Atacama
Large
Millimeter /
submillimeter
Array

Band 8 Cartridge Test Procedure: Image Rejection Ratio and Gain Compression

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Change Record

Version	Date	Affected Section(s)	Change Request #	Reason/Initiation/Remarks
A01	2008-10-05	All	–	Initial draft
A02	2010-06-04	S2.1.2 S4.2		Definition of gain compression was changed to 373K hot load. Add examples of data
B	2011-06-02	S2.2 S3 Fig.1 S3.1 S4.2		Add LO Frequency Change equipment Revise example of data

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1. Introduction

1.1. Purpose

This document describes procedures and test configurations needed to verify imaging rejection ratio (IRR) and gain compression specifications, given in the Band 8 Cartridge Specifications [AD1].

1.2. Scope

This document applies to the work-package for the Band 8 cartridge described by the statement of work in [RD1].

1.3. 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.

Reference	Document Title	ALMA Doc. Number
[AD01]	Band 8 Cartridge – Technical Specifications	FEND-40.02.08.00-001-A-SPE
[AD 02]	Cartridge Data Formats for Delivery to the Front End Integration Centers	FEND-40.09.03.00-032-A-DSN
[AD03]		

1.4. Reference documents

The following documents contain additional information.

Reference	Document Title	ALMA Doc. Number
[RD01]	Band 8 cartridge Acceptance Test Plan	FEND-40.02.08.00-034-PLA
[RD02]	"Sideband Calibration of Millimeter-Wave Receivers," Kerr, Pan, and Effland, 27 Mar 2001.	ALMA Memo #357
[RD03]	"Saturation by Noise and CS Signals in SIS Mixers," A. R. Kerr, 2002-04-05,	ALMA Memo #401
[RD04]	Band 8 Cartridge Test Procedure: Noise Performance and IF power	FEND-40.02.08.00-021-A-PRO

1.5. 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
IRR Image Rejection Ratio
LO Local Oscillator
NAOJ National Astronomical Observatory of Japan
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

1.6. Verb Convention

"Shall" and “must” are used when a specification or provision is mandatory. The verbs "should" and "may" indicate a specification or provision that is not mandatory

2. . Description

2.1. Specification

2.1.1. Image Rejection Ratio

[FEND-40.02.08.00-00190-00 / T]
The image-band suppression (for any LO frequency) shall be $\geq$ 10 dB over 90% of IF frequency range. Image-band suppression (for any LO frequency) shall be > 7 dB over entire IF frequency range.

2.1.2. Gain Compression

[FEND-40.02.08.00-00230-00 / T]
The large signal gain compression caused by the exchange of RF load temperatures of 77 and 373 K must be less than 5 %.

2.2. Verification Method

- IRR and gain compression specifications are measured for Band 8 cartridges at the IF output of the WCA with the first LO supplied by the ALMA project

- There are 4 outputs, dual polarization and 2SB, with the IF band of 4 – 8 GHz.
- IRR shall be measured every 100 MHz of IF with LO (26) frequencies 393, 396, 400, 404, 408, 412, 416, 420, 424, 428, 432, 436, 440, 444, 448, 452, 456, 460, 464, 468, 472, 476, 480, 484, 488, and 492 GHz.
- Method of IRR measurements is the same as [RD02]
- Gain compression shall be measured every 1 GHz of IF with LO (5) frequencies 393, 416, 444, 468, and 492 GHz.
- Method of Gain compression measurements is the same as [RD03]

3. Test Configuration

Figure 1 is a block diagram of the cartridge test system. The cartridge is installed in a cartridge test cryostat, and a chopper wheel switches the input beam between hot and cold loads. Four IF outputs, one for each sideband and polarization, enter the “Warm IF Plate” via a 4-to-1 input switch and are further amplified, attenuated, and bandwidth-filtered by a 4-8 GHz band pass filter or a 50 MHz YIG filter. The RF hot and cold load consists of a computer-controlled chopper wheel that reflects the beam onto a mirror and then into the LN2 bath housing the cold load or allows the beam to pass straight though to the room temperature load. The power detection is done with an Agilent 4419B power meter and an Agilent E4412A power sensor.

