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# Band 6 Cartridge Operating Manual

FEND-40.02.06.00-106-B-MAN

Version: B

Status: Released

2007-08-30

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# Change Record

| Version | Date | Affected Section(s) | Change Request # | Reason/Initiation/Remarks |
|---|---|---|---|---|
| A00 | 2006-09-21 | All | - | ARK: Initial |
| A01 | 2006-09-21 | All | - | Jee: Minor formatting, new signature box |
| A02 | 2006-09-28 | Many | - | Jee: ARK updated this based on action items from PAI review |
| A03 | 2006-10-03 | Few | - | Jee: minor formatting changes, deleted out of scope statement concerning cold cart. Body, added RD for room temp. tests. |
| A04 | 2006-10-04 | 2.2 | - | Jee: Implemented ARK's recommended wording changes. |
| A04 | 2007-06-11 | 4.6 | | ml: LO Power Optimization procedure information was added by Michael Lacasse. |
| B | 2007-08-29 | | | jee: Updated ALMA nums and released Rev B. |
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# 1. Introduction

## 1.1. Purpose

This document is the user guide and operating manual for the ALMA Band 6 Cartridge.

## 1.2. Scope

This document applies to the following level 3 work element: FEND-40.02.06.00, Band 6 Cartridge. The statement of work covering this work package is described in [RD1].

This is a manual for operating the first Band 6 Cartridge associated with a Warm Cartridge Assembly (WCA). This document does not include test data from individual assemblies. That data is unit/assembly specific and is included in separate documents.

## 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.

| Ref. | Document Title | ALMA Doc Number |
|---|---|---|
| [AD1] | Band 6 Cartridge Specifications Technical | FEND-40.02.06.00-001-A-SPE |
| [AD3] | Data Formats for Cartridge Operating Parameters | FEND-40.02.00.00-016-A-STD |
| [AD4] | Front End Integration Center Database Design Description | FEND-40.09.03.00-007-A-DSN |
| [AD5] | Band 6 Cartridge Acceptance Test Plan | FEND-40.02.06.00-072-B-PLA |
| [AD6] | Interface Control Document between WCA Connector Plate and Front End WCA Harness Plate | FEND-40.11.00.00-40.04.00.00-A-ICD |
| [AD7] | Band 6 Local Oscillator Driver Users Guide (Digital PLL version) | FEND-40.10.06.00-010-A-MAN |
| [AD8] | Band 6 Cartridge Test Procedure Noise Performance, Gain, and Power Density Slope | FEND-40.02.06.00-076-B-PLA |
| [AD9] | Band 6 Cartridge Test Procedure: Sideband Ratio (Image Rejection) Measurement | FEND-40.02.06.00-077-B-PLA |
| [AD10] | Band 6 Cartridge 001 Room Temperature Test Data | FEND-40.02.06.00-115-A-TDR |

### 1.4. Reference Documents

The following documents contain additional information.

| Reference | Document Title | ALMA Doc Number |
|---|---|---|
| [RD1] | Band 6 Cartridge Statement of Work | FEND-40.02.06.00-002-A-SOW |
| [RD2] | ALMA Cryostat Operating Procedure | FEND-40.03.00.00-019-B-MAN |
| [RD3] | PAI And On-site Acceptance Procedures For The ALMA Band 6 Cartridge | FEND-40.02.06.00-104-A-PRO |
| [RD4] | Band 6 Cartridge Test Procedure: Room Temperature Tests | FEND-40.02.06.00-124-A-PRO |
| [RD5] | ALMA FE Cartridge Power Distribution System Technical Specifications | FEND-40.04.08.00-004-A-SPE |

### 1.5. Acronyms

ESD ElectroStatic Discharge
HFET Heterostructure Field Effect Transistor
IF Intermediate frequency
LO Local Oscillator
OMT OrthoMode Transducer
WCA Warm Cartridge Assembly

## 2. Description

### 2.1. Equipment Definition

The Band 6 Cartridge is one of 10 receiver cartridges which will ultimately populate the front end cryostat. A photograph of the Band 6 cartridge assembly (without the WCA) is shown in Figure 1 and the cartridge baseplate is shown in Figure 2.

To fulfill its functional requirements as described in [AD1], the cartridge includes the cold optics (OMT, feed horn and mirrors), mixers and preamplifiers, LO frequency triplers, sensors for temperature monitoring, a heater for de-fluxing the mixer, and the necessary waveguide, coaxial, and wire interconnections and vacuum feedthroughs. The frame of the cartridge, including G-10 support sections and the different temperature stages, are supplied by RAL.

