# Memorandum

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| **To:** | File |
| **From:** | John Effland<br>John Webber |
| **Date:** | 2006-09-11 |
| **Revisions:** | 00 2006-09-05 jee Initial<br>01 2006-09-06 jee Incorporated Observing Scenario by Webber<br>02 2006-09-11 jee Changed sys temps to refer above atmosphere<br>03 2006-09-11 jcw Updated numbers in Table 1 |
| **Subject:** | Noise Temperature and Gain Slope Considerations for Band 6 Cartridge Operating over 4-12 GHz IF Band |

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2007.08.25 11:56:06 -04'00'

## 1. Summary, Conclusion, and Recommendations

This memo presents noise temperatures and noise power density slopes for the Band 6 Cartridge measured across the formal IF band from 6-10 GHz and also across the wider 4-12 GHz IF band. Although the number of cartridges measured is small, data measured to date suggests that Band 6 specifications could be met over the 4.5 to 11 GHz IF band. A straw man plan for spectral line observation is included.

It is recommended that formal changes should be made to IF bandwidth specifications for the Band 6 cartridge to prevent scheduling and production demands from further degrading performance outside the 6-10 GHz band.

## 2. Data

### 2.1 Noise Temperatures and Image Rejection

Figure 1 is a graph of noise temperature and image rejection of polarization 0 for Band 6 Cartridge 001 which is now in final acceptance testing. Figure 2 is the same measurements for polarization 1. Noise temperature specifications are easily met over the 6-10 GHz IF band and could likely be met over the 4.5 to 11 GHz IF band. Image rejection meets 10 dB specifications over the entire 4-12 GHz IF band.

IF bandwidth of the cartridge noise temperature is a strong function of the mixer's integrated preamplifier performance. That is, gain and noise temperature of the preamplifier generally determine the IF bandwidth of the mixer-preamplifier. Figure 3 summarizes the performance of all 37 preamplifiers built to date and includes the revised specification that should provide acceptable mixer-preamplifier performance from 4.5 GHz to 11 GHz.

### 2.2 Power Density and Power Density Slope

IF bandwidth of the Band 6 Cartridge is more limited by excessive slope of noise power density than by noise temperature bandwidth. The noise power density output from the cartridge is comprised of a mixer-preamplifier noise temperature term and another term that accounts for amplification of noise power input to the receiver.

Receiver gain amplifies the sky noise and ground pickup from sidelobes, and high gain slope maps directly to excessive slope in noise power density.

Cartridge power available in 100 MHz bandwidth was calculated from the following formula:

$$P_{100MHz}(f) = kB[T_{Source} + T_{Rx}(f)]G(f) \qquad \text{Eq. 1}$$

where:
- $P_{100\text{MHz}}(f)$ = receiver noise power (W) in 100 MHz bandwidth at cartridge output when observing a load at a temperature of $T_{Source}$ at an RF frequency of *f*.
- $T_{Rx}(f)$ = receiver noise temperature (K) at a particular RF
- $G(f)$ = cartridge gain at a particular RF
- k = Boltzmann's constant ($1.38 \times 10^{-23}$ W/K-Hz)
- B = equivalent noise bandwidth (approx. 100 MHz)

The source temperature, $T_{Source}$, is specified in the Band 6 Cartridge ICD to be 300K and consequently that temperature is used when testing the receiver.

Cartridge gain, *G(f)*, is calculated by differencing system noise power when the receiver is connected to hot and cold loads and dividing by the difference in the hot and cold load physical temperatures. This is the standard "ΔP/ΔT" technique and implementation details for the Band 6 cartridge are given on ALMA EDM[1].

The power density graphs plot output power density for each polarization's LSB and USB channels at each LO frequency. Power density calculations span the entire 4–12 GHz IF with bold sections depicting the 6-10 GHz spec band. Reducing the effective temperature viewed by the receiver beam can decrease the slope of the power density. Figure 4 compares noise power density (BW = 100 MHz) for both polarizations when the receiver is viewing:

- a 300K ambient load and
- 35K estimated for cold sky plus ambient terrain through sidelobe spill-over[2].

Note that there's little difference in slope for the two different input temperatures. All noise density slopes shown in this report are corrected by assuming the warm IF amps have integrated equalizers with 12 dB of compensating gain slope. These integrated amplifier-equalizers are on order but not yet delivered from the warm amplifier vendor AML Communications.

The Band 6 cartridge specification has two requirements for gain slope:

1) over any 2 GHz IF sub-band and
2) over the entire 4 GHz IF band.

To calculate gain slope over 2 GHz sub-bands, for each LO frequency, absolute values of maximum and minimum gains are subtracted from each other over a 2 GHz bandwidth with sliding center frequency. The result is a locus of gain slope values as the 2-GHz center frequency is slid across the entire IF bandwidth.

The green curves in the gain slope graphs show gain slope calculated over the 2 GHz bandwidth with sliding center frequency. The bold section of each curve identifies the specified 6-10 GHz IF band. The specification for maximum power density over 2 GHz is shown by the green dashed lines at 4 dB.