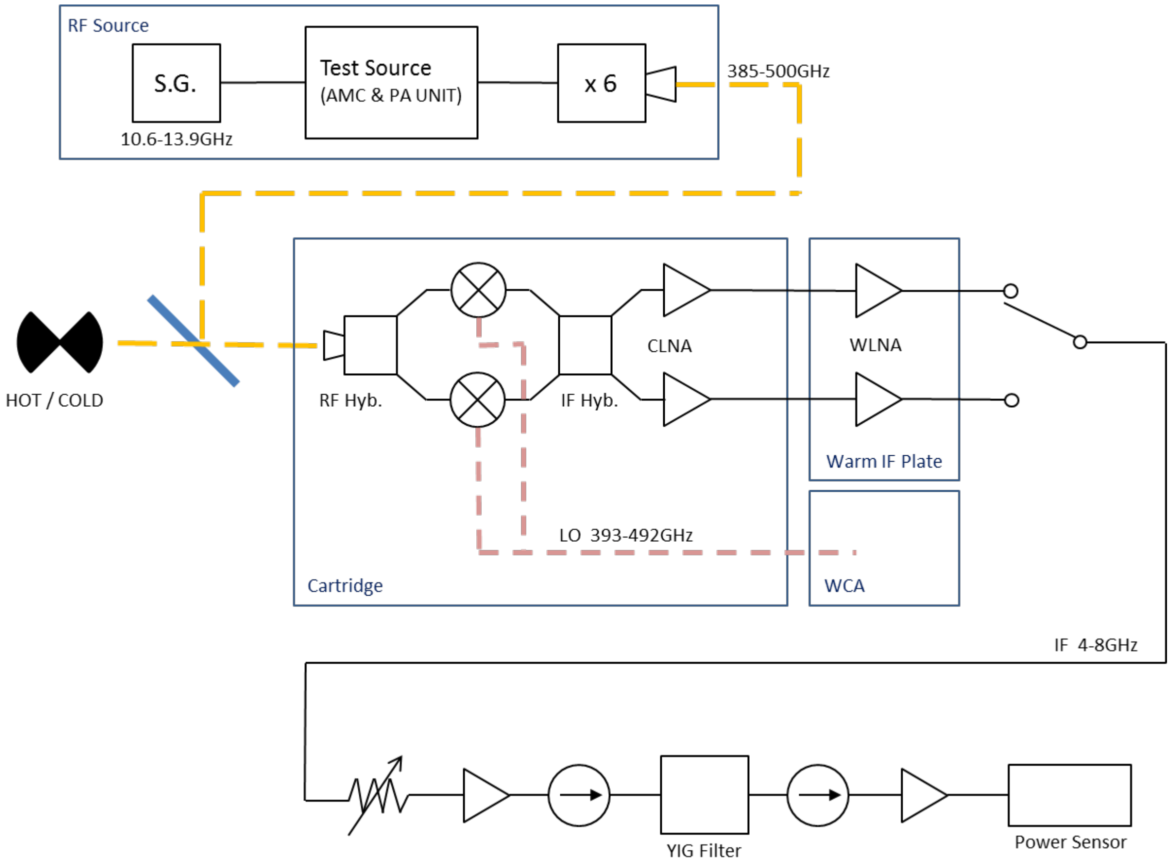

Figure 1: Typical Noise Temperature, Sideband Ratio, and Cartridge Gain Data. LO has been replaced with WCA.