Each Band 6 cartridge receives two linear polarizations from the subreflector of the telescope. The linear polarizations are separated in the OMT attached to the feed horn.

Each polarization channel has a sideband-separating SIS mixer with a pair of InP HFET IF preamplifiers and an external IF quadrature hybrid at whose output ports the downconverted upper and lower sideband signals are available.

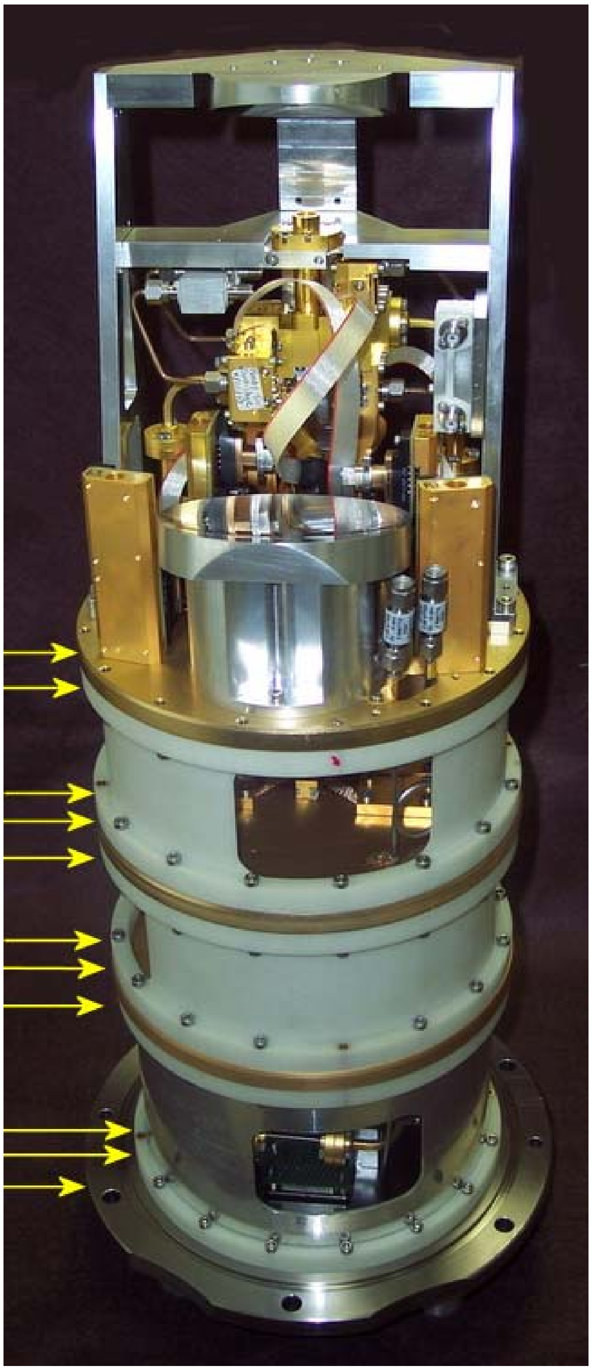

**Figure 1: Band 6 cartridge (without the WCA). Arrows indicate acceptable support locations.**

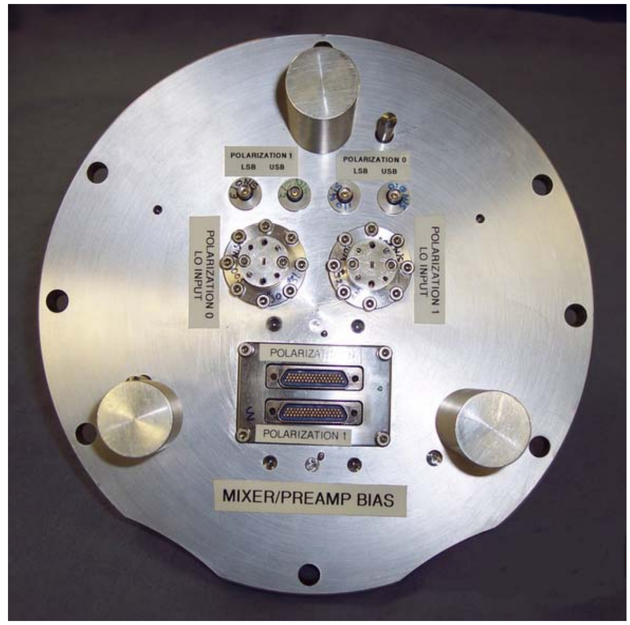


**Figure 2: Band 6 cartridge baseplate.**

### 2.2. Significant Parameters

- RF signal input (from the telescope): 211-275 GHz
- LO input (from the WCA): 73.67-88.33 GHz (221-265 GHz from the tripler to the mixer)
- IF output: 4-12 GHz with separate upper and lower sideband outputs. Specifications guaranteed over 6-10 GHz . Operation with degraded performance will be possible over the full 4-12 GHz IF. In particular, acceptable operation will be possible over 5-10 GHz IF to allow simultaneous observation of the $^{12}CO$ line (230.538 GHz) in the upper sideband with $^{13}CO$ and $C^{18}O$ (220.398 and 219.560 GHz) in the lower sideband.