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[1] "Band 6 Cartridge Test Procedure Noise Performance, Gain, and Gain Slope," FEND-40.02.06.00-076-A-PLA, 2006-04-26, http://edm.alma.cl/forums/alma/dispatch.cgi/iptfedocs/docProfile/101778

[2] System temperatures calculated in Appendix 1: Observing with Band 6 Cartridge 001 include an additional 7% receiver temperature to refer them above the atmosphere.

Noise power density slopes are shown in Figure 5 across a sliding 2-GHz IF bandwidth. Also shown in the figure is the 4 dB specification. The thicker curves are slopes for the 6-10 GHz IF band and the thinner curves show slopes for the entire 4-12 GHz band. Note that the slopes are met across the 6-10 GHz IF band with polarization 0 (assuming the equalizer is used) but exceed specifications for polarization 1. Both polarizations exceed noise power density slope specifications across the 4-12 GHz IF band. Reducing the input temperature from 300K to 35K reduces the maximum slopes by up to 1 dB.

Power density slope over the entire IF band, formally spanning 6-10 GHz, is calculated by subtracting the absolute values of the maximum and minimum gains in this 4 GHz bandwidth. This produces a single power density slope number for each LO frequency as shown by black points in the graphs. Maximum power density specifications over the entire IF band are shown by the black dashed line in the graphs.

Figure 6 shows noise power density slopes across the 6-10 GHz IF band. Receiver input temperatures of 35K change these slopes by a maximum of 0.5 dB.

# 3. Appendix 1: Observing with Band 6 Cartridge 001

Figure 7 and Figure 8 are graphs of noise temperature and image rejection for cartridge #1 for both polarizations at an LO frequency of 225 GHz. While we do not have adequate statistics for cartridges, the statistics for mixer-preamps suggest that other cartridges will be similar—but this is not guaranteed!

From these data, we calculate approximate system noise temperatures on the sky, assuming typical observing conditions for Band 6 (tau=0.07) give 35K contribution from sky, spillover, and resistive losses. The system temperatures are referred to above the atmosphere by including an additional 7% receiver noise temperature.

## 3.1 Noise Temperatures on the Sky

The minimum system noise will be in the 6-7 GHz area for both polarizations, and is about 78K for polarization 0 and 67K for polarization 1. In typical line observing, these will simply be averaged to give about 73K average system temperature. The corresponding value at 4.5 GHz IF is about 99K, and at 11 GHz it is about 105K.

## 3.2 Straw Man Observing Plan

A possible observing plan based on a set of lines suggested by Debra Shepherd has been used to generate a table of predicted system noise temperatures for 8 spectral lines in the region 219.945 to 230.538 GHz. We have chosen a first LO frequency of 225.039 GHz, which places $SO_2$ and $CH_3CN$ lines both at 4.309 GHz, one in upper and one in lower sideband. If this overlap is undesirable, a slight shift of the LO frequency by up to 100 MHz either direction would produce essentially the same results.

Table 1 shows the calculated system temperature for each of 8 spectral lines, averaged over the two polarizations, for this choice of first LO, under the assumption of 35K added noise for atmosphere and sidelobes and 7% more receiver noise added to refer the system temperature above the atmosphere.

| Table 1: Predicted System Noise Temperatures for Spectral Line Observations[3] | | | | |
|---|---|---|---|---|
| **Molecule** | **Sky freq (GHz)** | **First IF freq (GHz)** | **Sideband** | **$T_{sys}$ (K)** |
| $^{12}C^{18}O$ | 219.560 | 5.479 | L | 86 |
| SO | 219.945 | 5.094 | L | 97 |
| $CH_3OH$ | 220.079 | 4.960 | L | 99 |
| $^{13}C^{16}O$ | 220.398 | 4.641 | L | 103 |
| $CH_3CN$ | 220.730 | 4.309 | L | 101 |
| $SO_2$ | 229.348 | 4.309 | U | 96 |
| $CH_3OH$ | 229.759 | 4.720 | U | 101 |
| $^{12}C^{16}O$ | 230.538 | 5.499 | U | 84 |

## 4. Acknowledgements

The authors would like to thank Dave Schmitt for measuring the cartridge receiver noise temperatures.

[3] Calculations stored in sheet “StrawManPlan” in \\cvfiler.nrao.edu\cv-cdl-sis\Cartridge\SysEngr\GainSlope\TsysCart001.xls

