Band 6 Sidelobe Measurements Using a Room Temperature Receiver

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1. Introduction

1.1. Purpose

This document describes a series of amplitude-only beam pattern measurements of the Band 6 Cartridge using room temperature Schottky mixers. Patterns were measured with the Band 6 Cartridge Test System which includes the NAOJ test cryostat.

The pattern measurements were performed to isolate and mitigate the cause of the sidelobes present in the ALMA Band 6 cold cartridge assembly.

1.2. History and Summary

Sidelobes higher than 20 dB down from beam peak have been observed for some time [RD08], [RD09] while their cause,

- cold cartridge optics,
- IR filters and vacuum windows,
- the test cryostat,
- pattern measurement system, or
- a combination of these items

has never been determined.

Systematic measurements rapidly identified the vacuum window as a major contributor to the sidelobes while proving the IR filters contribute little to the sidelobes.

As suspicion grew that reflections from the vacuum window were at least part of the cause of the high sidelobes, past measurements began to make sense. John Webber and Geoff Ediss found the high sidelobes roughly correlated with the frequencies with poorest match for the vacuum windows. IRAM measured the match of the windows in February 2005 [RD05, Appendix 11] and one plot from that report is shown Figure 1.

IRAM found no sidelobes when they measured the Band 6 Cartridge at room temperature in August 2005 [RD06] and [RD05, Appendix 6], but Geoff Ediss notes that IRAM's measurements all occurred at frequencies where the vacuum window is well matched.

Bernard Lazareff predicted in March 2005 [RD03], that the sidelobes were likely due to reflections off the flange of the feed horn. Unfortunately, for reasons that remain unknown, his hypothesis was never tested. By using room temperature mixers, coupled with the methodical approach documented here and in the attached appendix, Bernard's hypothesis was confirmed, and the source of the sidelobes was finally determined and eliminated.

It is important to realize that these sidelobes may not cause the low and out-of-spec beam efficiencies near 89% measured in the FEIC. The beam efficiency specification, including loses and scattering, is 93%.

1.3. Scope

Measurements using the room-temperature mixers were conducted in three phases:

I. All IR filters and their mounting rings, the vacuum window and its mounting ring, were removed[1]
II. Just the vacuum window was installed in the optical path
III. With just the vacuum window installed in the optical path, absorber was placed around the rim of the feed horn

An appendix will describe the results of intermediate tests

1.4. Applicable documents

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

Table 1: Applicable Document List

Reference	Document Title	ALMA Doc. Number
[AD01]	Band 6 Cartridge – Technical Specifications	ALMA-40.02.06.00-001-A-SPE
[AD02]	ALMA Documentation Control Plan	ALMA-80.02.00.00-011-C-PLA
[AD03]	ALMA Documentation Standards	ALMA-80.02.00.00-003-G-STD

[1] In fact, as described in the appendix, initial measurements started with just a bare cartridge. The outer cryostat vessel and radiation shields were removed.

1.5. Reference documents

The following documents contain additional information.

Table 2: Reference Document List		
Reference	**Document Title**	**ALMA Doc. Number**
[RD01]	Front End Product Tree	TBD
[RD01]	Band 6 Cartridge – Statement of Work	FEND-40.02.06.00-002-A-SOW
[RD02]	Band 6 Cartridge – Management Plan	FEND-40.02.06.00-027-A.03-PLA
[RD03]	A Tentative Mechanism for the Origin of Sidelobes in the Band 6 Beam Pattern	FEND-40.02.06.01-036-A-REP
[RD05]	Optics Design Report	FEND-40.02.00.00-035-B-REP
[RD06]	Investigation into the sidelobe levels of the ALMA band 6 cartridge	FEND-40.02.06.01-024-A-REP
[RD07]	Band 6 Cartridge Test Procedure: RF Beam Pattern Measurement	FEND-40.02.06.01-035-A-PRO
[RD08]	Band 6 Beam Pattern Measurements, Cartridge B6-001 Update #12 Measurements through 2005-05-21	FEND-40.02.06.01-031-A-REP
[RD09]	Comparison of Sidelobes in Band 6 Cartridges SN 001, 002, and 004	FEND-40.02.06.01-033-A-REP
[RD10]	Comparison of Band 6 Sidelobes with IRAM and Gore-Tex IR Filters and with a Tilted and Un-tilted Vacuum Window	FEND-40.02.06.01-032-A-REP
[RD11]	Proposed Quartz Vacuum Window Designs for ALMA Bands 3 - 10	ALMA Memo #397

1.6. Acronyms

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

A	Test verification method is by Analysis
ALMA	Atacama Large Millimeter Array
CDR	Critical Design Review
FE	Front End
FEIC	Front End Integration Center
I	Test verification method is by Inspection
ICD	Interface Control Document
IF	Intermediate Frequency
IPT	Integrated Product Team
LO	Local Oscillator
NRAO	National Radio Astronomy Observatory
PAI	Preliminary Acceptance In-house
PAS	Provisional Acceptance On-Site (at FEIC)

PDR	Preliminary Design Review
R	Test verification method is by Review of design
RF	Radio Frequency
T	Test verification method is by Testing
WCA	Warm Cartridge Assembly

2. Acknowledgements

The authors would like to thank Bernard Lazareff, Matt Carter, Fabrice Coq, and François Mattiocco of IRAM for their technical assistance and for loaning to us the Schottky mixers and diplexers used to make these measurements.

3. Test Set Up

The test setup employed the same room temperature mixers and diplexers used by IRAM in the summer of 2005 to measure Band 6 cartridge patterns [RD06]. Although a complex pattern measurement system could have been constructed for the present tests, it was decided to troubleshoot the sidelobes using a simpler, amplitude-only test set-up shown in Figure 2. The beam scanner described in [RD07] moved the source, and recent software improvements reduced scan times per pattern from over 4 hours to 33 minutes. Evidence that patterns are now measured "on-the-fly" can be seen from the smearing of power levels adjacent to the noise floor. That artifact occurs only at low level and is considered insignificant. The spectrum analyzer was used as the pre-detection filter to reduce the bandwidth from 60 MHz available with the YIG filter to 300 kHz.

Patterns were measured from 211 GHz to 235 GHz, in increments of 4 GHz. Poor receiver sensitivity above 235 GHz prevented measurements from 235+ GHz to 275 GHz, but since all previous measurements showed sidelobes both above and below 235 GHz, the limited frequency range was considered acceptable for sidelobe investigations.

The reference coordinate system for the beam scans is shown Figure 3. Also, for some tests, the window was tilted by 5°, and the orientation of the tilt angle is included in Figure 3.

4. Phase I: Patterns with No IR Filters or Vacuum Windows

For the Phase I measurements, all components in the optical path between the cartridge and signal source were removed, including:

- IR filters and their mounting rings, and
- the vacuum window and its mounting ring.

Figure 4 and Figure 5 are photos of the test cryostat in this configuration. Initial measurements of the bare cartridge with no vacuum vessel or radiation shields showed ~15 dB sidelobes. These were found to originate from surfaces of the cryostat and the test apparatus that had been left uncovered by absorber. Once absorber covered most of the test system illuminated by the source, the sidelobes present with the bare cartridge were eliminated.