## 3. Shipping, Unpacking and Assembly

### 3.1. Cartridge ESD Protection

In order to protect the sensitive components in the cartridge (*i.e.* SIS junctions, HFETs, temperature sensors) from both excessive DC bias and electrostatic discharges (ESD), a protection circuit is mounted on the vacuum side of the main cartridge flange. ESD protection is realized by parallel connected 2 terminal devices with appropriate threshold voltages.

However, no ESD protection circuits are foolproof, and it is still possible to damage the cartridge by ESD. For that reason, it is essential to follow the following procedures for transporting and unpacking a cartridge.

### 3.2. Shipping

The cartridge is always sealed within ESD protective packaging material. It should only be moved from and to ESD safe areas described below.

### 3.3. Preparation for unpacking

A clean “ESD safe” area consisting of the following items should be established at any location in which the cartridge is to be handled.

- A properly grounded static-dissipative surface on which to place the cartridge.
- Static-dissipative floor and floor mat.
- A grounding wire connected to the base plate of the cartridge.

- A properly grounded conductive wrist-strap for each person to wear while handling the product.

The wrist strap and grounding wire should be connected to the same ground as the static-dissipative surface.

### 3.4. Unpacking the cartridge

- Place the shipping container on the static-dissipative surface.
- Open the shipping container and place the ESD protective packaging containing the cartridge on the static-dissipative surface.
- Cut the antistatic sealing tape, remove the cartridge, and place it on the static dissipative surface. (Save all ESD protective packaging for later.)

Any required visual inspection should be performed at this time.

Before moving the cartridge to another location, it must be replaced in an antistatic bag.

### 3.5. Handling the Cartridge

The cartridge may be damaged if it is supported in the wrong place. The acceptable support locations are the base plate, the 110 K, 15 K and 4 K plates, and the thick G-10 rings attached to those plates, as indicated by the yellow arrows in Figure 1. In particular, the following should be noted:

- The aluminum A-frame structure and its cross-members which support the mirrors and feed horn at the cold end of the cartridge should never be touched. A small deformation could throw the optics seriously out of alignment.
- The edges of the 4K , 15K, and 110K plates should never be touched with bare hands. Cleanliness of these edges is essential to ensure good thermal contact in the receiver cryostat. Talc-free gloves should always be worn while handling the cartridge.
- The G-10 glass-epoxy shells between stages are thin and subject to damage if they are used to support the cartridge other than in the proper cradle which distributes the load.
- The large O-ring in the baseplate must be kept clean and undamaged.
- No part of the WCA should be used to lift or support the cartridge assembly.

### 3.6. Assembling the Cartridge, Bias Module, WCA, and Cryostat

Tools required: Hex wrenches and ball drivers M4, M5, M6.

a) Attach the bias module to the cartridge baseplate with two screws.
b) Fit the WCA to the cartridge, paying attention to the blind-mate waveguide, coaxial, and multi-pin connectors.
c) Engage the overall assembly into the cryostat using the cartridge loader.
d) Insert the baseplate M8 screws.
e) Attach the DC power supply cable at the rear of the WCA.
f) Attach the serial input/output cable at the back of the WCA.

# 4. Band 6 Cartridge Operation and Settings

## 4.1. Cartridge Description

A block diagram of the Band 6 cartridge is shown in Figure 3 Each cartridge receives two linear polarizations, designated "0" and "1", from the subreflector of the telescope. The beam from the subreflector enters the cartridge through the cryostat vacuum window and two infrared filters (all considered part of the cryostat). It is then focused by the two offset ellipsoidal mirrors into the corrugated feed horn. The linear polarizations are separated in the OMT attached to the feedhorn and fed to separate receiver channels. Each polarization channel has a sideband-separating SIS mixer with a pair of InP HFET IF preamplifiers and an IF quadrature hybrid at whose output ports the downconverted upper and lower sideband signals are available. Each sideband separating mixer contains two Nb/Al-AlOx/Nb SIS mixer chips, each with four SIS junctions in series. Each SIS mixer is biased through a six-wire bias-T contained in the corresponding IF amplifier. To maximize the usable IF bandwidth while minimizing the receiver noise temperature, the IF amplifiers are attached directly to the mixer block with no isolator. To reduce baseline ripple, 2 dB attenuators are inserted in series with the coaxial cables from the IF hybrid to the base plate. Each mixer has an iron magnetic circuit, energized by a superconducting solenoid, to suppress Josephson currents in the junctions. Also attached to each mixer is a Si-diode temperature sensor and a heater resistor for degaussing if necessary.