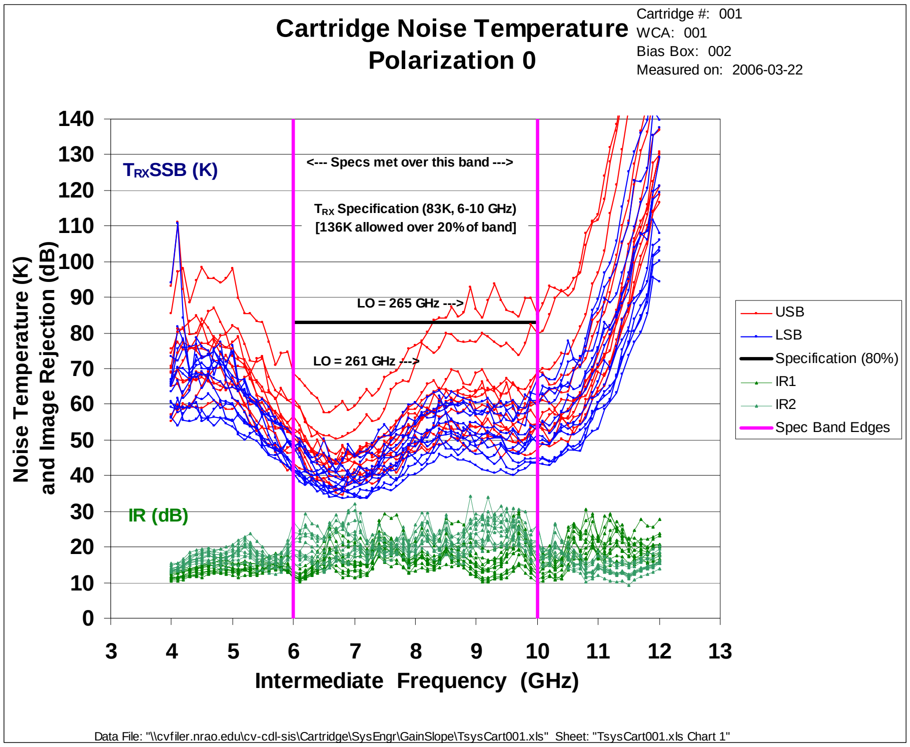



**Figure 1: Receiver Noise Temp and Image Rejection, Pol 0, Band 6 Cartridge 001**

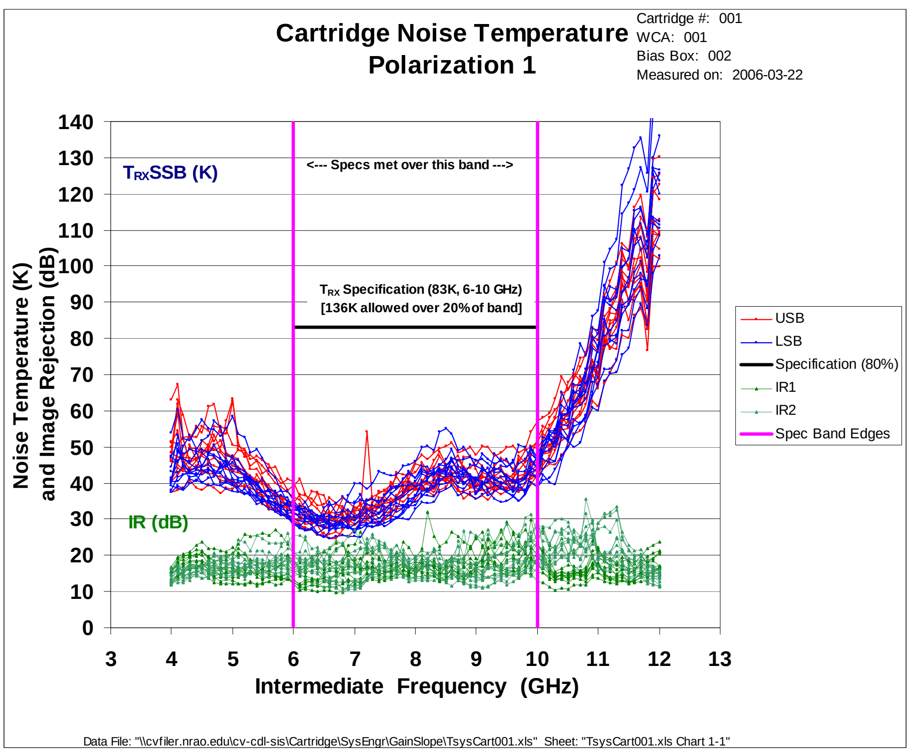



