USB	Pol0 LSB	Pol1 USB	Pol1 LSB
92	2.39	2.87	2.23	7.02
96	2.81	3.05	1.75	7.35
100	3.35	3.36	2.33	7.84
104	3.54	3.28	2.45	7.36
108	3.21	3.81	1.77	7.36

Table 10 – Band 3 Full IF-band power variation

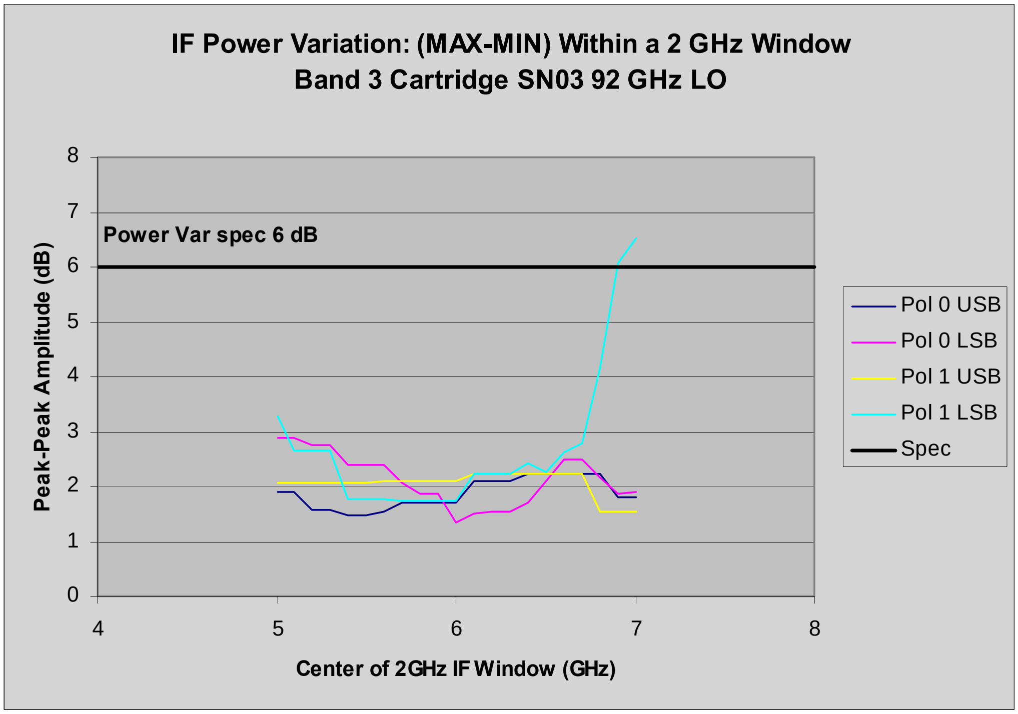


Figure 31 - Band 3 IF Power Variation 92 GHz LO

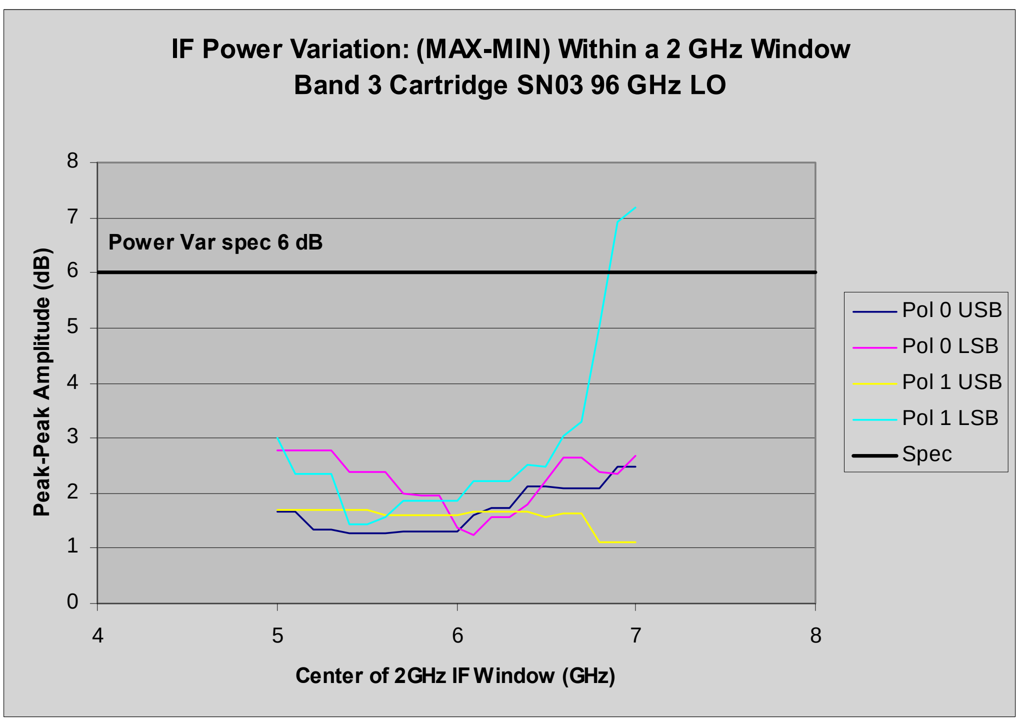


Figure 32 - Band 3 IF Power Variation 96 GHz LO

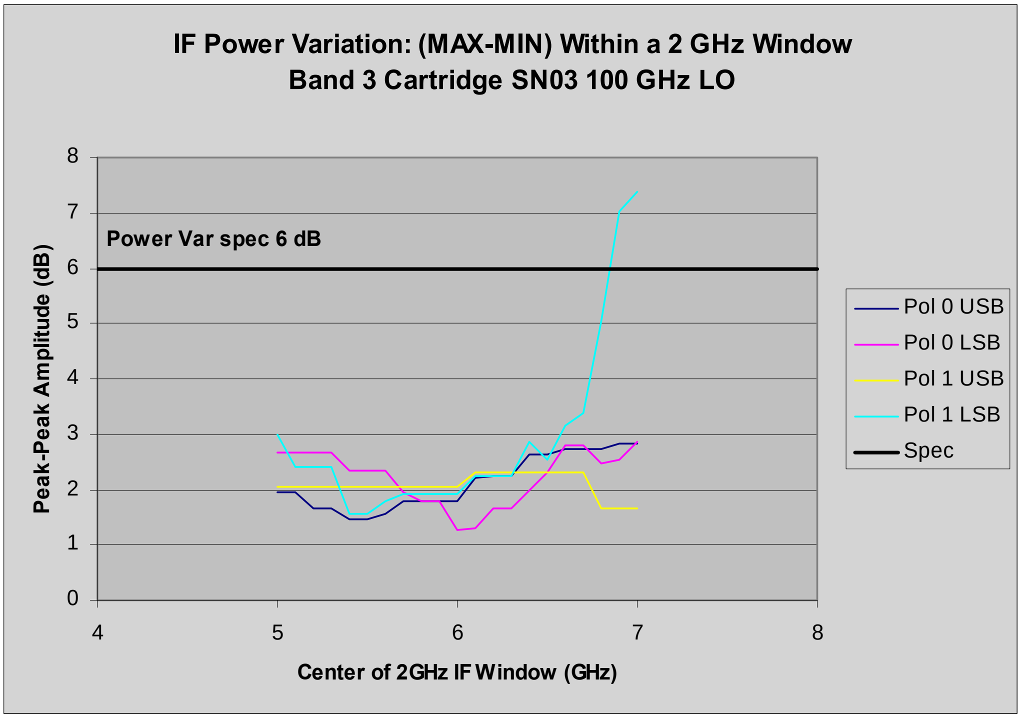


Figure 33 - Band 3 IF Power Variation 100 GHz LO

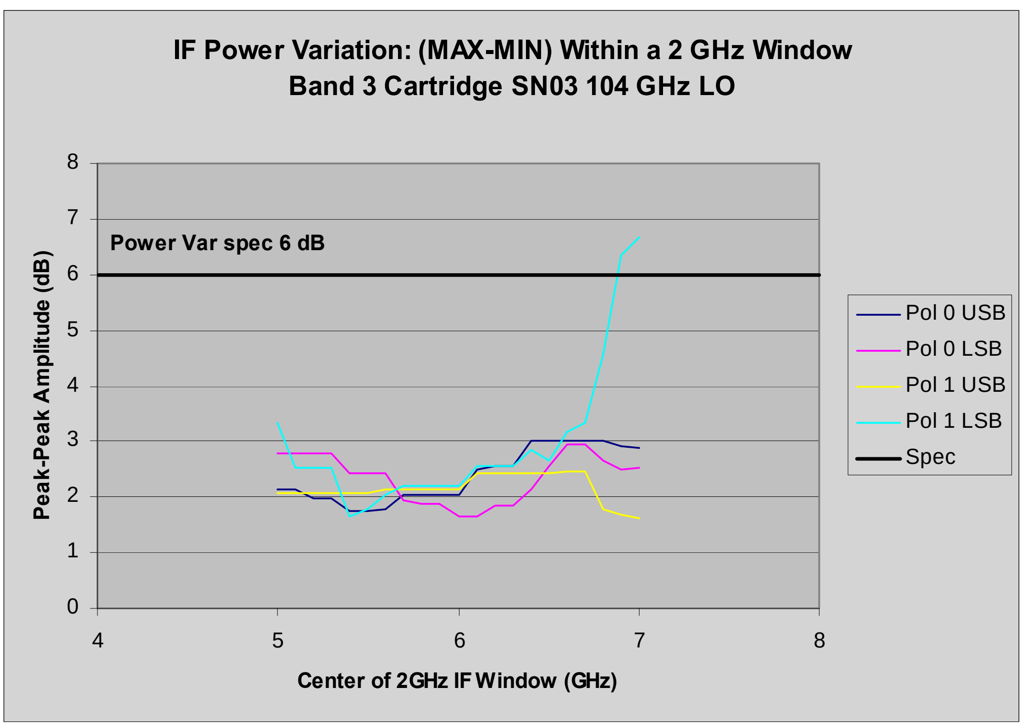


Figure 34 - Band 3 IF Power Variation 104 GHz LO

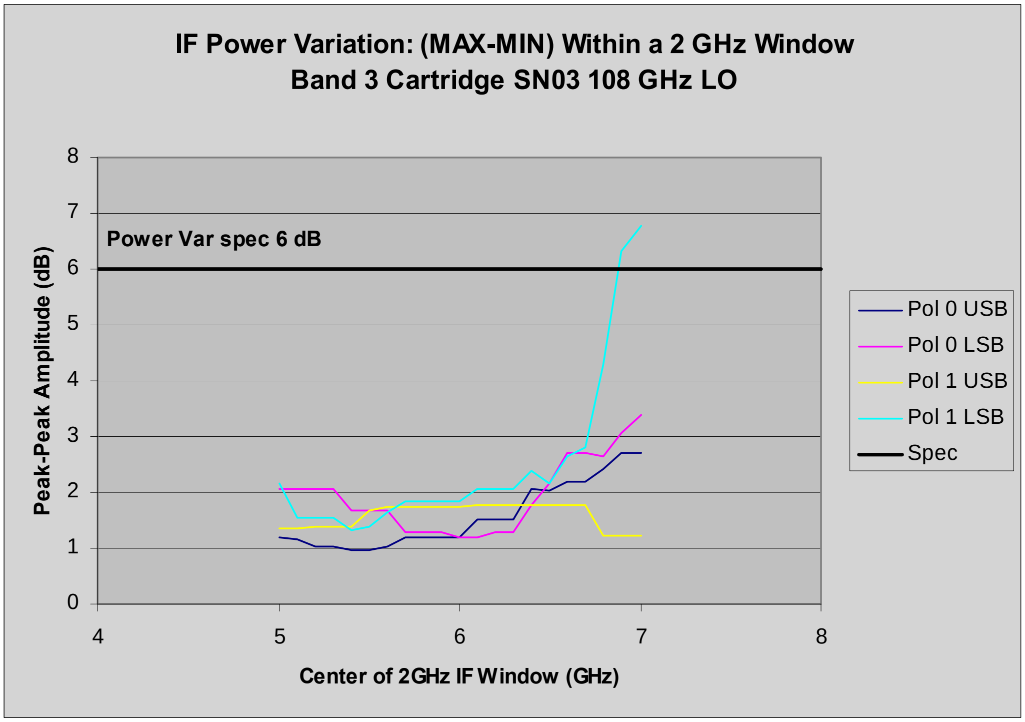


Figure 35 - Band 3 IF Power Variation 108 GHz LO

Band 6

	Full IF-band power variation (dB peak-to-peak) Spec = max 10 dB			
LO Frequency (GHz)	Pol0 USB	Pol0 LSB	Pol1 USB	Pol1 LSB
221	7.64	7.28	12.87	11.86
241	7.04	7.99	11.00	9.97
265	7.35	8.31	10.43	12.03

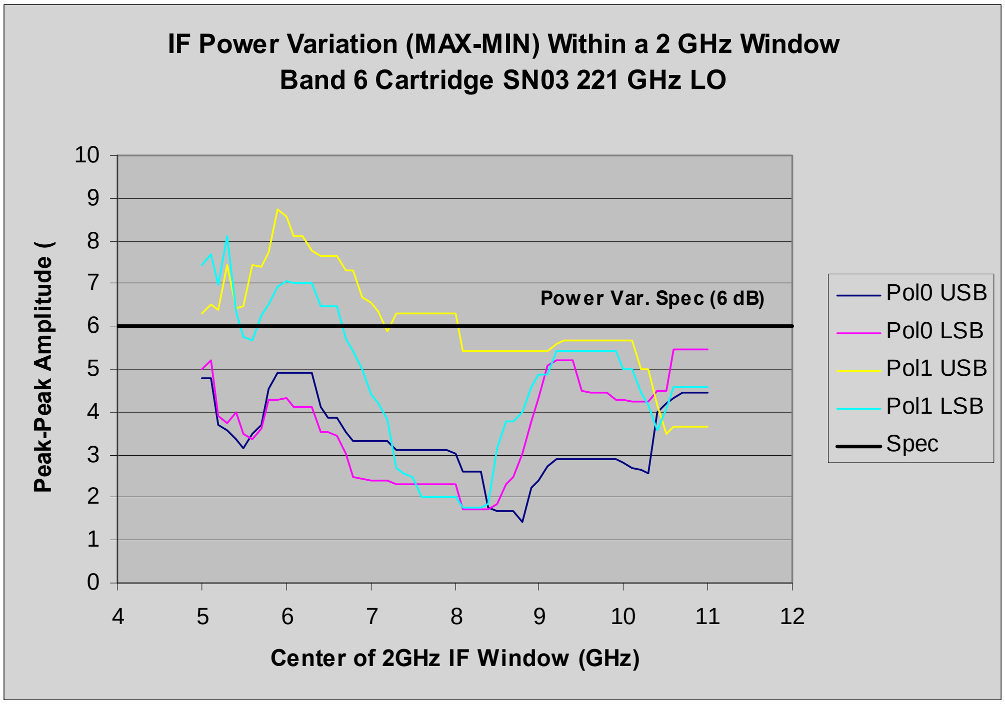


Figure 36 - Band 6 IF Power Variation 221 GHz LO

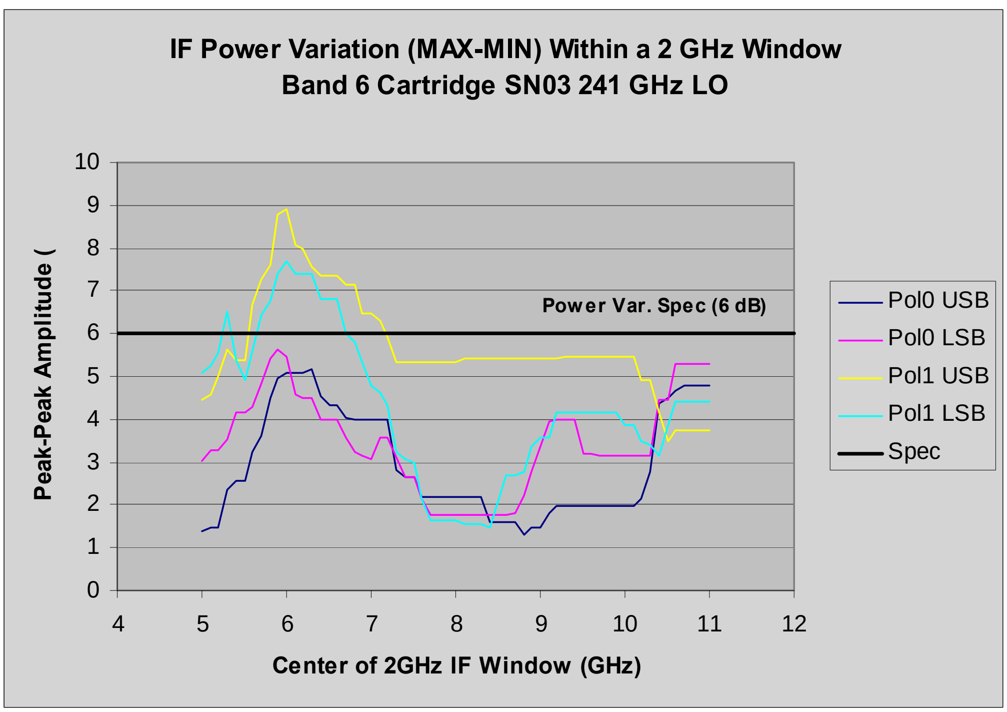


Figure 37 - Band 6 IF Power Variation 241 GHz LO

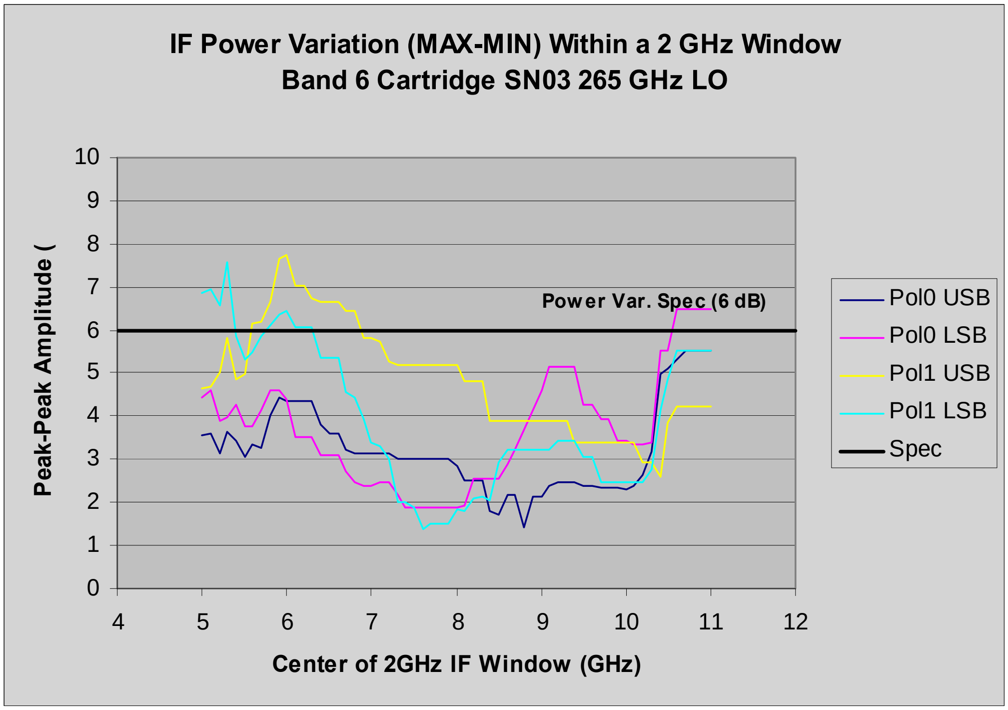


Figure 38 - Band 6 IF Power Variation 265 GHz LO

Band 7

	Full IF-band power variation (dB peak-to-peak) Spec = max 10 dB			
LO Frequency (GHz)	Pol0 USB	Pol0 LSB	Pol1 USB	Pol1 LSB
283	5.49	3.77	3.32	3.36
323	6.80	3.85	2.93	3.03
365	4.35	4.85	1.94	2.74

Table 11 – Band 7 Full IF-band power variation

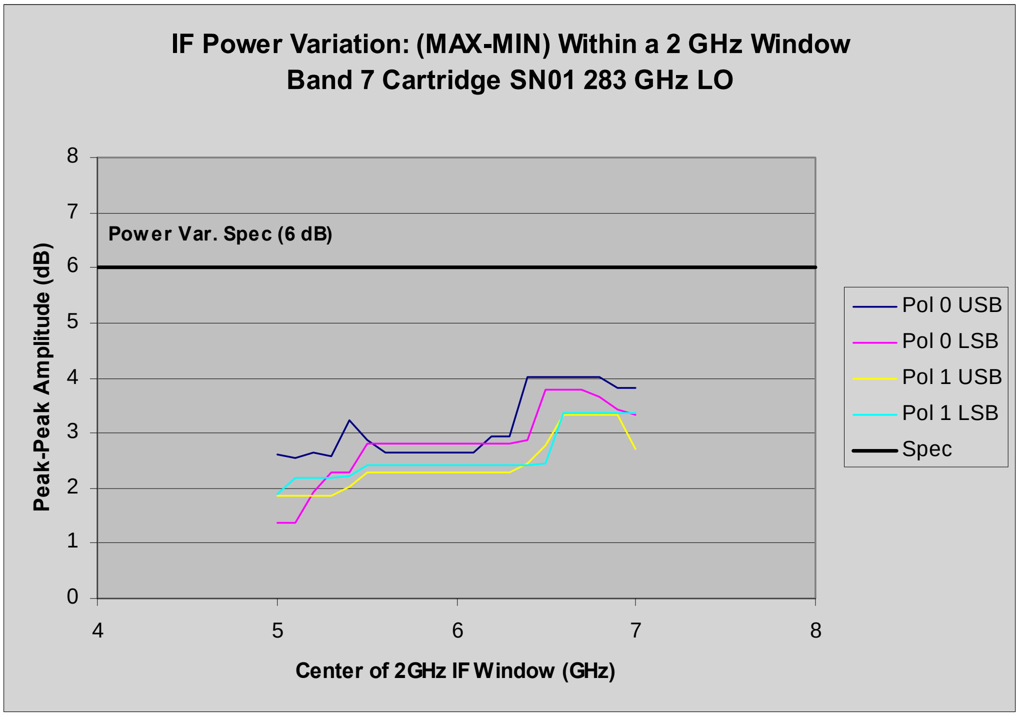


Figure 39 - Band 7 IF Power Variation 283 GHz LO

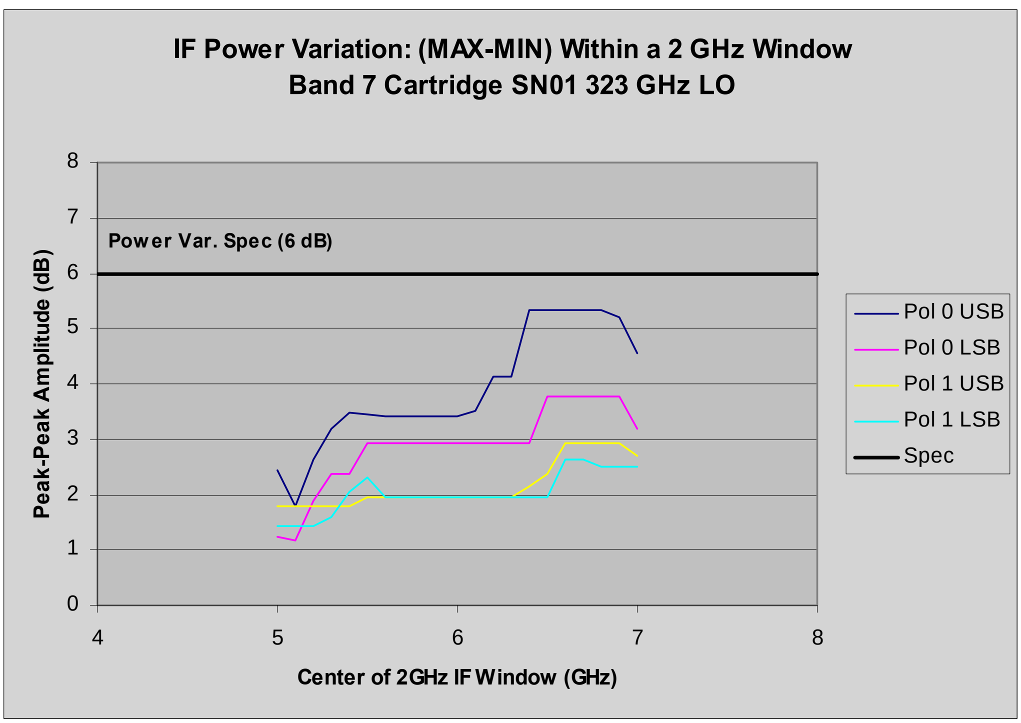


Figure 40 - Band 7 IF Power Variation 323 GHz LO

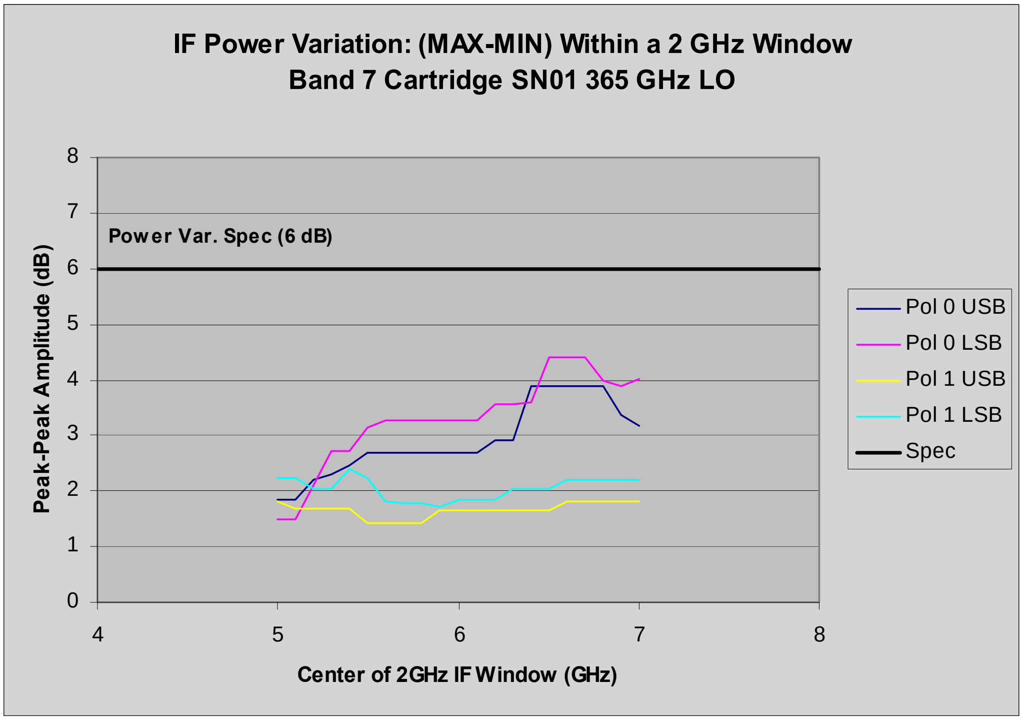


Figure 41 - Band 7 IF Power Variation 365 GHz LO

Band 9

	Full IF-band power variation (dB peak-to-peak) Spec = max 11 dB	
LO Frequency (GHz)	Pol0	Pol1
614	8.05	5.17
662	7.74	4.88
710	7.86	5.14

Table 12 – Band 9 Full IF-band power variation

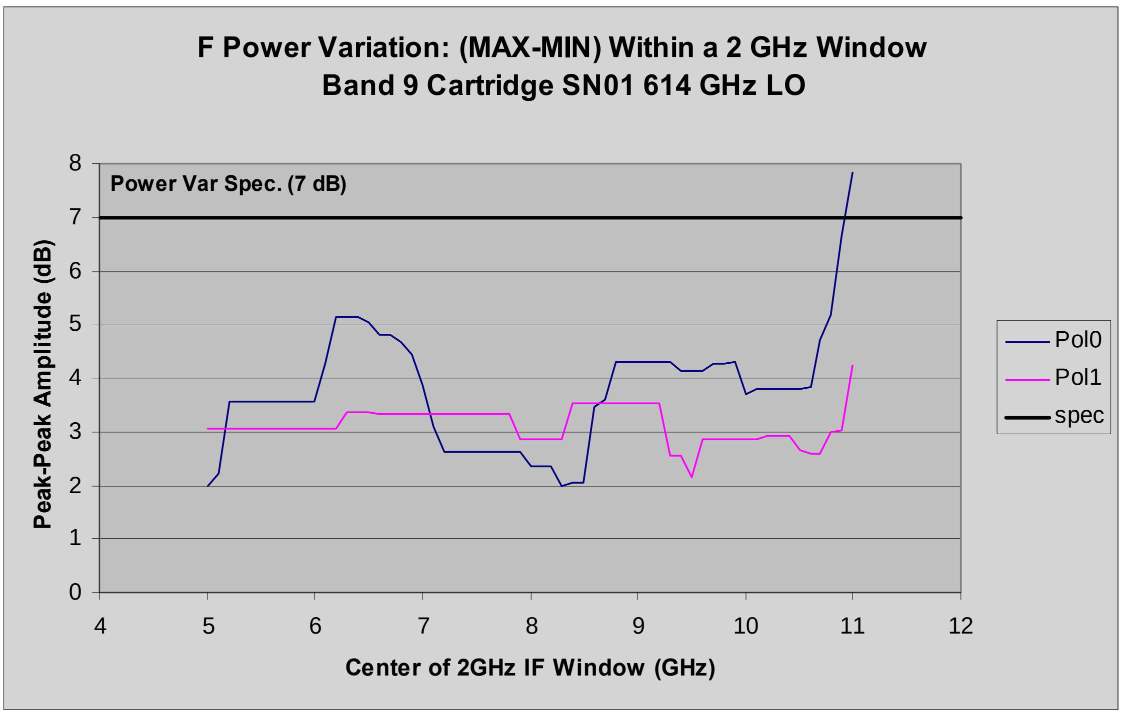


Figure 42 - Band 9 IF Power Variation 614 GHz LO

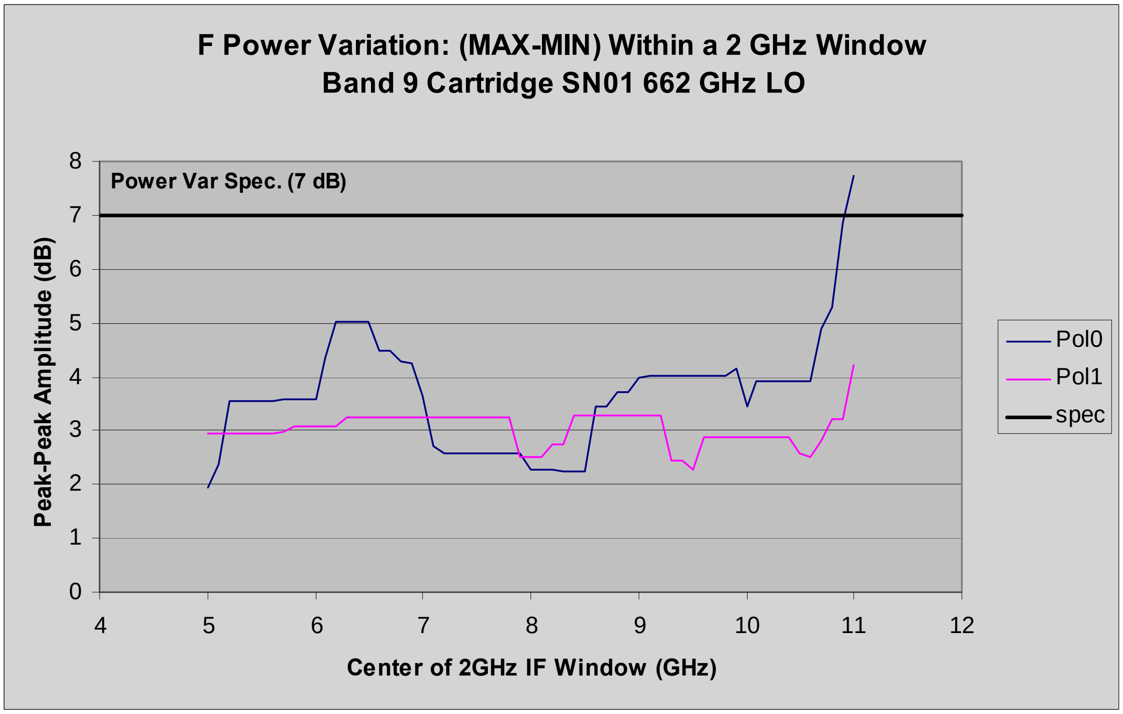


Figure 43 - Band 9 IF Power Variation 662 GHz LO

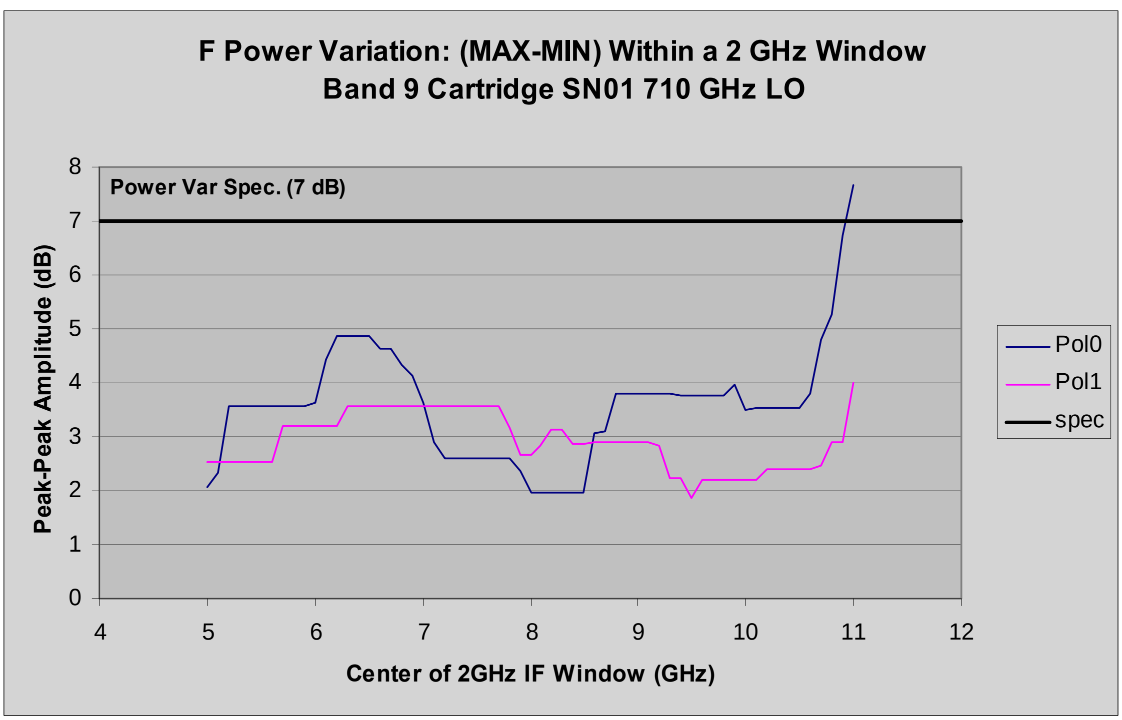


Figure 44 - Band 9 IF Power Variation 710 GHz LO

3.1.7 Amplitude stability

[FEND-40.00.00.00-00170-00 / T]
This section only applies to the operational mode.
Specification to be verified: The IF amplitude stability, measured at each of the IF outputs of the Front-End, shall comply with the following requirement:

- The Allan variance, $\sigma^2(T)$, of the IF output power in the IF band (specified in section 3.3.3) shall be less than 5.0×10^{-7} for T in the range of $0.05 \text{ s} \le T \le 100$ s and 4.0×10^{-6} for T = 300 seconds.
  This corresponds to an Allan standard deviation of 7.07×10^{-4} and 2.0×10^{-3}, respectively.