## 4.2. DC Power Requirements

**Table 1**, abstracted from [AD-6], indicates the power available to the warm cartridge/cold cartridge assembly.

**Table 1: Cartridge Harness Plate DC Power Input Connector**

| Signal | Specification | Destination |
|---|---|---|
| +6V_FILT | 6V ± 10%, <1 mV p-p ripple, 0.425 A | Cartridge Bias Module |
| -6V_FILT | -6V ± 10%, <1 mV p-p ripple, 0.150 A | Cartridge Bias Module |
| +24V | 24V ± 10%, <1 mV p-p ripple, 0.210 A | Cartridge Bias Module |
| +24V | 24V, 0.300 A | First LO – YIG |
| +15V | 15 V ± 0.2V , <1 mV p-p ripple, 1.707A | First LO Electronics |
| -15V | -15 V ± 0.2 V, <1 mV p-p ripple, 0.840 | First LO Electronics |
| +6V | 6.0 – 6.3, <1 mV p-p ripple, 5.085 A | First LO Electronics, LO M&C |
| AMP_PWR | 8V ± 0.2 V, <1 mV p-p ripple, 0.900 A | Warm IF amplifiers |

## 4.3. Cartridge Operating Parameters

In the following list, the number of polarizations and the number of items per polarization are indicated in parentheses – e.g. (2 x 2). Independent variables are indicated in red, dependent variables in blue. Fixed (non-adjustable) quantities are shown in green.

- Mixer: Each sideband separating mixer contains two SIS mixer chips and has one magnet circuit.
  - Bias voltage (2 x 2)
  - Bias current (2 x 2)
  - Magnet current (2)
  - Heater voltage (2)
- Preamp: Three stages + LED
  - First stage:
    - Drain voltage (2 x 2)
    - Gate voltage (2 x 2)
    - Drain current (2 x 2)
  - Second stage:
    - Drain voltage (2 x 2)
    - Gate voltage (2 x 2)
    - Drain current (2 x 2)
  - Third stage:
    - Drain voltage (2 x 2)
    - Gate voltage (2 x 2)
    - Drain current (2 x 2)
  - LED:
    - Voltage (2 x 2)
- Postamp-equalizer: Single supply
  - Voltage (2 x 2)
  - Temperature Sensor: on each mixer
  - Bias current (2)
  - Voltage (2)