**Figure 2: Receiver Noise Temp and Image Rejection, Pol 1, Band 6 Cartridge 001**

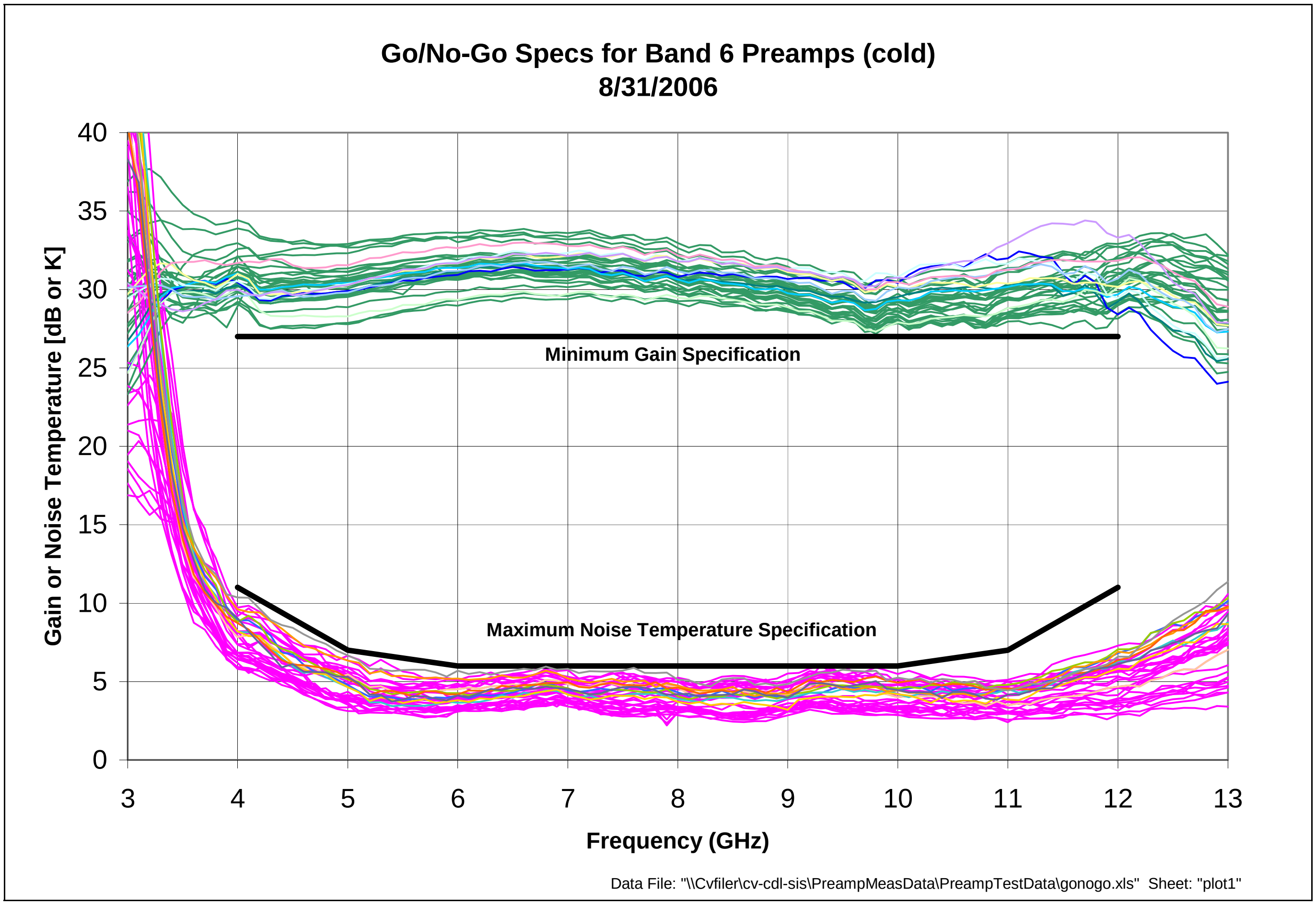
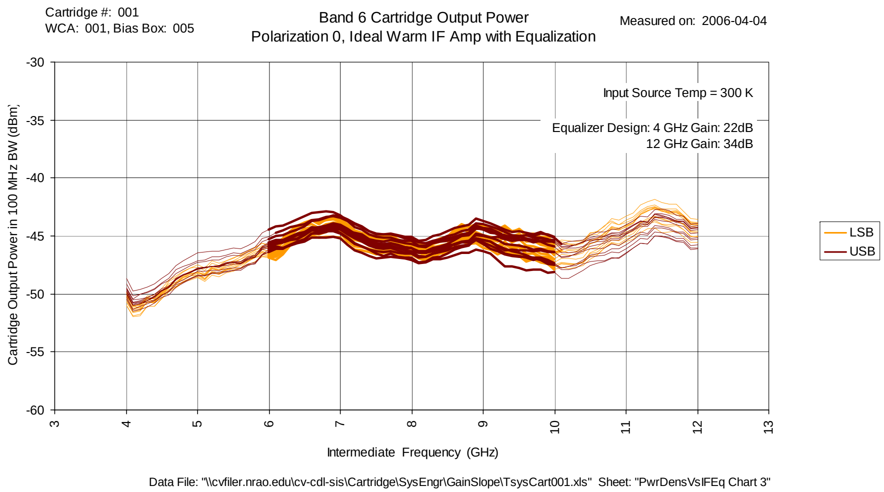
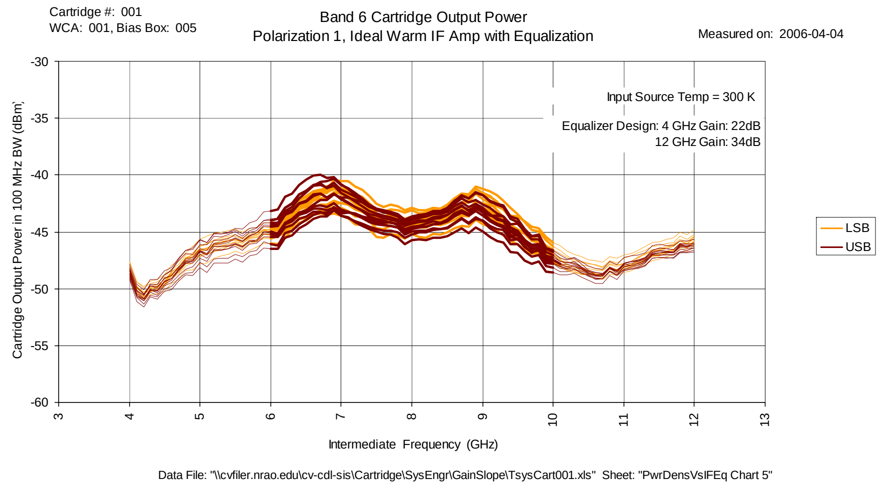