Table 3 shows patterns measured with just the cryostat vacuum vessel and radiation shields, but no windows or filters. The patterns have symmetrical beam shapes and no sidelobes present at any measured frequencies.

5. Phase II: Patterns with just the ALMA Vacuum Window

Significant sidelobe levels were measured when just the ALMA vacuum window was installed in the test cryostat. As described in the Appendix, installation of both the 15K and 110K IR filters without the vacuum window caused relatively weak (~26 dB down) sidelobes. The vacuum window mounting frame was also eliminated as a sidelobe source, as described in the Appendix. Additionally, a vacuum window made by D. Koller [RD11] resulted in sidelobe levels similar as those seen by IRAM's window [RD05, Appendix 11].

Table 4 shows sidelobe patterns measured with the untilted vacuum window. That is, the window is parallel to the top of the NAOJ test cryostat.

Table 5 shows patterns at just 211 GHz, now measured with the vacuum window tilted 5° with respect to top surface of the test cryostat, as shown in the photo of Figure 7 . These patterns were measured with the tilt angle orientation stepped consecutively by 45°about the axis of the window opening. Figure 3 provides the coordinate system for the orientation of the tilt angle.

Table 5 shows that rotating the 5° tilted window about the center of the window causes the sidelobe to move around the main beam, but the general sidelobe level remains constant.

Also, patterns measured at a reference frequency of 219 GHz, where no sidelobes have ever been measured, continued to show no sidelobes at all orientation angles. This is as expected, because as shown in Figure 1, the vacuum window is well matched at this frequency with a return loss of better than 30 dB.

6. Phase III: Patterns with Absorber on Rim of Feed Horn

To confirm Bernard's hypothesis, AN-72 absorber was installed on the rim of the feed horn, as shown in Figure 8. Note that cold cartridge patterns were measured previously with absorber installed over the feed horn mounting flange [RD08, Update # 8, Figure 9], but not on the rim of the feed horn, as shown in Figure 9.

Table 6 shows patterns measured with absorber installed on the rim of the feed horn, and they are essentially devoid of sidelobes.

For this measurement, AN-72 absorber was also installed on the top of the 15K and 110K radiation shields, but that had no affect on the patterns. This was proven by confirming that the sidelobes returned when absorber was removed from the rim of the feed horn while retaining the absorber on the tops of both radiation shields.