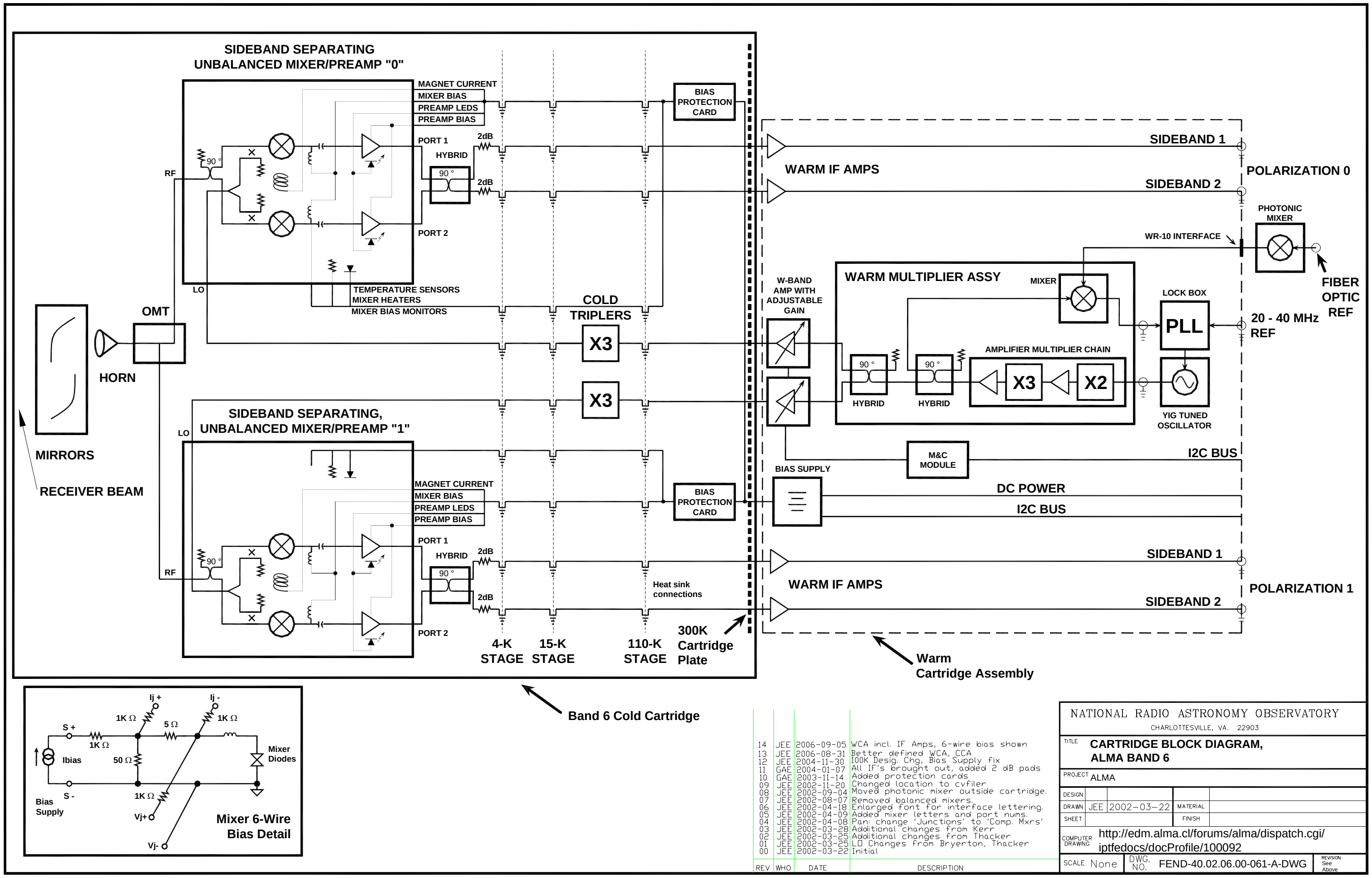


**Figure 3: Block diagram of the cartridge, including the Warm Cartridge Assembly (WCA)**

## 4.4. The Monitor & Control Interface

All the adjustable parameters of the cartridge are controlled through the cartridge monitor and control interface. The two main screens are shown in Figure 4 and Figure 5.

## 4.5. Room Temperature Cartridge Verification

Functional room temperature verification testing of the cartridge is completed using the following steps in conjunction with the Monitor and Control Interface, and the room temperature test data supplied with each cartridge [AD10].

With the cartridge at room temperature:

(a) Bias the four preamplifiers (12 stages) as indicated in the room temperature cartridge data [AD10]. Verify that monitored values are within the listed ranges.

(b) Bias the four mixer chips to the junction voltages indicated in the room temperature cartridge data [AD10]. Verify that monitored values are within the listed ranges.

(c) Adjust the two magnet currents to a **MAXIMUM** of +/- 10 mA; exceeding this level will damage the magnet circuitry at room temperatures. Verify that the appropriate magnet voltage and current [AD10] is displayed.

(d) Verify that the temperature sensors listed in the room temperature test data are reading properly.

(e) Momentarily enable the mixer defluxing heaters. Verify proper current levels.

(f) Momentarily enable the HEMT LED's. Visually confirm that all 6 LED's are illuminated, for each polarization.

(g) Record the I(V) characteristics of the four mixer chips and verify that they are close to those in the cartridge room temperature data [AD10].