Result:

Band 3

Band 3 was measured at 100 GHz LO, both locked to the laser synthesizer and unlocked. The spec lines are shown on both the locked and unlocked charts, however the specification only applies when the LO is locked.

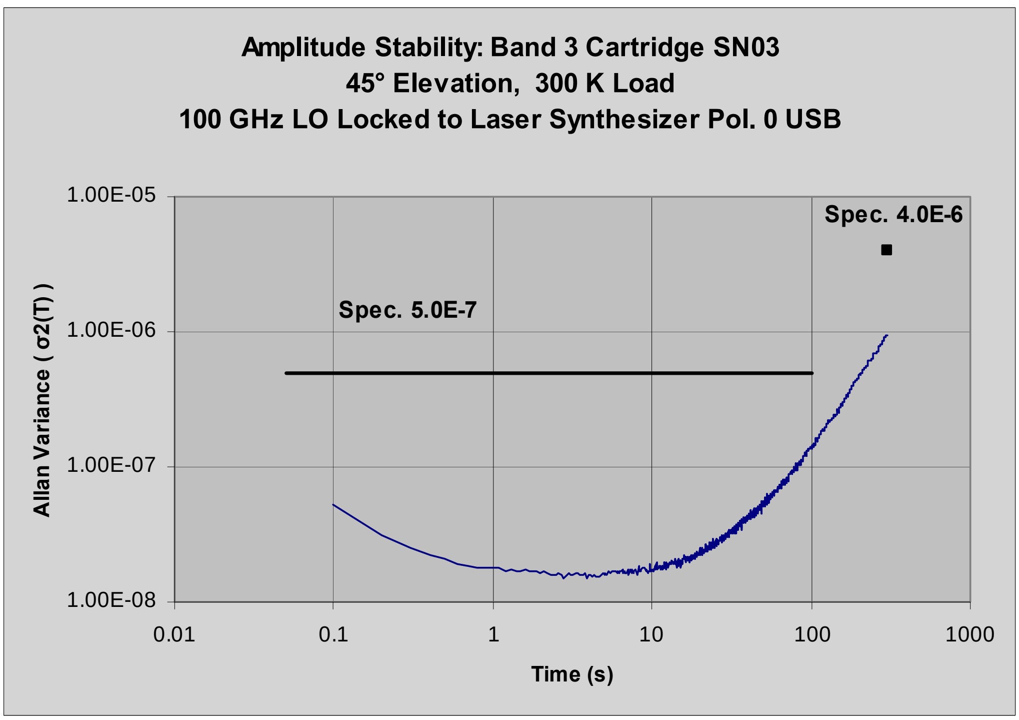


Figure 45 - Band 3 Locked Amplitude Stability Pol0 USB

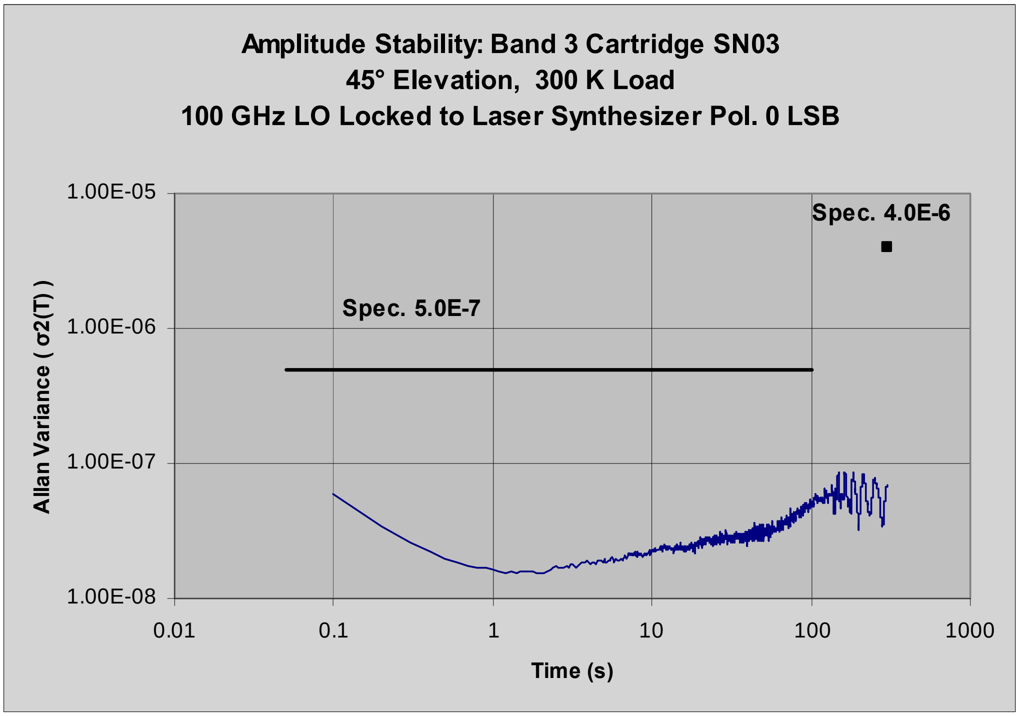


Figure 46 - Band 3 Locked Amplitude Stability Pol0 LSB

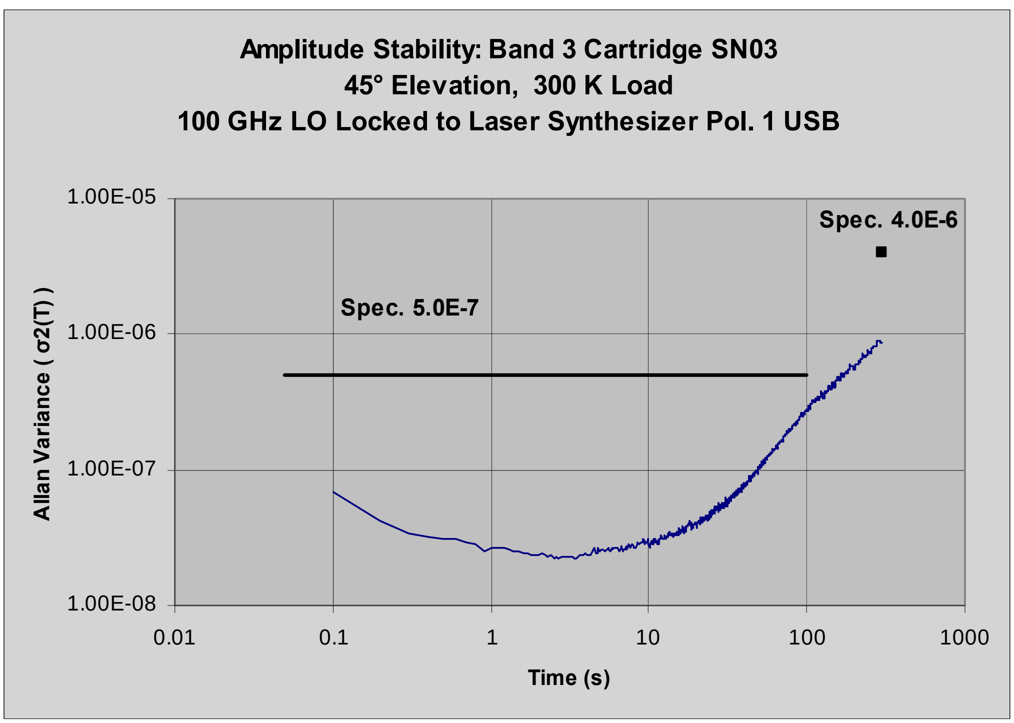


Figure 47 - Band 3 Locked Amplitude Stability Pol1 USB

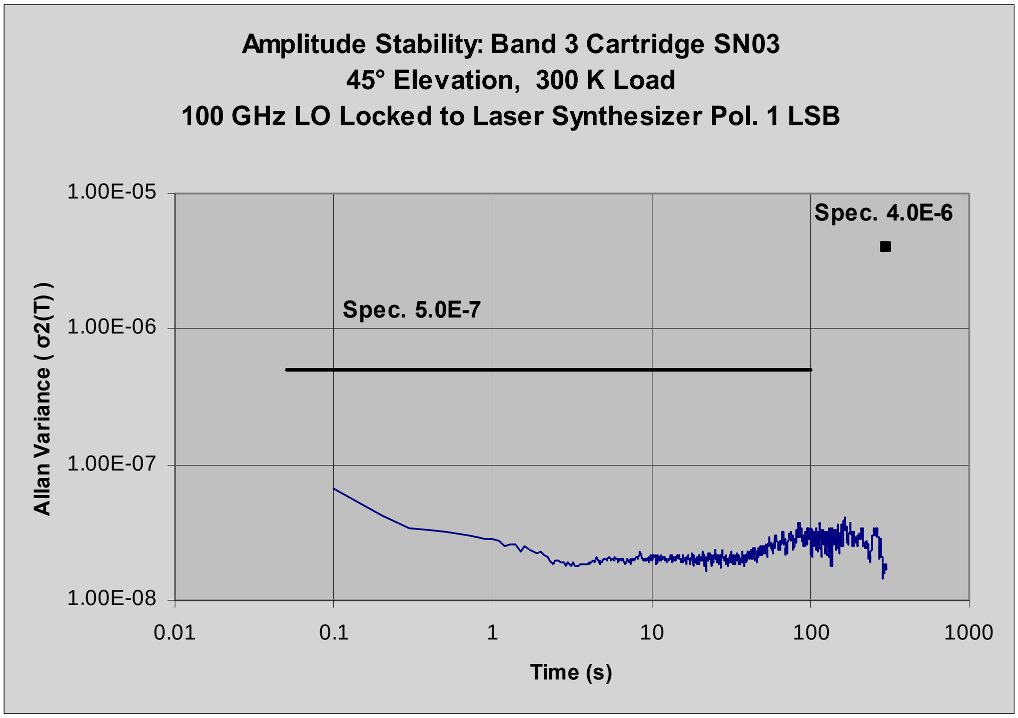


Figure 48 - Band 3 Locked Amplitude Stability Pol1 LSB

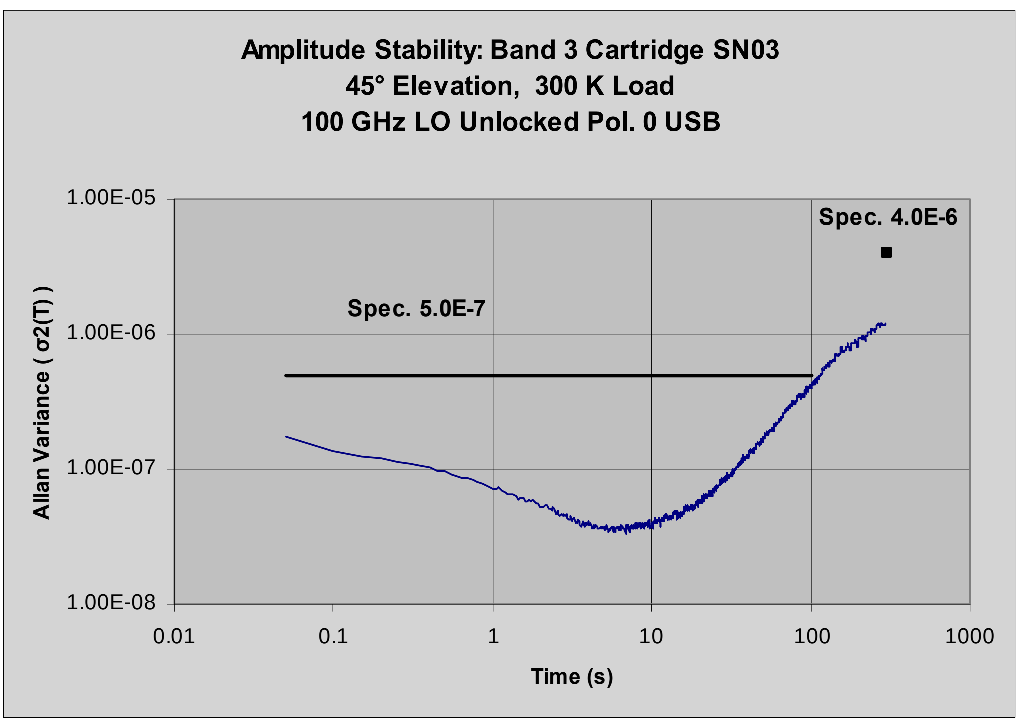


Figure 49 - Band 3 Unlocked Amplitude Stability Pol0 USB

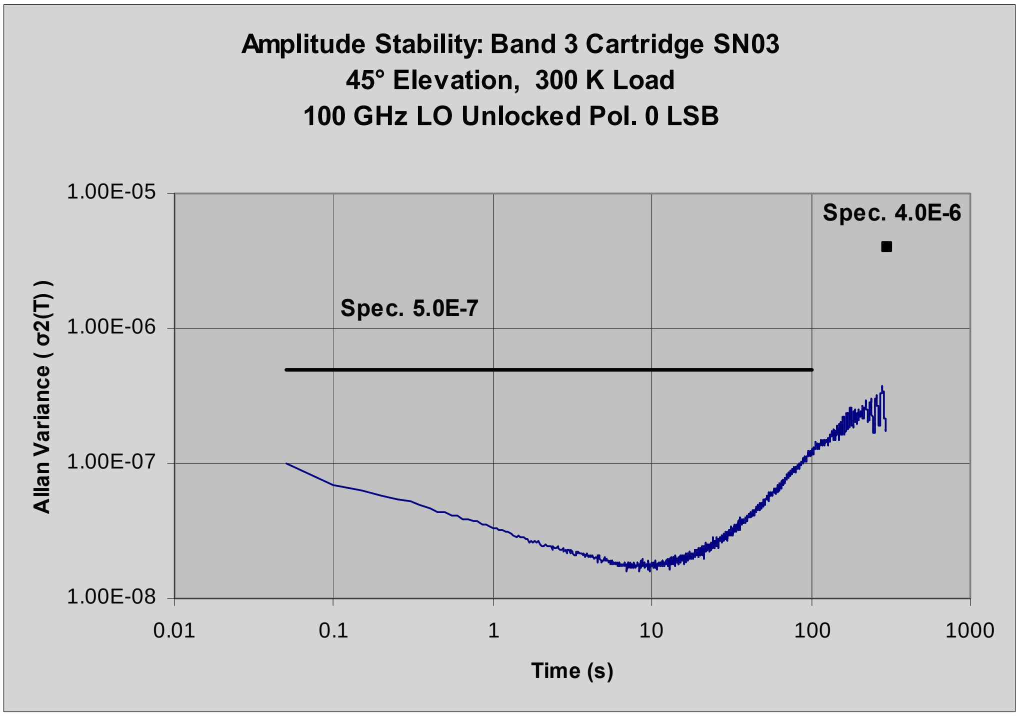


Figure 50 - Band 3 Unlocked Amplitude Stability Pol0 LSB

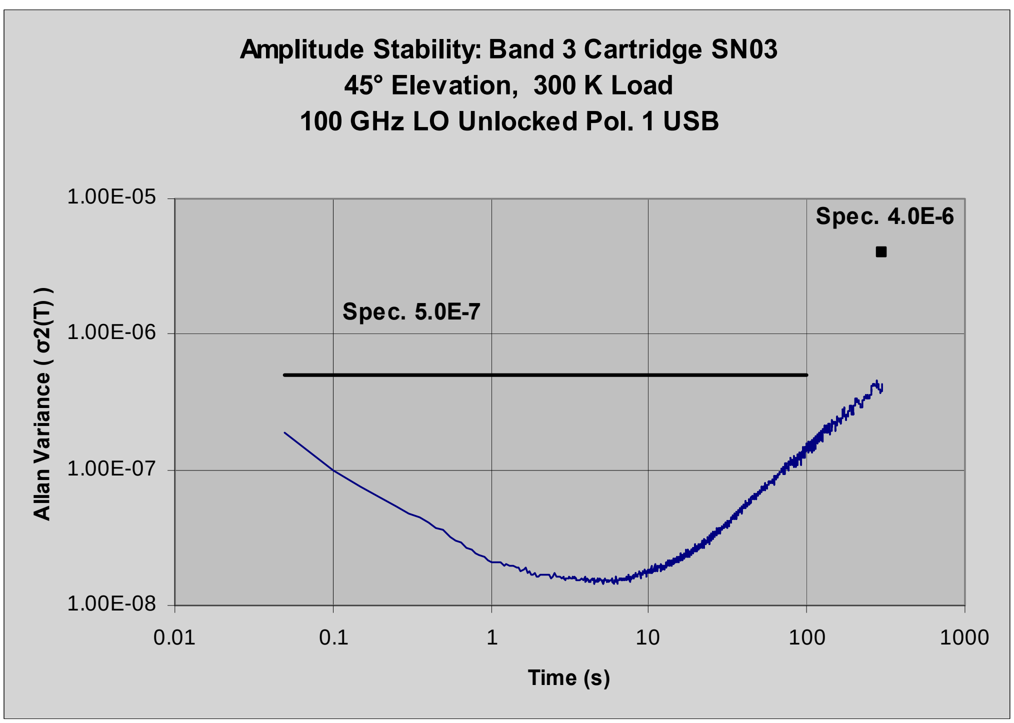


Figure 51 - Band 3 Unlocked Amplitude Stability Pol1 USB

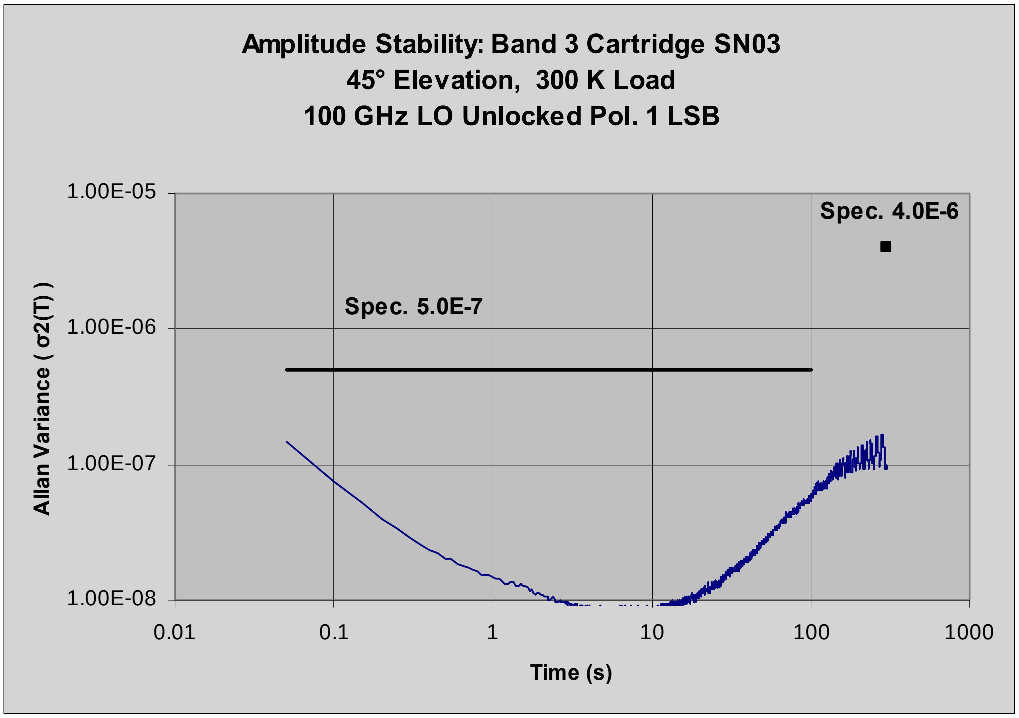


Figure 52 - Band 3 Unlocked Amplitude Stability Pol1 LSB

Next band 3 was measured unlocked while the tilt table was rotated twice from zero to 90 degrees and back again, allowing for some settling time at each position. One power meter was placed directly at the FE IF bulkhead output. The other was in the test system rack, but with the IF processor bypassed. Figure 53 shows the resulting amplitude drifts. Note that for one of the traces on this chart, cables outside of the front end are moving as the tilt angle changes. Therefore not all of the drift is attributable to the front end. For measurements made "at bulkhead" the power sensor is connected directly to the IF output with no additional cable.

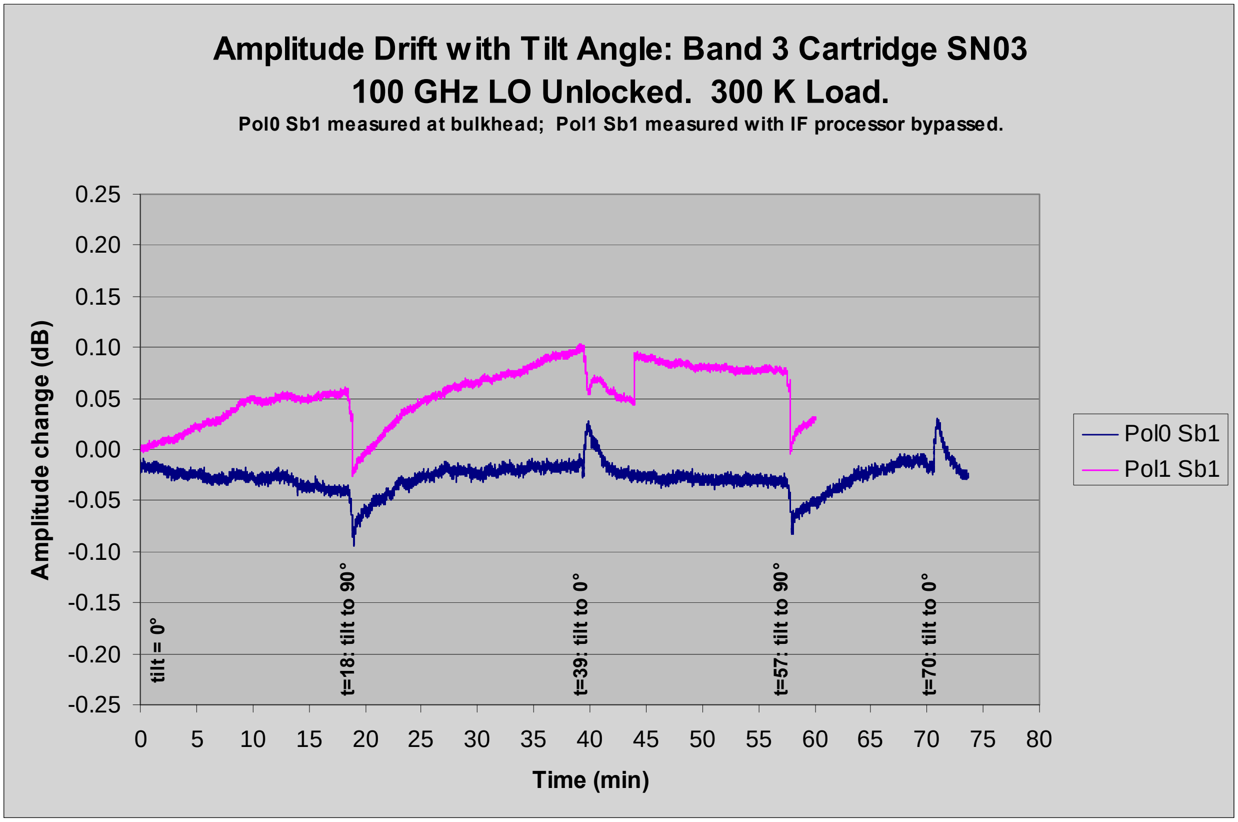


Figure 53 - Band 3 amplitude drift while tilting

We believe the jump in amplitude at 44 minutes is due to a cable or connector external to the front end being disturbed at that time. In later tests we took care to bundle all external IF and reference cables so that they move smoothly as the table tilts.

Band 6

Band 6 was measured at 241 GHz LO, both locked to the laser synthesizer and unlocked. The spec lines are shown on both the locked and unlocked charts, however the specification only applies when the LO is locked.