**Figure 3: Widened Spec Masks for IF Amplifiers**

**Figure 4: Noise Power Density, Assuming Equalizers in Warm IF Amps**

<table>
<tr><td></td><td>Polarization 0</td><td>Polarization 1</td></tr>
<tr><td>$T_{sky} + T_{spillover} = 300K$</td><td>
</td><td>
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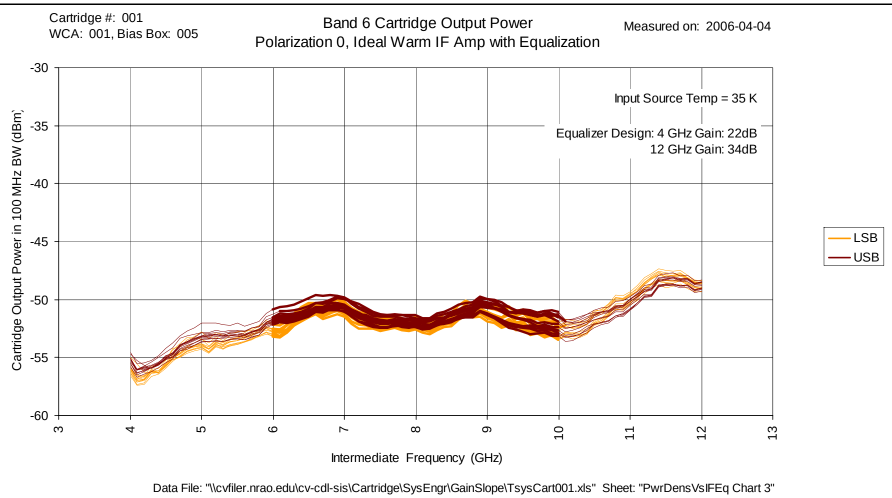
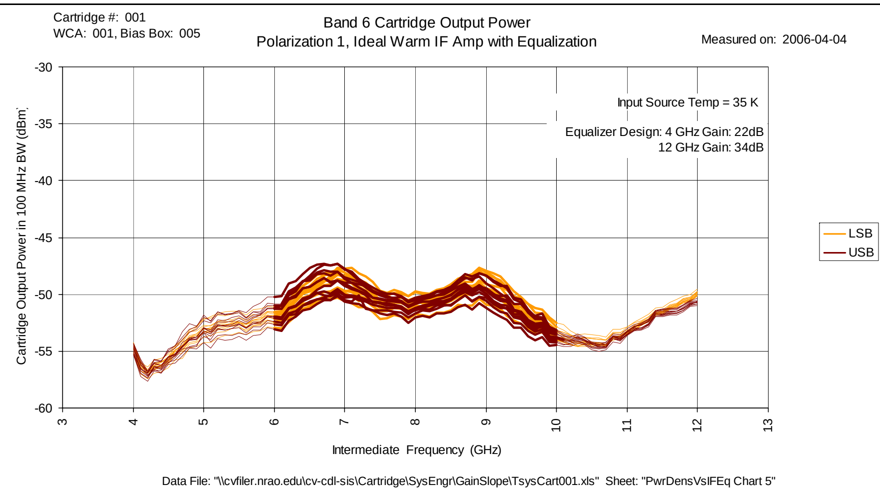
<tr><td>$T_{sky} + T_{spillover} = 35K$</td><td>
</td><td>
</td></tr>
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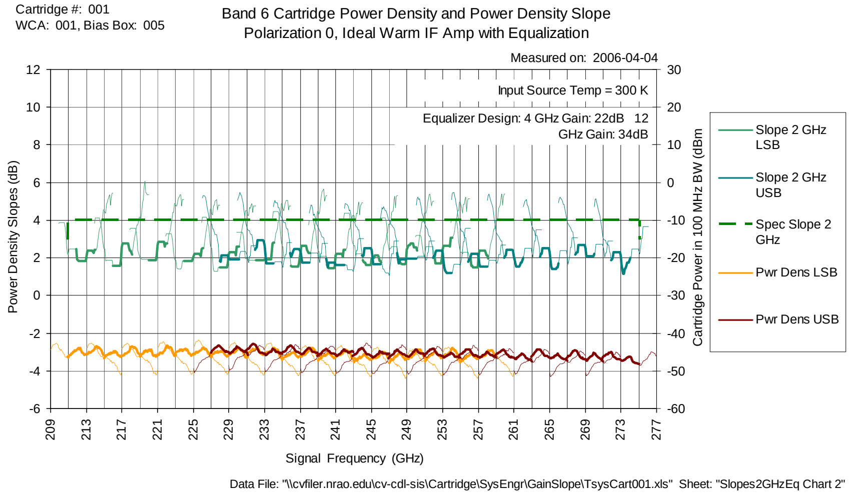
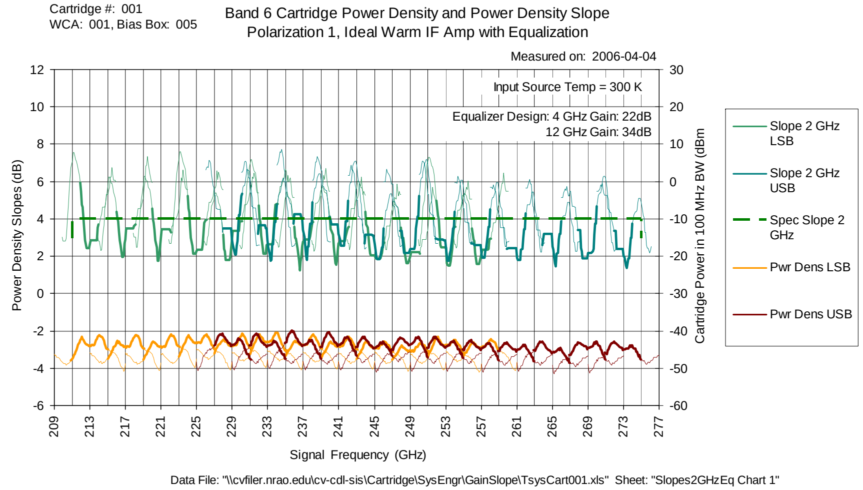
## Figure 5: Gain Slope in 2 GHz IF Bandwidth, Assuming Equalizers in Warm IF Amps