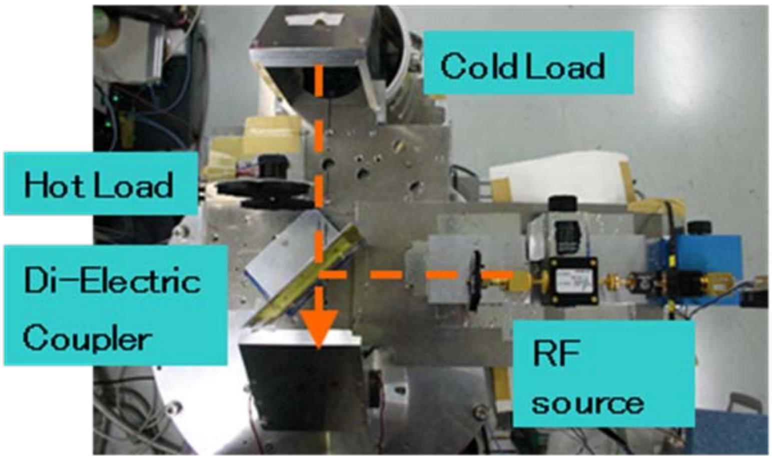

Figure 2 Setup on the top of the cartridge test cryostat for IRR and gain compression.