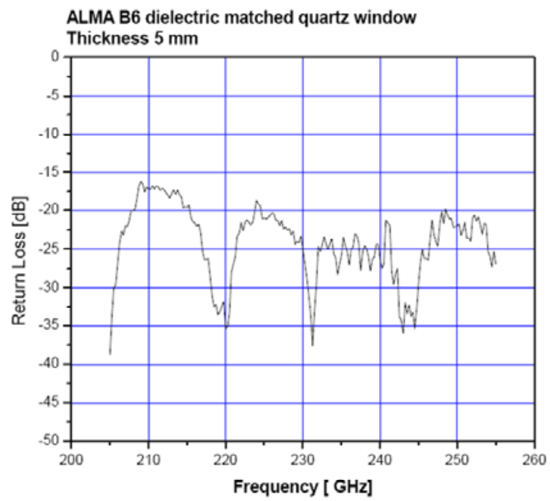


Figure 1: ALMA Band 6 Vacuum Window Return Loss

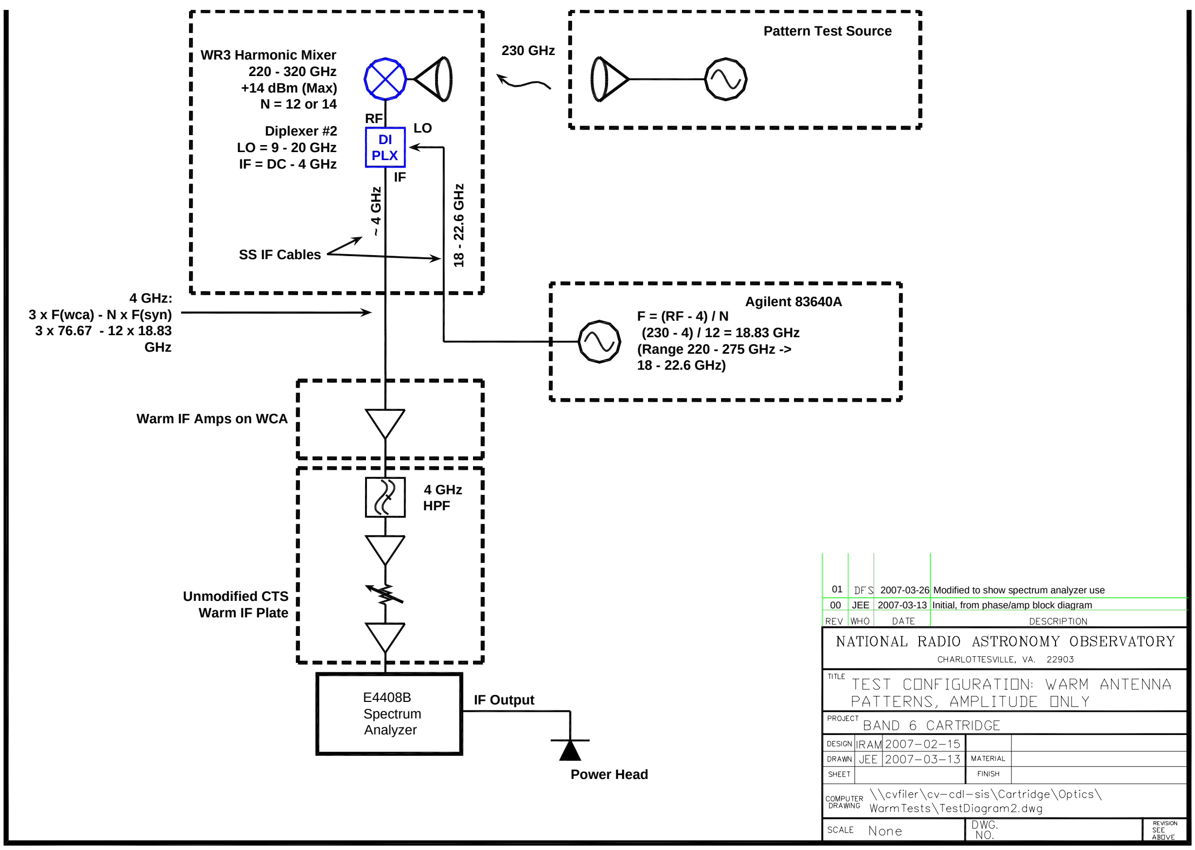


Figure 2: Room Temperature Mixer Pattern Measurement Test Setup

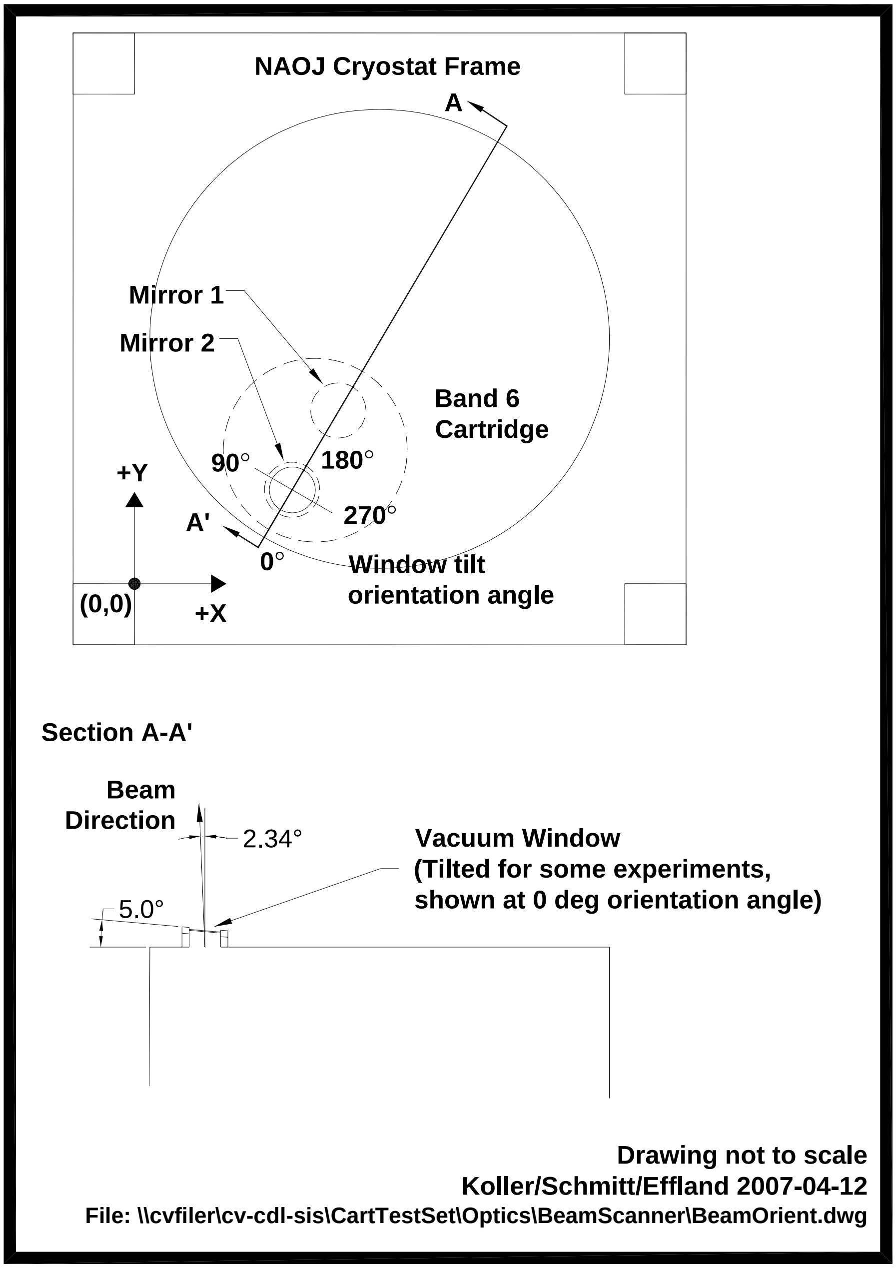


Figure 3: Coordinate Systems for Pattern Measurements

Figure 4: AN-72 Absorber on top of NAOJ Cryostat with all IR filters and window removed

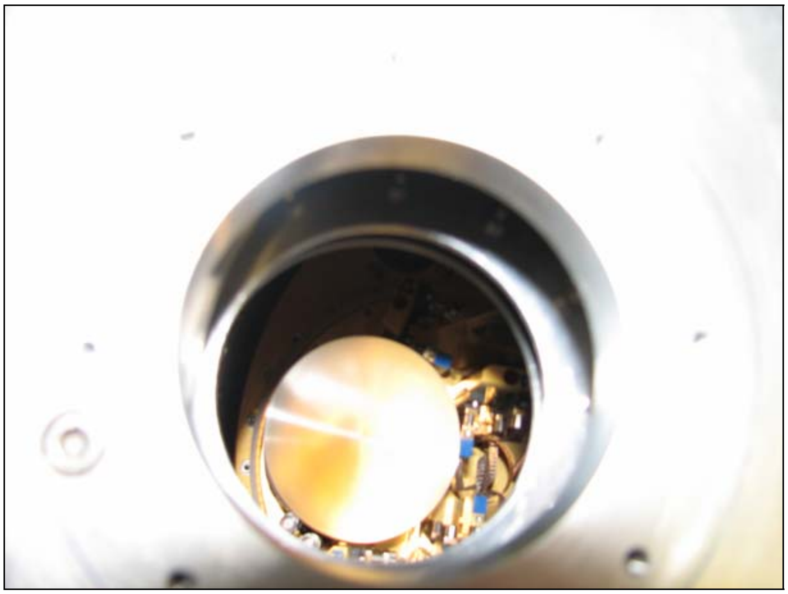
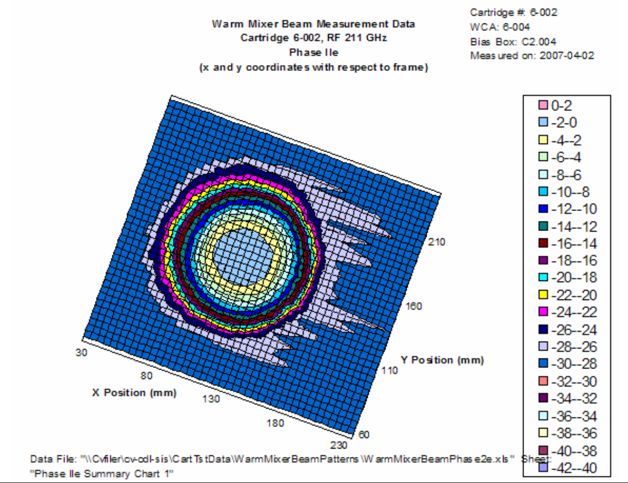
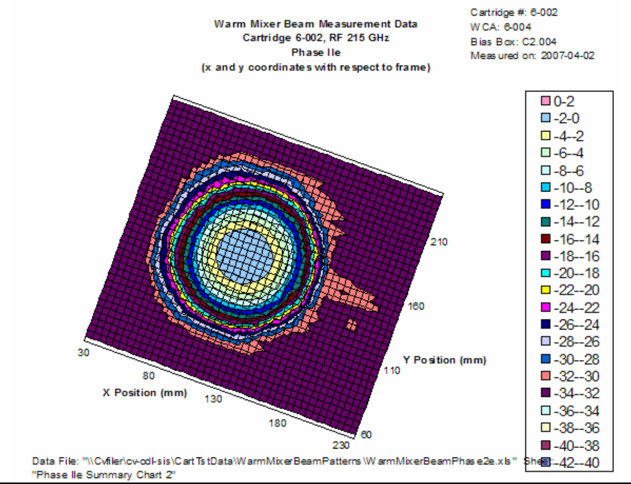