### $T_{sky} + T_{spillover} = 300K$

**Polarization 0**

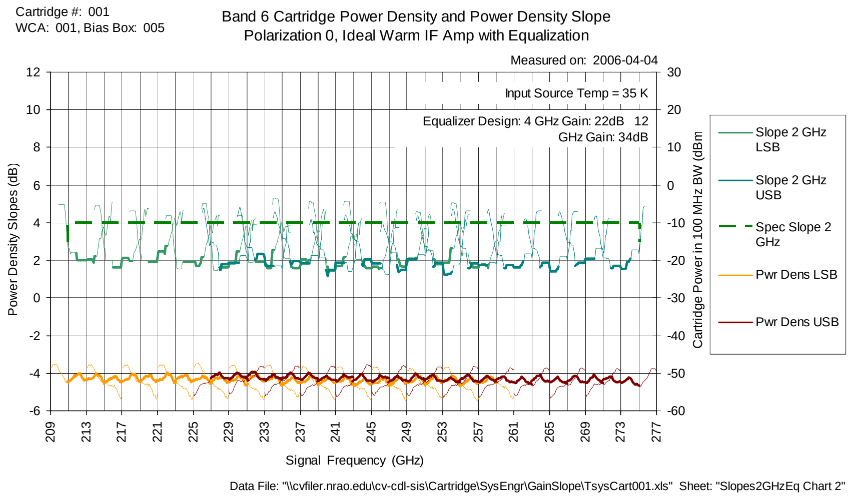



**Polarization 1**




### $T_{sky} + T_{spillover} = 35K$

**Polarization 0**




**Polarization 1**