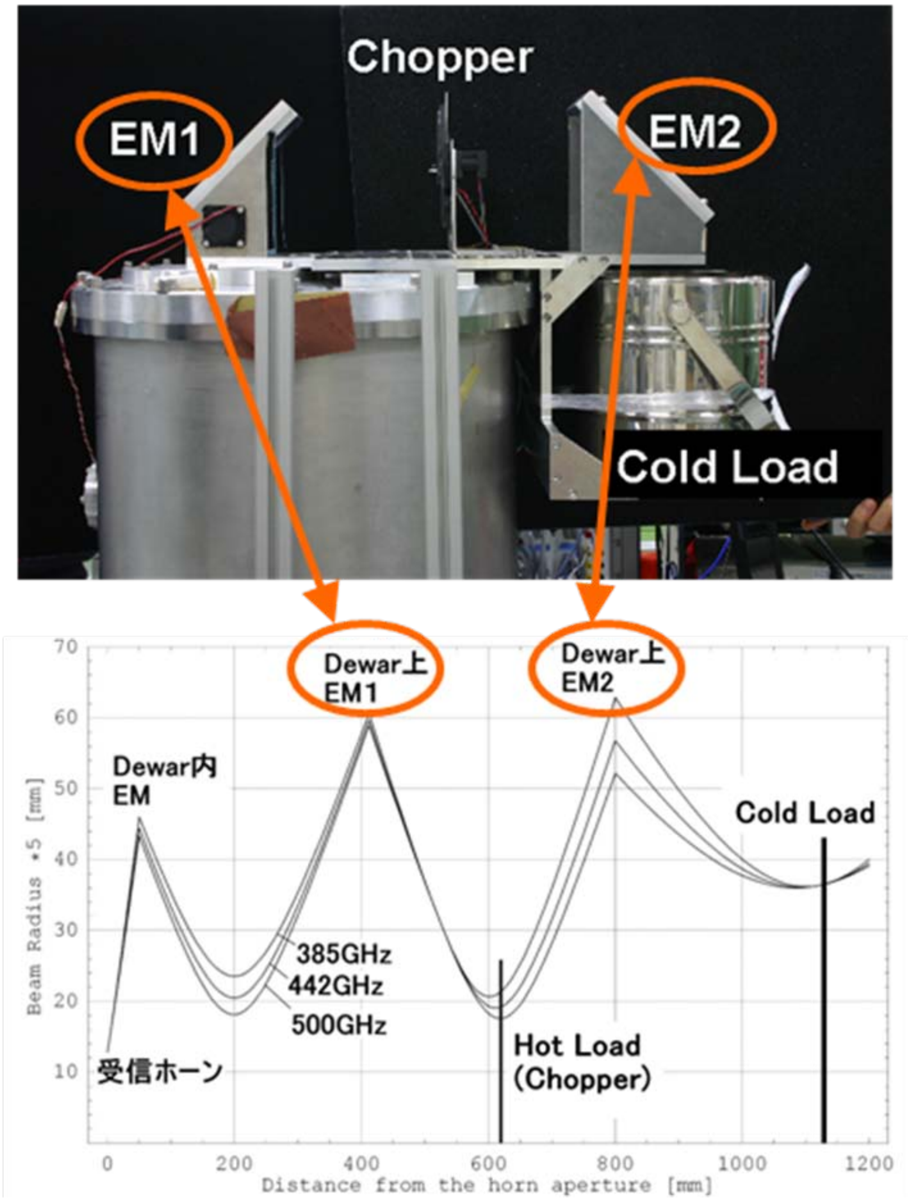

Figure 3 Optics on the top of the cartridge test cryostat.

3.1. <u>Equipment</u>

- Agilent 4419B power meter and an Agilent E4412A power sensor.
- YIG filter: Micro Lambda Wireless, Inc MLFP-62018PD
- A sideband source is consist of ANRITSU MG3694A, Beam Scanner Test Plate (BeaSTS) , VDI x6 multiplier

3.2. Calibration

3.3. Basic Test Concepts

The ALMA Band 8 receiver includes two polarizations Pol0 and Pol1, with two IF outputs (LSB and USB) per polarization. Receiver noise performance is measured by computer control of an absorbing vane (cold/hot load selection), a YIG filter tunable across the IF bandpass, and an Agilent E4419B dual-channel power meter [RD04].

For each LO frequency, the software automatically sweeps the YIG filter across the 4-8 GHz IF band (100 MHz steps, 50 MHz bandwidth), records the IF power output with hot and cold loads and finally derives the system noise temperature.
Basic method of IRR and gain compression measurement procedures are given in [RD02] and [RD03], respectively.
The RF signal from the source is coupled quasi-optically to hot and cold loads. Optics for both Y-factor and a signal source was designed with 5 times of Gaussian beam radius. They are frequency-independent at the horns.

All tests are performed with the temperature of the test cryostat's 4K stage stabilized at 4.0 +- 0.1 K.

Method of IRR measurements is the same as [RD02]

1) With a USB test signal injected, output power at both port is measured.

$$M_U = \frac{P_U}{P_L}$$

2) With a LSB test signal injected, output power at both port is measured.

$$M_L = \frac{P_L}{P_U}$$

3)Change of output power at Upper and Lower port are measured when the input Cold load (77K noise source) is replaced by a Hot load (300K noise source).

$$M_{DSB} = \frac{\Delta P_U}{\Delta P_L}$$

(4)The desired IRR are obtained as follows.

$$R_U = M_U \cdot \frac{M_L M_{DSB} - 1}{M_U - M_{DSB}}$$

$$R_L = M_L \cdot \frac{M_U - M_{DSB}}{M_L M_{DSB} - 1}$$

Method of Gain compression measurements is the same as [RD03]. Percentage Gain compression can be obtained by following equation.

$$G.C. = 100 \cdot \left(1 - \frac{V_{HS} - V_{H}}{V_{CS} - V_{C}}\right) \quad \%.$$

VHS : IF power level with the Hot load and the CW test signal is on
VH : IF power level with the Hot load only
VCS : IF power level with the Cold load and the CW test signal is on
VC : IF power level with the Cold load only