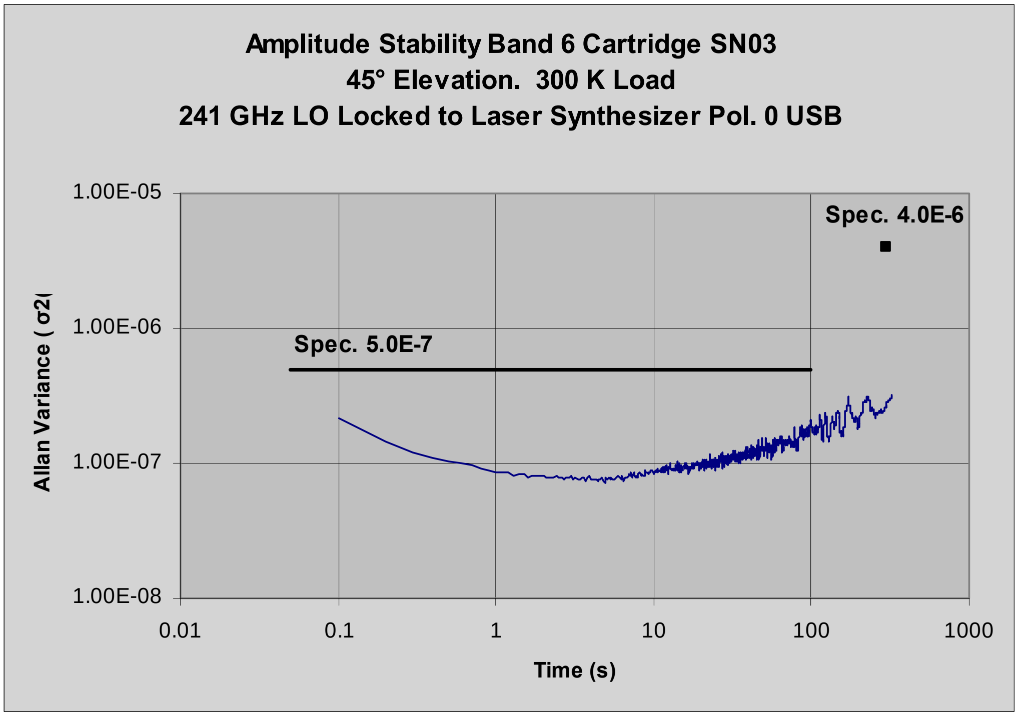


Figure 54 - Band 6 Locked Amplitude Stability Pol0 USB

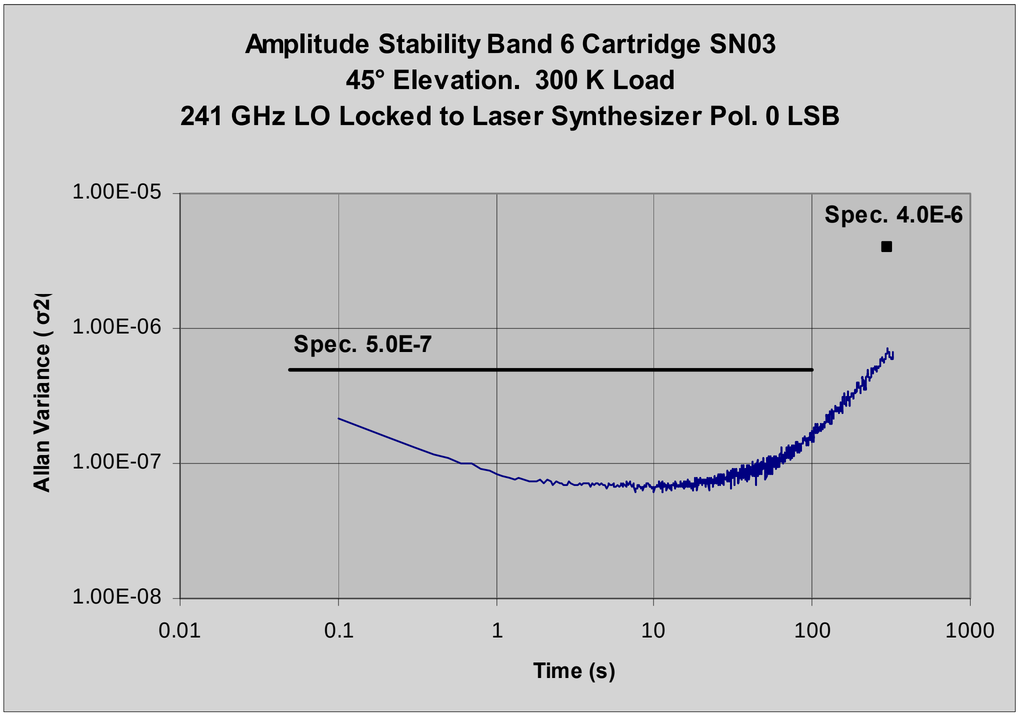


Figure 55 - Band 6 Locked Amplitude Stability Pol0 USB

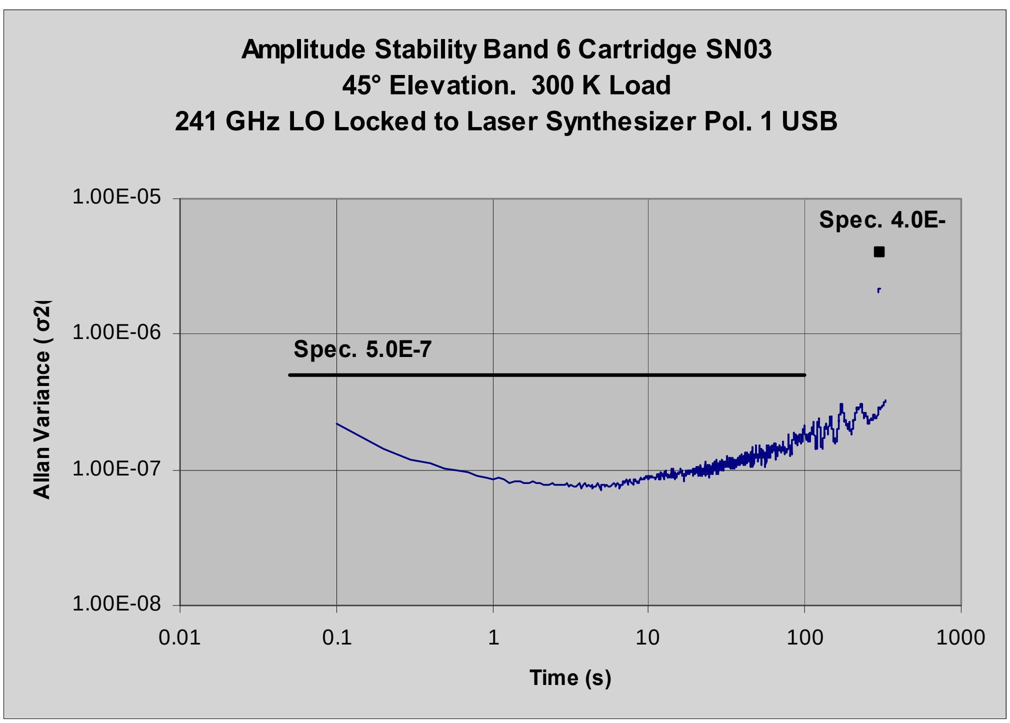


Figure 56 - Band 6 Locked Amplitude Stability Pol0 USB

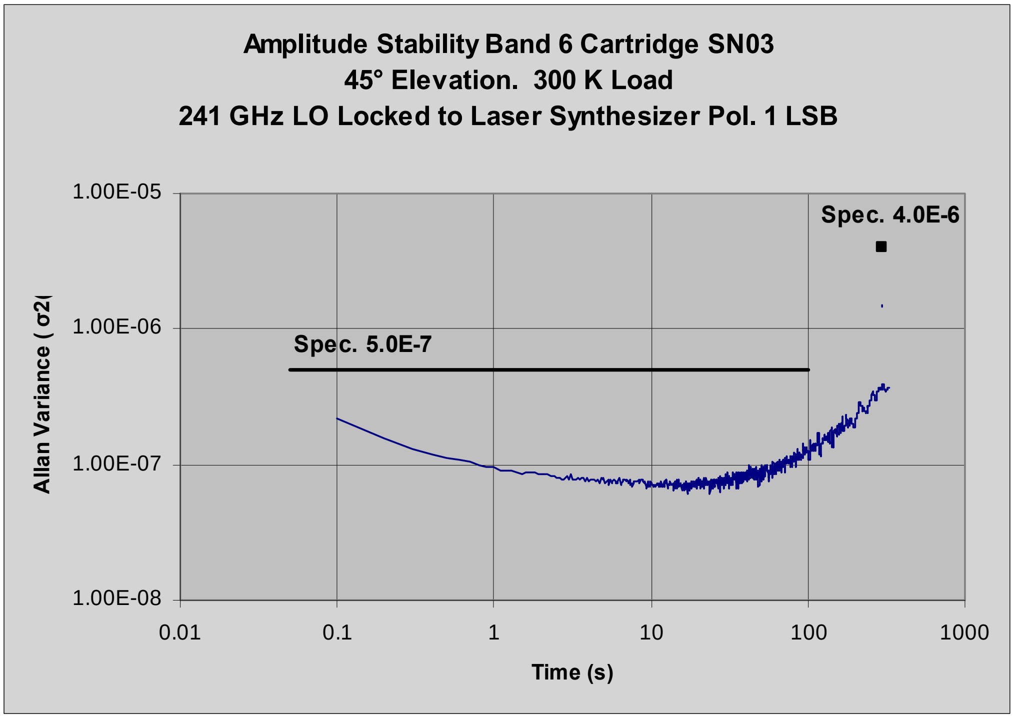


Figure 57 - Band 6 Locked Amplitude Stability Pol0 USB

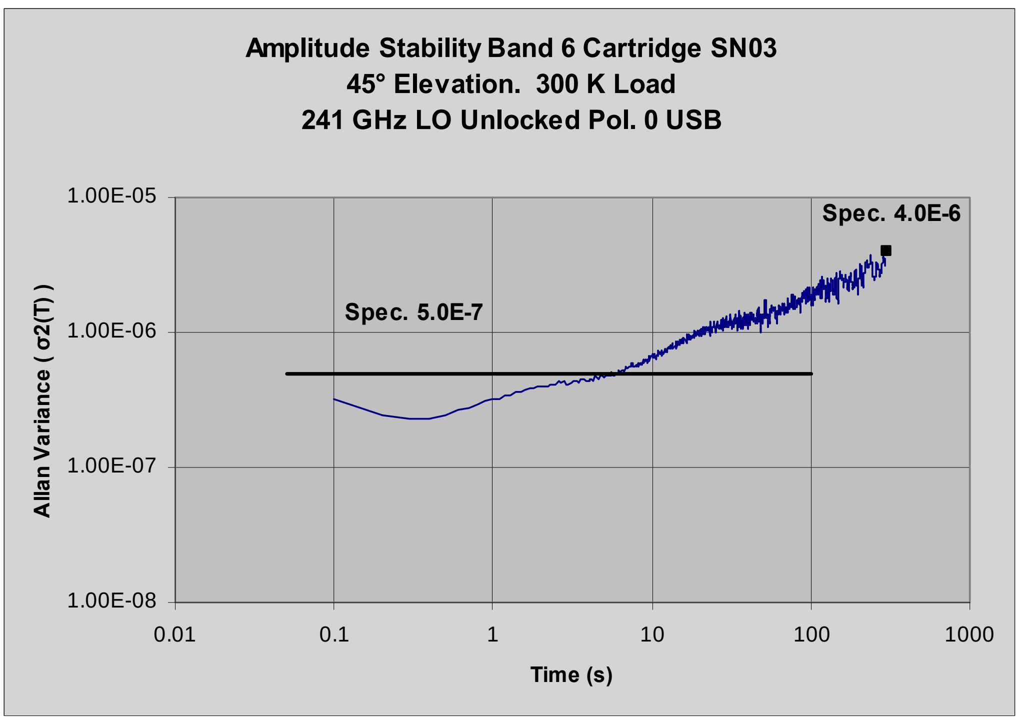


Figure 58 - Band 6 Unlocked Amplitude Stability Pol0 USB

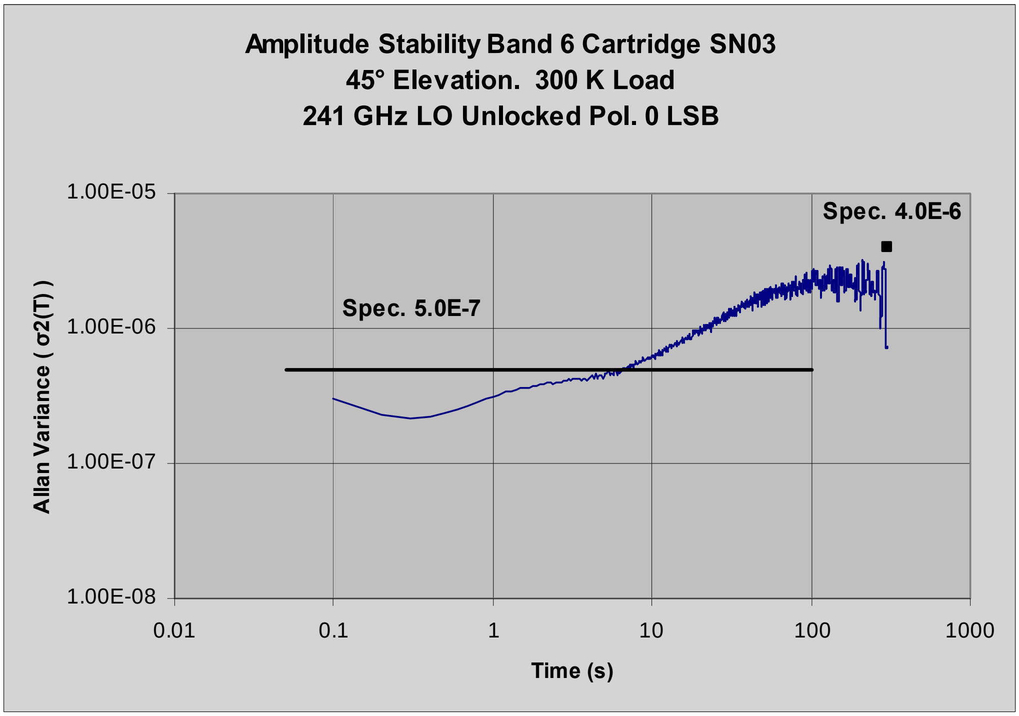


Figure 59 - Band 6 Unlocked Amplitude Stability Pol0 LSB

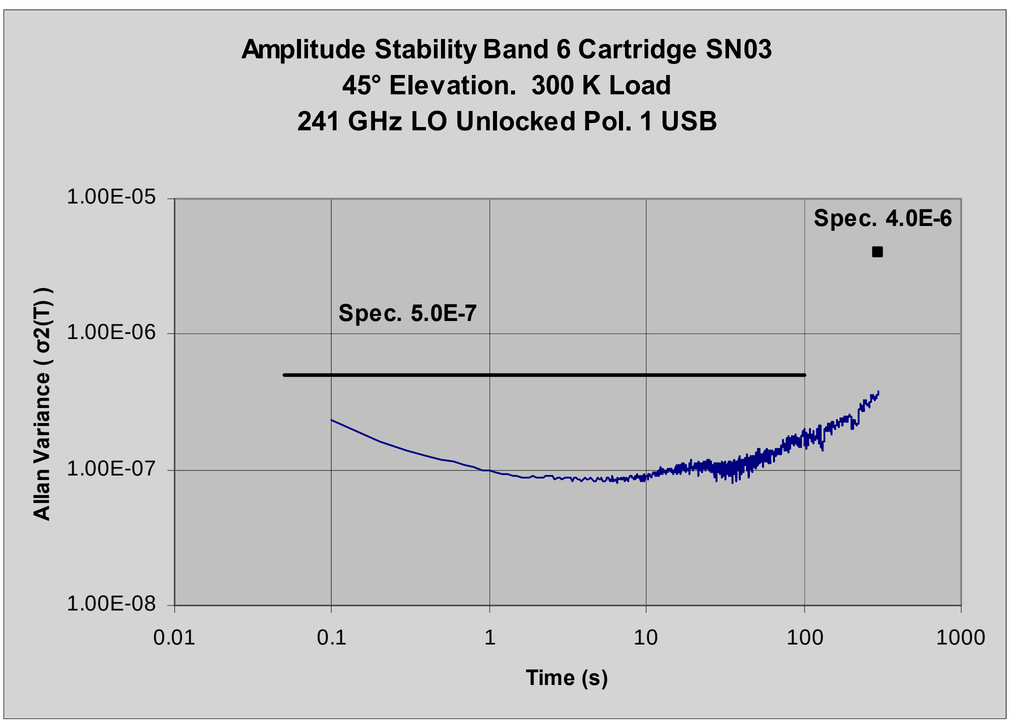


Figure 60 - Band 6 Unlocked Amplitude Stability Pol1 USB

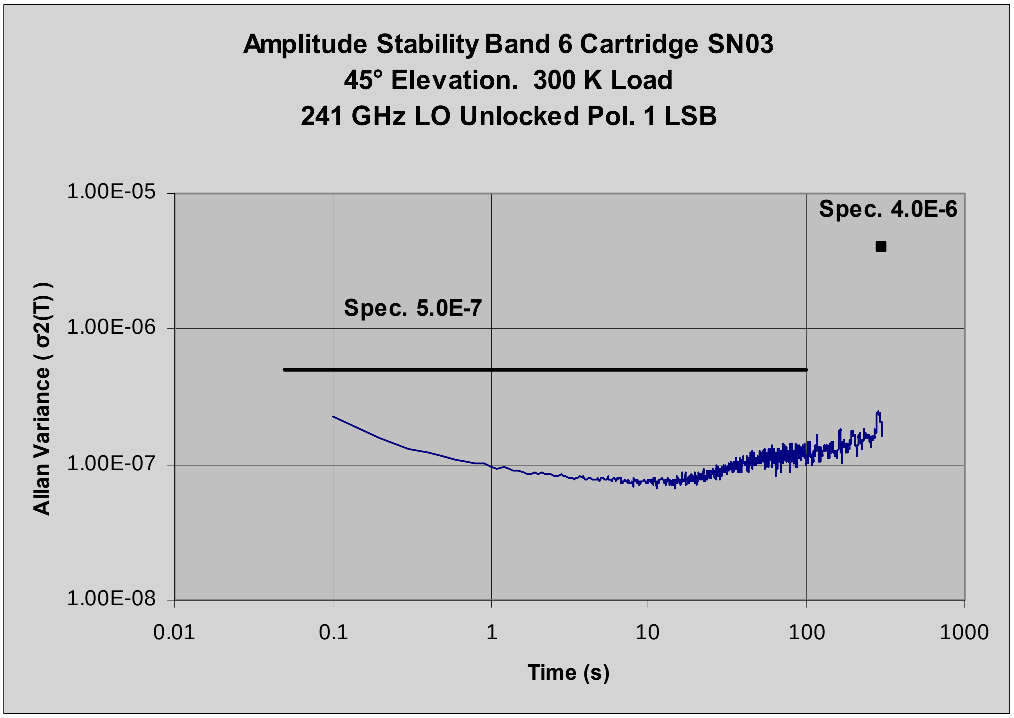


Figure 61 - Band 6 Unlocked Amplitude Stability Pol1 LSB

We measured the band 6 amplitude drift while moving the tilt table. The setup differed from that for band 3 in that it's LO was locked to the laser synthesizer, and we took care to stabilize the external IF cables and optical fiber so that they would move smoothly when tilted. The result is given in Figure 62. Note that for both of the traces on this chart, cables outside of the front end are moving as the tilt angle changes. Therefore not all of the drift is attributable to the front end.

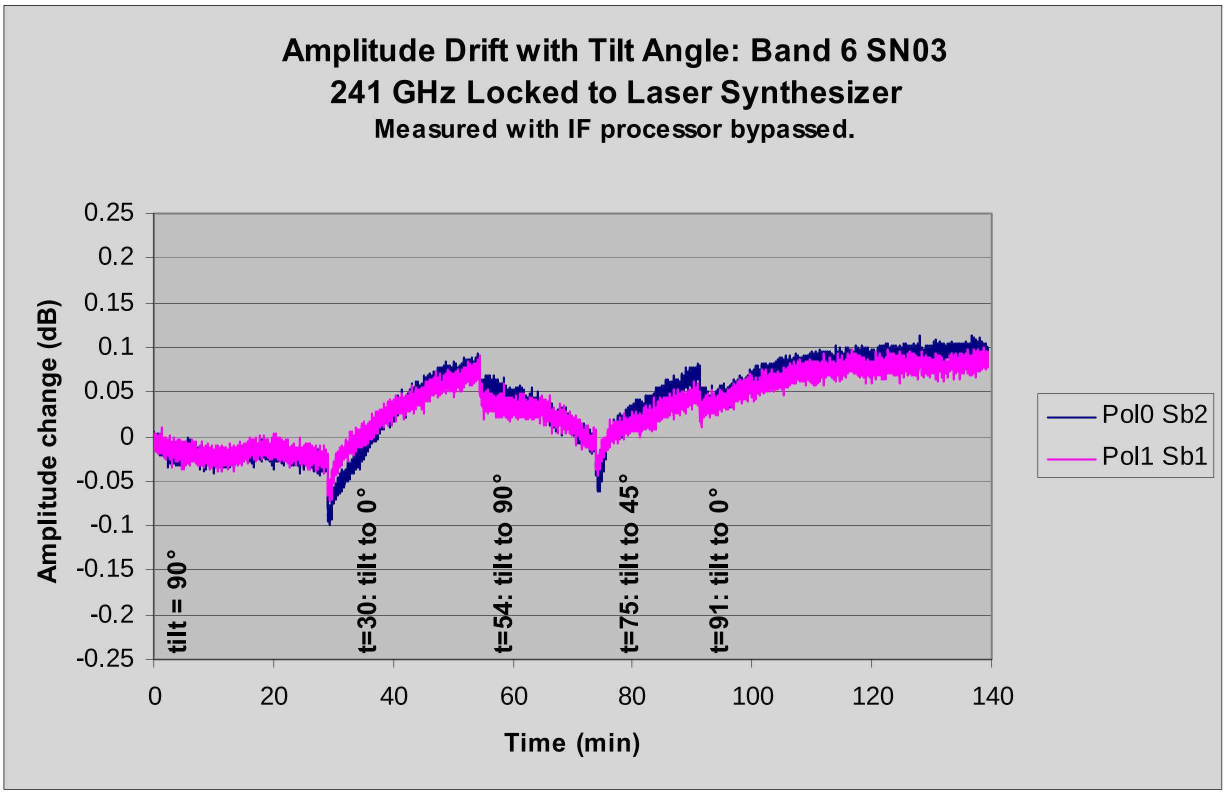


Figure 62 - Band 6 locked LO - Amplitude drift while tilting

Band 7

Band 7 was measured at 323 GHz both locked and unlocked. It performed far better when locked. The spec lines are shown on both the locked and unlocked charts, however the specification only applies when the LO is locked.

