1. Introduction

This document provides software specifications for the cartridge measurement system. These specifications describe the cartridge characteristics that the software will measure, the plots provided, and tables available as output data. Such specifications are essential to prevent scope changes that always wreak havoc with software project schedules.

To simplify software design, coding, and testing, the cartridge measurement software will share many design elements with the mixer measurement software.

2. References

All data will be stored in a database, and the details of that design are available at

http://www.cv.nrao.edu/~jeffland/dbSchema3.pdf.

3. Software Specifications

Section 3.1 lists what the software will measure and subsequent sections describe how it will be measured.

3.1 List of Measurements

The "test receiver" in the cartridge measurement system consists of the cascade of the cartridge, warm IF system, and power sensors. The software will measure or calculate the following cartridge characteristics:

1. I-V curves
2. Magnet current
3. LO frequency[1]
4. LO power[2]
5. USB and LSB cartridge noise temperatures
6. USB and LSB cartridge gain
7. LO noise
8. Mixer physical temperature

Cartridge noise temperature and gain are calculated by measuring first the overall test receiver noise temperature and gain, then measuring and removing from those measurements the noise temperature and gain contributions of the warm IF system. This requires measuring the following additional characteristics:

9. USB and LSB test receiver noise temperature
10. USB and LSB test receiver gain
11. IF noise temperature
12. IF gain

Other ancillary measurements that are required either for calculating noise temperatures and gains or for general reference are:

13. RF hot load and IF hot and cold load physical temperatures[3]

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[1] See Section 3.4.3 for a discussion of limitations when measuring LO frequency.

[2] See Section 3.4.3 for a discussion of limitations when measuring LO power levels.

14. Dewar physical temperatures and compressor line pressures

3.2 Measured Parameters

Table 2 lists cartridge and test receiver characteristics that are measured by the system and will be stored in the database. Note that cartridge noise temperature and gain are calculated from these measured parameters and are listed in Table 3.

Table 2: Measured Parameters -- Cartridge Testing

Parameter	Notes
Mixer Bias	
Voltage	
Current	
Magnet current	
LO frequency	
LO power	
Effective cold load temperature	
Physical Temperatures: RF Hot load[3] 90K stage 20K stage 4K stage Mixer	
Refrigerator Pressures Supply side Return side	
Warm IF system attenuator value	
Frequency of the IF system	
Noise Powers with: • Test receiver connected to hot load • Test receiver connected to cold load • Warm IF system connected to noise diode turned on • Warm IF system connected to noise diode turned off	

3.3 Calculated Parameters

Table 3 lists the characteristics that are calculated from the measured data stored in the database. The calculated parameters will be stored in the database but can always be derived again from the stored measured data.

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[3] RF *cold* load temperature is not measured but is treated by the software as a parameter that can be changed manually and is used as the effective cold load temperature during noise temperature calculations.

Table 3: Calculated Parameters -- Cartridge Testing

Calculated Parameter	Notes
Receiver USB and LSB noise temperature	
Cartridge USB and LSB noise temperature	
Receiver gain	
Cartridge gain	
Warm IF system noise temperature	
Warm IF system gain	
Standard deviation of mixer bias current	(Identifies instabilities)
LO noise	

3.4 Measurement Procedures

The cartridge test software uses interim bias cards and monitor and control boards provided by Tucson. In most cases, manual control of the interim bias cards and M&C boards *via* a front-panel knob is not possible and requires the computer.

3.4.1 I-V Curves

The system will command the bias voltage to sweep between limits set by the operator. Mixer bias and voltage will then be read back by the software *via* the monitor and control system and stored in a database. This means the bias voltage stored in the database may not exhibit equal step sizes.

3.4.1.1 Manual Intervention

The operator sweeps the mixer bias voltage, observes the I-V curve on the oscilloscope, and manually adjusts the Tucson-provided magnet current (using the CAN bus) to minimize the Josephson peaks.

3.4.1.2 Risks

The bias supplies and software control must be able to change the bias voltage rapidly so the operator can quickly minimize the Josephson peaks. The interim bias supplies are controlled via the CAN bus and it is unknown how fast the mixer bias voltage can change using the interim supplies. In the production version of the bias supplies, which will be controlled using the I^2C bus, it is essential to specify how fast the bias voltage must change so that the Josephson peaks can be identified and reduced.