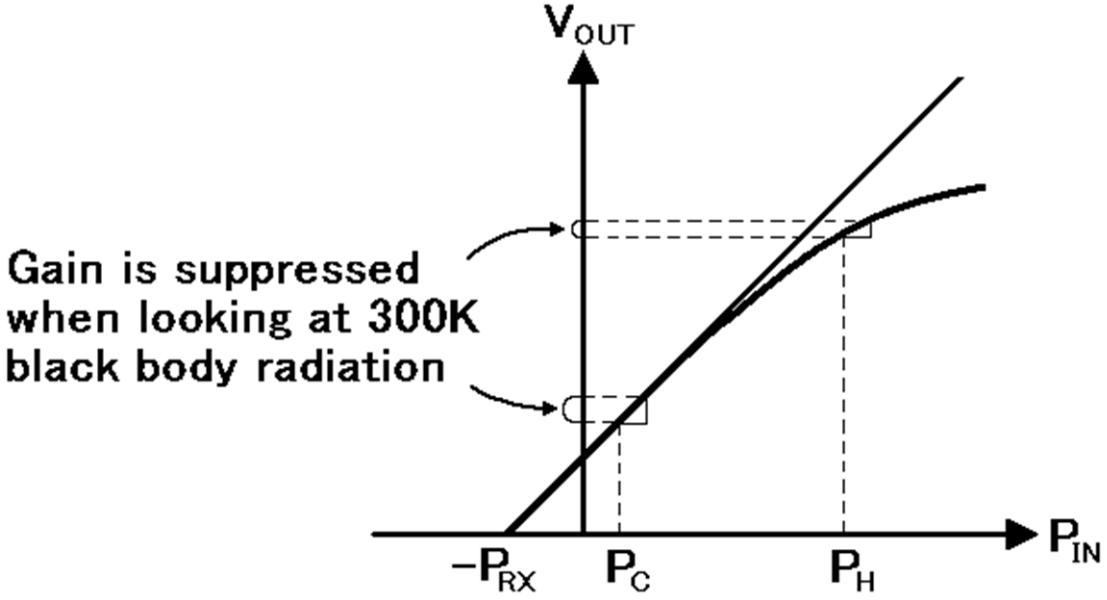

Figure 4 Concept of gain compression

Gain compression is measured with 300 K hot load and 77 K cold load. The value is linearly extrapolated to 373 K hot load as

$$G.C.(373K) = G.C.(300K) \cdot \frac{373 - 77K}{300 - 77K}$$

4. Test Procedure

4.1. Test Flow

Most of the steps shown below are under computer control. In Figure 2, a flow chart of test procedure is shown.

1. Execute health test to turn on cartridge, initialize bias settings, and verify proper functioning of cartridge components.
2. Select the LO frequency.
3. Using the software, manually enter mixer junction voltage, junction current.
4. Configure the Warm IF Plate input switch to select polarization 1, USB.
5. Rotate the chopper to the ambient load position. Then adjust the Warm IF plate attenuator so that the power meter is near upper end of a range switching point, typically -30 dBm.
6. Measure and record hot-load power for USB, then switch to LSB on Warm IF plate and measure hot- and cold-load powers for LSB.
7. Tune the sideband source to the USB and measure signal power in both sideband outputs.
8. Tune the sideband source to the LSB and measure signal power in both sideband outputs.
9. Switch the Warm IF Plate input to the noise source to measure the noise temperature of that subsystem.
10. Record ambient room temperature, mixer bias points, Warm IF Plate IF attenuator settings, LO frequency and IF.
11. Step the YIG filter on the Warm IF Plate to the next IF and repeat steps 4 to 10.
12. Repeat steps 4 to 11 after switching receiver output to polarization 1.
13. Use the equations below to calculate the receiver and cartridge noise temperature, cartridge gain, Warm IF Plate noise temperature and noise power density.