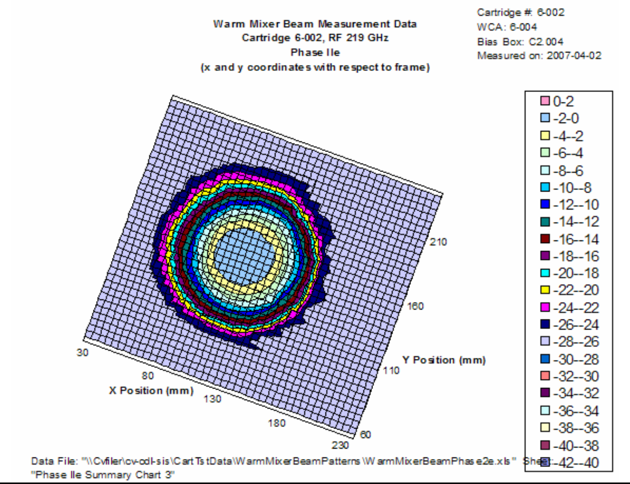
Figure 5: Band 6 Cartridge in NAOJ Cryostat with IR filters and window removed

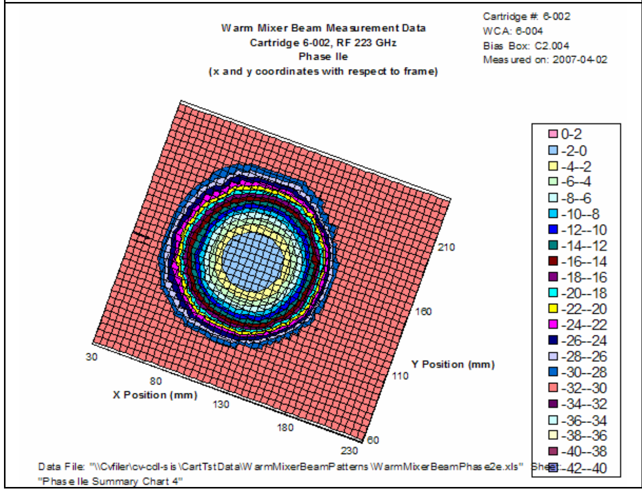
(AN-72 absorber removed from cryostat top for photograph)

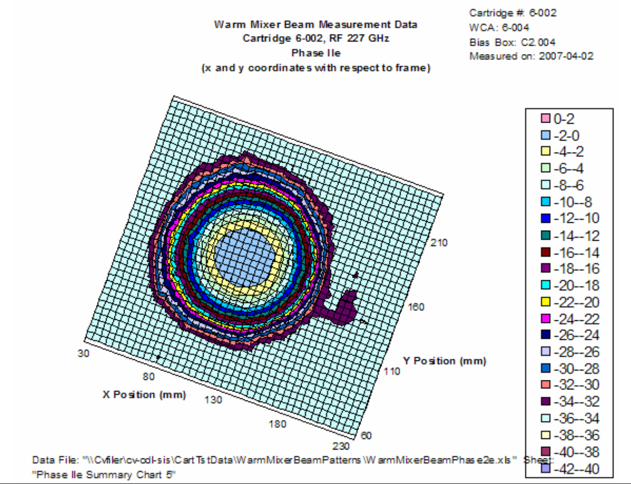
Table 3: Band 6 Pattern Measurements: All IR Filters and Windows removed from Cryostat

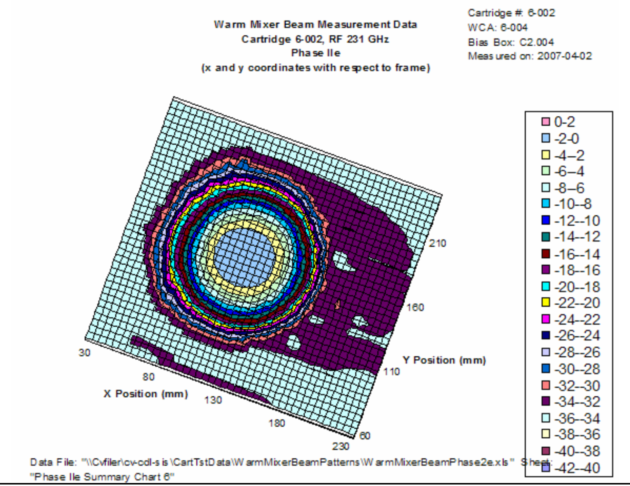












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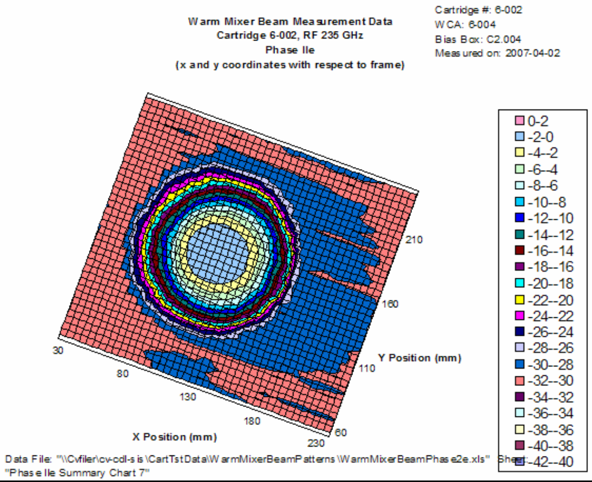

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Figure 6: ALMA Band 6 Vacuum Window