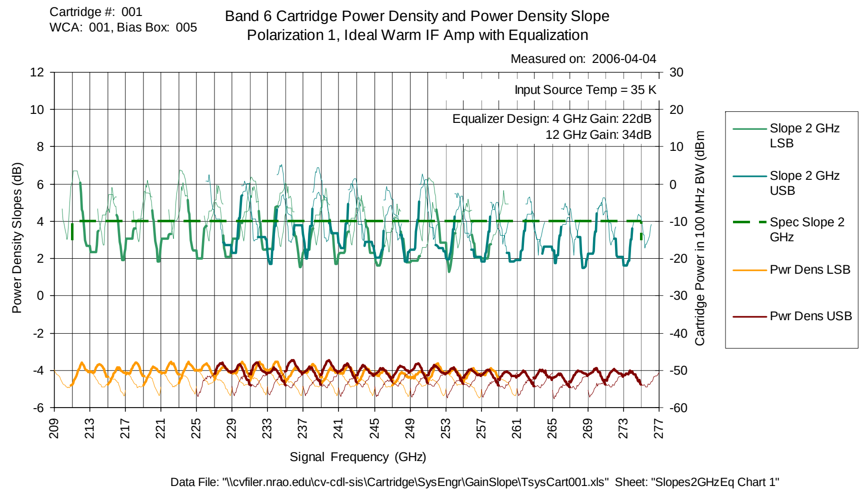
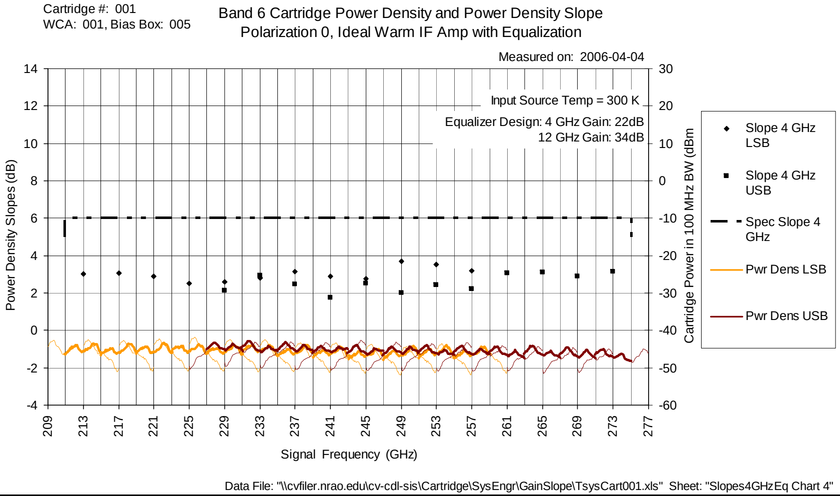
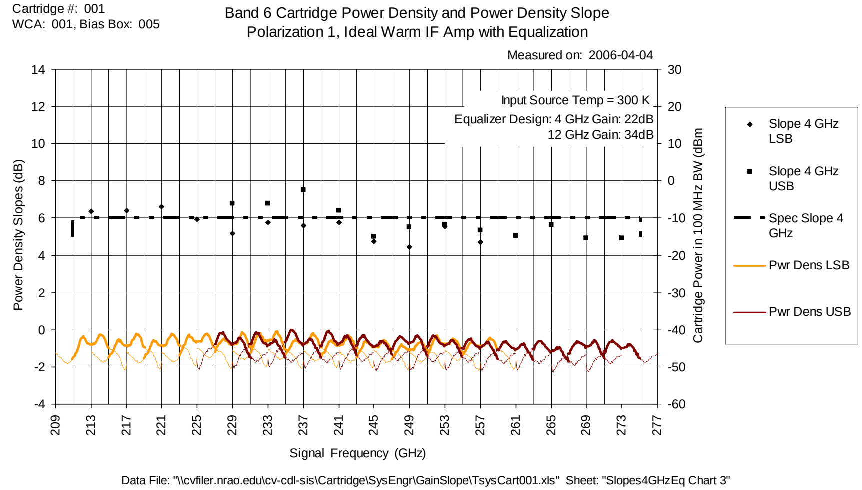
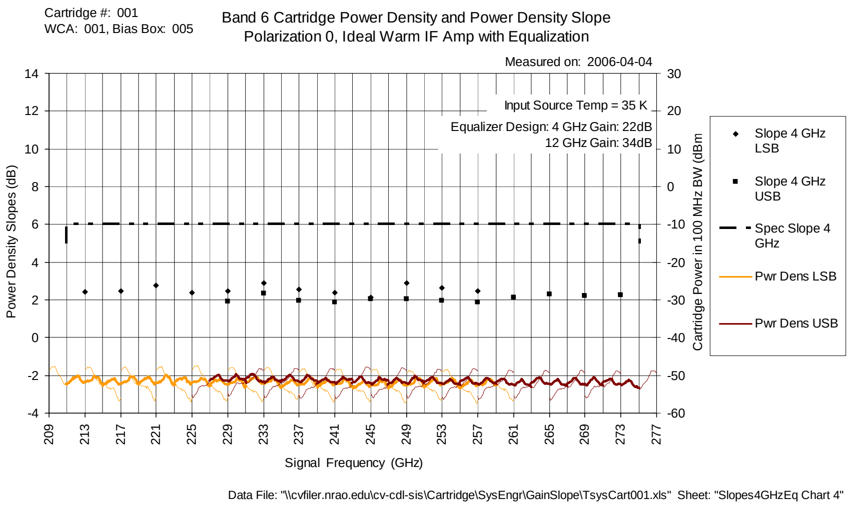
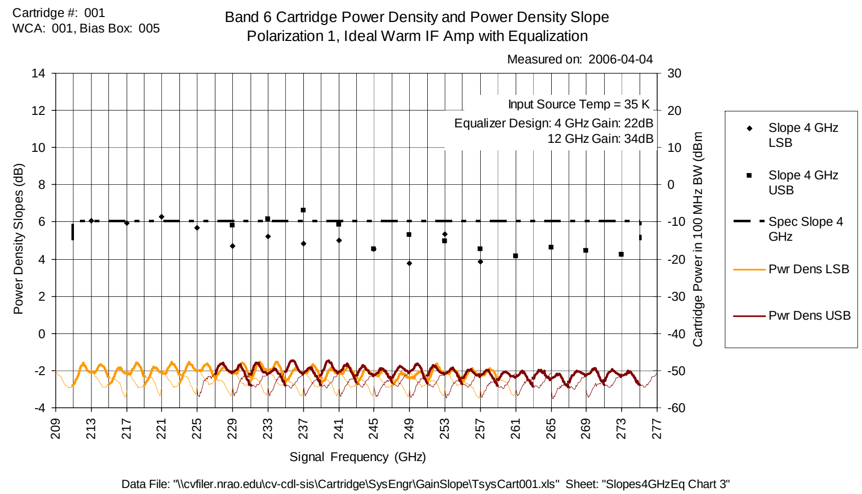