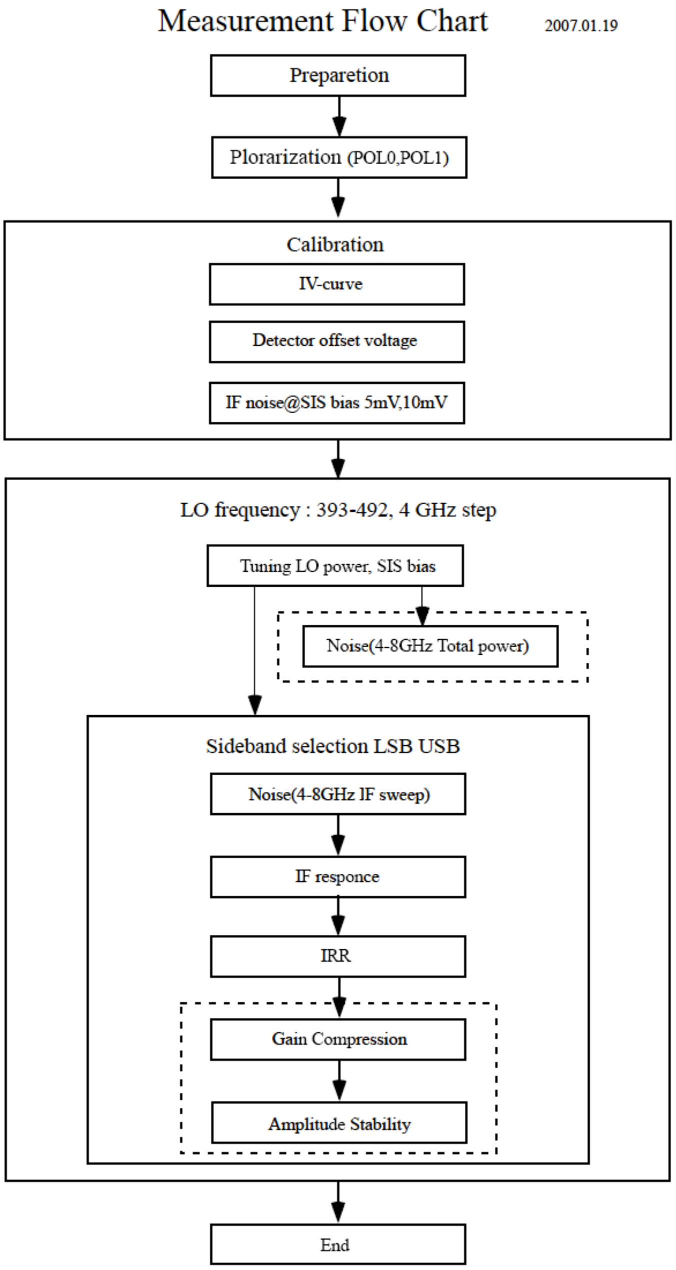

Figure 5 Flow chart of Cartridge tests including Noise, IF, IRR, Gain compression and Amplitude stability.