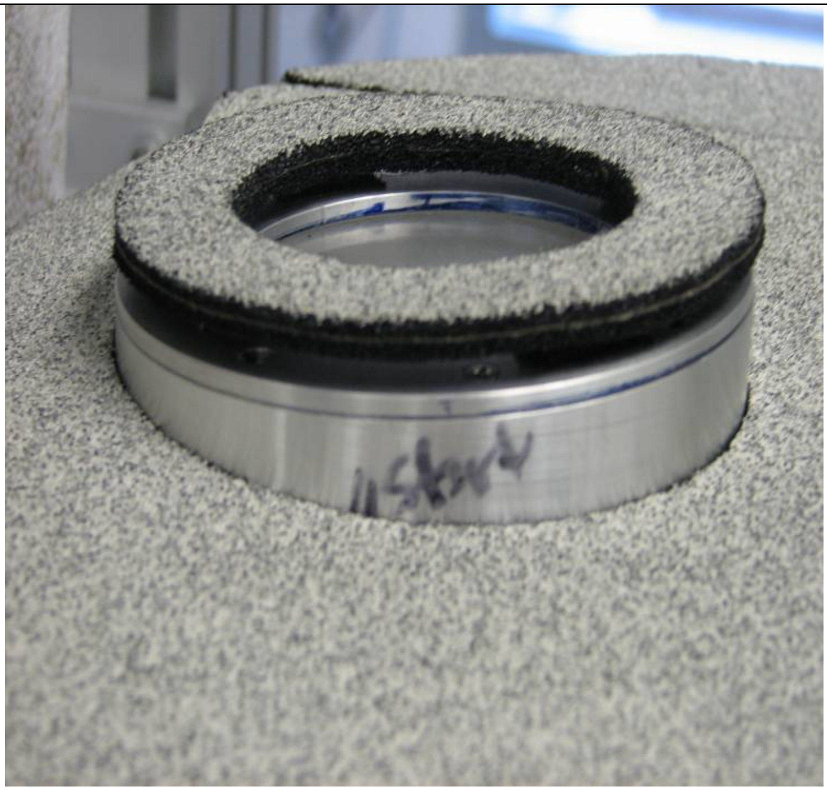
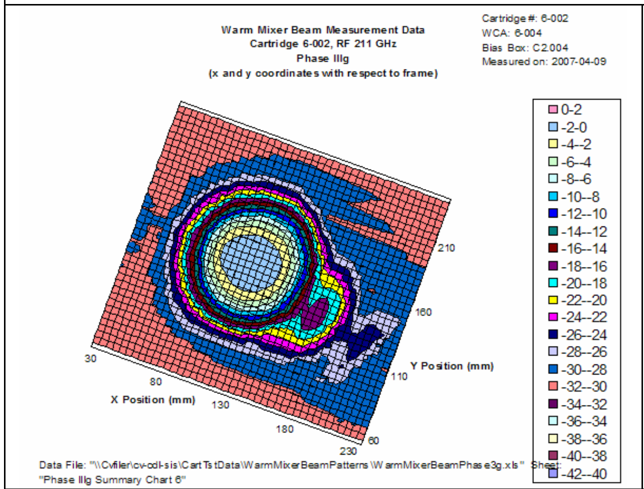
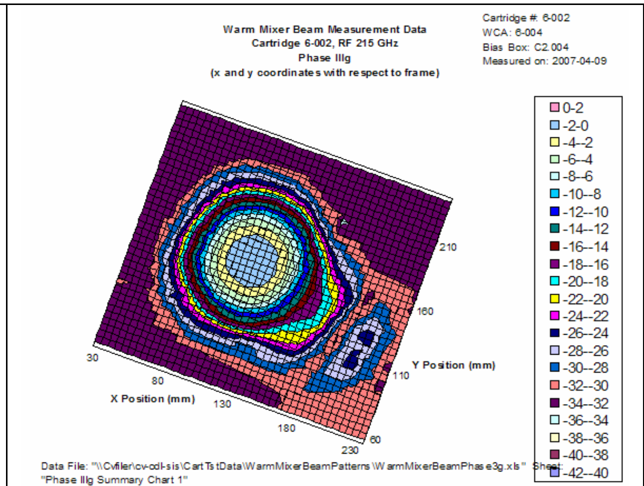
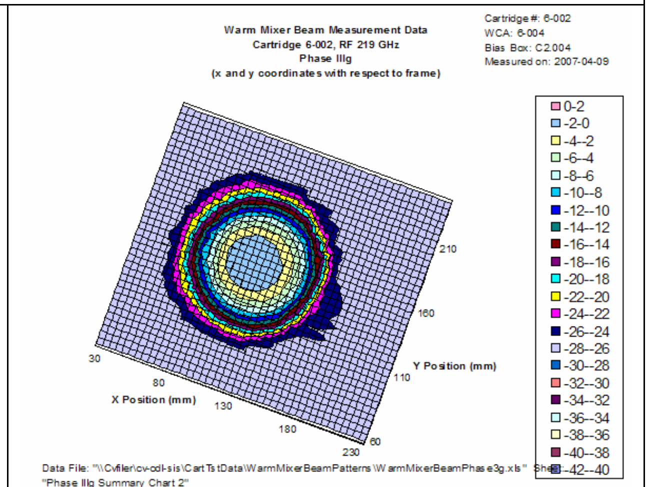


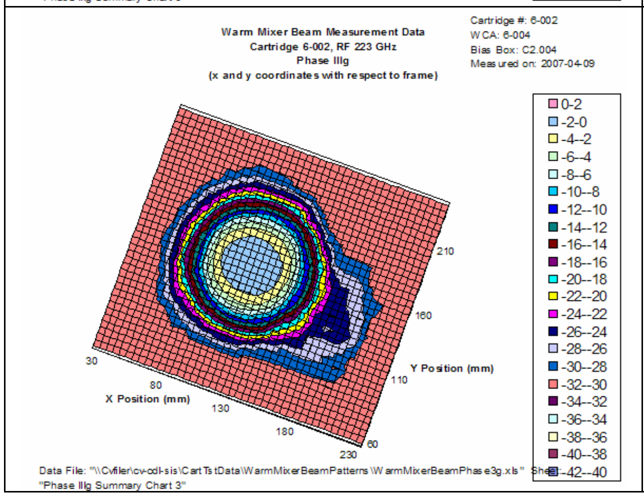
Figure 7: Vacuum Window Tilted 5°

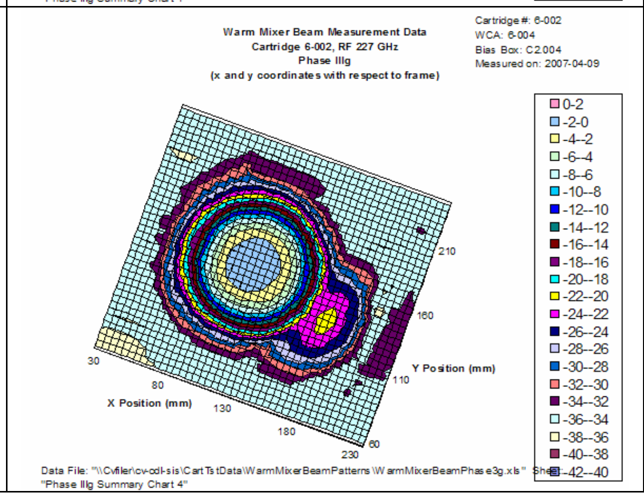
Table 4: Band 6 Cartridge Patterns with Vacuum Window (No Tilt) only: No IR filters or IR mounting rings











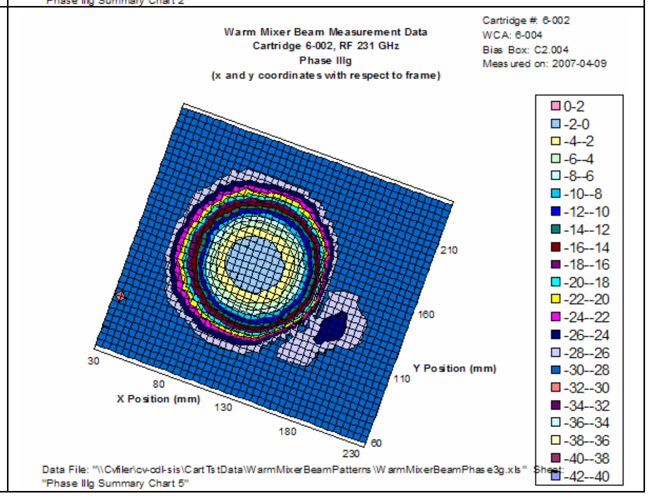


Table 4: Band 6 Cartridge Patterns with Vacuum Window (No Tilt) only: No IR filters or IR mounting rings