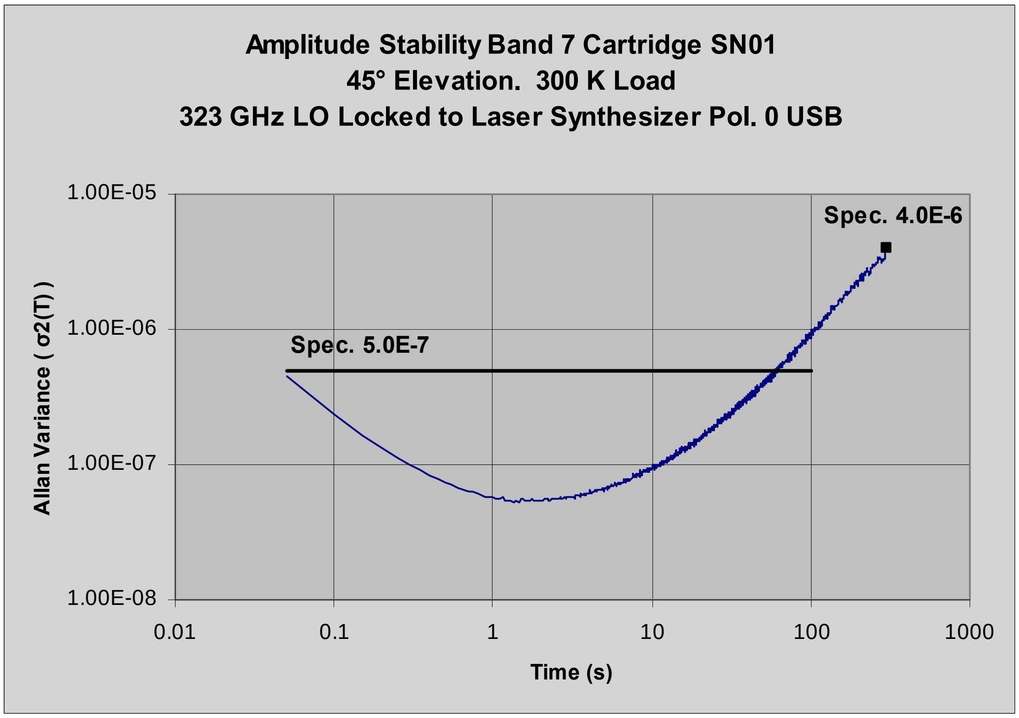


Figure 63 - Band 7 Locked Amplitude Stability Pol0 USB

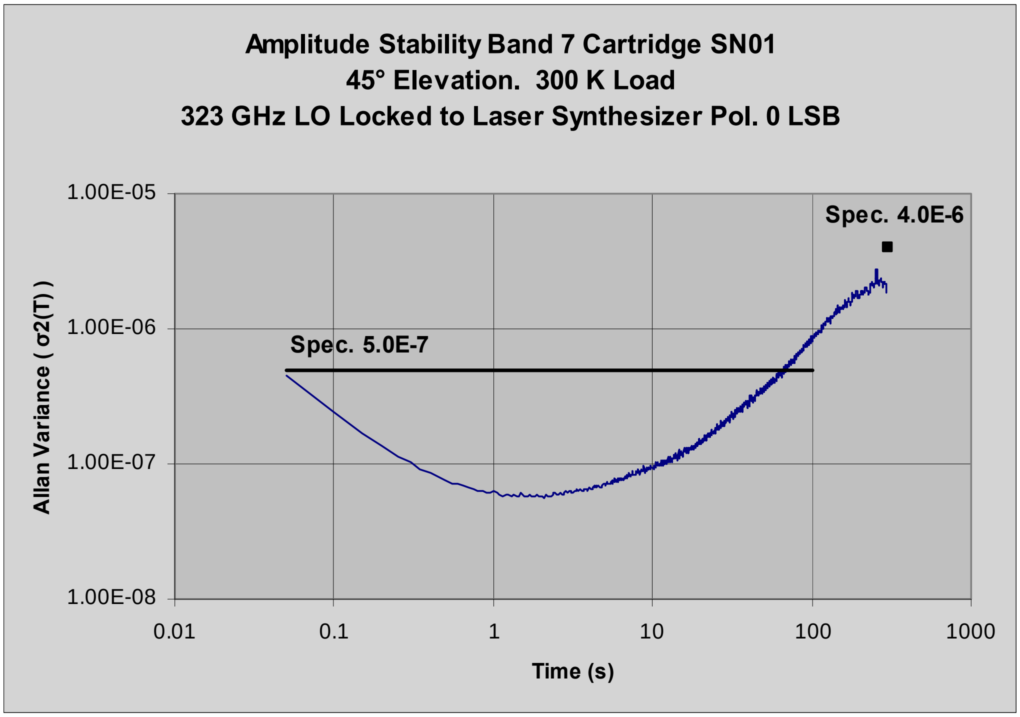


Figure 64 - Band 7 Locked Amplitude Stability Pol0 LSB

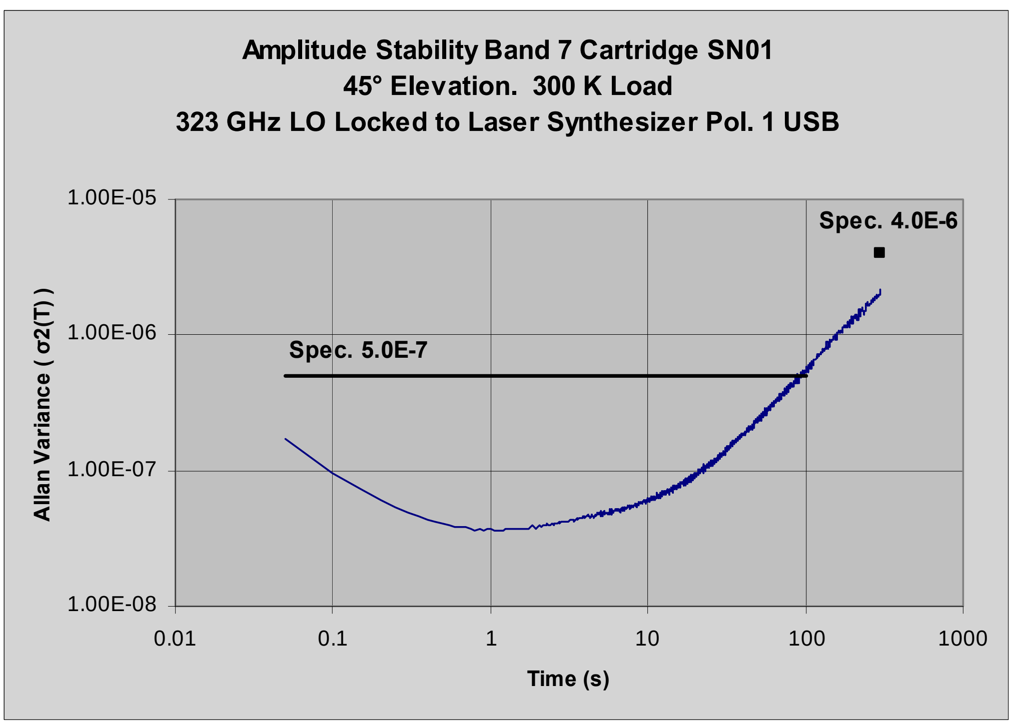


Figure 65 - Band 7 Locked Amplitude Stability Pol1 USB

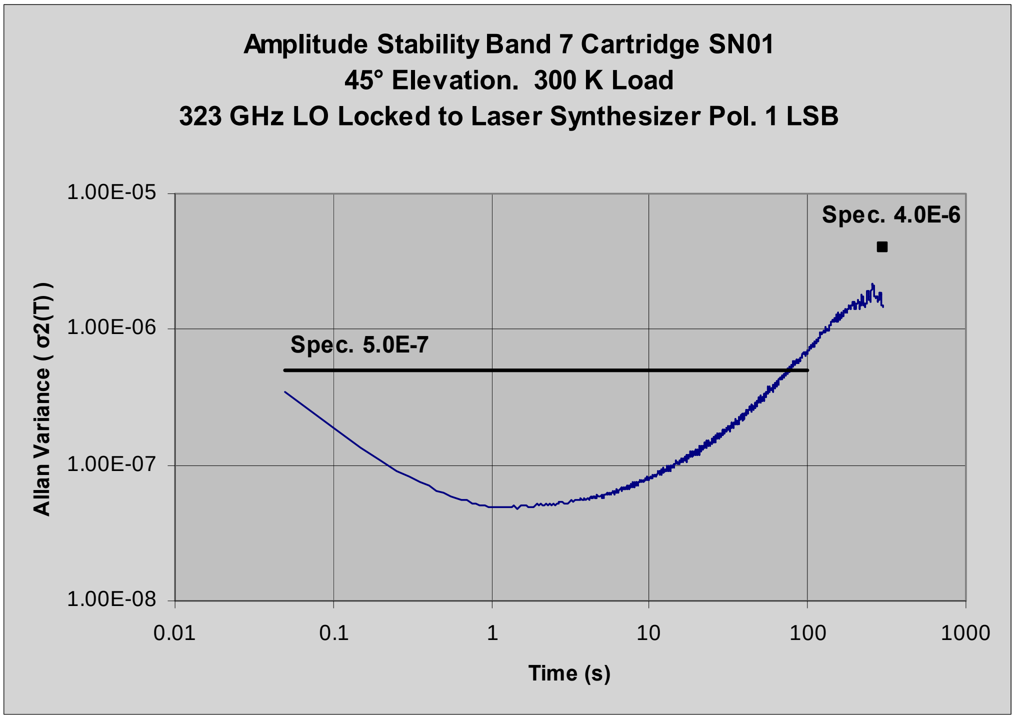


Figure 66 - Band 7 Locked Amplitude Stability Pol1 LSB

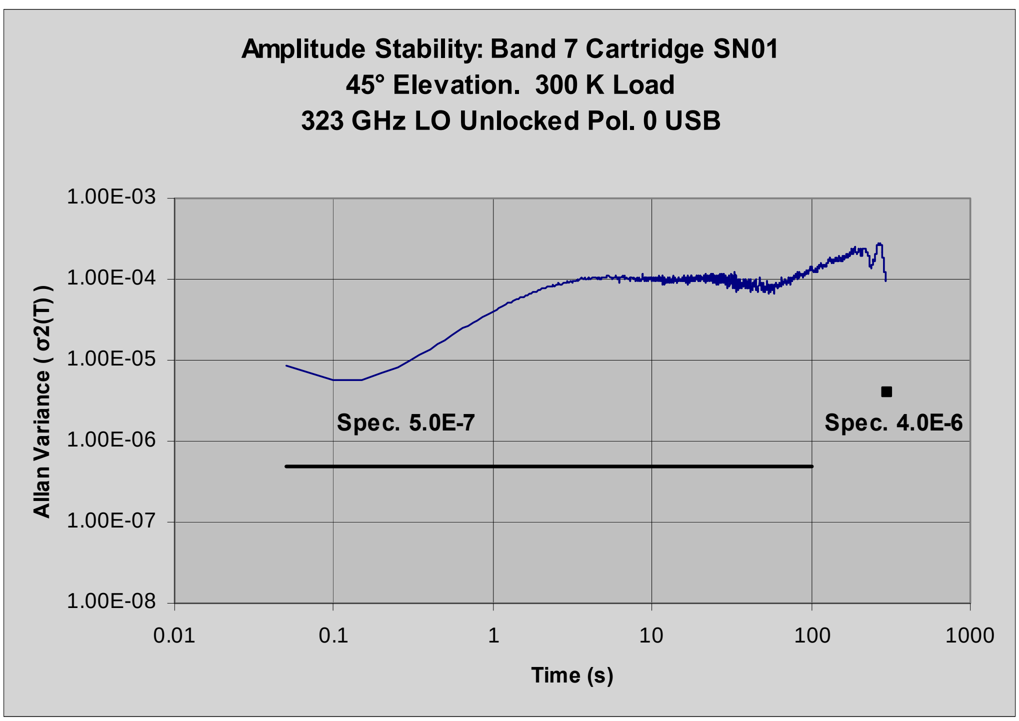


Figure 67 - Band 7 Unlocked Amplitude Stability Pol0 USB

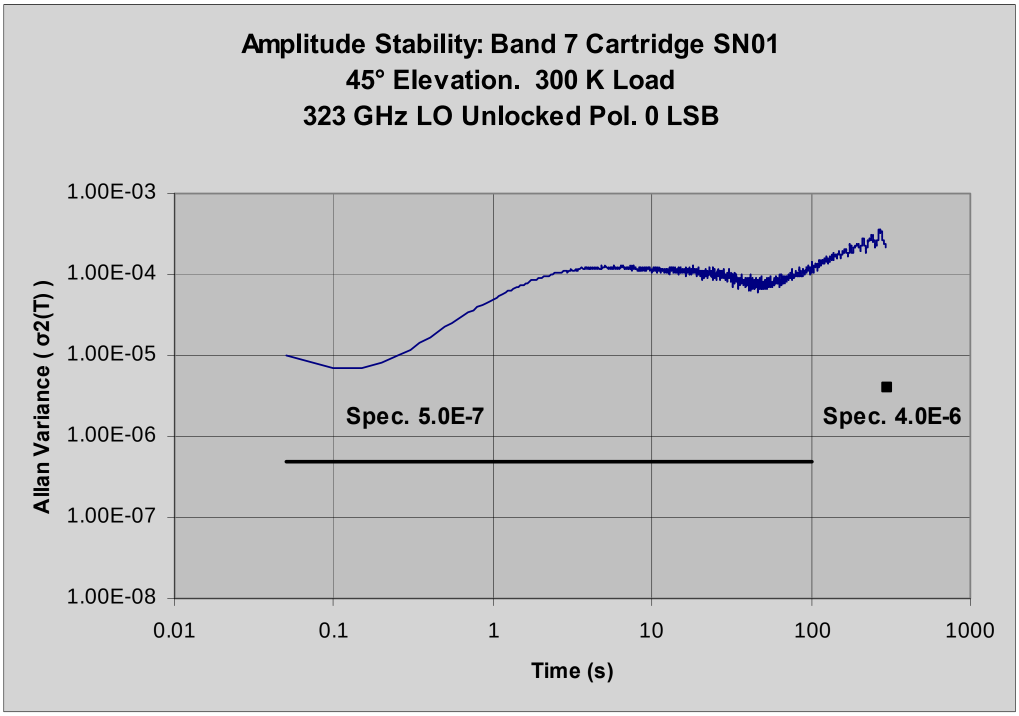


Figure 68 - Band 7 Unlocked Amplitude Stability Pol0 LSB

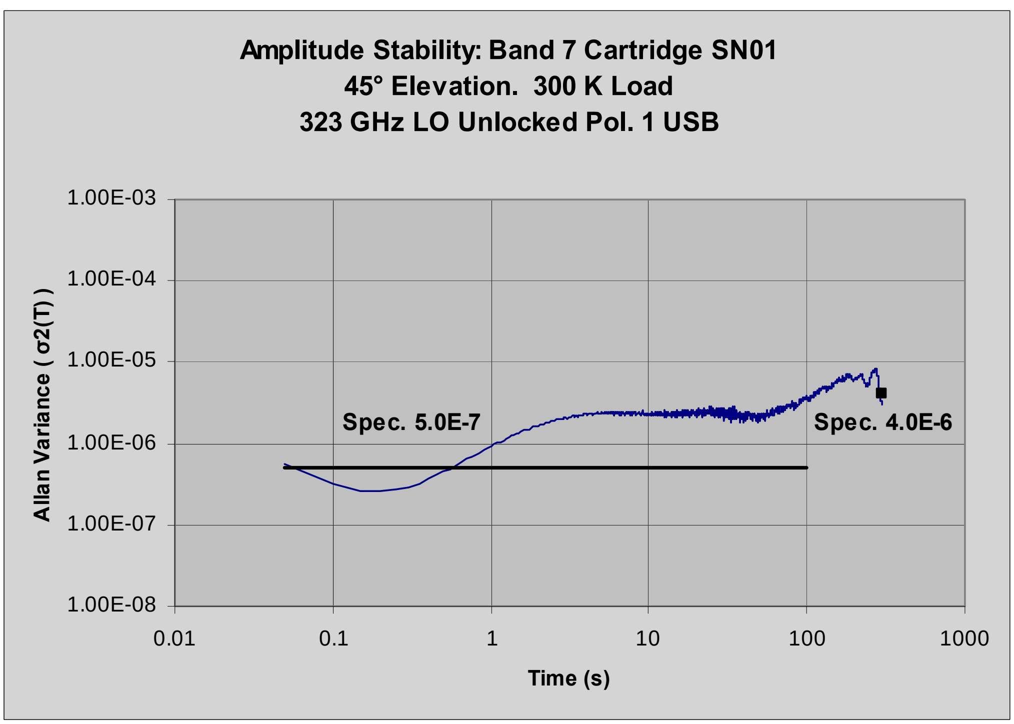


Figure 69 - Band 7 Unlocked Amplitude Stability Pol1 USB

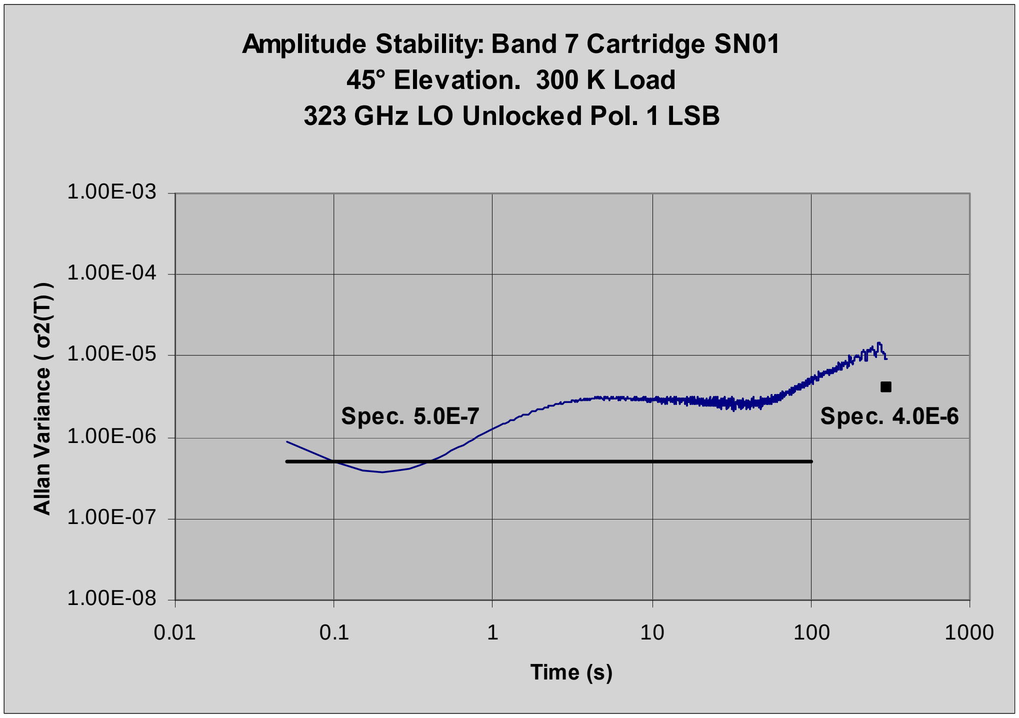


Figure 70 - Band 7 Unlocked Amplitude Stability Pol1 LSB

As with the other bands, the amplitude was measured while moving the tilt table. The resulting amplitude drifts are shown in Figure 71. Note that for two of the traces on this chart, cables outside of the front end are moving as the tilt angle changes. Therefore not all of the drift is attributable to the front end. For measurements made "at FE IF output connector" the power sensor is connected directly to the IF output with no additional cable.

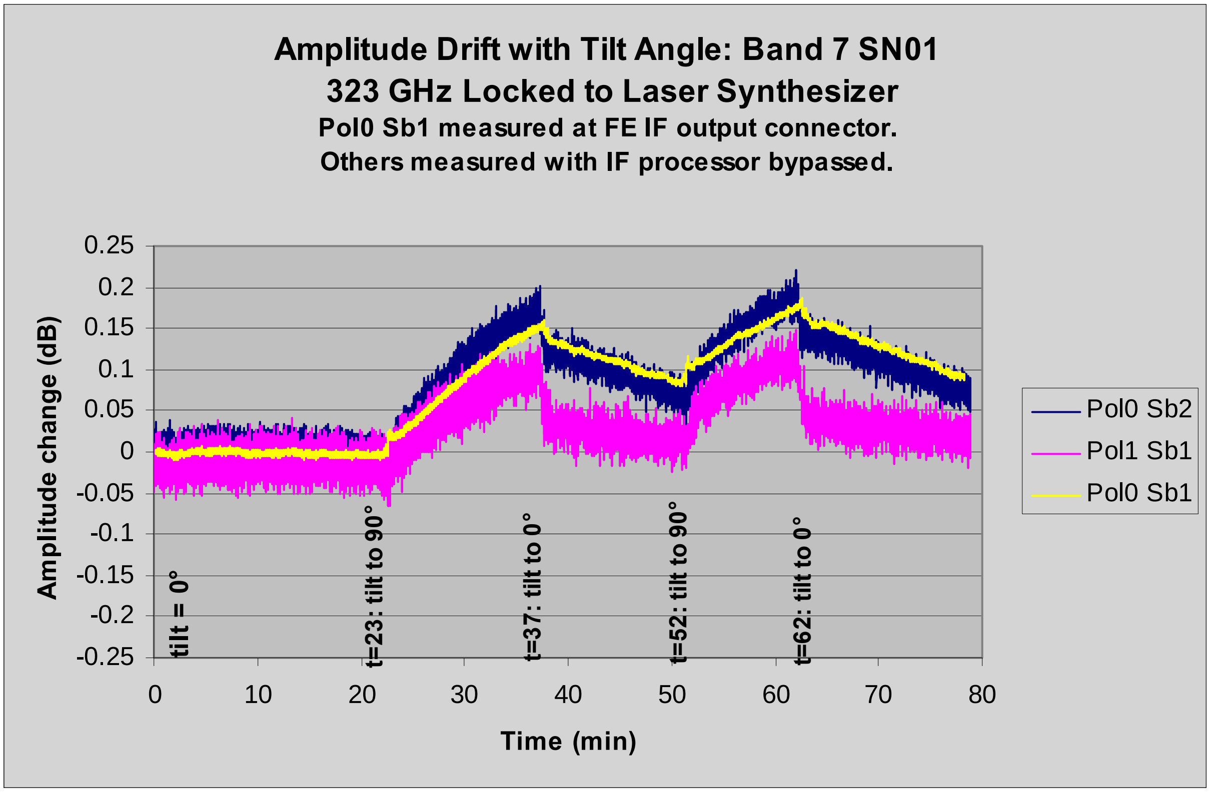


Figure 71 - Band 7 - Amplitude drift while tilting.[5]

[5] There is > 20 dB difference between the power levels between the yellow trace and the other two traces.

Band 9

Band 9 was measured at 662 GHz LO both locked and unlocked. The spec lines are shown on both the locked and unlocked charts, however the specification only applies when the LO is locked.

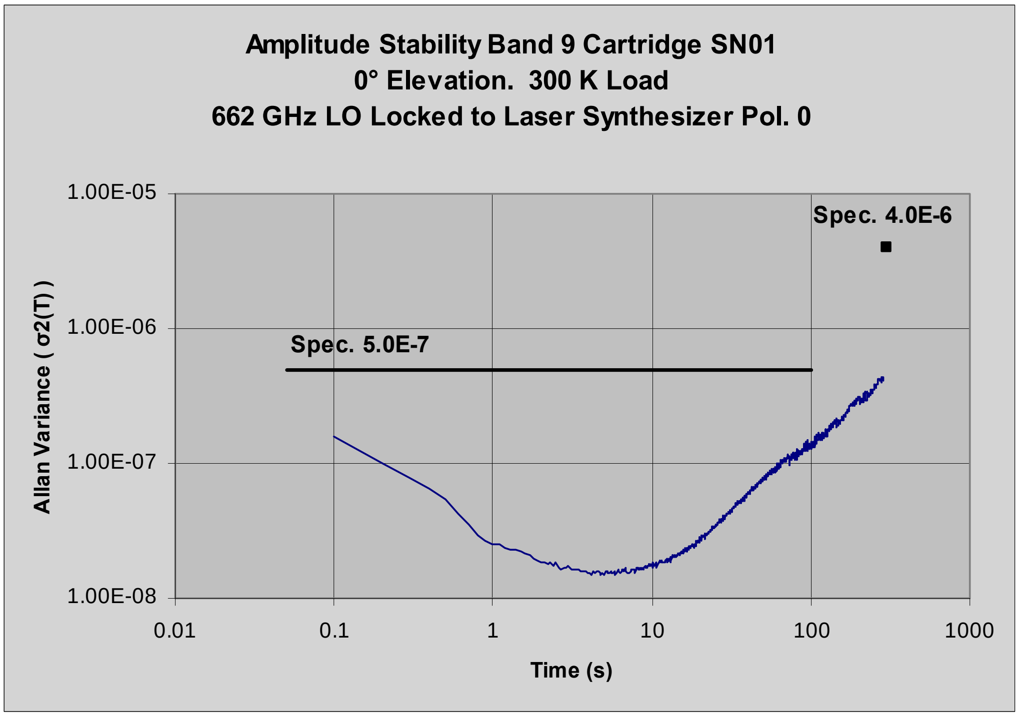


Figure 72 - Band 9 Locked Amplitude Stability Pol0

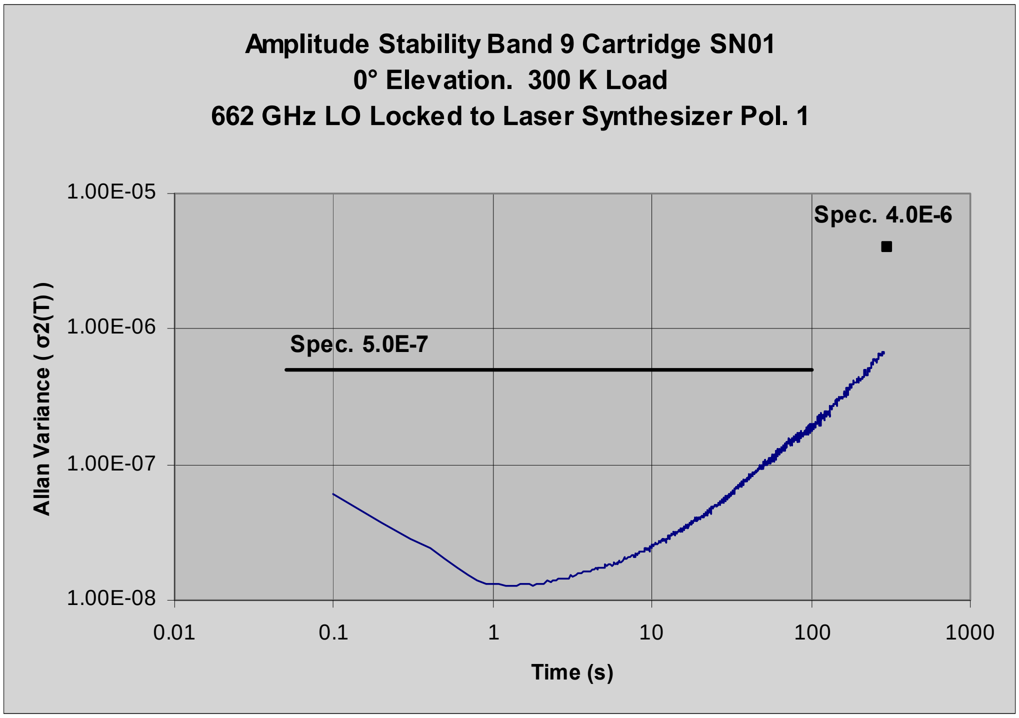


Figure 73 - Band 9 Locked Amplitude Stability Pol1

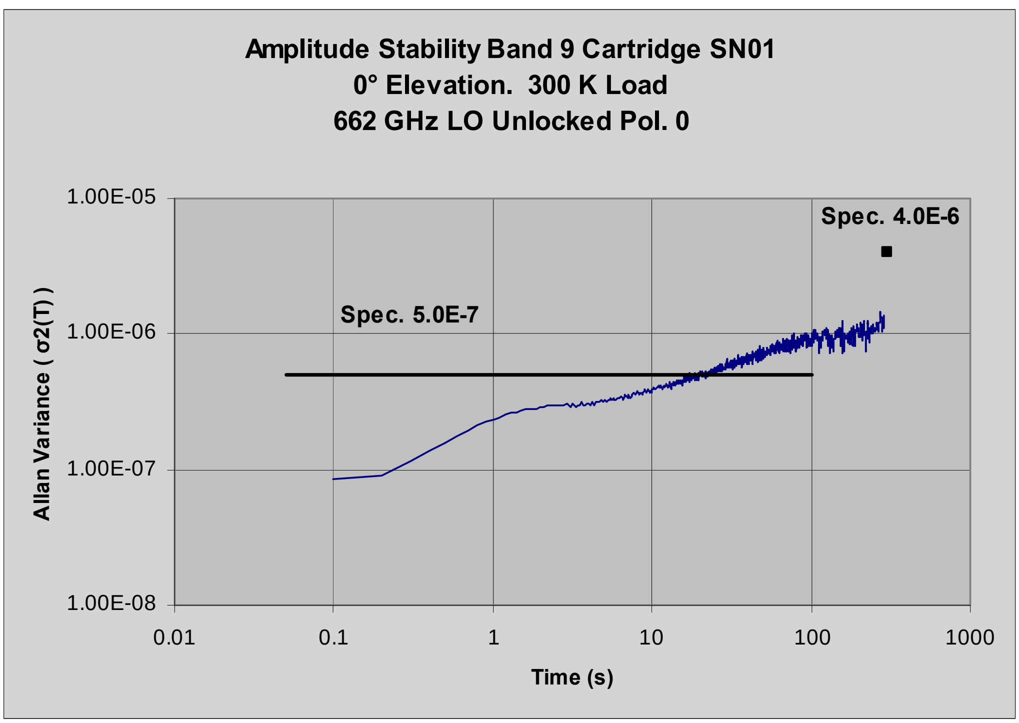


Figure 74 - Band 9 Unlocked Amplitude Stability Pol0

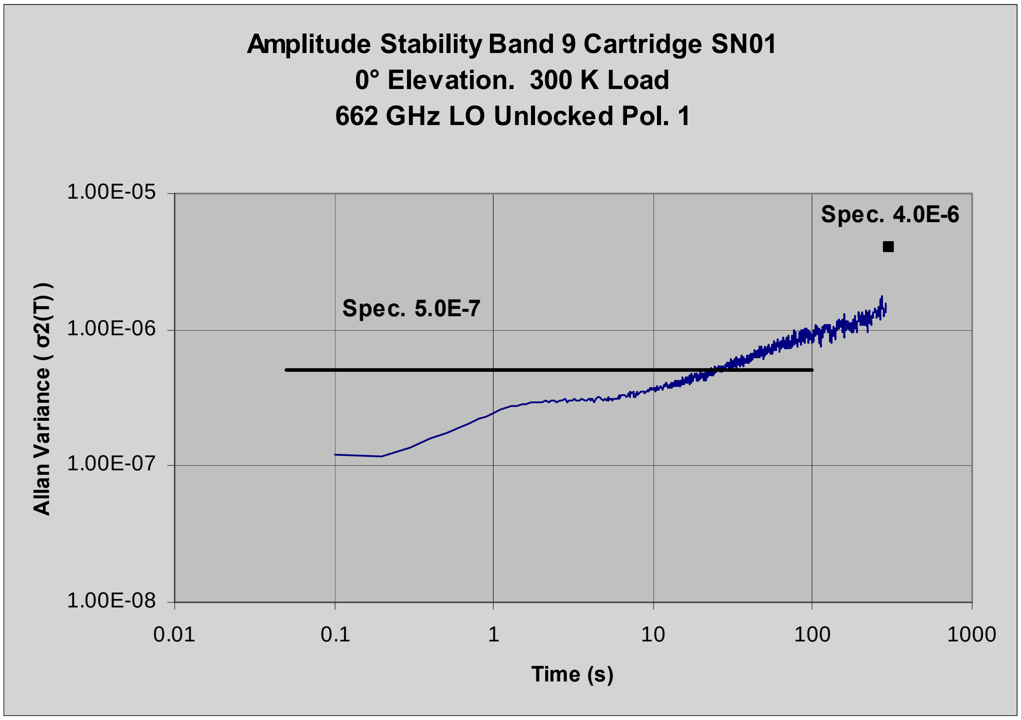


Figure 75 - Band 9 Unlocked Amplitude Stability Pol1

Finally, the amplitude was measured while moving the tilt table. The resulting amplitude drifts are shown in Figure 76. Note that for one of the traces on this chart, cables outside of the front end are moving as the tilt angle changes. Therefore not all of the drift is attributable to the front end. For measurements made "at FE IF output connector" the power sensor is connected directly to the IF output with no additional cable.

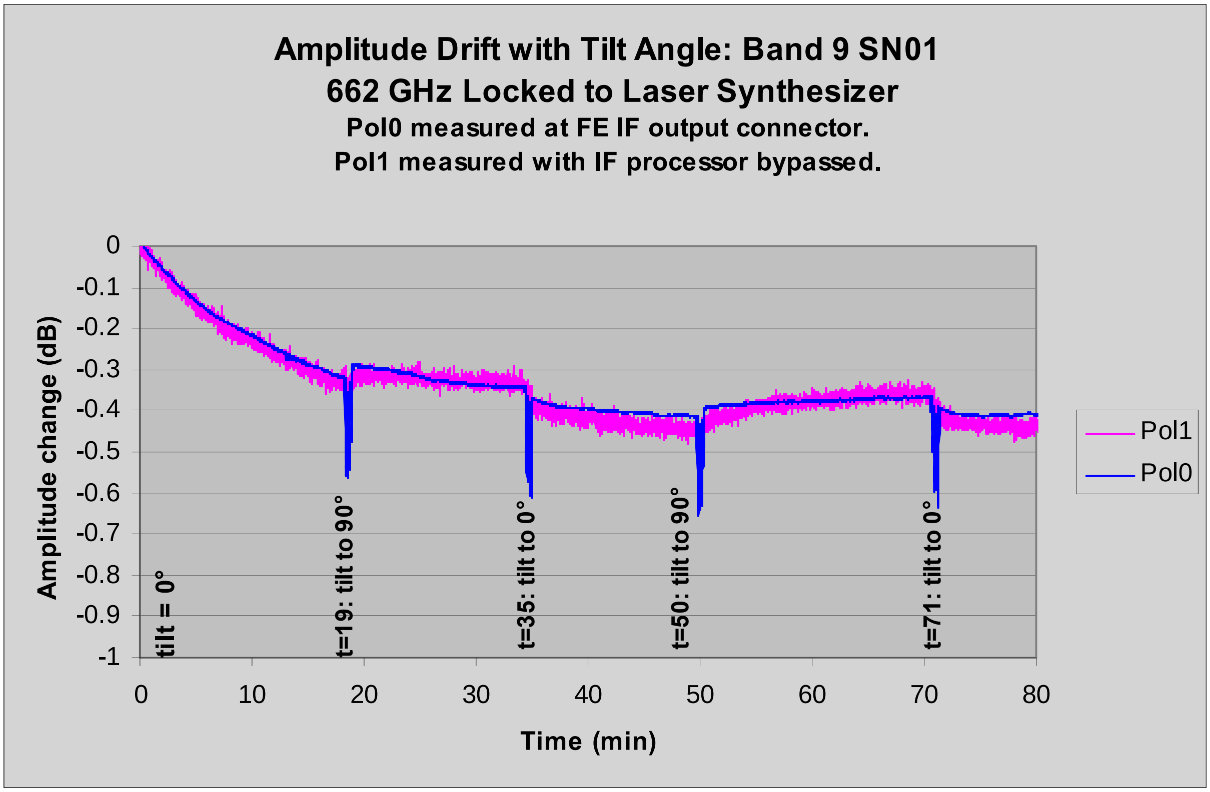


Figure 76 - Band 9 Amplitude drift while tilting

3.1.8 Signal path phase stability

[FEND-40.00.00.00-00180-00 / T]

Specification to be verified: For all frequencies within the IF pass-band the signal path transfer function shall maintain the following phase stabilities:

- Long term (delay drift) 20 s $\leq$ T < 300 s - 10 fs

The signal path shall include all Front-End components and be measured at the IF outputs of the Front-End. The required phase stability excludes any contribution from the first local oscillator. The delay drift requirement refers to the 2-point standard deviation with a fixed averaging time, τ, of 10 seconds and intervals, T, between 20 and 300 seconds.

The system shall typically operate for at least one hour with no step discontinuities in the system delay exceeding 10 fs.

Result:

Not Measured. Measurement requires the LORTM, which has not yet been delivered.

3.1.9 IF phase variations

[FEND-40.00.00.00-00185-00 / A, T]

Specification to be verified: Within the IF band, variations from the average IF phase shall be less than: 6.4^o rms in any 31 MHz portion of the IF band specified in section 2.3.3 Not verified. See [AD17].

Result:

Not Measured.

3.2 Cryogenics and vacuum requirements

3.2.1 Evacuation and cool-down time

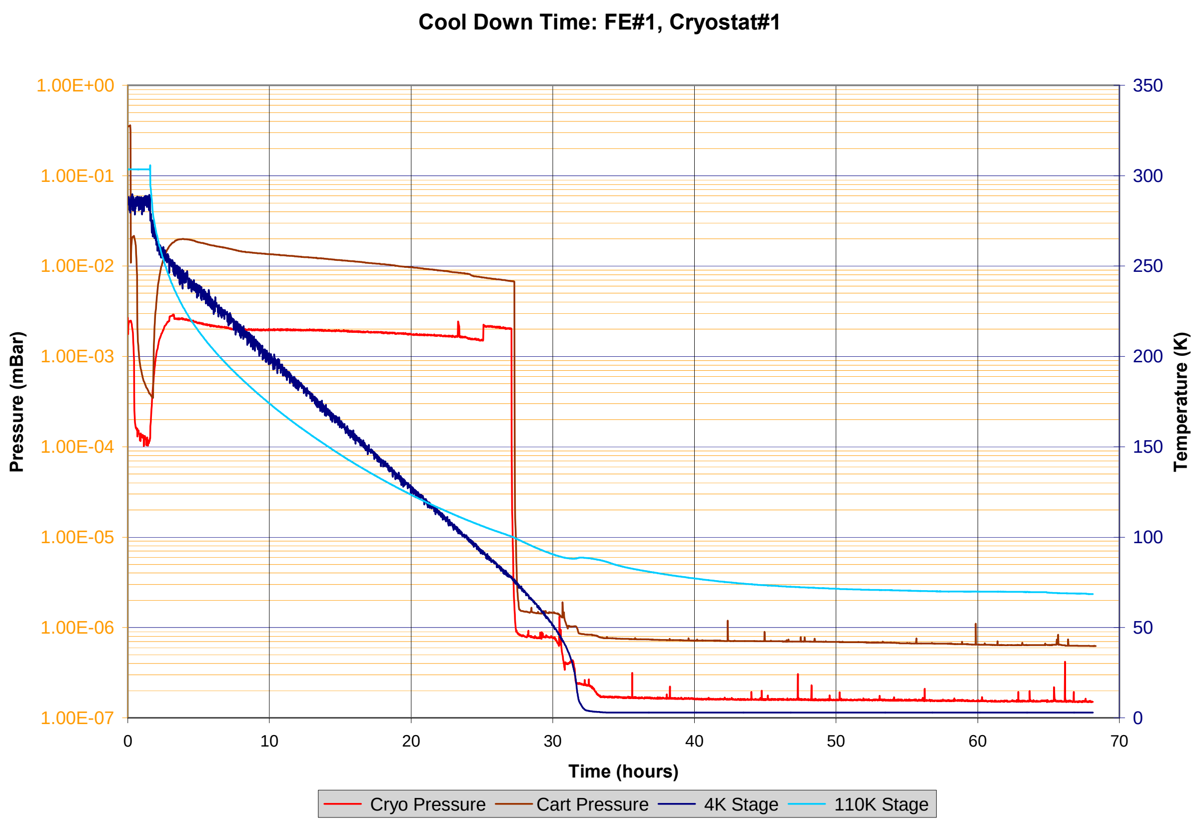
[FEND-40.00.00.00-00190-00 / T]

Specification to be verified: The period required to evacuate the vacuum parts of the Front End from atmospheric pressure and to cool to operating temperatures (with all cartridges installed) shall be a maximum of 48 hours. Note that this may be achieved with the aid of a high-throughput external backing pump.

Result:

This was measured after the recent refurbishment of the cryostat cold head. Due to a problem with one of the power supplies, the gate valve closed shortly after the cooldown started. At around 25 hours this was discovered and the gate valve was opened for a short time. Therefore, this data may not be representative of the expected cooldown time, though it is believed to be close.

The two pressure measurements, labelled "Cryo Pressure" and "Cart Pressure" are measured using two different instruments. The Cryo Pressure is measured using the front end's onboard vacuum gauge. Cart Pressure is measured using an auxiliary test set and software connected to the RS-232 port of the vacuum gauge. The latter is separated from the former by a rather small opening, so the factor of 10 difference between the two is expected.



3.2.2 Warm-up time

[FEND-40.00.00.00-00200-00 / T]

Specification to be verified: The warm-up of the cooled parts of the Front End from operating to ambient temperature shall take a maximum of 40 hours.

Result:

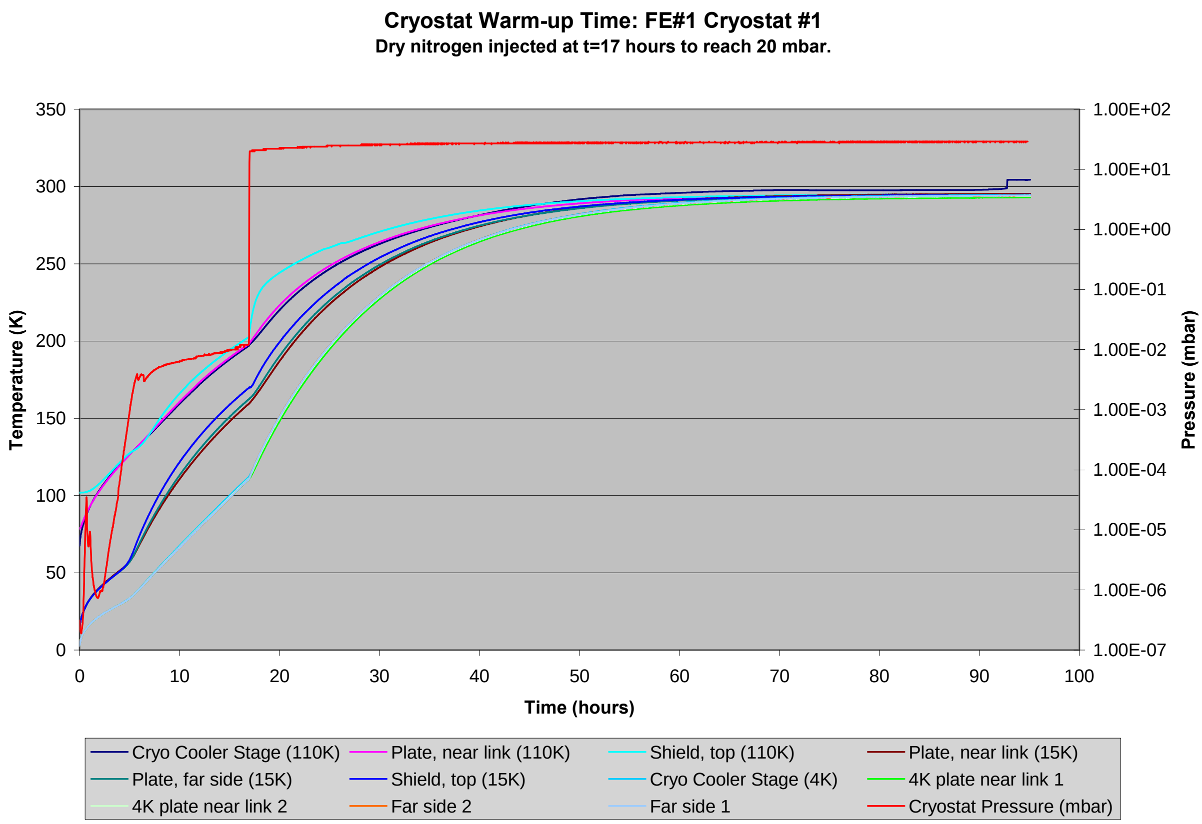


Figure 77 - Cryostat Warm-up time

3.2.3 Vacuum integrity

[FEND-40.00.00.00-00210-00 / AT]

Specification to be verified: The vacuum parts of the Front End shall have a sufficient vacuum integrity to enable continuous operation without mechanical pumping for at least one year.