4.2. Example of data

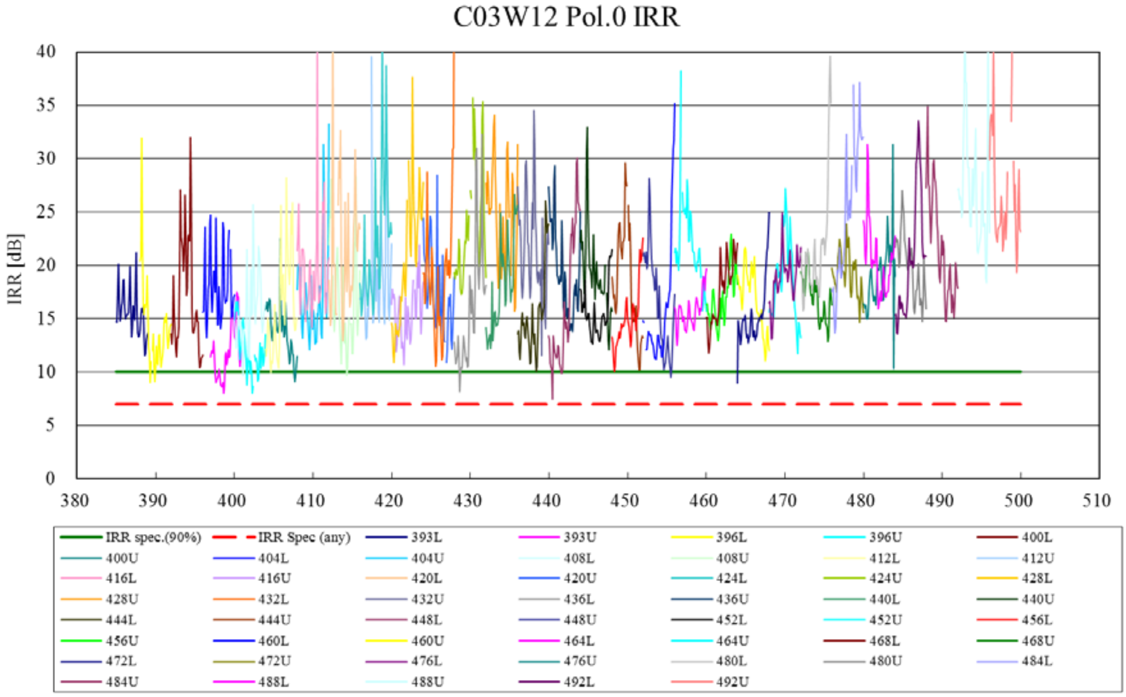

Figure 6 Example of image rejection ratio (IRR) ob Band 8 cartridge

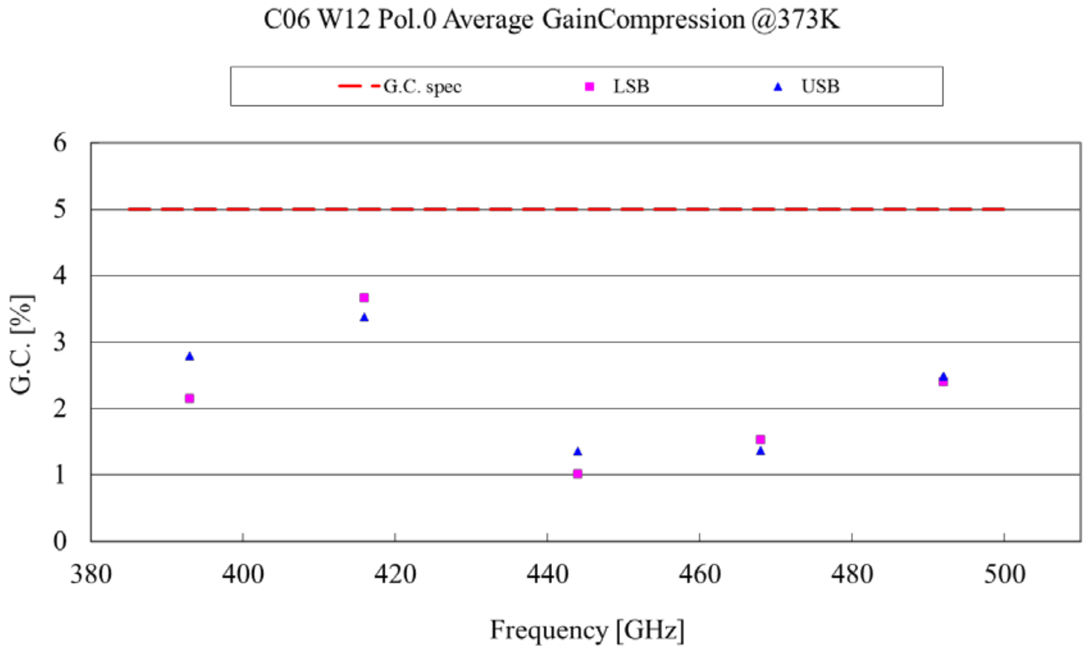

Figure 7 Example of Gain compression measurement

5. Error Analysis

Error analysis of gain compression is as follows.