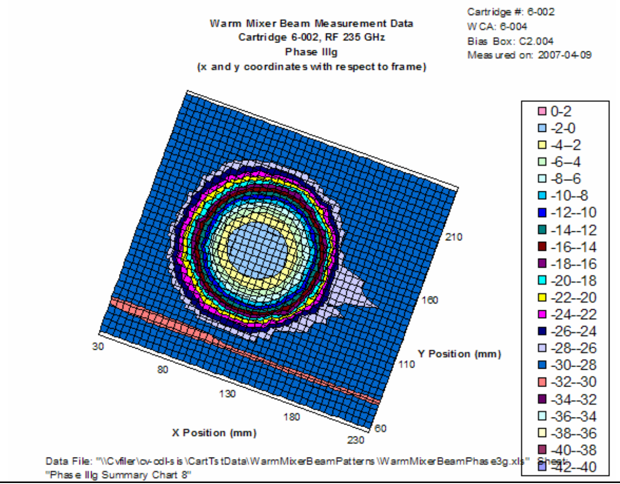
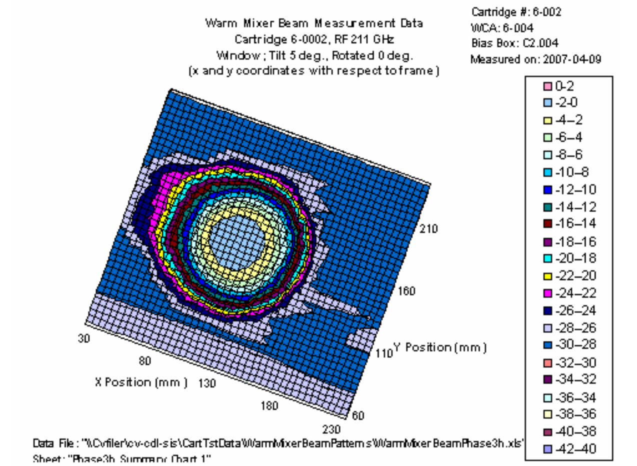
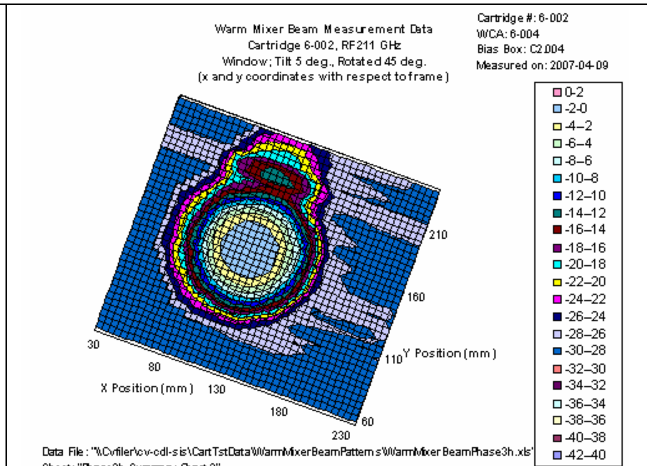
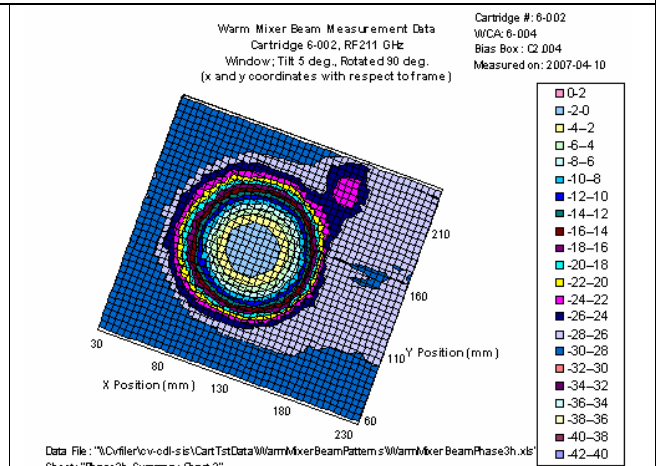
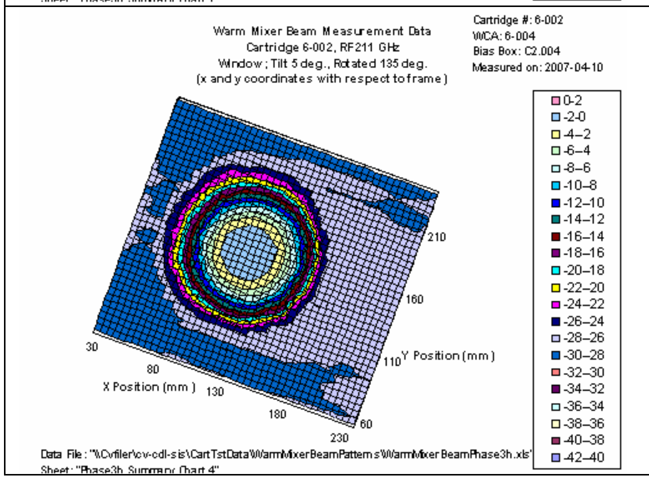


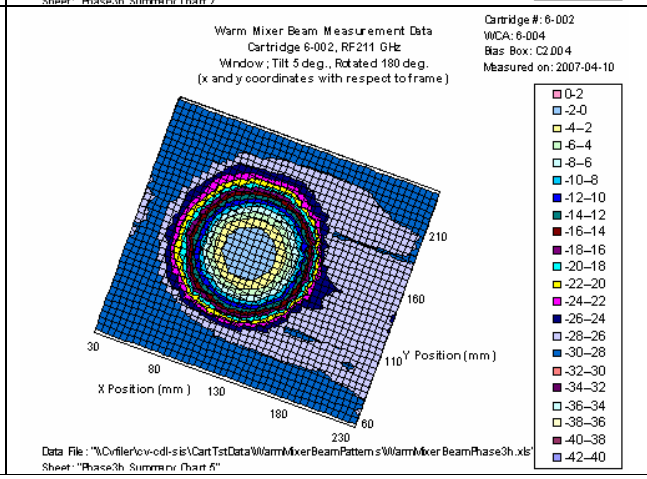
Table 5: Band 6 Cartridge Patterns with Vacuum Window Tilted 5° and Tilt Angle Orientation as a parameter, No IR filters or rings