Result: The pressure inside the cryostat after final warm up (after being cold for xx hours) was xx mbar. This is estimated to result in a hold time of xx year(s) that is much larger than the specification.

Not Measured.

3.3 Optics Requirements

This section applies only to the operational mode.

3.3.1 Beam performance

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

Band 3

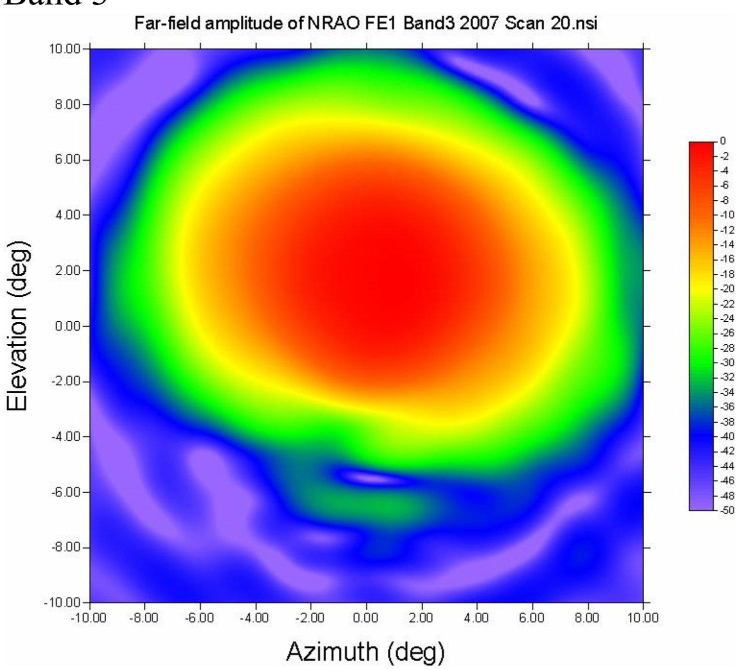


Figure 78 86 GHz Pol 0 Co-pol. elevation 45

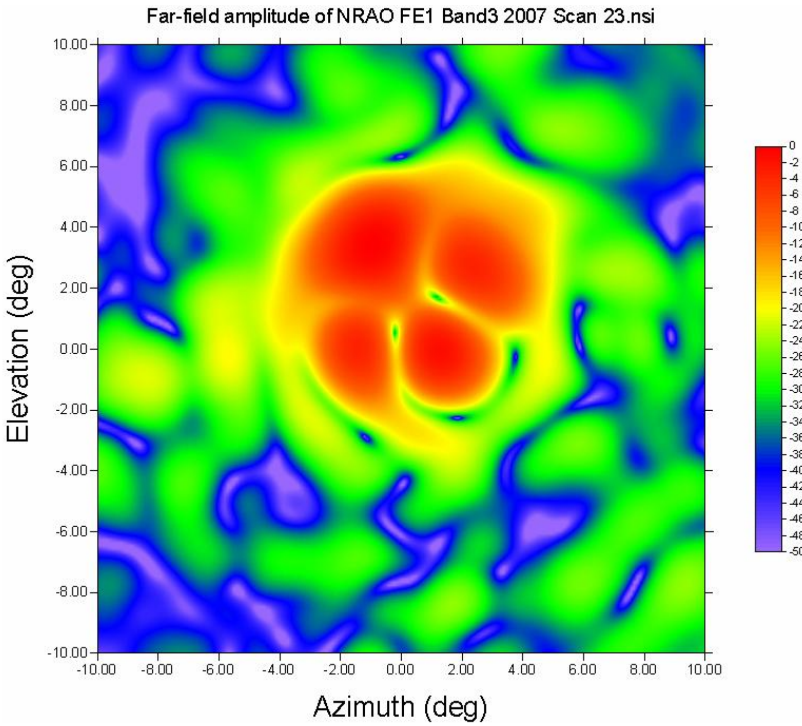


Figure 79 86 GHz Pol 0 Cross-pol. elevation 45

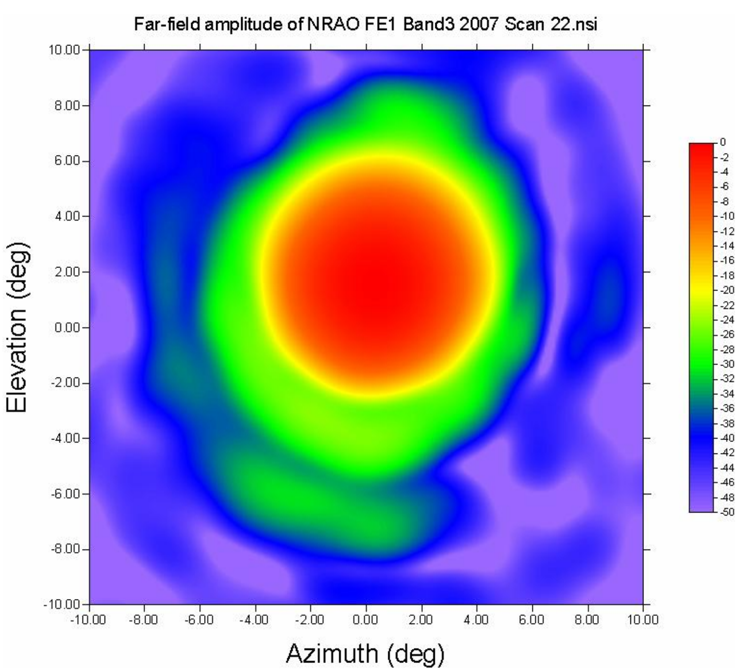


Figure 80 86 GHz Pol 1 Co-pol. elevation 45

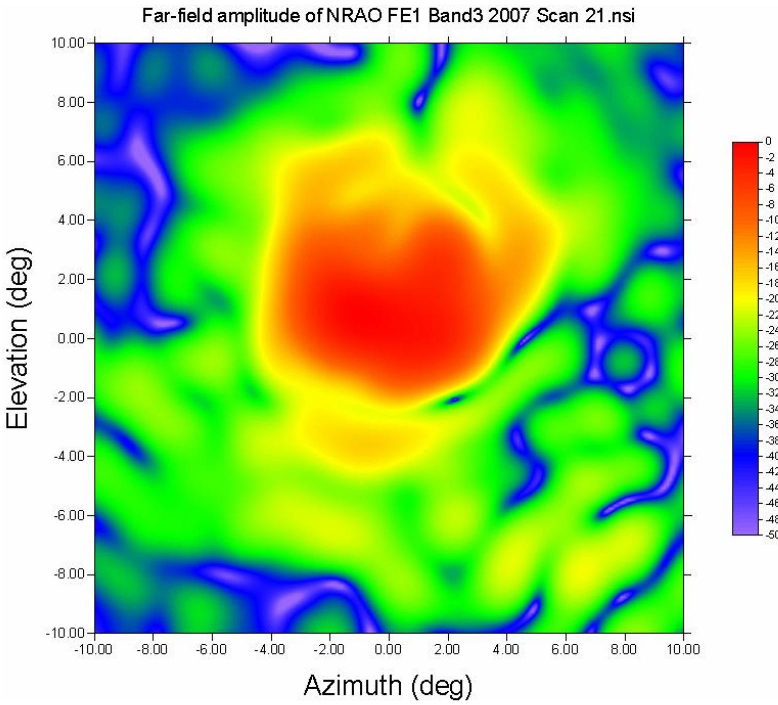


Figure 81 86 GHz Pol 1 Cross-pol. elevation 45

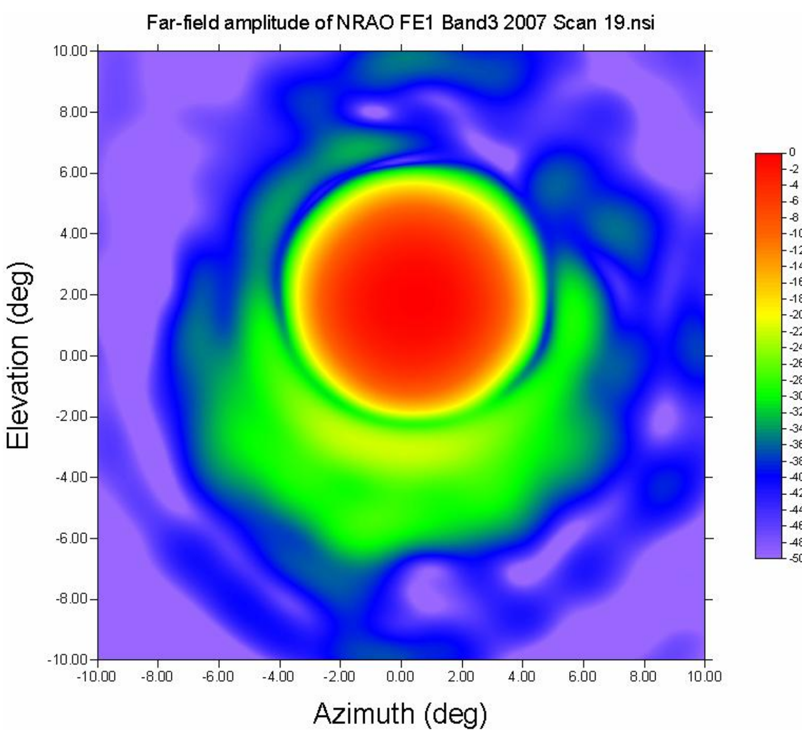


Figure 82 94 GHz Pol 0 Co-pol. elevation 0

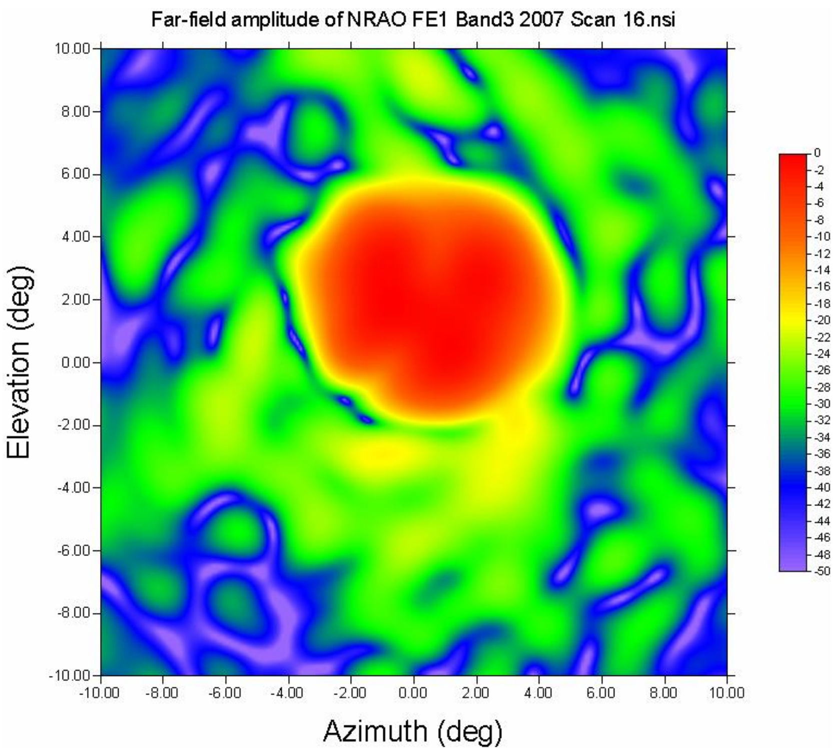


Figure 83 94 GHz Pol 0 Cross-pol. elevation 0

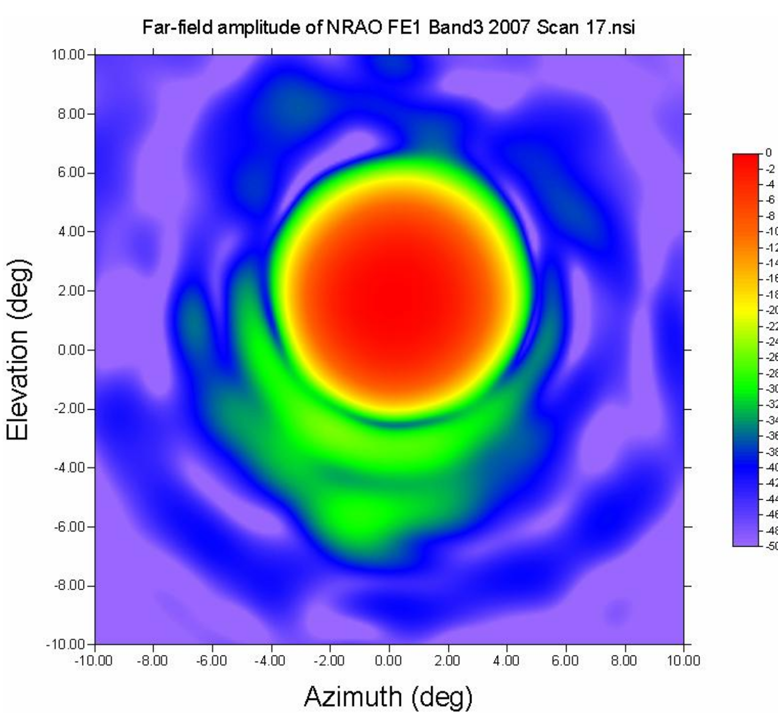


Figure 84 94 GHz Pol 1 Co-pol. elevation 0

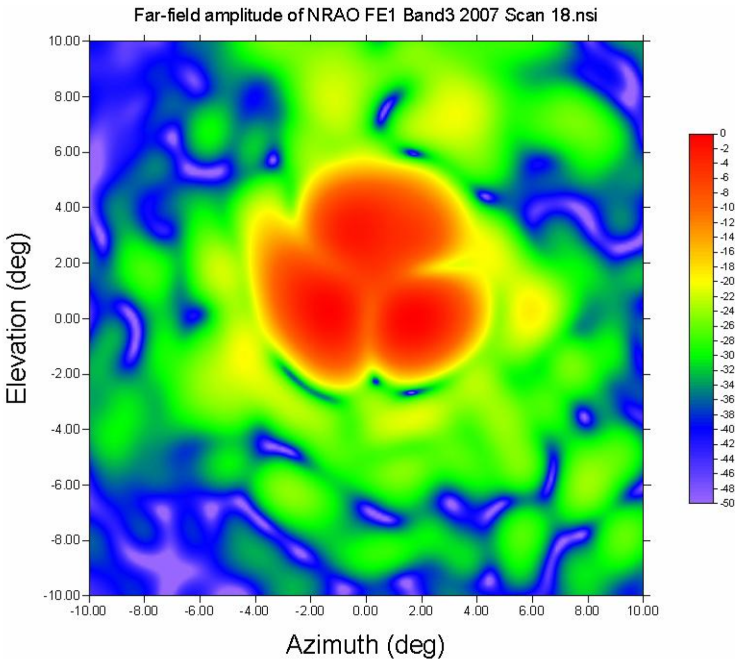


Figure 85 94 GHz Pol 1 Cross-pol. elevation 0

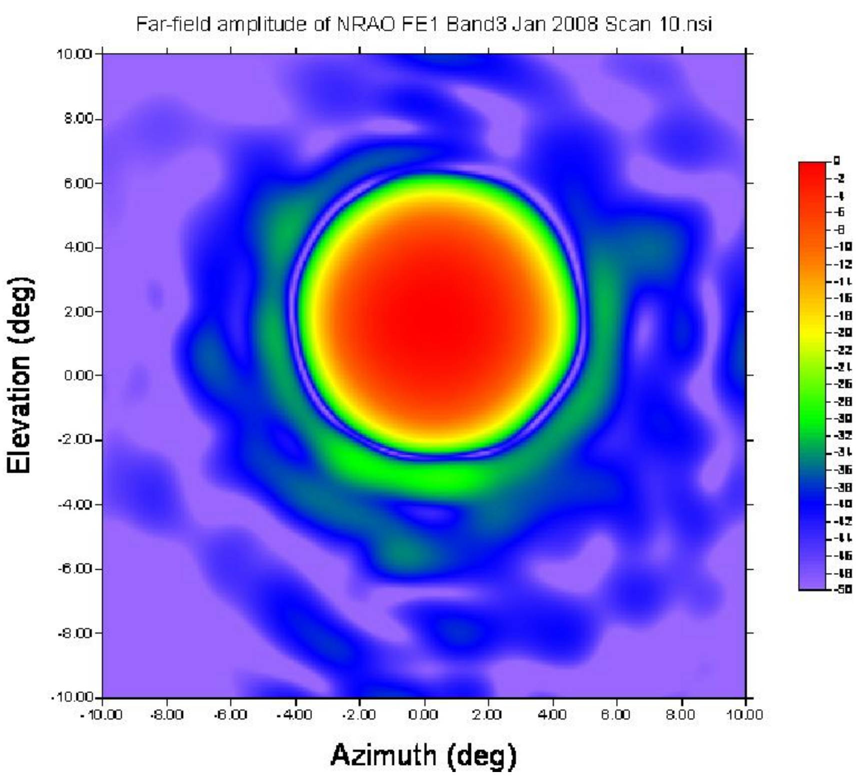


Figure 86 94 GHz Pol 0 Co-pol. elevation 45

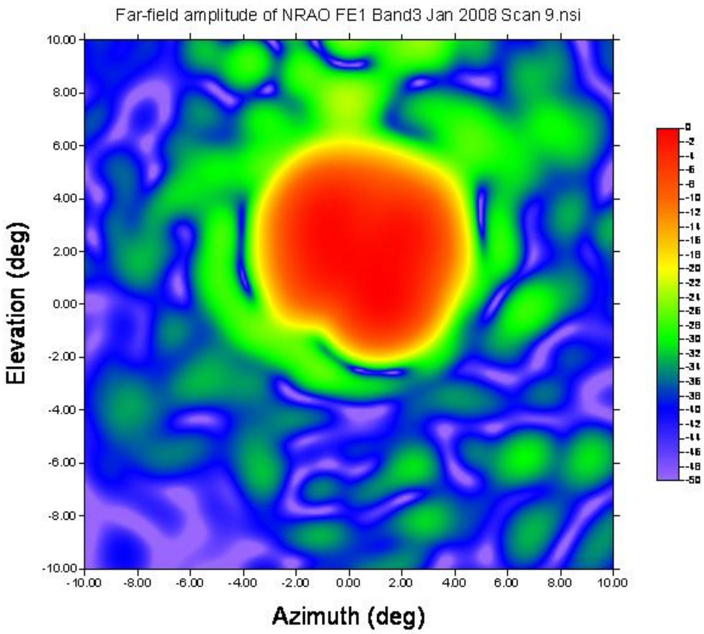


Figure 87 94 GHz Pol 0 Cross-pol. elevation 45

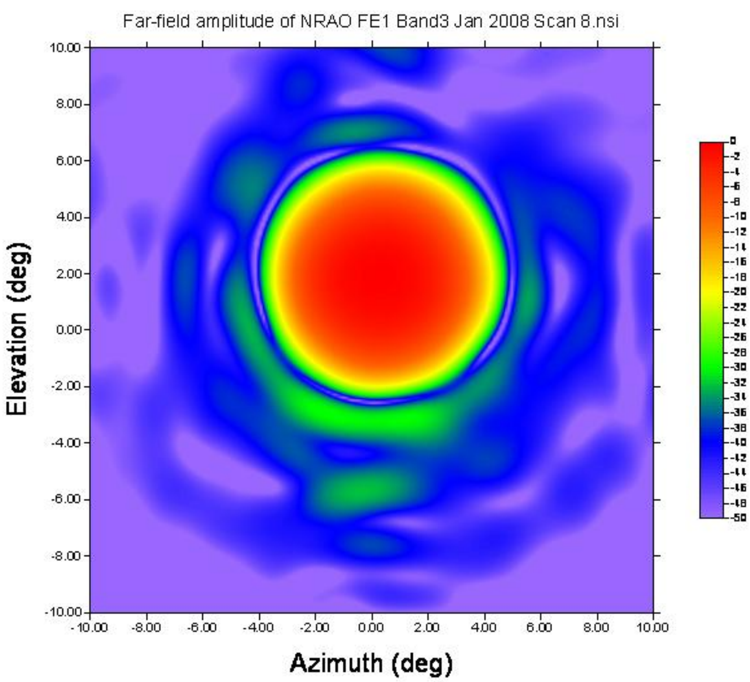


Figure 88 94 GHz Pol 1 Co-pol. elevation 45

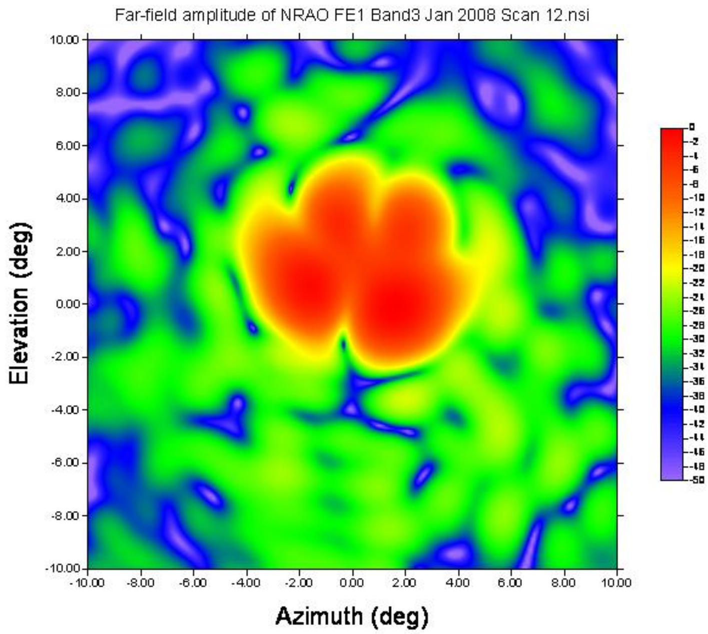


Figure 89 94 GHz Pol 1 Cross-pol. elevation 45

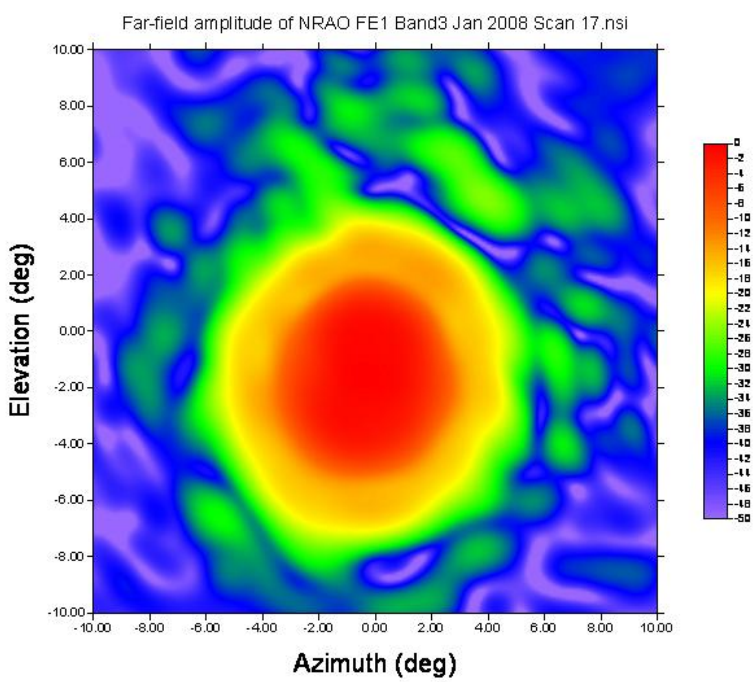


Figure 90 115 GHz Pol 0 Co-pol. elevation 45