$$\sigma_{\mathrm{GC}}^2 \simeq \sigma_{\mathrm{V_{HS}}}^2 \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{HS}}}\right)^2 + \sigma_{\mathrm{V_H}}^2 \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_H}}\right)^2 + \sigma_{\mathrm{V_{CS}}}^2 \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{CS}}}\right)^2 + \sigma_{\mathrm{V_C}}^2 \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_C}}\right)^2$$
$$+ 2\,\sigma_{\mathrm{V_{HS}V_H}}^2 \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{HS}}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_H}}\right) + 2\,\sigma_{\mathrm{V_{HS}V_{CS}}}^2 \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{HS}}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{CS}}}\right) + 2\,\sigma_{\mathrm{V_{HS}V_C}}^2 \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{HS}}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_C}}\right)$$
$$+ 2\,\sigma_{\mathrm{V_H V_{CS}}}^2 \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_H}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{CS}}}\right) + 2\,\sigma_{\mathrm{V_H V_C}}^2 \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_H}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_C}}\right) + 2\,\sigma_{\mathrm{V_{CS}V_C}}^2 \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{CS}}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_C}}\right)$$

If typical values assumed,

$$\sigma^2_{\mathrm{V_{HS}}} \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{HS}}}\right)^2 = 1.5003$$

$$\sigma^2_{\mathrm{V_{H}}} \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{H}}}\right)^2 = 0.001131$$

$$\sigma^2_{\mathrm{V_{CS}}} \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{CS}}}\right)^2 = 2.3358$$

$$\sigma^2_{\mathrm{V_{C}}} \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{C}}}\right)^2 = 0.0004607$$

$$2\ \sigma^2_{\mathrm{V_{HS}V_{H}}} \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{HS}}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{H}}}\right) = -0.05760$$

$$2\ \sigma^2_{\mathrm{V_{HS}V_{CS}}} \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{HS}}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{CS}}}\right) = -3.5415$$

$$2\ \sigma^2_{\mathrm{V_{HS}V_{C}}} \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{HS}}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{C}}}\right) = 0.03311$$

$$2\ \sigma^2_{\mathrm{V_{H}V_{CS}}} \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{H}}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{CS}}}\right) = 0.07508$$

$$2\ \sigma^2_{\mathrm{V_{H}V_{C}}} \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{H}}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{C}}}\right) = -0.001116$$

$$2\ \sigma^2_{\mathrm{V_{CS}V_{C}}} \left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{CS}}}\right)\left(\frac{\partial \mathrm{GC}}{\partial \mathrm{V_{C}}}\right) = -0.04209$$

the largest factor of the error is $\sigma^2_{\mathrm{VHS\,VCS}}$
which means instability of sideband CW source.

6. Data Formats

Data shall be stored as specified in CSV format [AD02].

6.1. IRR

Filename: **BBNNNN_IMAGE_SUPPRESSION**
One row per combination of (FreqLO, CenterIF, BWIF, Pol, SB):
keyBand, keyDataSet, fkCartAssys, TS, FreqLO, CenterIF, BWIF, Pol, SB, R
R is given in dB of image suppression.

6.2. Gain Compression

Filename: **BBNNNN_GAIN_COMPRESSION**
One row per combination of (FreqLO, Pol, SB):
keyBand, keyDataSet, fkCartAssys, TS, FreqLO, Pol, SB, Compression
Compression is given as percentage.

BB = 08
NNNN = keyCartAssys is an integer which identifies the particular cartridge configuration being tested. Other values needed for these data files are:

keyBand = 8 for Band 8 cartridge,
keyDataSet= an integer which indicates serial number of dataset for a particular cartridge assembly,
fkCartAssys = keyCartAssys,
TS = timestamps strings date YYYY-MM-DD HH:MM:SS.
FreqLO = frequency of LO
Pol = 0 or 1
SB = an integer where 1 = USB and 2 =LSB