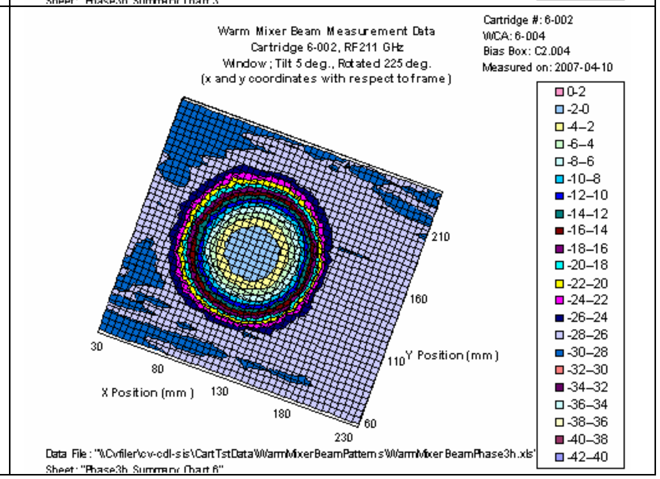
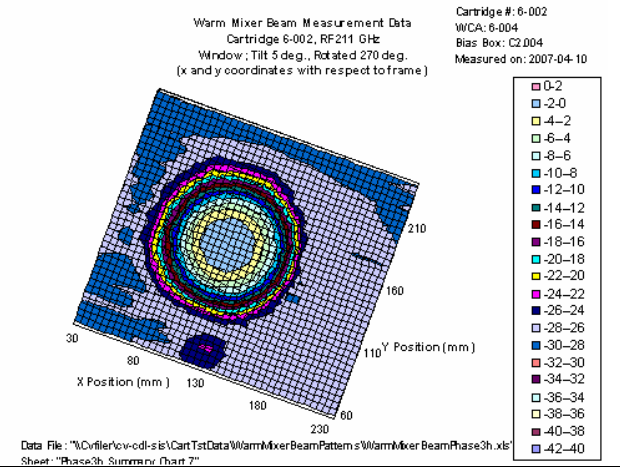
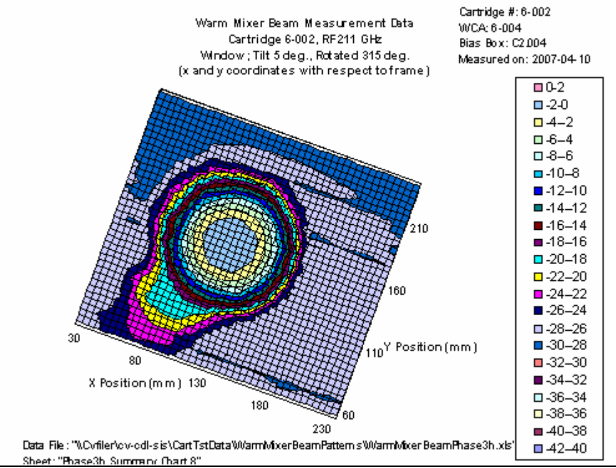


Table 5: Band 6 Cartridge Patterns with Vacuum Window Tilted 5° and Tilt Angle Orientation as a parameter, No IR filters or rings

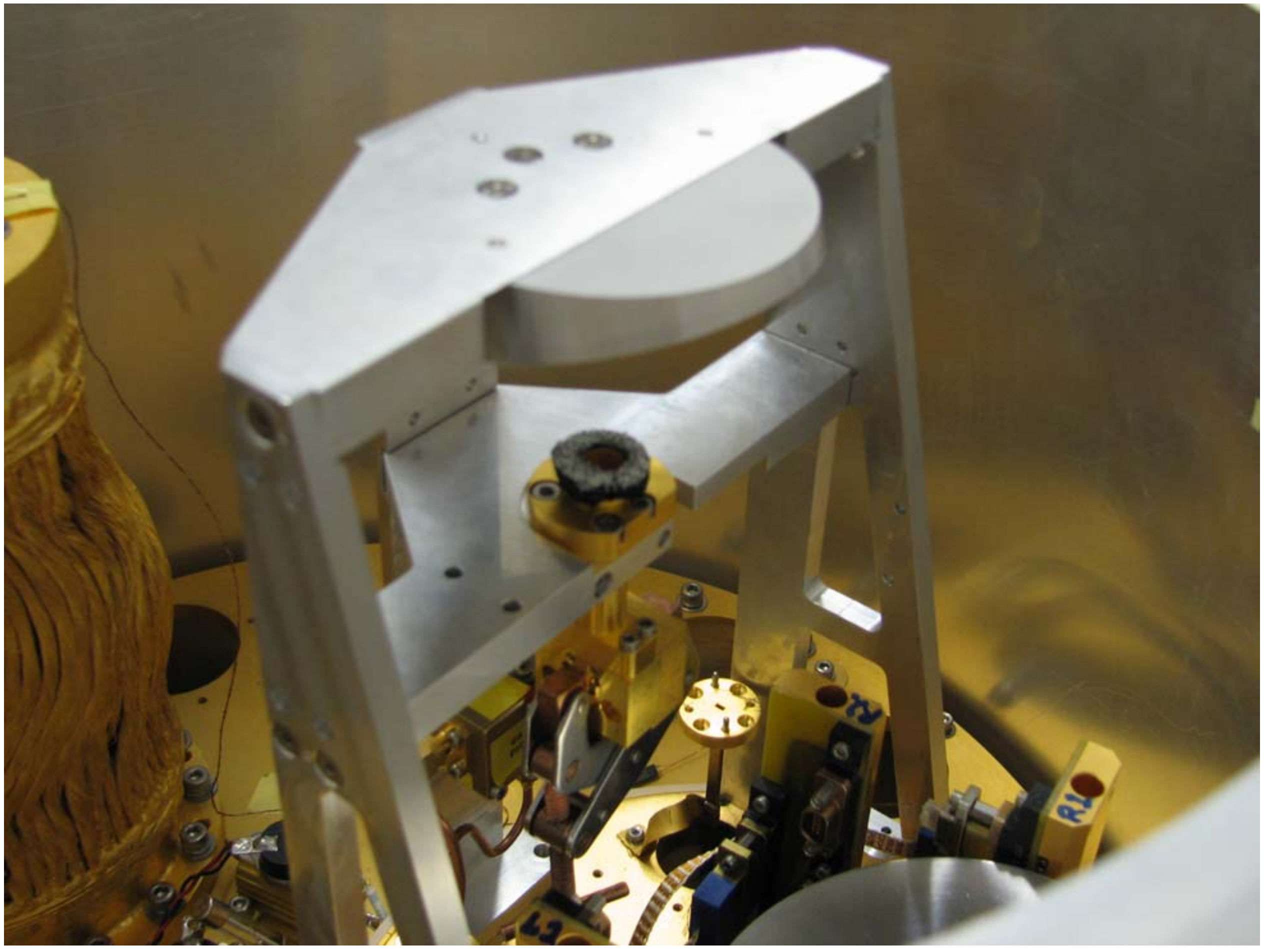
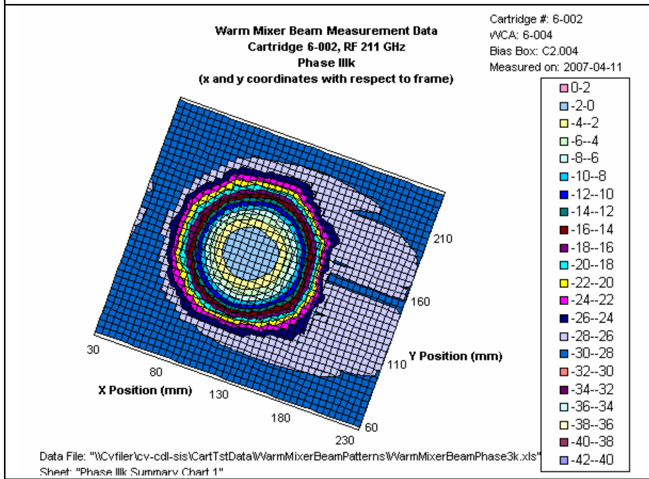
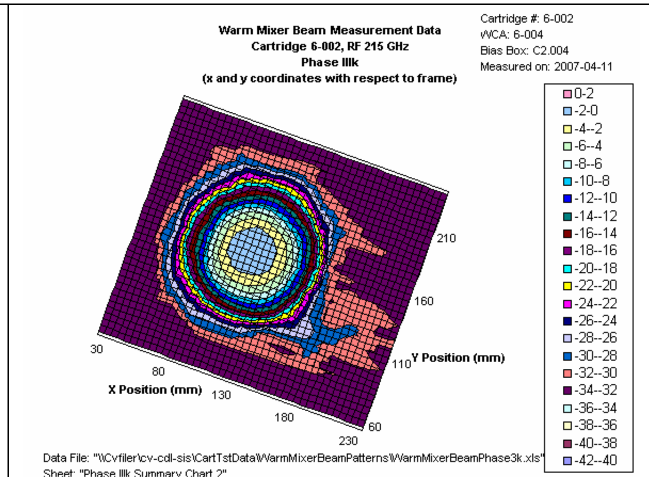
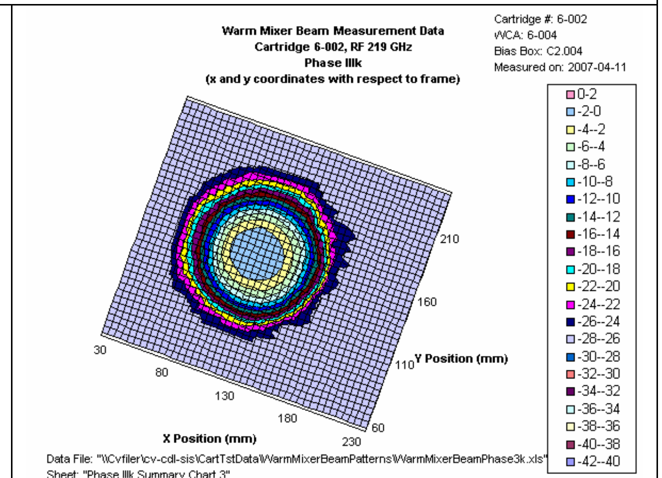