3.4.2 Measurement of Magnet Current

The interim system measures magnet current using the Tucson-designed magnet supply that is controlled *via* the CAN bus. The magnet supply on the production system will most likely be controlled using the I^2C bus.

3.4.2.1 Risks

None

3.4.3 LO Frequency and LO power

The system will command the active multiplier and other modules associated with the LO to the proper frequency and power level. The power level will be controlled using the gate voltage on a W-Band power amplifier.

3.4.3.1 Risks

There are no plans to verify independently the frequency or power level of the LO. The measurement system cannot detect if the LO locks on a spurious signal and outputs the LO at an erroneous frequency. In addition, no independent monitoring of LO output level is planned. The LO level will be measured as a function of the amplifier gate voltage *a priori* using a power meter and the results will be stored in a database look-up table. Multiplier changes or even simple waveguide changes could render the lookup table obsolete.

3.4.4 Receiver Noise Temperature

The noise temperature of the entire measurement system, including the cartridge and warm IF systems, will be measured using a chopper wheel to switch automatically between the RF hot and cold loads.

Noise power will be measured with the power meter and perhaps the square law detector. Although the power meter should yield potentially higher accuracy measurements, a noise diode is also planned for the system to provide graphs of estimated receiver noise temperatures in real-time for tuning. It is hoped to use the noise diodes for the formal noise measurements to significantly decrease measurement times.

3.4.4.1 Risks

None

3.4.5 Cartridge and IF Noise Temperatures

The noise temperature of just the cartridge, without the noise added by the warm IF subsystem, will be measured by subtracting from the receiver temperature the noise contribution of the warm IF system. Noise figure and gain of the warm IF subsystem will be measured by using a noise diode to generate a known noise ratio at its input. The noise diode output level will be adjusted using an attenuator to deliver about the same noise power to the warm IF as is delivered by the cartridge.

3.4.5.1 Risks

None

3.4.6 Cartridge and IF Gain

Cartridge gain at each IF is found using the usual "$\Delta P/\Delta T$" equation by taking the ratio of measured noise powers to temperatures when the receiver input is connected to hot and cold loads. The gain of the receiver, which includes the cartridge and the warm IF subsystem, is obtained by alternately changing the receiver's beam between hot and cold loads using the chopper wheel:

$$G_{RF} = \frac{1}{kB}\left(\frac{P_{hRF} - P_{cRF}}{T_{hRF} - T_{cRF}}\right)$$

where

G_{RF} is the total receiver gain,
P_{hRF} is the power output from the total receiver when its input is connected to a hot load,
P_{cRF} is the power output from the total receiver when its input is connected to a cold load,
T_{hRF} is the radiometric temperature of the hot load connected to the RF input,
T_{cRF} is the radiometric temperature of the cold load connected to the RF input.

In a similar way, the gain of the warm IF subsystem is measured using a noise diode at its input to provide known noise powers corresponding to the diode's biased (on) and unbiased (off) states.

Gain of just the cartridge is found by normalizing overall receiver gain by the warm IF system gain, which becomes:

$$G_{Cartridge} = \left(\frac{P_{hRF} - P_{cRF}}{P_{hIF} - P_{cIF}} \right) \left(\frac{T_{hIF} - T_{cIF}}{T_{hRF} - T_{cRF}} \right)$$

where

$G_{Cartridge}$	is the gain of the cartridge,
P_{hRF}	is the power output from the receiver when its input is connected to a hot load,
P_{cRF}	is the power output from the receiver when its input is connected to a cold load,
P_{hIF}	is the power output from the IF system when its input is connected to a biased noise diode,
P_{cIF}	is the power output from the IF system when its input is connected to an unbiased noise diode,
T_{hRF}	is the radiometric temperature of the hot load connected to the receiver input,
T_{cRF}	is the radiometric temperature of the cold load connected to the receiver input,
T_{hIF}	is the equivalent noise temperature of the biased noise diode connected to the IF input, and
T_{cIF}	is the equivalent noise temperature of the unbiased noise diode connected to the IF input.

3.4.6.1 Risks

None

3.4.7 LO Noise

LO equivalent noise temperature, referred to the Dewar input, will be measured by comparing noise powers when the component mixers are normally biased (*i.e.* mixer bias voltages are of opposite polarities) and when both component mixers are supplied with the same polarity bias voltages. See http://www.cv.nrao.edu/~jeffland/LOTemps6.pdf for the measurement theory.