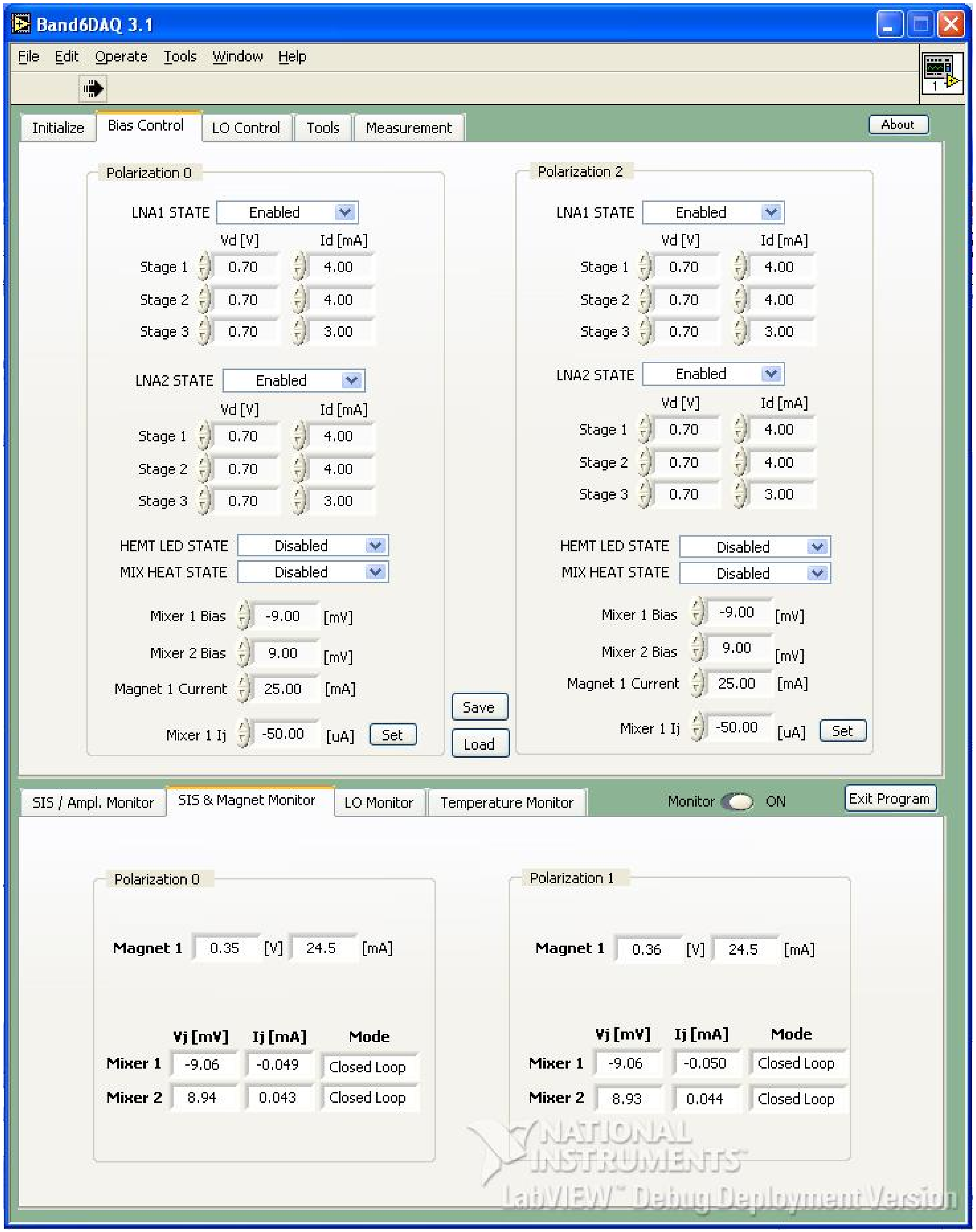


**Figure 4: Bias control interface**

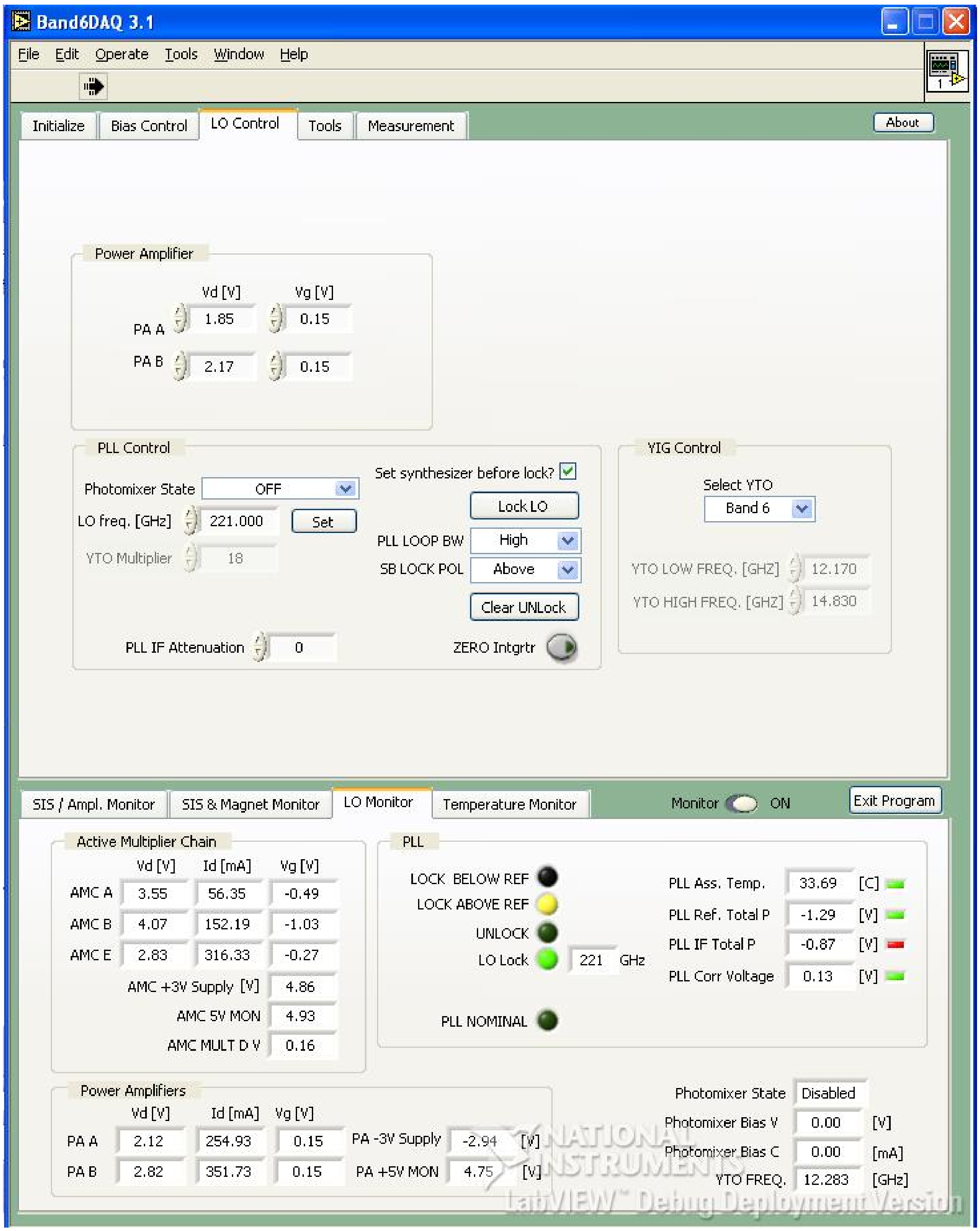


**Figure 5: LO control interface**

## 4.6. Cartridge Tuning Sequence

With the cartridge at its cryogenic operating temperature:

(a) Bias the four mixer chips to the junction voltages indicated in the cartridge data.

(b) Adjust the two magnet currents to the values indicated in the cartridge data.

(c) Bias the four preamplifiers (12 stages) as indicated in the cartridge data.

(d) (Power to the postamplifier-equalizer is always on when power is applied to the WCA.)

(e) Record the I(V) characteristics of the four mixer chips and verify that they are close to those in the cartridge data. Typical I(V) curves are shown in Figure 6.

(f) Turn on the LOs for each polarization channel as directed in the [AD7] with the desired LO frequency and minimum output power.

(g) Adjust the LO power to each polarization channel to give the mixer currents indicated in the cartridge data. An efficient procedure is described below.

(h) Record the pumped I(V) characteristics of the four mixer chips and verify that they are close to those in the cartridge data. Typical curves are shown in Figure 6.

(i) For each polarization channel, record the total IF power *vs.* mixer bias voltage over the range 8-10 mV (both mixers biased at the same voltage). If bumps or sharp features are present on the total power *vs.* bias voltage curve, adjust the magnet current to suppress them.

(j) If bumps remain on the total power vs. bias voltage curve, use the degaussing procedure described below and repeat step (i).

(k) Return the mixer bias voltages to the values given in the cartridge data.

The receiver is now ready for operation.

LO Power Optimization Procedure:

Adjust the LO Power Amp voltage between 0 and 2.5V to achieve mixer currents indicated in the cartridge data. An efficient procedure uses a PID algorithm with the following parameter values:

Proportional Gain (Kc) = -0.0002

Integral Time (Ti, min) = 0.001

Derivative Time (Td, min) = 0.001

This algorithm assumes mixer current in micro-Amps and Power Amp voltage in Volts.

Degaussing Procedure:

(a) Use the mixer heater to raise the mixer temperature to 12 K.

(b) Increase the magnet current to the maximum value $I_{max}$ (100 mA) given in the cartridge data.