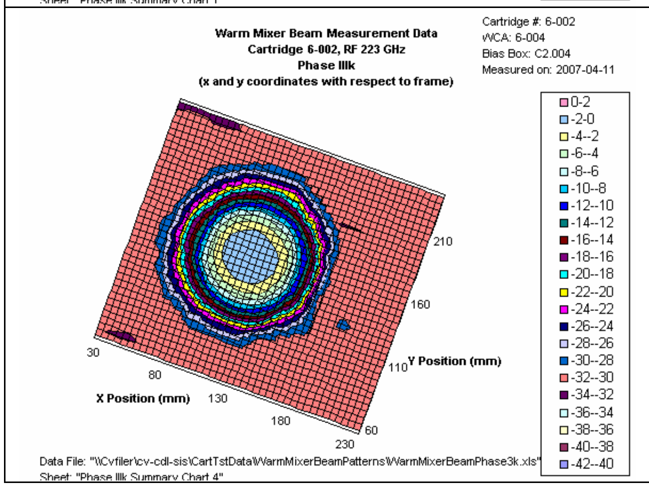
Figure 8: Room temperature tests of Band 6 Cartridge with AN-72 absorber installed on horn rim

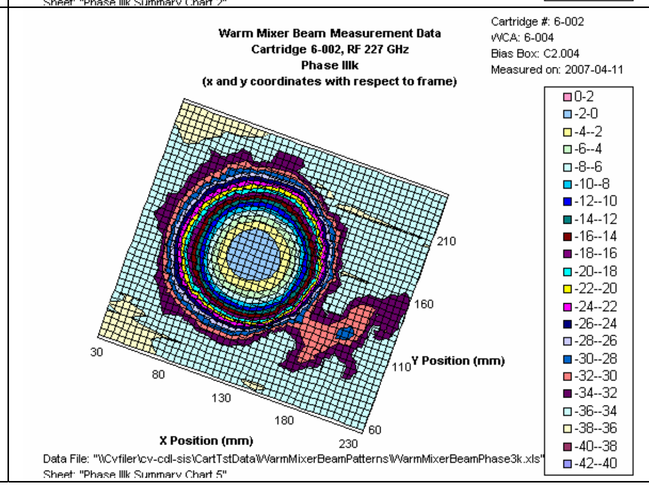
Table 6: Band 6 Cartridge Patterns with AN-72 absorber over Horn Rim. Vacuum Window (No Tilt) included, but no IR filters or rings











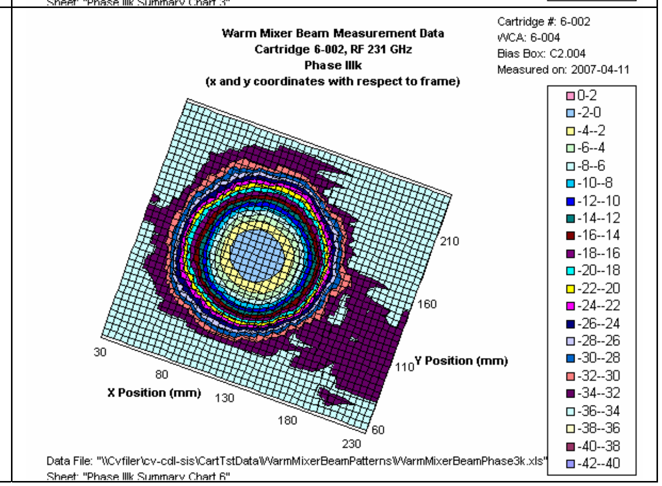


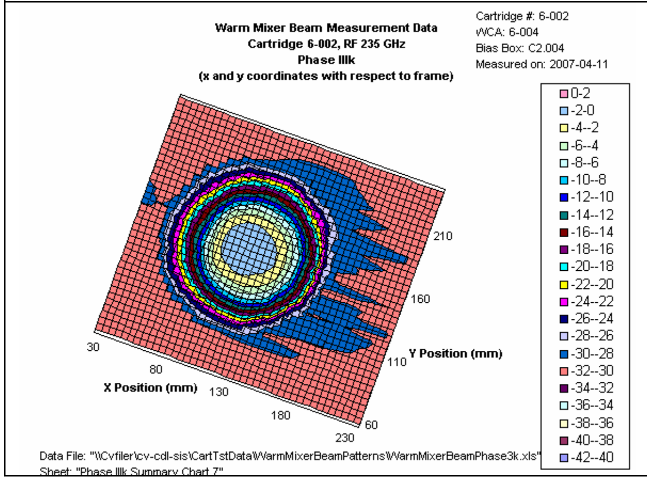
Table 6: Band 6 Cartridge Patterns with AN-72 absorber over Horn Rim. Vacuum Window (No Tilt) included, but no IR filters or rings		
		

Figure 9: Absorber *near* horn for patterns with cold cartridge, 2005-02-22