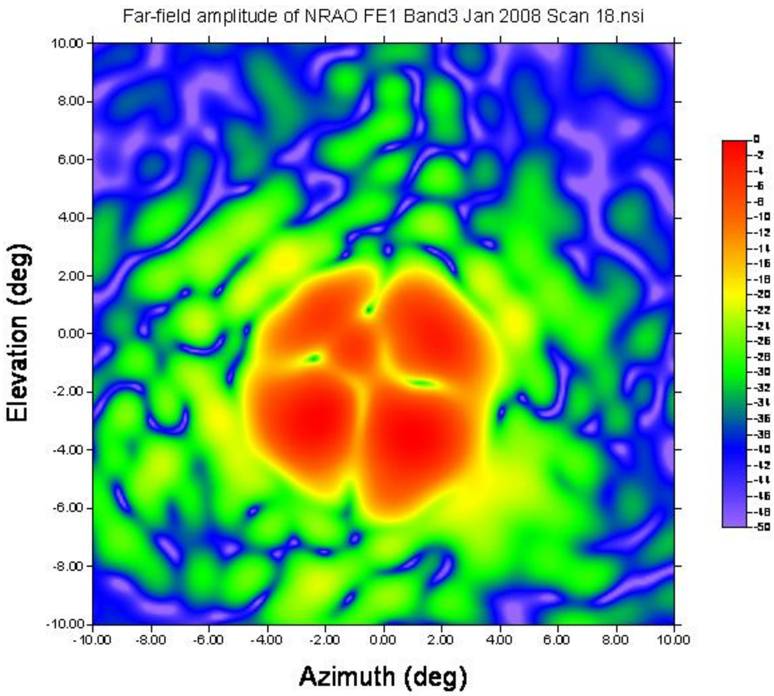


Figure 91 115 GHz Pol 0 Cross-pol. elevation 45

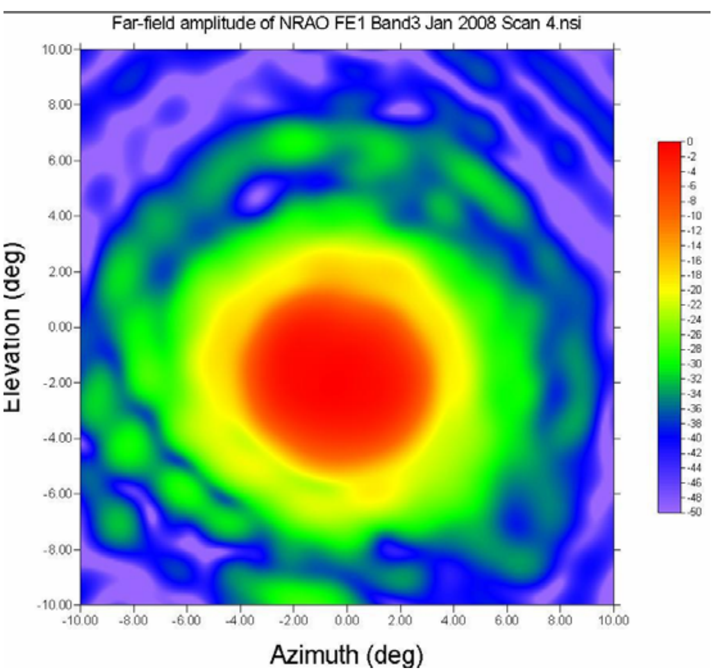


Figure 92 115 GHz Pol 1 Co-pol. elevation 45

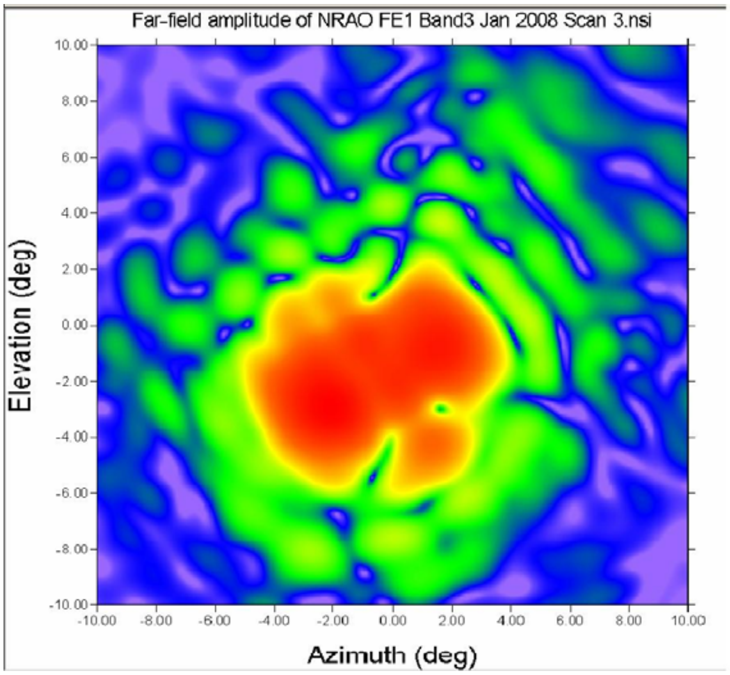


Figure 93 115 GHz Pol 1 Cross-pol. elevation 45

Band 6

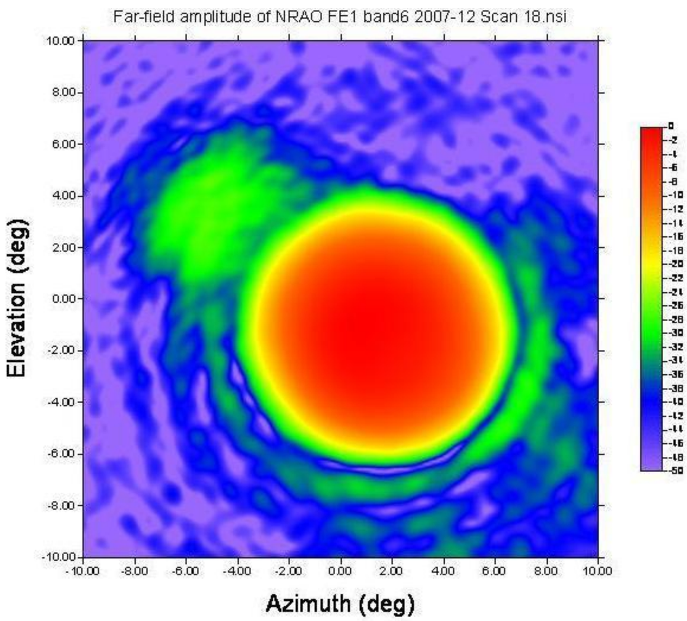


Figure 94 239 GHz Pol 0 Co-pol. elevation 45

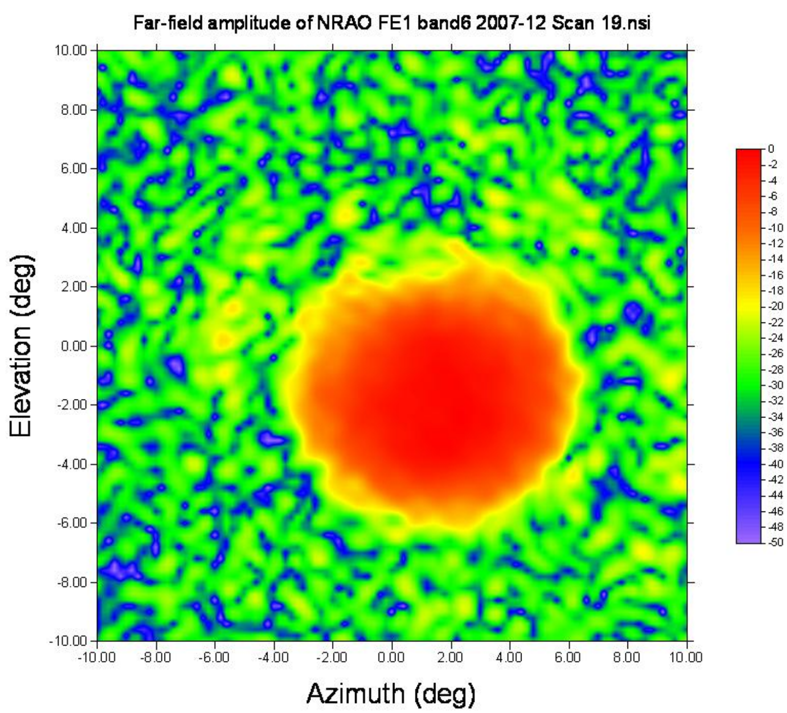


Figure 95 239 GHz Pol 0 Cross-pol. elevation 45

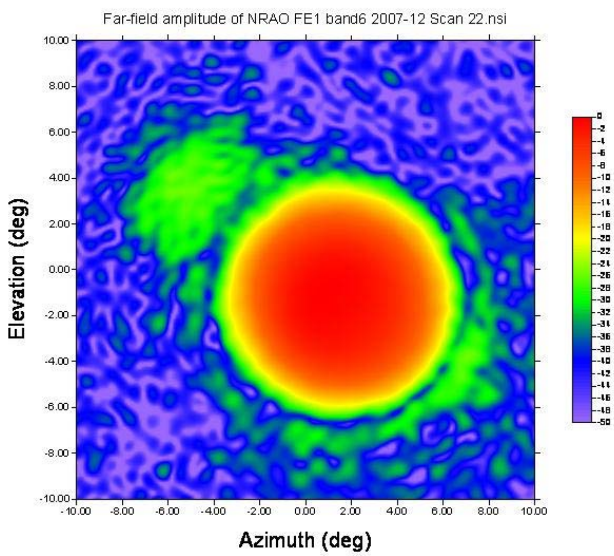


Figure 96 239 GHz Pol 1 Co-pol. elevation 45

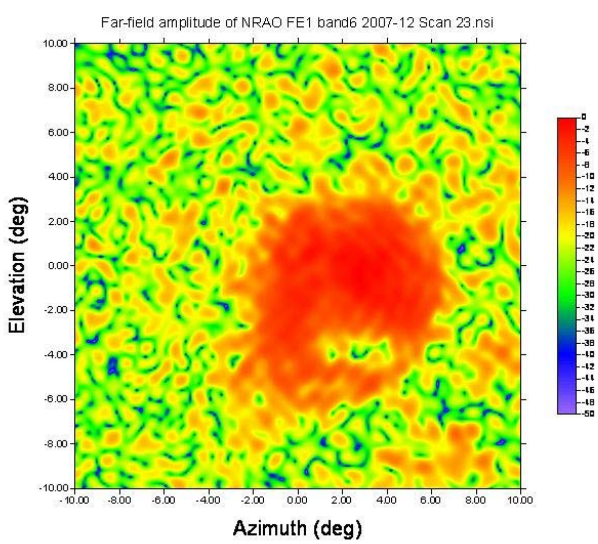


Figure 97 239 GHz Pol 1 Cross-pol. elevation 45

Band 7

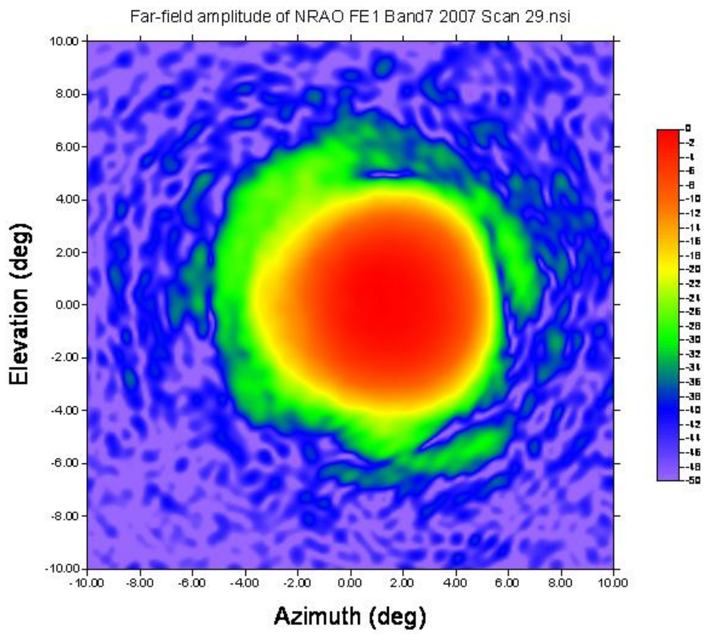


Figure 98 277 GHz Pol 0 Co-pol. elevation 45

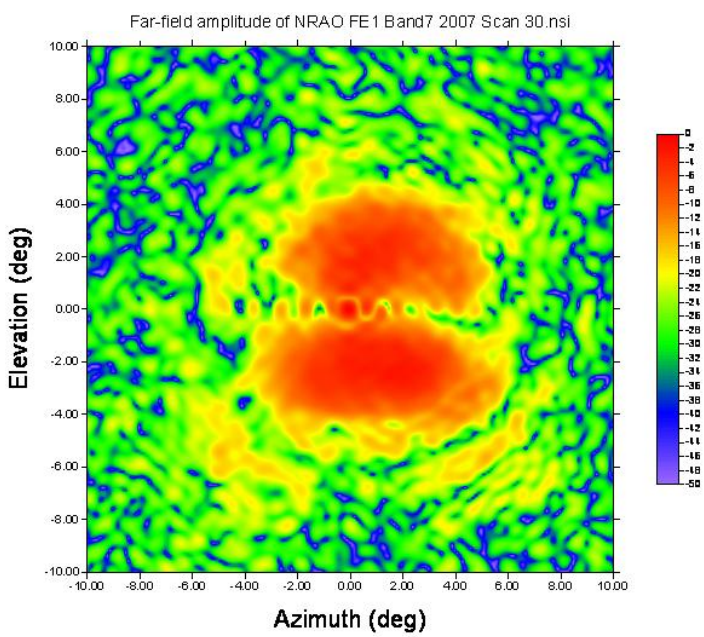


Figure 99 277 GHz Pol 0 Cross-pol. elevation 45

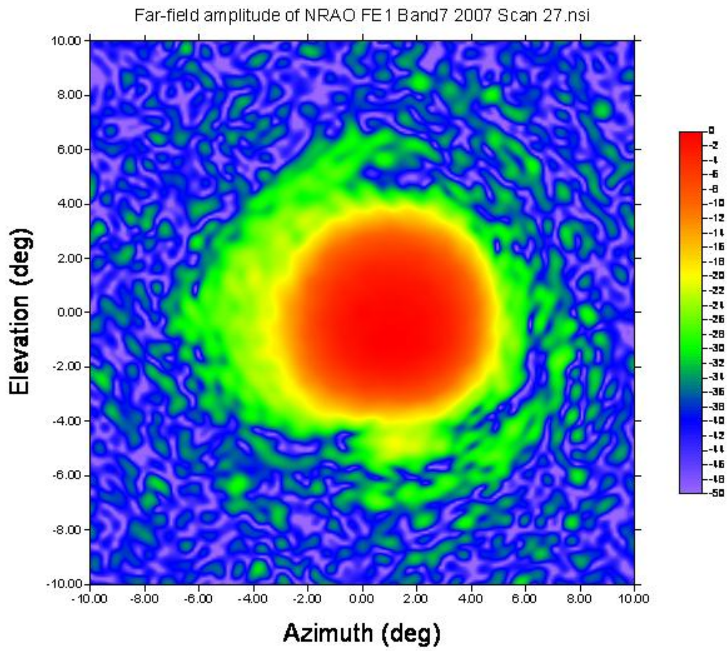


Figure 100 277 GHz Pol 1 Co-pol. elevation 45

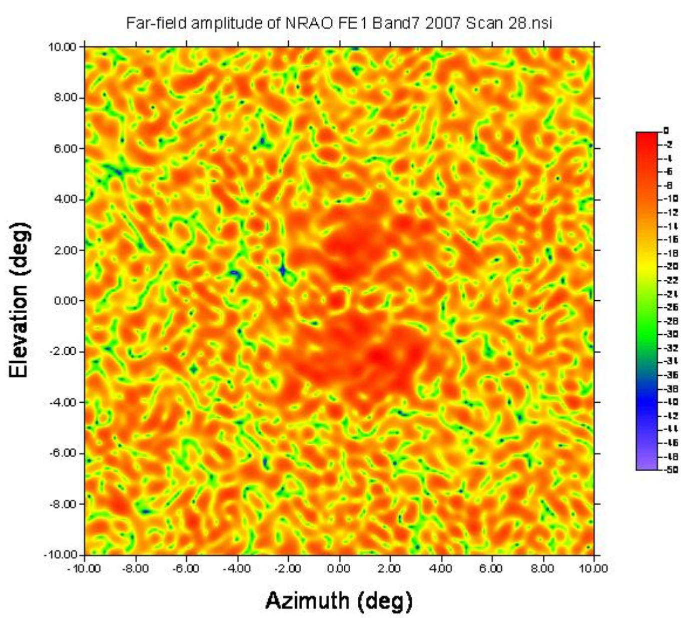


Figure 101 277 GHz Pol 1 Cross-pol. elevation 45

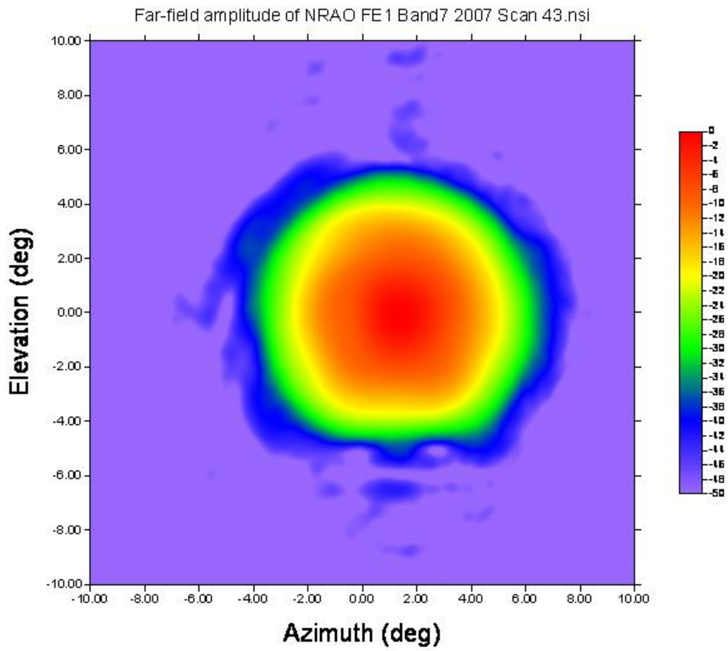


Figure 102 317 GHz Pol 0 Co-pol. elevation 0

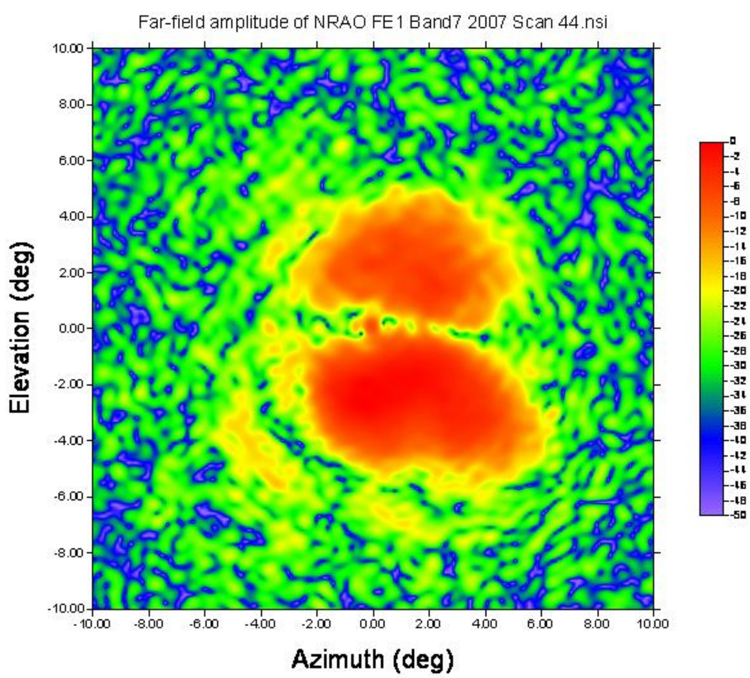


Figure 103 317 GHz Pol 0 Cross-pol. elevation 0

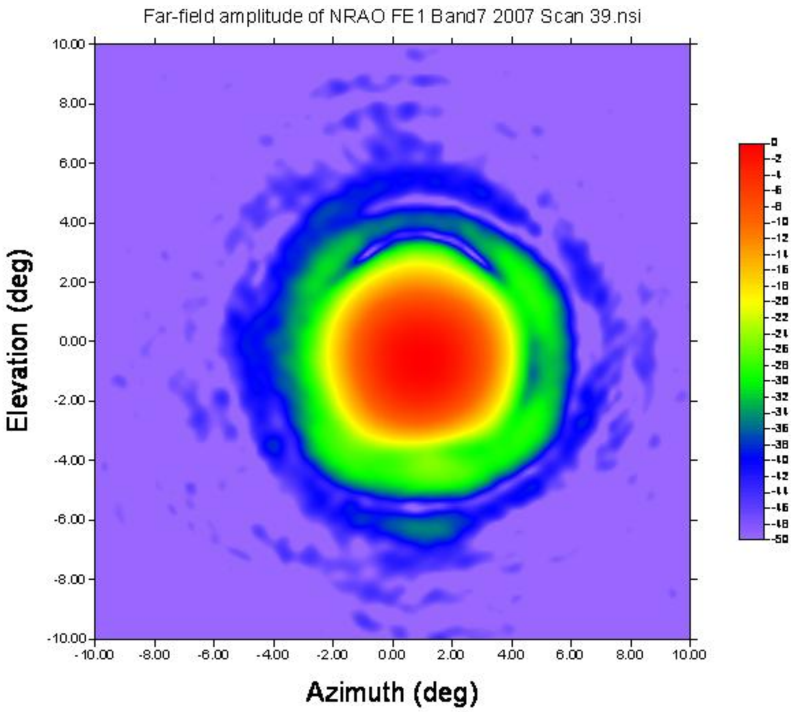


Figure 104 317 GHz Pol 1 Co-pol. elevation 0[6]

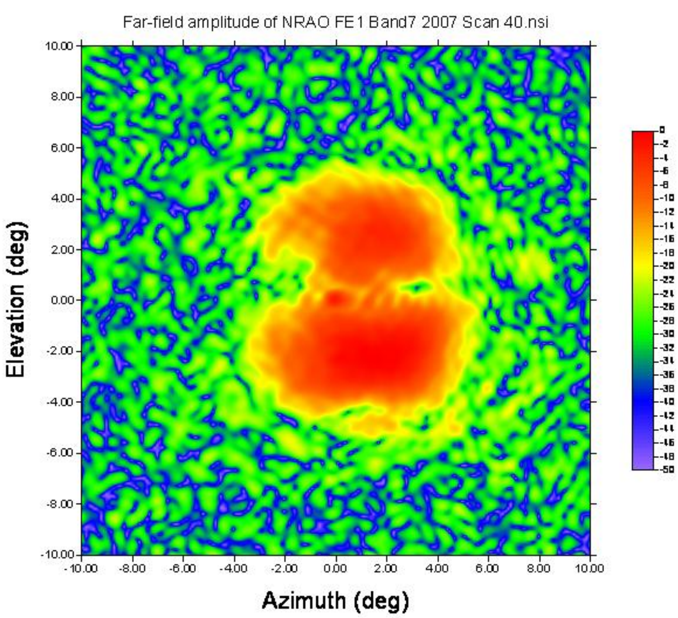


Figure 105 317 GHz Pol 1 Cross-pol. elevation 0

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

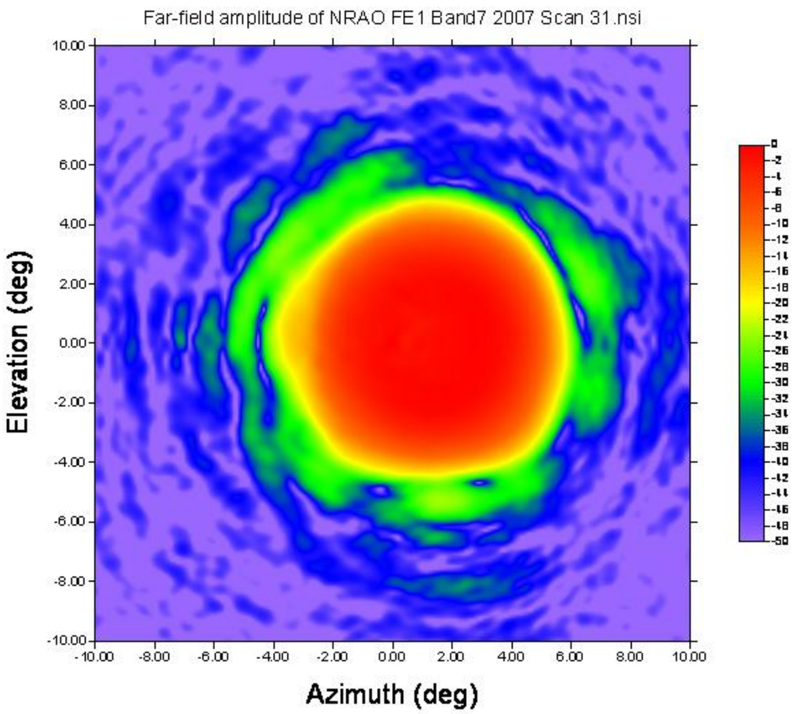


Figure 106 317 GHz Pol 0 Co-pol. elevation 45[7]