(c) Monotonically decrease the current until it reaches the negative value $-I_{max}$.

(d) Monotonically increase the current until it reaches the positive value $0.5I_{max}$.

(e) Continue changing the current between positive and negative values in the sequence: + 100, -100, +50, -50, +20, - 20, +10, -10, +5, - 5,+2,-2, +1, -1, 0 mA.

(f) Switch off the mixer heater and allow the temperature to stabilize.

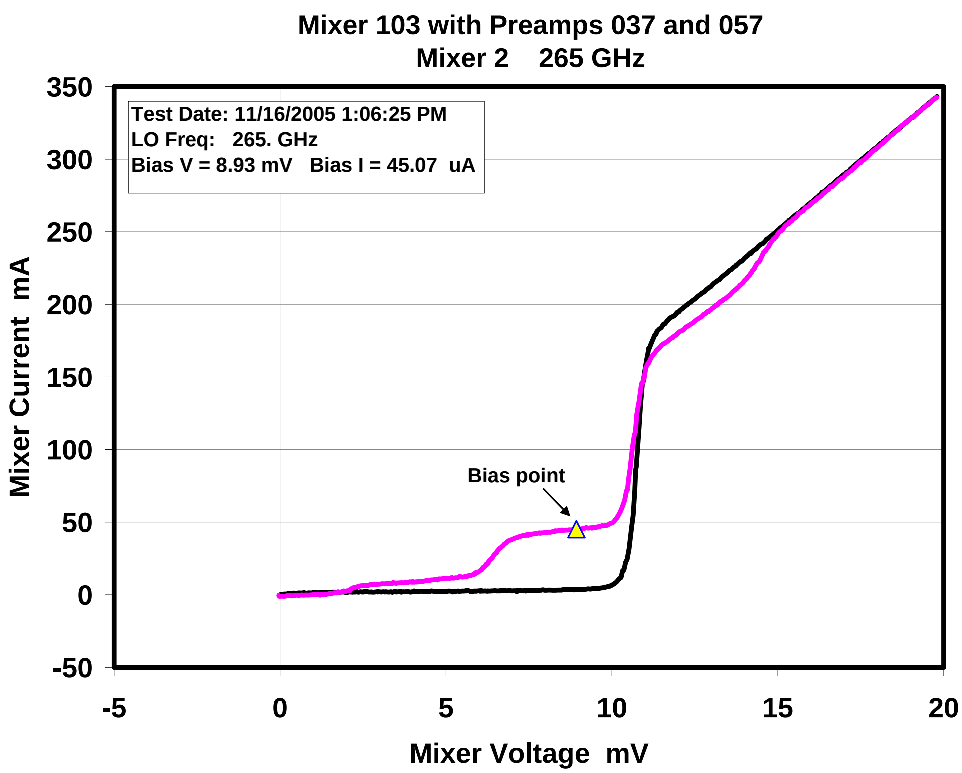


**Figure 6: Typical I(V) curves for a Band 6 mixer without LO power applied (black curve) and with LO power applied (pink curve).**

## 4.7. Verification of Cartridge Performance

The primary performance parameters of the cartridge installed in the receiver cryostat are, for each polarization:

1. Single-sideband receiver noise temperature $T_{R\ SSB}$ in each sideband.
2. Receiver gain $G_R$ in each sideband.
3. Image rejection IR in each sideband.

The receiver noise temperature is most easily determined using the Y-factor method with room-temperature and liquid nitrogen temperature black-body radiators placed in front of the receiver. Because the image rejection is imperfect, the measured upper- and lower-sideband receiver noise temperatures must be corrected as described in ALMA Memo 357 to obtain the true $T_{R\ SSB}$.. The procedure for this measurement is described in detail in [AD8].

The receiver gain can also be deduced from the above hot/cold load measurements. If the power at the receiver output, measured in a bandwidth B defined by a filter at the output, is $P_H$ with the hot load in front of the receiver, and $P_C$ with the cold load, the receiver gain $G = (P_H – P_C)/kB(T_H – T_C)$. This value of gain should be corrected for the imperfect image rejection, but if the image rejection ∃ 10 dB, the correction is less than 0.5 dB, which is not significant for most purposes. The procedure for this measurement is described in detail in [AD8].

The image rejection is measured using a small RF test signal (whose power level need not be known) first in one sideband then in the other. In each case, the LSB and USB IF output powers engendered by the test signal are measured. The image rejection for each sideband is deduced as described in ALMA Memo 357. The procedure for this measurement is described in detail in [AD9].