3.4.7.1 Risks

None

3.4.8 Sideband Rejection Ratio

The sideband rejection ratio will be determined from measuring IF output levels while reversing mixer bias with a constant signal injected by the sideband source. Only one sideband is output from the cartridge, so sideband rejection cannot be measured with the general technique described in Kerr *et. al.'s* ALMA Memo 357.

3.4.8.1 Risks

Measuring sideband rejection ratio with only one IF output available from each polarization hasn't been tested thoroughly so subtle effects may degrade measurements accuracy.

3.4.9 Dewar Physical Temperatures and Pressures

The system will monitor and record physical temperatures of the following stages:

90K

20K
4K
Mixer
RF hot load

The following pressures will also be recorded:

Refrigerator supply line
Refrigerator return line
Vacuum pump vacuum
Dewar vacuum

3.4.9.1 Risks

Different programs cannot generally share commanding and reading the same instruments, such as temperature meters. Ideally, a monitoring program will constantly monitor and record in the database temperatures and pressures, but that prevents the measurement programs from also collecting temperatures. One solution is to store the most recent temperature and pressure data into a shared memory array that multiple programs could access.

3.5 Results

Table 4 itemizes the graphs of measurement results that will be available from the system. All graphs will be 2-dimensional types because 3-dimensional plots, while useful for R&D purposes, have limited utility for documenting the results of production systems.

Table 4: Graphs Available from Cartridge Measurement Software

Dependent Variable	Independent Variable	Parameter	Notes
Mixer bias current	Mixer bias voltage	LO on LO off	
Total power at a particular IF	Mixer bias voltage	Rcvr switched to RF hot load Rcvr switched to RF cold load	Total power can be graphed on the same plot as I-V data
Receiver noise temperature	IF	LO frequency	
	LO frequency	IF	
	Mixer bias voltage	LO frequency	Fixed IF
		IF	Fixed LO
Cartridge noise temperature	IF	LO frequency	
	LO frequency	IF	
Cartridge gain	IF	LO frequency	
	LO frequency	IF	
IF noise temperature	IF	LO frequency	Referred to receiver input
IF gain	IF		Referred to receiver input
Dewar physical temperatures and pressures	Time		

3.6 Optimum Mixer Operating Point

The software will record into the database the optimum mixer operating point for each LO frequency. The optimum operating point includes the following characteristics:

1) Mixer bias voltage,

2) Mixer bias current,
3) Magnet current, and
4) LO power.

Future effort will involve actually determining the optimum mixer operating point, as discussed in Section 3.9 below.

3.7 Diagnostic Tests

Experience with the JT-2 mixer measurement system demonstrated the importance of confirming that the warm IF system is operating nominally by measuring its noise figure and frequency response.

Software will be developed to use a suitable 3-13 GHz signal generator and measure the gain as a function of IF. A noise diode (which can be controlled by the computer using the existing driver in the Switch Chassis) will be controlled to measure the noise temperature of the warm IF system.

LO power will be controlled by changing the gate voltage on the HFET in the W-Band power amplifier. Software will measure and store in the database the LO power output from the LO plate as the command voltage is changed.

Table 5: Diagnostic Tests and Data

Dependent Variable	Independent Variable	Parameter	Notes
Gain of warm IF system	IF	IF attenuator value	
Noise Temperature of warm IF system	IF	IF attenuator value	
LO power	LO level control command voltage	LO frequency[2]	

3.8 Automation of Cool-Down Tasks

The software will monitor Dewar temperatures and pressures, and when the Dewar temperature is sufficiently low, the software will automatically throw the vacuum valve and turn off the vacuum pump.

3.9 Determination of Optimum Bias Point

The software shall search the following parameter space to find the volume containing the optimum noise temperature:

1. Bias voltage
2. Bias current
3. Magnet current
4. LO power
5. IF Frequency

The optimum volume in this multi-dimensional space is defined as that region with the lowest possible noise temperature consistent with a stable bias voltage and current, which is determined by the suppression of Josephson effects. A limit on the standard deviation of the bias current shall be used to determine the acceptable range for the optimum.