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

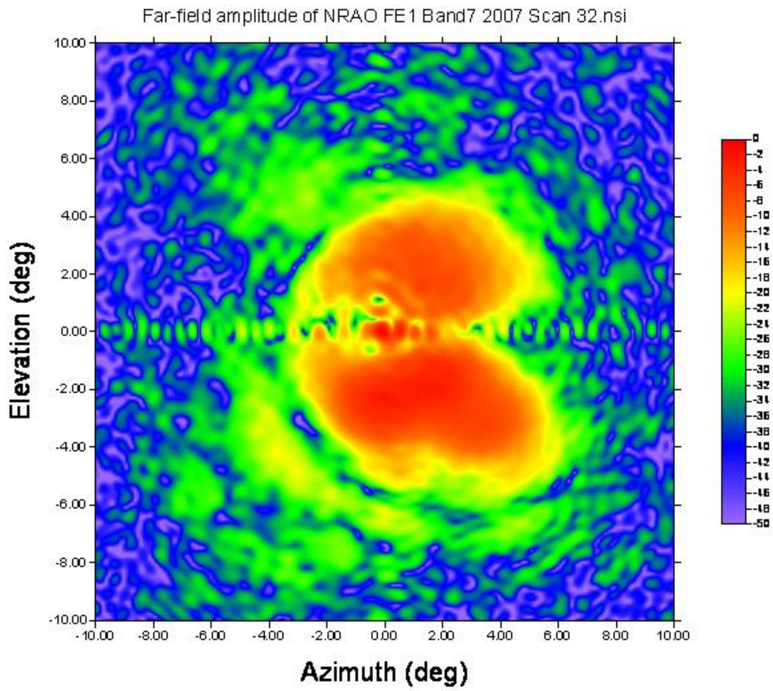


Figure 107 317 GHz Pol 0 Cross-pol. elevation 45

Band 9

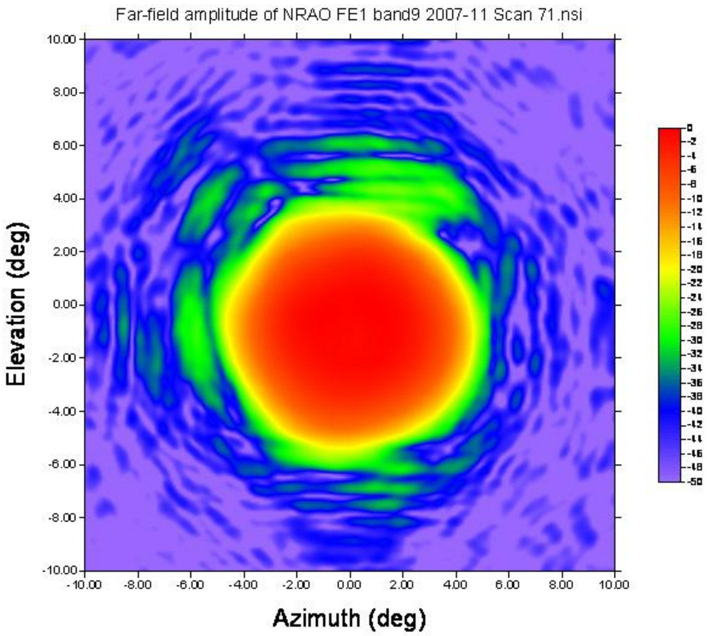


Figure 108 620 GHz Pol 0 co-pol. elevation 45

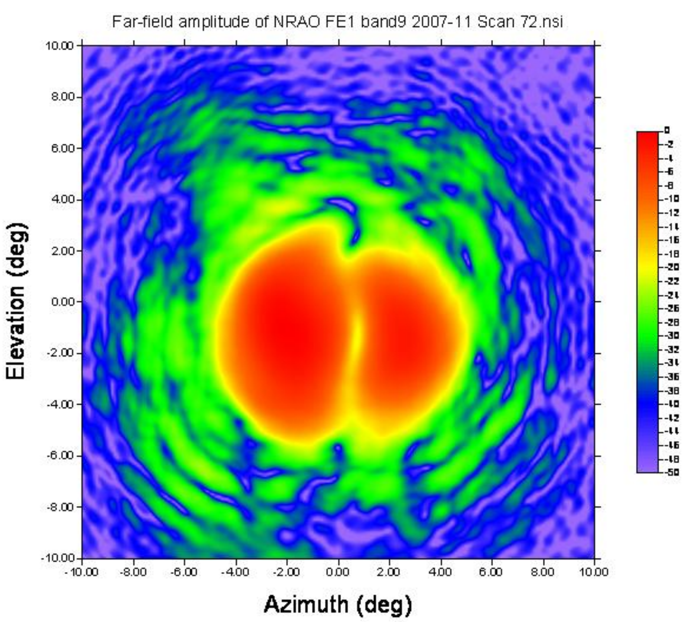


Figure 109 620 GHz Pol 0 cross-pol. elevation 45

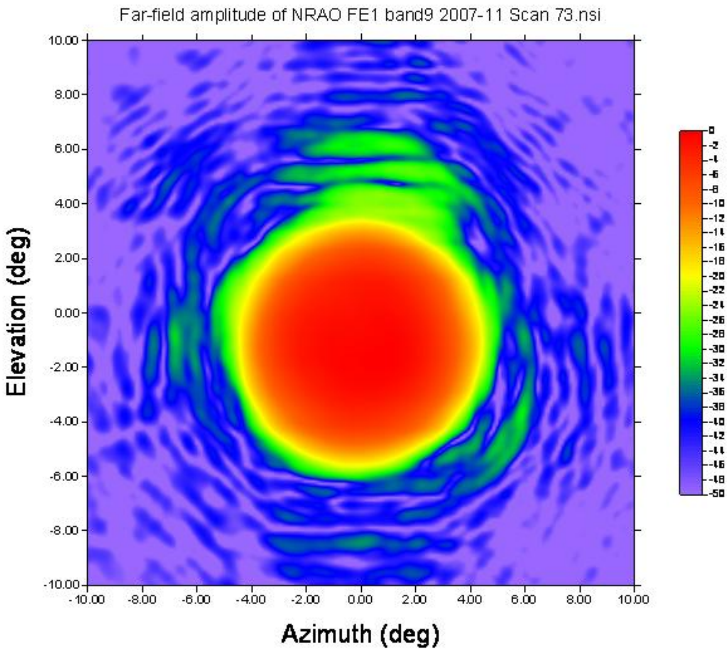


Figure 110 620 GHz Pol 1 co-pol. elevation 45

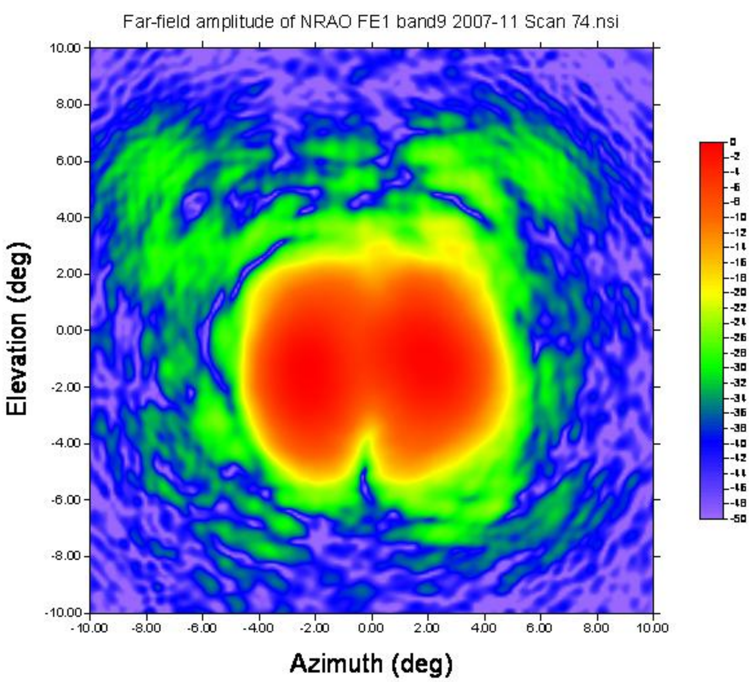


Figure 111 620 GHz Pol 1 cross-pol. elevation 45

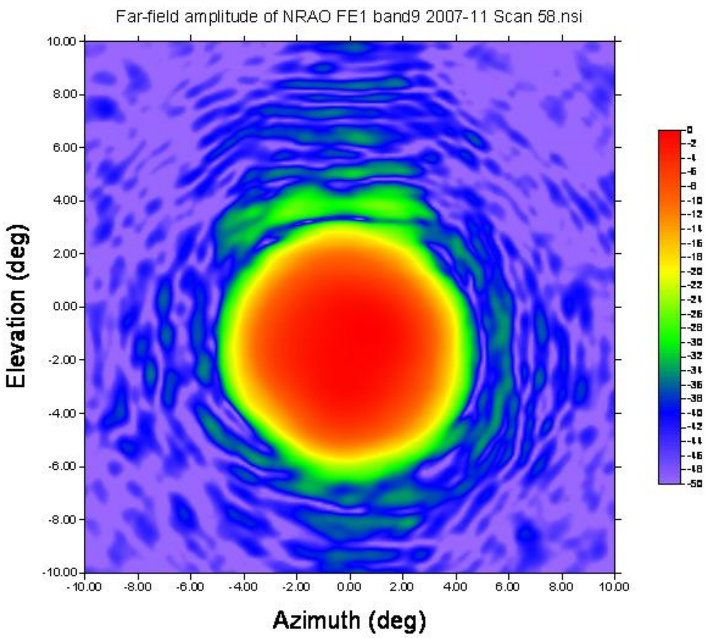


Figure 112 661 GHz Pol 0 co-pol. elevation 0

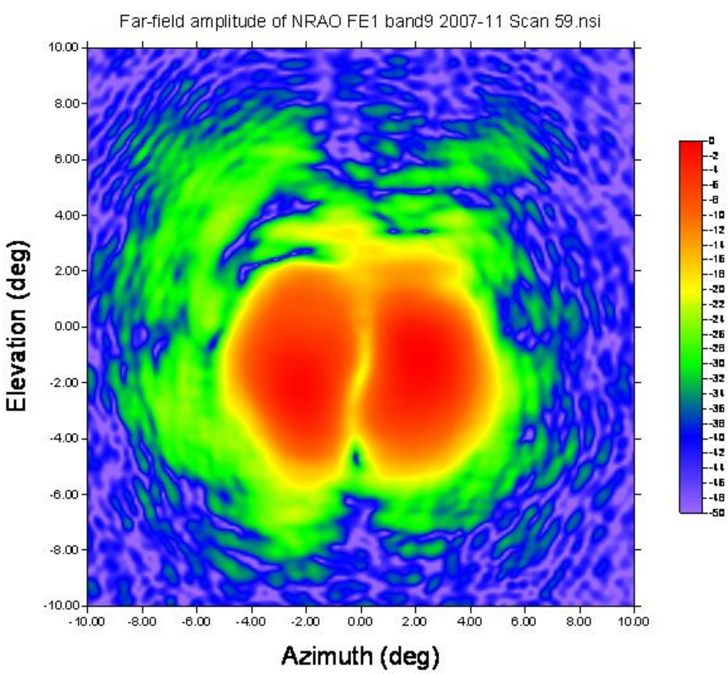


Figure 113 661 GHz Pol 0 cross-pol. elevation 0

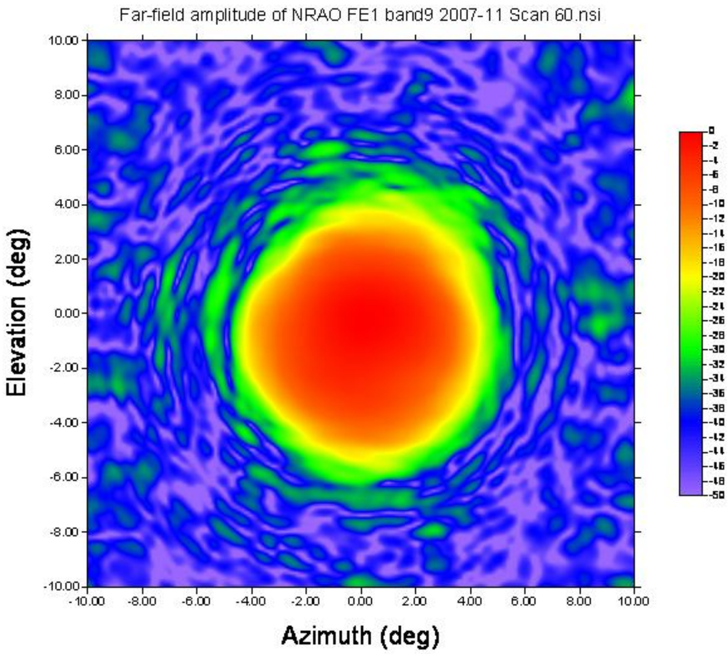


Figure 114 661 GHz Pol 1 co-pol. elevation 0

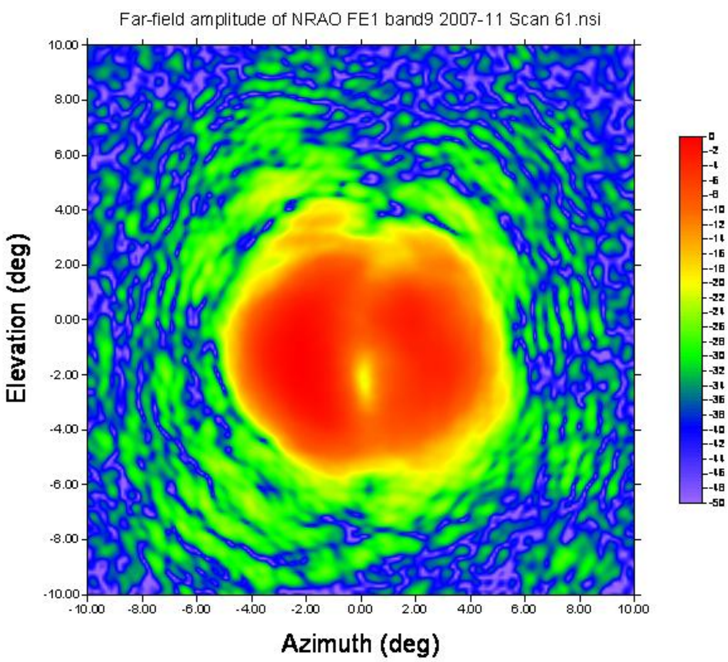


Figure 115 661 GHz Pol 1 cross-pol. elevation 0

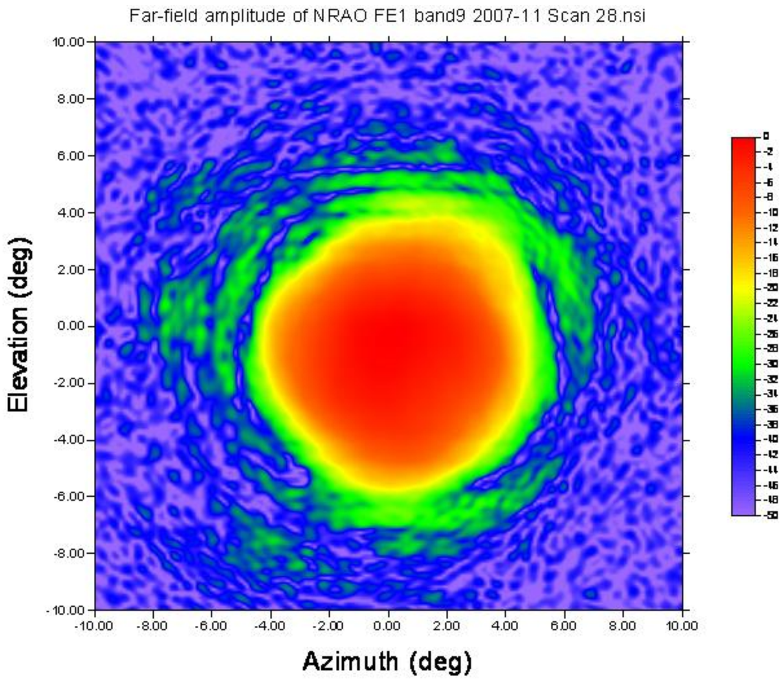


Figure 116 661 GHz Pol 0 co-pol. elevation 45

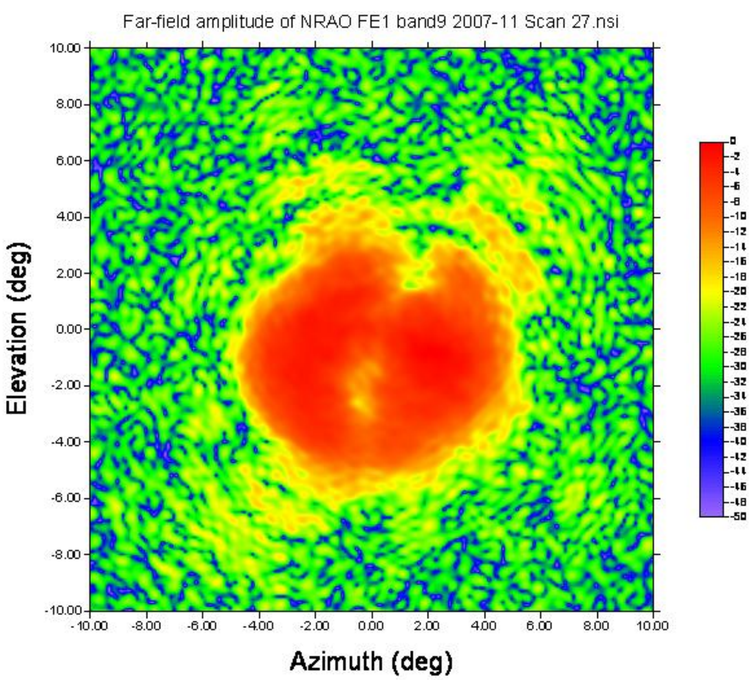


Figure 117 661 GHz Pol 0 cross-pol. elevation 45

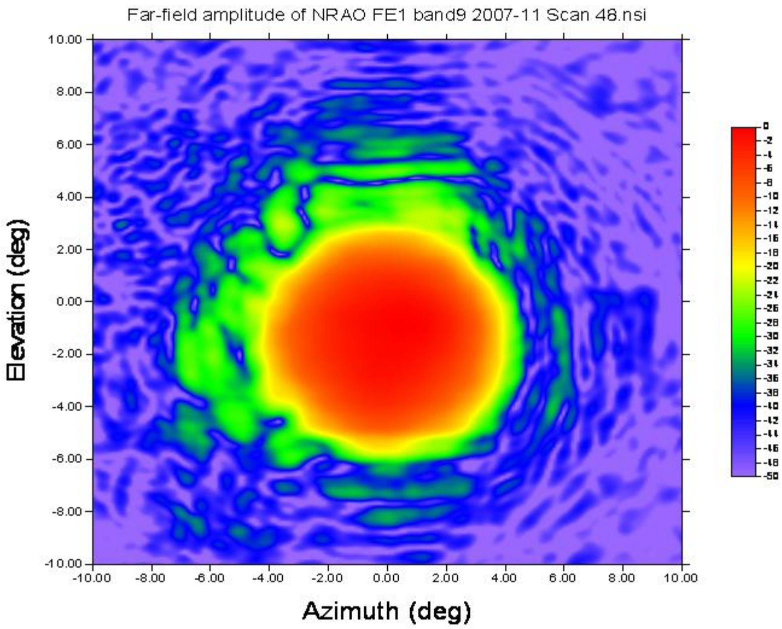


Figure 118 661 GHz Pol 1 co-pol. elevation 45

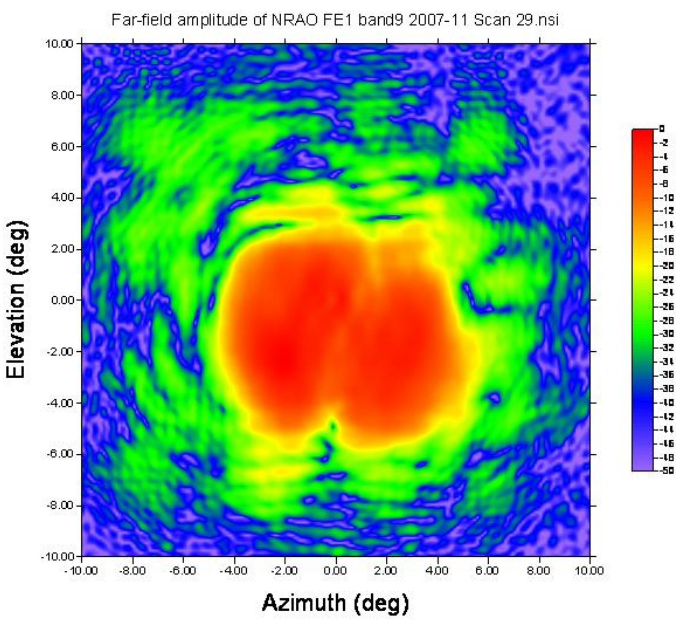


Figure 119 661 GHz Pol 1 cross-pol. elevation 45

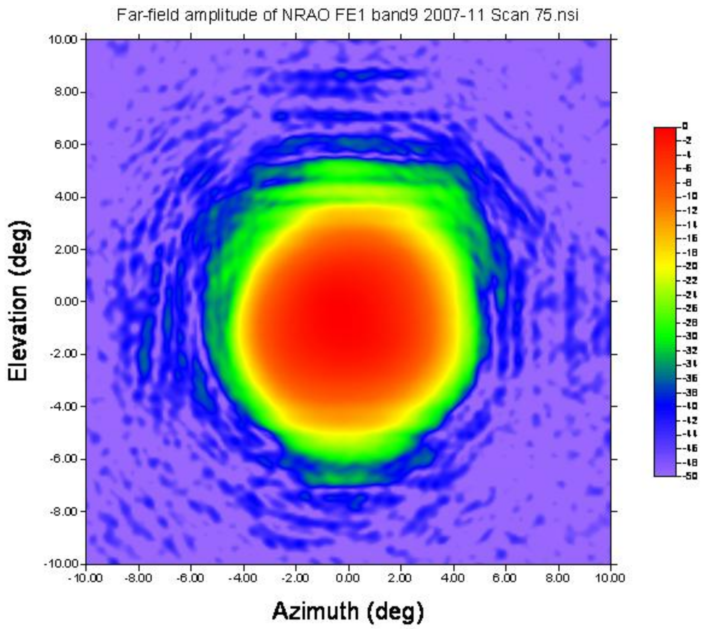


Figure 120 700 GHz Pol 0 co-pol. elevation 45

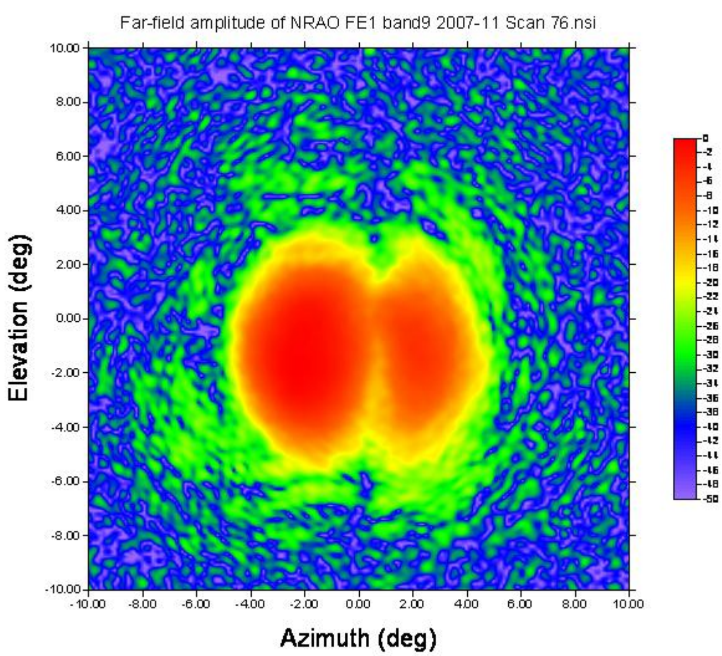


Figure 121 700 GHz Pol 0 cross-pol. elevation 45

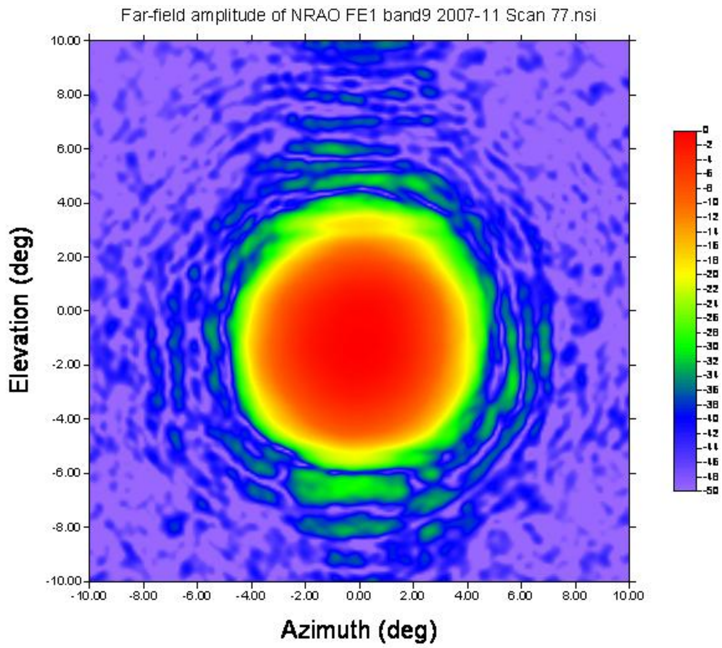


Figure 122 700 GHz Pol 1 co-pol. elevation 45

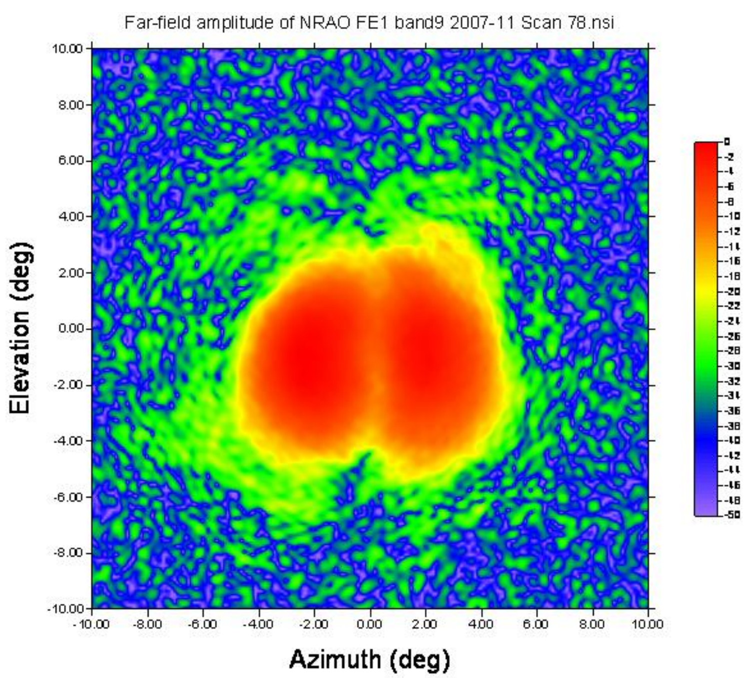


Figure 123 700 GHz Pol 1 cross-pol. elevation 45

3.3.1.1 Aperture efficiency FE assembly contribution

[FEND-40.00.00.00-00220-00 / A]

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

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

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

The requirement can be summarized by the following expression:

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

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

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

Result:

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

Band 3

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

Band 6

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

Band 7

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

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

Band 9

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

Individual requirements are defined for the following efficiency contributions:

3.3.1.2 Taper efficiency

[FEND-40.00.00.00-00222-00 / AT]

Specification to be verified: The taper efficiency of the tertiary optics inside the FE assembly shall exceed 80 % for all ten bands. This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.

Result:

Band 3

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

Band 6

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

Band 7

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

Band 9

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

3.3.1.3 Spillover efficiency

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

Result:

Band 3

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

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

Band 6

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

Band 7

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

Band 9

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

3.3.1.4 Polarization efficiency

[FEND-40.00.00.00-00226-00 / AT]

Specification to be verified: The polarization efficiency of the tertiary optics system shall exceed 99.5 % for all ten bands.

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

Result:

Band 3

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

Band 6

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

Band 7

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

Band 9

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

3.3.1.5 Focus efficiency

[FEND-40.00.00.00-00228-00 / AT]

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

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

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

Result:

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

Band 3

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

Band 6

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

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

Band 7

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

Band 9

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

3.3.2 Polarization requirements

3.3.2.1 Polarization State

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

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

3.3.2.2 Polarization Configuration

[FEND-40.00.00.00-00255-00 / RI]

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

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

3.3.2.3 Absolute Polarization Alignment Accuracy

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

Result:

Not measured.

3.3.2.4 Relative Polarization Alignment Accuracy

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

Result:

Not measured.

3.3.2.5 Cross talk between orthogonal polarization receiver channels

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

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

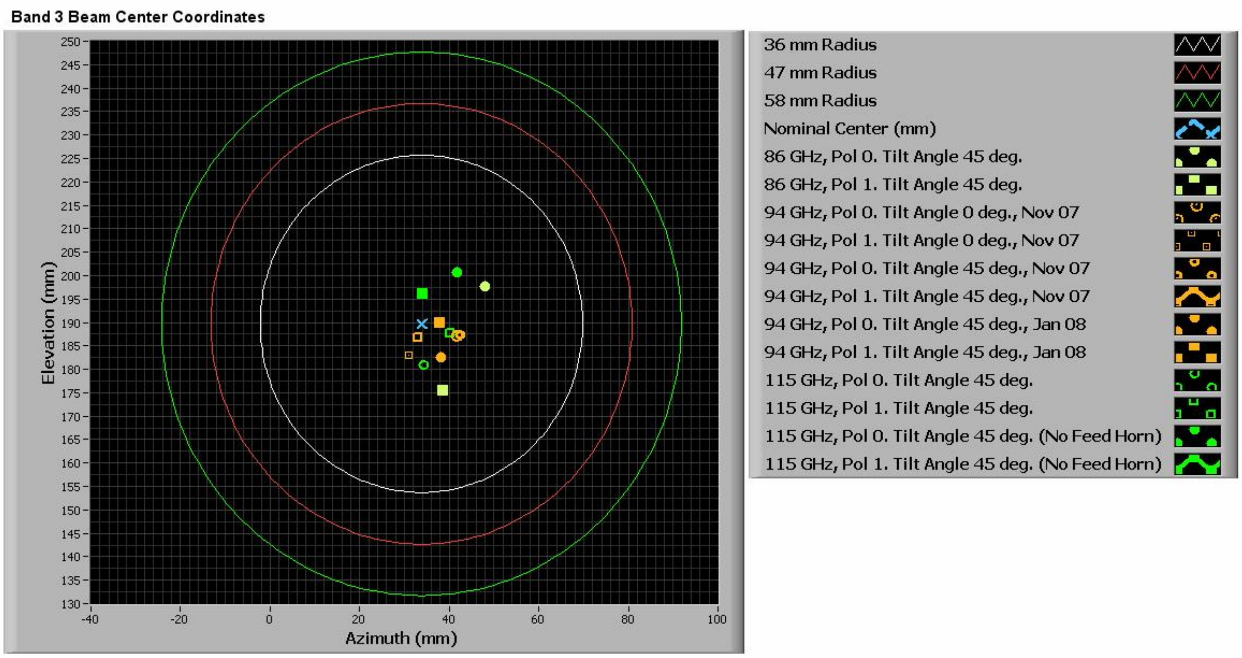
3.3.2.6 Beam squint

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

Result:

Band 3

On secondary



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

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

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

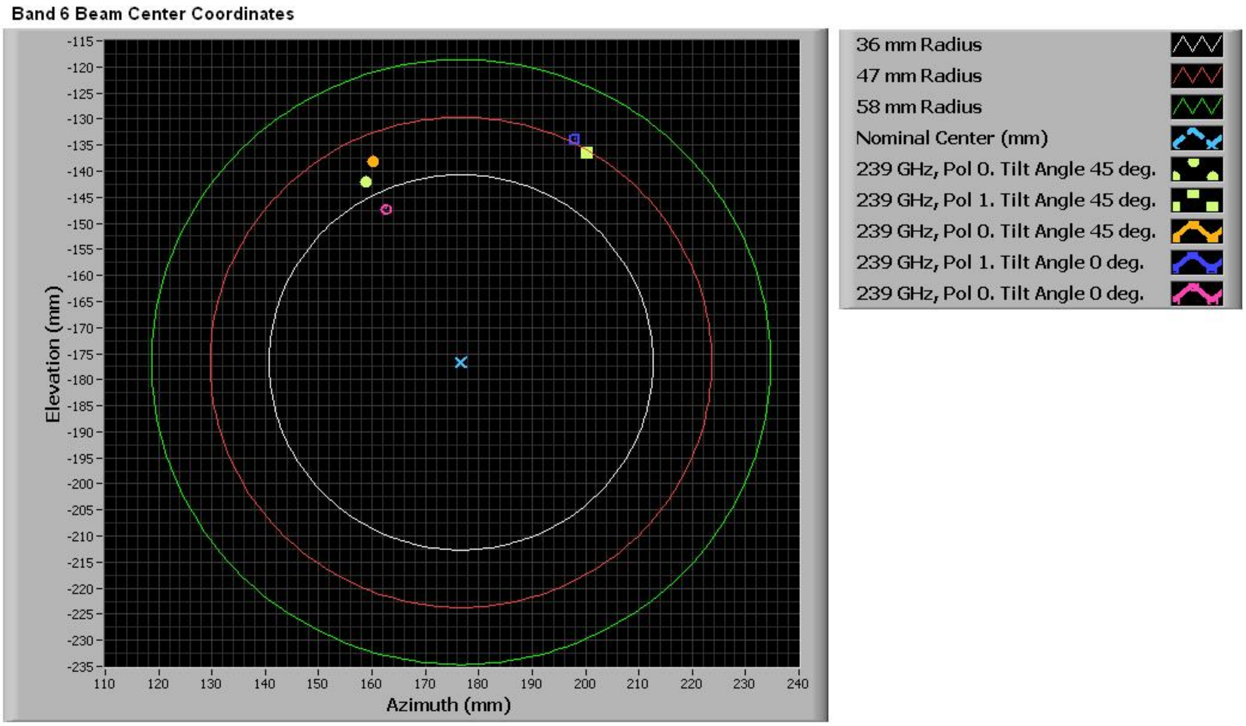
On sky

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

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

Band 6

On secondary



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

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

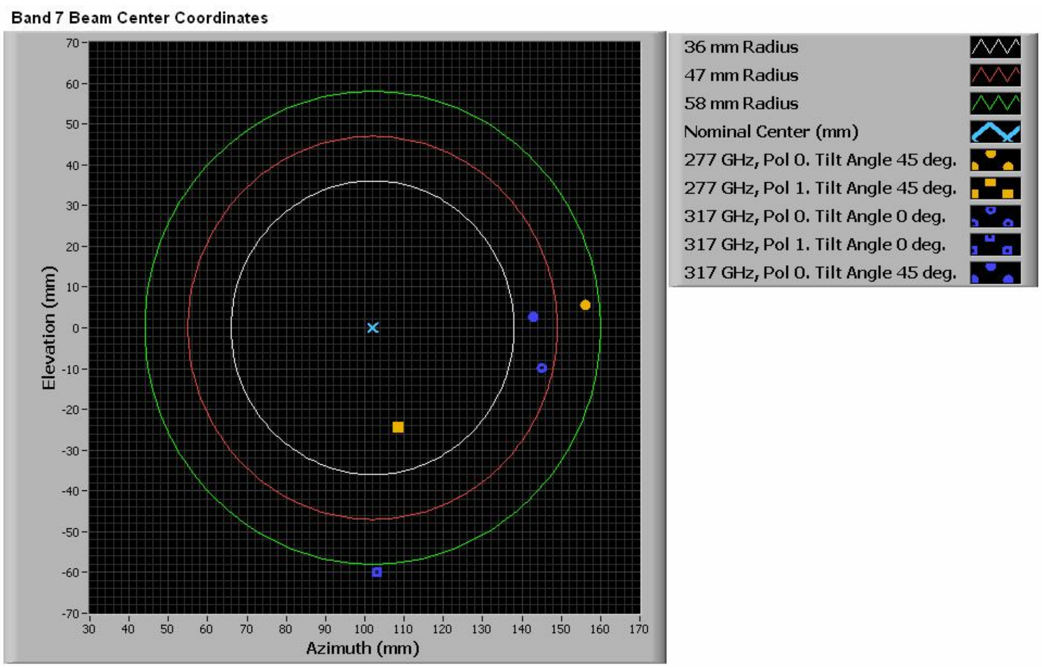
Frequency	Tilt angle degrees	Azimuth difference degrees	Elevation difference degrees
239	45	0.396	-0.053
239	0	0.368	-0.075

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

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

Band 7

On secondary



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

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

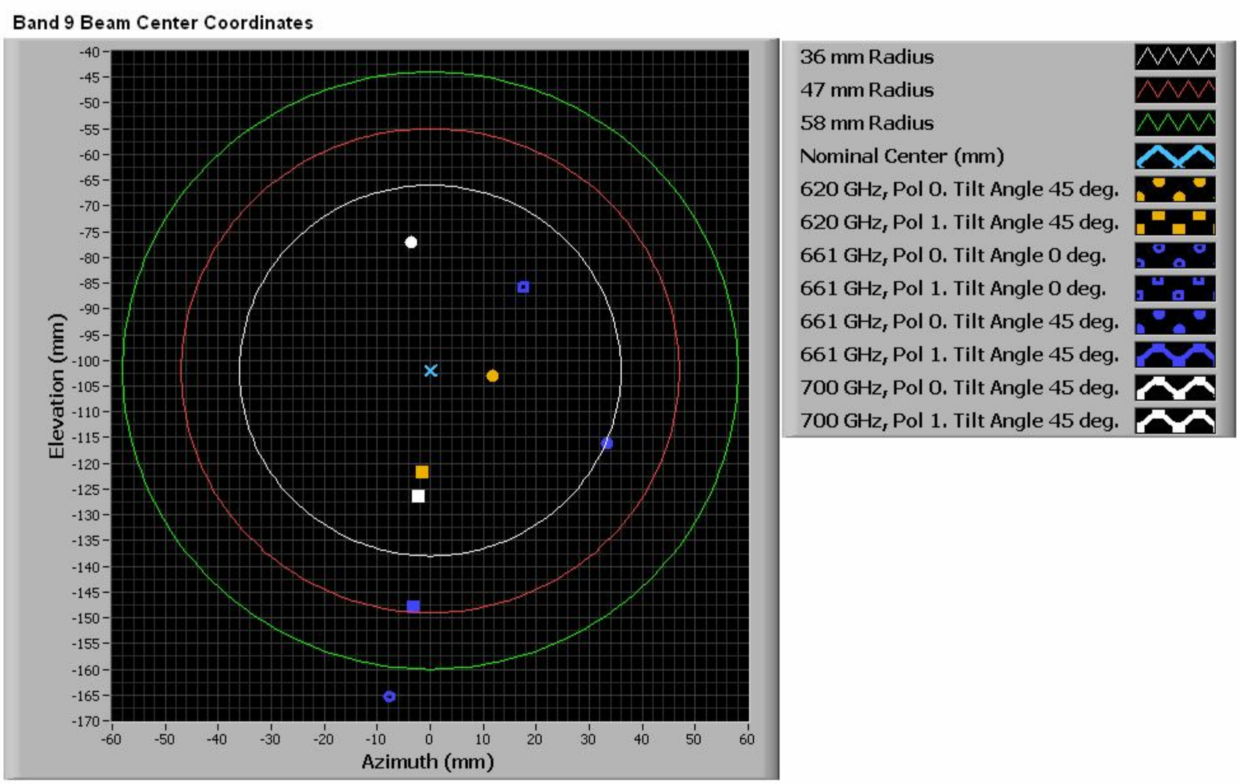
Frequency	Tilt angle degrees	Azimuth difference degrees	Elevation difference degrees
277	45	-0.45	-0.29
317	0	-0.40	-0.48

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

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

Band 9

On secondary



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

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

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

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

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

3.3.3 Widgets

3.3.3.1 Solar Attenuator

[FEND-40.00.00.00-00290-00 / R]
Specification to be verified: A solar attenuator shall be provided to allow solar observations. The attenuator shall be inserted into the signal path of any of the ALMA bands under remote control. Not verified. See [AD17].

3.3.3.1.1 IR attenuation

[FEND-40.00.00.00-00300-00 / T]
Specification to be verified: If the solar attenuator is inserted into the RF beam of a cartridge, it shall attenuate the 10 micron (TBC) radiation by at least 20 dB. Not verified. See [AD17].

3.3.3.1.2 RF attenuation

[FEND-40.00.00.00-00320-00 / T]
Specification to be verified: The solar attenuator shall attenuate the RF signal, over the frequency range as defined by requirement [FEND-40.00.00.00-00060-00 / R], by 13 - 16 dB. Not verified. See [AD17].

3.4 Amplitude Calibration

[FEND-40.00.00.00-00330-00 / R]
Specification to be verified: Means for periodic amplitude calibration of all the Front-End bands shall be provided. The calibration assembly is stand-alone and as such shall include all necessary power supplies and monitor and control electronics. Not verified. See [AD17].

3.4.1 Calibration cycle

[FEND-40.00.00.00-00340-00 / RT]
Specification to be verified: A complete calibration cycle for a particular band, involving the presentation of loads of differing effective temperature, shall not take longer than 9 seconds. Not verified. See [AD17].

3.4.2 Calibration repeatability

[FEND-40.00.00.00-00350-00 / RT]
Specification to be verified: The repeatability of the amplitude calibration shall be better then 1 % for frequencies below 300 GHz and better then 3 % for all other frequencies covered by the ALMA Front-End. Not verified. See [AD17].

3.5 Water Vapour Radiometer

[FEND-40.00.00.00-00360-00 / RI]
Specification to be verified: The Front-End assembly shall include a radiometer to allow the measurement of the amount of precipitable water vapour along the signal path, using the 183 GHz water line. This instrument shall operate simultaneously with the selected cartridge and shall illuminate the sub-reflector. It is a stand-alone assembly and as such must include all necessary LO sources, coupling optics, signal processing, power supplies and monitor and control electronics. Not verified. See [AD17].

3.5.1 WVR beam position

[FEND-40.00.00.00-00370-00 / AT]
Specification to be verified: The centre of the WVR beam shall be within 10 arc-minutes of the centre of the beam for any cartridge. Not verified. See [AD17].

3.5.2 WVR sensitivity

[FEND-40.00.00.00-00380-00 / T]

Specification to be verified: The computed RMS path error of the WVR shall be less than 10*(1+w_v) µm, with w_v being the precipitable water vapour along the line of sight in millimetres and w_v is in the range from 0,3 to 5 mm. This sensitivity shall be achieved with a time resolution of 1 second. Not verified. See [AD17].

3.5.3 WVR accuracy

[FEND-40.00.00.00-00385-00 / T]
Specification to be verified: The WVR shall provide an estimate of w_v to an accuracy of better than 2%. Not verified. See [AD17].

3.5.4 WVR stability

[FEND-40.00.00.00-00390-00 / T]
Specification to be verified: The sensitivity of the WVR as defined above shall be achieved with a time resolution of 1 second and be maintained over time periods of up to 10 minutes and for changes in zenith angle, z, of up to 3 degrees, or of 10% in the value of sec(z) when z is greater than 60 degrees. Not verified. See [AD17].

3.5.5 WVR tuning range and step size

[FEND-40.00.00.00-00400-00 / R]
Specification to be verified: The tuning range of the LO signal present in the RF mixer shall be from 183.300 to 183.350 GHz, with tuning steps no larger than 10 kHz. Not verified. See [AD17].

4 MECHANICAL AND ELECTRICAL REQUIREMENTS EVALUATED

4.1 Mass

[FEND-40.00.00.00-00460-00 / T]
Specification to be verified: The mass of the Front-End components attached to the Antenna Flange shall not exceed 980 kg.. The mass of the auxiliary electronics chassis fixed to the receiver cabin floor shall not exceed 200 kg. Details can be found in ICD [AD3].

Result:

Insert mass.

4.2 Centre of Gravity

[FEND-40.00.00.00-00470-00 / T]
Specification to be verified: The centre of gravity of the Front-End component attached to the FESS shall comply with [AD3].

Result:

4.3 Eigen-frequency

[FEND-40.00.00.00-00480-00 / A]
Specification to be verified: The lowest Eigen-frequency of any Front-End sub-assembly that is directly attached to the antenna shall be at least 18 Hz.