**Figure 6: Gain Slope in 4 GHz IF Bandwidth, Assuming Equalizers in Warm IF Amps**

| | Polarization 0 | Polarization 1 |
|---|---|---|
| $T_{sky} + T_{spillover}$ = 300K |  |  |
| $T_{sky} + T_{spillover}$ = 35K |  |  |

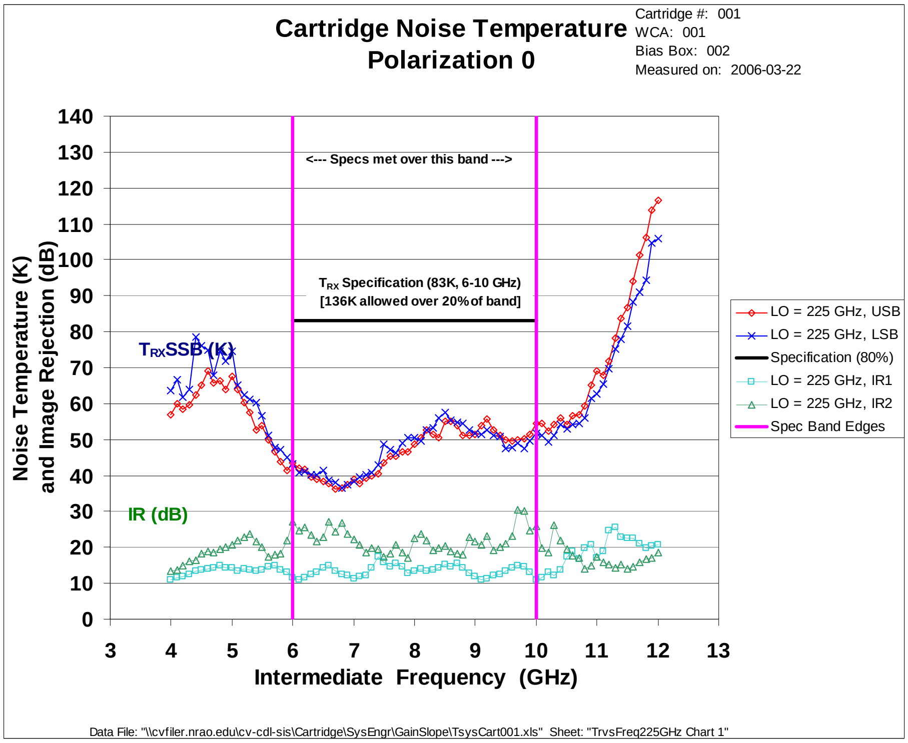



**Figure 7: Receiver Noise Temperature for LO = 225 GHz, Pol 0**

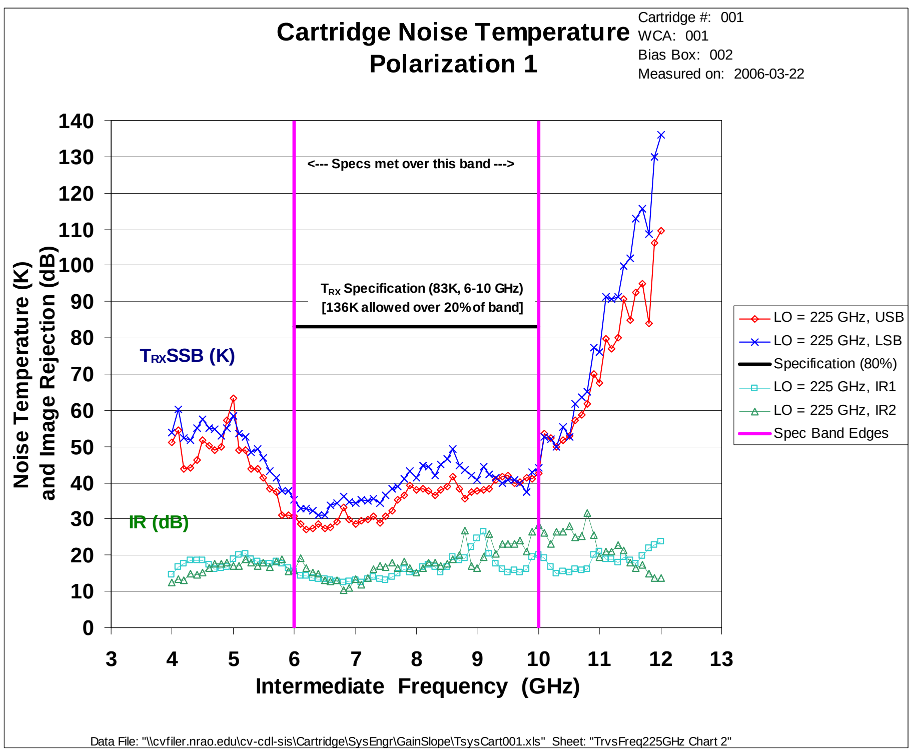



**Figure 8: Receiver Noise Temperature for LO = 225 GHz, Pol 1**