Result: This is a design verification task by analysis of modelling/simulations and/or experimental data at the CDR. This verification was not part of the FEIC acceptance tests / PAI. See [AD17].

4.4 Volume

[FEND-40.00.00.00-00490-00 / R]

Specification to be verified: The volume occupied by the Front-End assembly shall comply with [AD3].

Result: This is a design verification task by review and measurements. Compliance noted into the compliance matrix [AD18].

4.5 Orientation

[FEND-40.00.00.00-00500-00 / T]
Specification to be verified: The Front-End components within the antenna cabin shall meet all performance requirements over a range of gravity vectors from 0 to 90 degrees. This rotation occurs about the antenna elevation-bearing axis. Details can be found in the ICD [AD3]. The compressor and its control unit shall meet its performance requirements at tilt angles up to 10º in any orientation.

Result:

Measurements were already made as a function of elevation angles where relevant.

4.6 Thermal Load

[FEND-40.00.00.00-00510-00 / T]
Specification to be verified: During normal operation, the power dissipation of the combined Front-End components installed in the receiver cabin shall not exceed 4 kW. Details can be found in the ICD [AD3].

Result:

The components supplied by the FEIC (excluding the calibration widgets and WVR) dissipate less than 1 kW.

4.7 Power requirements

[FEND-40.00.00.00-00520-00 / T]
Specification to be verified: The Front-End electrical power requirements shall be in accordance with [AD3]. The main power shall be single-phase 230 VAC/50 Hz and three-phase 400 VAC/50 Hz. Details can be found in [AD10].

Result:

The power supply draws 4.05A at 230VAC when the FE is fully operational with band 3,7,9 active.

5 OPERATING CONDITIONS EVALUATED

5.1 Stabilization time

5.1.1 Stabilization time from non-operational to operational modes

[FEND-40.00.00.00-00530-00 / T]
Specification to be verified: When starting from the non-operational mode, the Front-End shall be operational (meet all applicable specifications) within 15 minutes.

Result:

Not Measured.

5.1.2 Stabilization time after fast-slew

[FEND-40.00.00.00-00535-00 / T]

Specification to be verified: Within 100 ms of a fast-slew, all operational specifications shall be met.

Result:

Not Measured.

5.2 Repeatability

[FEND-40.00.00.00-00540-00 / T]
Specification to be verified: Following a full fast switching cycle with a duration of 5 minutes the Front-End shall exhibit an amplitude change of less than $2x10^{-3}$ RMS (TBC) and a phase change of less than 0.7° RMS (TBC).

Result: Not verified at PAI. See [AD17]. See also the plots of amplitude vs. tilt angle in section 3.1.7 of this document.

5.3 Simultaneous operation of bands

[FEND-40.00.00.00-00550-00 / R]
This section only applies to the operational and stand-by modes.
Specification to be verified: Astronomical observations will involve the use of one frequency band at a time – there will be no dual frequency observations. In addition to the band in operation, band 3 (when it is not being used directly) shall be maintained in the stand-by mode for phase-calibration purposes. One other band may also be in standby mode to prepare for a band-change. The water-vapour monitoring radiometer shall operate simultaneously with any of the observing bands.

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

5.4 Band Selection

This section only applies to the operational and stand-by modes.

5.4.1 Selection of a standby band

[FEND-40.00.00.00-00560-00 / T]
Specification to be verified: Selection and operation of a band that has been in standby mode shall take less than 1 second.

Result:

5.4.2 Selection of new observing band

[FEND-40.00.00.00-00570-00 / T]
Specification to be verified: The time to reach the standby mode from the non-operational mode shall not exceed 15 min. (this is to allow thermal equilibrium to be reached).

Result:

5.4.3 Narrow-band frequency switching

[FEND-40.00.00.00-00580-00 / T]
Specification to be verified: Switching between two frequencies less than 25 MHz at the FLOOG apart shall take no more than 10 ms. Note that this applies to switching within (rather than between) bands. The frequency shall stay within the limits of a band as set in Table 3.

Result:

5.4.4 Frequency changes within a band

[FEND-40.00.00.00-00590-00 / T]
Specification to be verified: Moving between frequencies more than 25 MHz at the FLOOG apart within a particular band shall take no more than 1 second. The frequency shall stay within the limits of a band as set in Table 3.

Result:

5.5 Local Oscillator

This subsection only applies to the operational mode.

5.5.1 First local oscillator phase stability

[FEND-40.00.00.00-00600-00 / T]
Specification to be verified: The phase stability of the portion of the first local oscillator that is located within the Front-End, but excluding the reference signal [AD16], shall be less than:

- Short term (phase noise) $T < 1$ s - 38 fs
- Long term (delay drift) $20 \text{ s} \leq T < 300$ s - 13 fs

The short term phase noise requirement refers to the rms deviation from a 10-sec average. The requirement is on the integrated phase noise from the highest significant frequency (~1 MHz) down to 1Hz.
The delay drift requirement refers to the 2-point Allan Standard Deviation with a fixed averaging time, τ, of 10 seconds and intervals, T, between 20 and 300 seconds.

Result: Not a FEIC PAI verification item. See [AD17].

5.5.2 First local oscillator phase settling time

[FEND-40.00.00.00-00630-00 / T]
Specification to be verified: Following a 180 degree phase change from the first LO offset generator the LO phase shall settle to within 5 degrees of its final value within 1 µs. It shall also be possible to switch the phase (again by changing the phase of the first LO offset generator) by 90 degrees. There shall be no ambiguity in phase.

Result: Not a FEIC PAI verification item. See [AD17].

5.5.3 First local oscillator spurious CW signals

[FEND-40.00.00.00-00631-00 / T]
See section 3.1.3

5.6 Monitoring and Control

[FEND-40.00.00.00-00640-00 / RT]
Specification to be verified: All functions of the Front-End assembly shall be remotely controlled and monitored. The monitoring shall be detailed enough to indicate the status of the assembly and to allow troubleshooting. Monitoring and control shall be available at all times during observation. Details can be found in the applicable ICDs [AD6, AD7, AD8, AD14, AD15].
Each unit having a dedicated AMB node shall be self identifying to the AMB.

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

5.7 Environmental operating condition

5.7.1 Altitude

[FEND-40.00.00.00-00650-00 / R]
Specification to be verified: The operating altitude of the Front-End assembly shall be 0 - 5200 m.

Result:
This is a design verification task by review. See related airflow and thermal measurements in [AD20].

5.7.2 Thermal Environment

[FEND-40.00.00.00-00660-00 / T]
Specification to be verified: The Front-End assembly shall meet all of its operational performance requirements at ambient temperatures between 16° C and 22° C. The maximum temperature gradients in the air shall not exceed more than 1 degree C per hour.
In any mode, the Front-End shall survive without damage temperatures excursions of -10° C to 50° C.

Result:
Measurements were made at one temperature in the operational range. See related airflow and thermal measurements in [AD20].

5.7.3 Relative Humidity

[FEND-40.00.00.00-00670-00 / R]
Specification to be verified: The Front-End assembly shall meet its performance with a non-condensing relative humidity between 20 % and 80 %.

Result:
Measurements were made at one RH value in the operational range. See also [AD21].

5.7.4 Vibration

[FEND-40.00.00.00-00680-00 / AT]
Specification to be verified: The Front-End assembly shall comply with [AD1]. Not verified. See [AD17].

5.7.5 Acceleration

[FEND-40.00.00.00-00690-00 / AT]
Specification to be verified: The Front-End assembly shall comply with [AD1]. Not verified. See [AD17].

5.7.6 Cleanliness

[FEND-40.00.00.00-00700-00 / I]
Specification to be verified: The Front-End assembly shall meet its performance under the conditions outlined in [AD1]. Not verified. See [AD17].

5.7.7 Storage and shipping conditions

[FEND-40.00.00.00-00710-00 / IT]
This section applies only to the storage mode.
Specification to be verified: The Front-End assembly shall comply with [AD1].
Result: Not verified on the first article. See [AD17].

5.7.8 EMC

[FEND-40.00.00.00-00720-00 / T]
Specification to be verified: The Front-End assembly shall comply with [AD2][AD3].

Result: Not verified on the first article. See [AD17]. But see section 2.1.1

5.7.9 RFI

[FEND-40.00.00.00-00730-00 / T]
Specification to be verified: The IF signal isolation between any operational band and all stand-by bands shall be more than 30 dB. The RF emission of any cartridge in the 175-191 GHz range shall be at least 10 dB less than the WVR signal level at its maximum IF frequency resolution. The emission of the WVR shall not exceed 0 dBm at the WVR LO frequency (183 GHz) and -45 dBm at all other frequencies.

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

5.7.10 Grounding and Isolation

[FEND-40.0000.00-00740-00 / IR]
Specification to be verified: The Front-End assembly shall be grounded in compliance with [AD9].

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

6 RELIABILITY, AVAILABILITY AND MAINTAINABILITY REQUIREMENTS EVALUATED

6.1 Continuous use

[FEND-40.00.00.00-00750-00 / R]
Specification to be verified: The Front-End assembly shall be designed for continuous use.

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

6.2 MTBF

[FEND-40.00.00.00-00760-00 / A]
Specification to be verified: The mean time between failures of a Front-End assembly shall exceed 11.000 hours.

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

6.3 MTTR

[FEND-40.00.00.00-00770-00 / A]
Specification to be verified: At the OSF, the mean time to repair the Front-End assembly shall be less than 48 hours. Note that this does not include warm-up or cool-down time.

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

6.4 MTTS

[FEND-40.00.00.00-00775-00 / A]
Specification to be verified: At the OSF, the mean time required to service the Front-End assembly shall be less than 48 hours. Note that this does not include warm-up or cool-down time.

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

6.5 Lifetime

[FEND-40.00.00.00-00780-00 / A]
Specification to be verified: The lifetime of the Front-End assembly shall be greater than 15 years.

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

6.6 Front-End assembly exchange time

[FEND-40.00.00.00-00785-00 / A]
Specification to be verified: The exchange of a Front-End assembly at an antenna shall take less than 2 hours.

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

6.7 Preventive maintenance

[FEND-40.0000.00-00790-00 / R]
Specification to be verified: In general there shall be no periodic preventive maintenance required for the Front-End assembly.
Exceptions to this include the calibration device, cryo-cooler, compressor, control unit and vacuum pump.

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

6.7.1 Preventive maintenance interval cryo-cooler and pumps

[FEND-40.00.00.00-00792-00 / R]
Specification to be verified: The maintenance interval for the cryo-cooler and associated pumps shall be greater than 10,000 hours.

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

6.7.2 Preventive maintenance interval cryo compressor

[FEND-40.0000.00-00795-00 / R]
Specification to be verified: The maintenance interval for the compressor shall be greater than 20,000 hours.

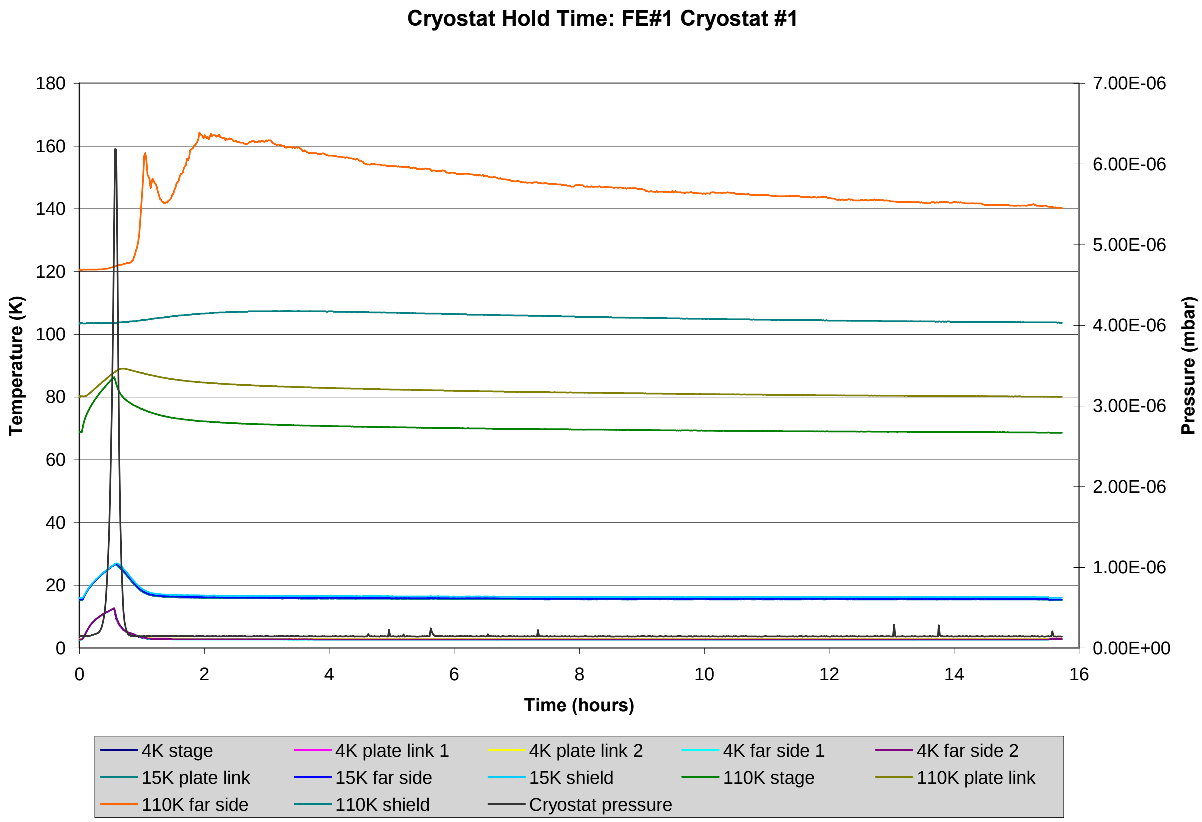
Result: This is a design verification task by review. This verification was not part of the FEIC acceptance tests / PAI. See [AD17].

6.8 Hold times

[FEND-40.00.00.00-00800-00 / T]

Specification to be verified: The cryostat shall be able to accommodate a power interruption of 30 minutes maximum duration and after return of power be able to return to the normal operational mode, fulfilling all applicable specifications in this mode, within 6 hours. This shall be achievable at any time in the nominal 1 year of operation between regular preventive maintenance.

Result:



According to [AD22], the temperature drift on the stages may be as follows:

4 K: less than 2 mK / minute
15 K: less than 50 mK / minute
110 K: less than 100 mK / minute

In the chart above, the temperature drifts at the 6½ hour mark are, respectively 1 mK, 5 mK, 10 mK per minute.[8]

[8] The cryostat is considered to be in specification, even though the 110 K shield temperature has not stabilized at the 6½ hour mark.

VERIFICATION WITH RESPECT TO VARIOUS ICD REQUIREMENTS, SAFETY DESIGN, ELECTRICAL DESIGN, EMC REQUIREMENTS AND ENVIRONMENTAL REQUIREMENTS

6.9 Antenna-FE ICD

6.9.1 The indoor compressor unit shall have lugs for crane handling.

ANTE-FEND114
I At the OSF

6.9.2 The outdoor compressor unit shall have lugs for crane handling.

ANTE-FEND122
I At the OSF

6.9.3 Strain relief and bending radius compliance of the gas lines.

ANTE-FEND137II
I At the OSF

~~6.9.4 Mounting elements used to install the auxiliary chassis (power supply) should be flush with the floor.~~

~~ANTE-FEND146~~

6.9.5 It should be possible to manipulate the auxiliary chassis (power supply) using a fork-lift.

ANTE-FEND147
ANTE-FEND184
I

6.9.6 Front-end total mass.

ANTE-FEND155
See section 4.1.

6.9.7 Mass of indoor compressor unit.

ANTE-FEND157

6.9.8 Mass of outdoor compressor unit.

ANTE-FEND159

6.9.9 Sharp edge hazard.

ANTE-FEND176
I

6.9.10 Front end assembly lifting mount attachments.

ANTE-FEND183
I

6.9.11 Earthquake compliance

ANTE-FEND192

6.9.12 HVAC heat load compliance. (dissipation into room).

ANTE-FEND194
T
See [AD 20].

6.9.13 HVAC heat load compliance. (dissipation directly into the HVAC system).
ANTE-FEND197
T
OK.
Final report the OSF

6.9.14 Heat dissipation of indoor compressor unit.
ANTE-FEND200
T
Not measured

6.9.15 Heat dissipation of outdoor compressor unit.
ANTE-FEND203
T
Not measured

6.9.16 Cables to and from the indoor and outdoor compressor units should be qualified for outdoor use.
ANTE-FEND207
I
(?) Hans Rudolf

6.9.17 Beam waist requirements
ANTE-FEND358

6.9.18 Attachment points should be labelled for maximum lifting capacity
ANTE-FEND315
I
OK

6.9.19 Operating manuals for lifting equipment
ANTE-FEND315

6.9.20 Confirm that the following equipment is delivered by the FE: Gas lines, power and control cables for indoor compressor control unit, appropriate lifting mounts for front end assembly and other heavy units including power supply etc, special handling instructions and documentation.
ANTE-FEND334
through
ANTE-FEND339
I
Ongoing.

6.10 FE IF-BE IF ICD

6.10.1 IF Output connectors - mechanical & electrical requirements.

FEND IF-BEND IF 83
I

This is also verified by using a polarized RF source in front of the receiver window. By adjusting the source orientation relative to each band's polarization alignment, and by adjusting the source RF frequency above or below the cartridge LO frequency, it can be shown that the source signal appears at the proper polarization and sideband output.

Band 3

For band 3, a much simpler approach was taken than for band 6 (below.) The setup, using the beam scanner equipment was as follows:

At angle=0 degrees the feed horn's E vector is aligned with the band 3 warm optics secondary mirror, in the radial direction cryostat and is therefore co-polarized with Pol0.

FreqLO = 100 GHz (locked)
FreqRF = 94 GHz (locked)
YIG filter = 5.955 GHz
A sheet of AN-72 absorber was placed over the receiver window to act as an attenuator.

	IF Total Power (dBm)			
Angle(deg)	IF0 Pol 0 USB	IF1 Pol 0 LSB	IF2 Pol 1 USB	IF3 Pol 1 LSB
0	-28.21	-12.43	-40.48	-32.01
45	-29.58	-12.76	-27.96	-8.3
90	-38.7	-29.63	-26.54	-7.27

So at 0 degrees, the signal is strongest in Pol0 LSB, which is where it is expected. The image appears in the Pol0 USB. At 90 degrees, the signal appears in Pol1 LSB.

Band 6

At angle=0 degrees, the source feed's E vector is aligned with the radial direction of the cryostat and is therefore co-polarized with Pol0. A sheet of AN-72 absorber was placed over the receiver window to act as an attenuator.

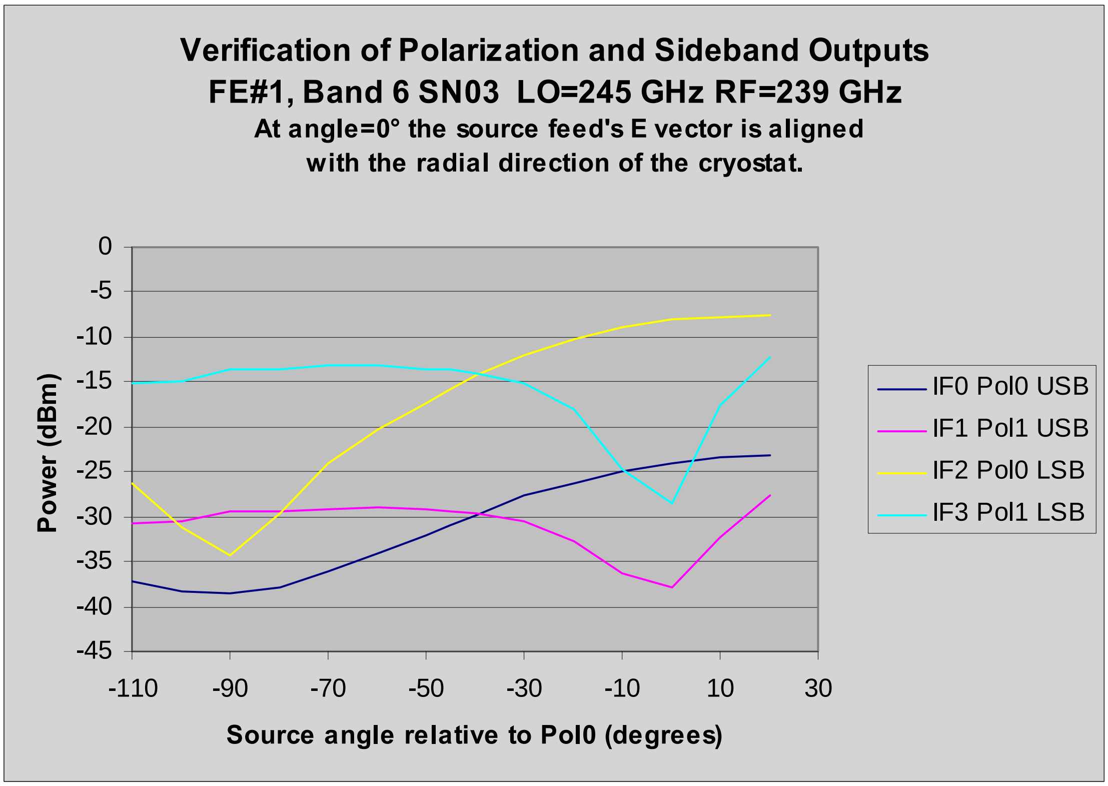


Figure 124 - Band 6 verification of polarization and sideband outputs - LSB

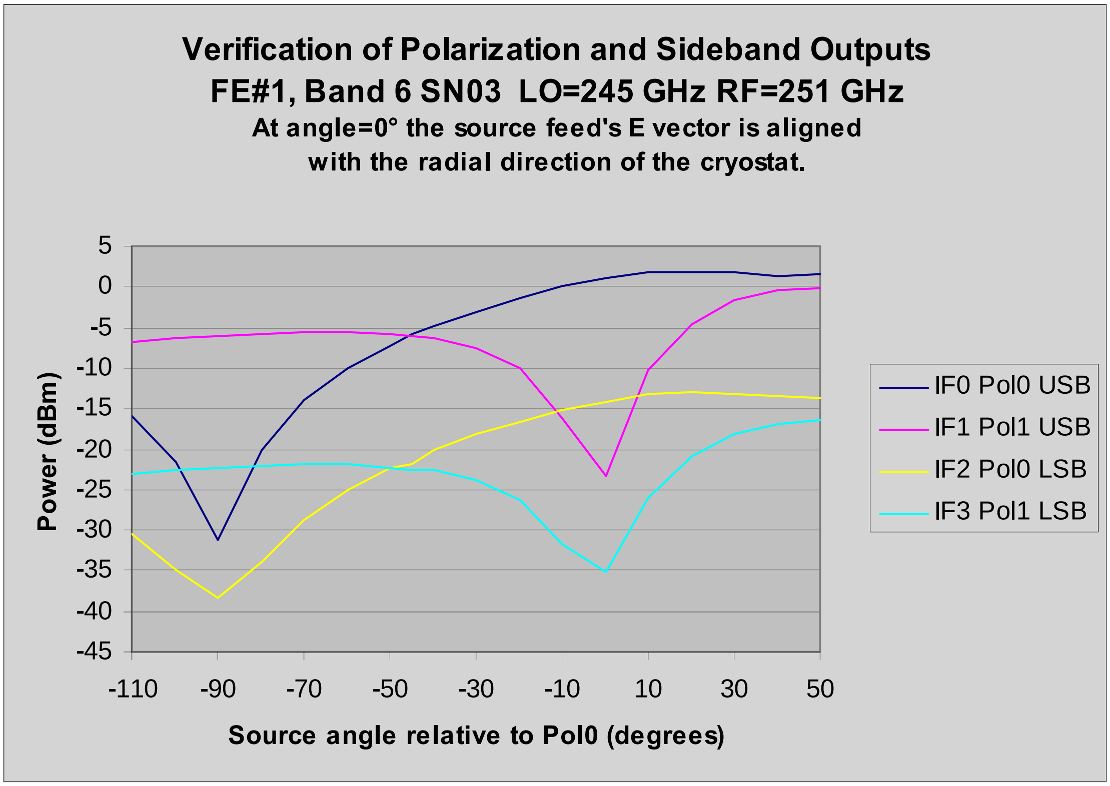


Figure 125 - Band 6 verification of polarization and sideband outputs -USB

Band 7

The setup, using the beam scanner equipment was as follows:

At angle=0 degrees the feed horn's E vector is aligned with the radial direction cryostat and is therefore co-polarized with Pol0.

FreqLO = 323 GHz (locked)
FreqRF = 317 GHz (locked)
YIG filter = 5.907 GHz
A sheet of AN-72 absorber was placed over the receiver window to act as an attenuator.

	IF Total Power (dBm)			
Angle(deg)	IF0 Pol 0 USB	IF1 Pol 0 LSB	IF2 Pol 1 USB	IF3 Pol 1 LSB
0	-22.01	-9.53	-22.61	-16.32
45	-24.17	-15.20	-21.57	-9.98
90	-25.16	-23.83	-20.50	-6.74

So at 0 degrees, the signal is strongest in Pol0 LSB, which is where it is expected. The image appears in the Pol0 USB. At 90 degrees, the signal appears in Pol1 LSB.

Band 9

The setup, using the beam scanner equipment was as follows:

At angle=0 degrees the feed horn's E vector is aligned with the radial direction cryostat and is therefore co-polarized with Pol0.

FreqLO = 662 GHz (locked)
FreqRF = 656 GHz (locked)
YIG filter = 6.746 GHz (unexpectedly far from 6 GHz.)
A sheet of corrugated cardboard was placed over the receiver window to act as an attenuator.

	IF Total Power (dBm)	
Angle(deg)	IF0 Pol 0 USB	IF2 Pol 1 USB
0	-10.14	-21.36
45	-13.60	-8.98
90	-30.94	-8.11

So at 0 degrees, the signal is strongest in Pol0, which is where it is expected. At 90 degrees, the signal appears in Pol1.

6.10.2 IF Power level requirements

FEND IF-BEND IF 214

6.10.3 Dust covers on IF connectors

FEND IF-BEND IF 208
I
In Progress

6.11 FE LO – BE LO ICD

6.11.1 Confirm that each WCA has a photomixer with its DC bias connector and optical fiber (in protective sleeve) hooked up.

FEND LO – BEND LO 139
I

6.11.2 FLOOG input connectors (mechanical and accessibility requirements).

FEND LO – BEND LO 190
FEND LO – BEND LO 192
FEND LO – BEND LO 194
FEND LO – BEND LO 196
I

6.12 FEND-Computing ICD

6.12.1 Location and type of CAN bus connector
I

~~6.12.2 CAN bus connector type (AMB 11-pin Amphenol circular type)~~

6.12.3 Compliance to monitoring requirement
T
Tested with FE engineering software

6.12.4 Compliance to control requirement
T
Tested with FE engineering software

6.12.5 Compatibility with ALMA computing software
T
To be tested with FE#2 prior to FE#1 PAS at OSF.

6.12.6 Provision for debug mode
T
Tested with FE engineering software

6.12.7 Correct node-ID (0x13)
T
Tested with FE engineering software

6.12.8 Software auto start
T
Tested with FE engineering software

~~6.12.9 Unused sensor reporting~~
~~6.12.10 Unused status bits~~
~~6.12.11 Unused bits in control words~~
~~6.12.12 Sideband convention~~

6.12.13 Operational, Non operational and Standby modes
T
Tested with engineering software.

6.12.14 Compliance to floating point ANSI/IEEE 754 (MSB first)
T
Tested with engineering software

6.13 Safety Design Specifications
NOTE: The Calibration widgets are not part of FEIC deliverables accompanying the FE assembly

6.13.1 Adequate protection for electrocution hazard
SAF 74
I

6.13.2 Compliance to safety requirements for lifting points
SAF 112

SAF 113
SAF 114
I

6.13.3 Vacuum safety
Verify functionality of vacuum interlocks.
T

6.14 AC Plugs, sockets, outlets, and couplers

6.14.1 Compliance to three contact requirements (2 poles plus side earthing), for both mains and UPS. Earthing contact position at 6h
EPLU-00080-00
EPLU-00120-00
EPLU-00150-00
I
Compliant
Not inspected.

6.14.2 Compliance to voltage ratings, for both mains and UPS
EPLU-00090-00
EPLU-00140-00II
I
Compliant
Not inspected.

6.14.3 Compliance to current rating
EPLU-00100-00II
I
Compliant
Not inspected.

6.14.4 Use of appliance couplers within assemblies
EPLU-00170-00II
I
Compliant
Not inspected.

6.15 Electrical Design Requirements

6.15.1 Compliance to the requirement of an independent temperature switch to power off the assembly
EELE-00090-00
Not provided in FE#1.
Interim power supply does have this. Tested. Documented?

6.15.2 Monitoring of all interlock status should be possible via software
EELE-00110-00
T
Vacuum interlock status cannot directly be monitored, but it can be inferred from the system state.

Cartridge power distribution system interlock can be inferred by observing that cartridge voltage monitor points are near zero when they are expected to be nonzero.

6.15.3 Compliance to Protective Earth (PE) connecting point labelling requirement

EELE-00220-00
I

6.15.4 Compliance to "make first, break last" requirement for protective earth ground connection on plug in units and connectors

EELE-00340-00
I

6.15.5 Isolation Test Voltage > 1500 V AC, 50 Hz

EELE-00380-00
Not tested for FE#1

6.15.6 Isolation Resistance > 100 MΩ

EELE-00390-00
Not tested for FE#1

6.15.7 Isolation Capacitance < 50 pF

EELE-00400-00
Not tested for FE#1

6.15.8 Compliance to cable routing requirements

EELE-00450-00
I

6.15.9 Compliance to requirement to protect cables against abrasion

EELE-00460-00
I

6.15.10 Cable arrangement should allow rapid connection/disconnection

EELE-00480-00
I

6.15.11 It should be possible to remove and replace any particular cable

EELE-00490-00
I

6.15.12 Cable routing should allow for the possibility of replacement of connectors

EELE-00500-00
I

6.15.13 Mixing of different EMC classes of signals on the same connector to be avoided

EELE-00570-00
I

6.15.14 Routing of wires should be in proximity of metallic structures as much as possible. Signal and control cables should be bundled separately from the power cables.

EELE-00580-00

EELE-01010-00
I

6.15.15 Compliance to labelling requirement for external connectors

EELE-00780-00
I

6.15.16 Compliance to the requirement that connector housings are in direct surface contact to the mounting structure

EELE-00790-00
Not tested for FE#1

6.15.17 Compliance to electrical bonding requirement between plugged in units and equipotential plane

EELE-01040-00
Not tested for FE#1

6.15.18 Compliance to the requirement of the thickness of bonding strap

EELE-01050-00
I

6.15.19 Compliance to the specification of terminal blocks

EELE-01070-00
EELE-01080-00
I

6.15.20 Compliance to the requirement of warning labels for live wire terminations, and segregation of AC and DC circuits

EELE-01100-00
I

6.15.21 AC equipment should be outfitted with circuit breakers

EELE-01140-00
I

6.15.22 Labelling requirements

EELE-01250-00
EELE-01260-00
I

6.16 EMC Requirements

6.16.1 Compliance to Immunity limit requirements for rectangular step voltage change on AC mains

EEMC-00080-00
Not tested for FE#1

6.16.2 Compliance to immunity requirements against voltage dips on AC mains

EEMC-00090-00
Not tested for FE#1

6.16.3 Compliance to immunity against short voltage interruptions

EEMC-00100-00

Not tested for FE#1

6.16.4 Compliance to ESD requirements

EEMC-00110-00

through

EEMC-00200-00

Not tested for FE#1