# Memorandum

**To:** File

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**Date:** 2006-05-10

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**Subject:** Gain Slope Correction Using Warm IF Amps for Band 6 Cartridges

## 1. Summary

Previous results for the Band 6 Cartridge showed gain slopes exceeding specifications by 5.1 dB for the 2 GHz spec and 6.6 dB for the 4 GHz spec[1]. Passive equalization analyzed in that memo shows dramatic improvement in gain slope, but at the expense of output power levels which fall as much as 8 dB below specifications.

This memo describes how equalizers in the warm IF amplifiers improve gain slope performance while maintaining output power levels that meet specifications. A summary of cartridge performance compared to specifications with and without equalization is given in Table 1.

**Table 1: Gain Slope and Output Power Summary**

| **Specifications** | | **Results (6-10 GHz IF)<br>Entries in bold exceed specs** | |
|---|---|---|---|
| | | **No Equalizer** | **Equalizer in Warm IF Amps** |
| Gain Slope, Any 2 GHz | ≤ 4 dB P-P | Cart 001:<br>Pol 0: **5.5** dB<br>Pol 1: **9.0** dB<br>Cart 003:<br>Pol 0: **5.3** dB<br>Pol 1: **9.1** dB | Cart 001:<br>Pol 0: 3.2 dB<br>Pol 1: **6.0** dB<br>Cart 003:<br>Pol 0: 3.0 dB<br>Pol 1: **4.2** dB |
| Gain Slope, 4 GHz IF band | ≤ 6 dB P-P | Cart 001:<br>Pol 0: **9.7** dB<br>Pol 1: **12.6** dB<br>Cart 003:<br>Pol 0: **9.3** dB<br>Pol 1: **9.8** dB | Cart 001:<br>Pol 0: 4.0 dB<br>Pol 1: **7.8** dB<br>Cart 003:<br>Pol 0: 3.1 dB<br>Pol 1: **6.9** dB |
| IF Power Output | $P_{min} \geq$ - 27 dBm | Cart 001:<br>Pol 0: **-27.5** dBm<br>Pol 1: -24.0 dBm | Cart 001:<br>Pol 0: -25.2 dBm<br>Pol 1: -23.5 dBm |
| | $P_{max} \leq$ -23 dBm | Cart 001:<br>Pol 0: **-20.7** dBm<br>Pol 1: **-19.5** dBm | Cart 001:<br>Pol 0: **-19.7** dBm<br>Pol 1: **-19.5** dBm |

## 2. Calculation of Gain and Gain Slope

Cartridge gain was calculated by taking the difference in system noise power when the receiver is connected to hot and cold loads and dividing that difference 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[2].

The bottom orange and brown curves of the gain slope graphs plot cartridge gain for LSB and USB channels for each LO frequency. The graphs include cartridge gains spanning the entire 4–12 GHz IF with bold sections depicting the 6-10 GHz spec band.

[1] "Gain Slope Measurements of Band 6 Cartridges 001 and 003," FEND-40.02.06.00-097-A-TDR, 2006-05-01, http://edm.alma.cl/forums/alma/dispatch.cgi/iptfedocs/folderFrame/102148

[2] "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

As shown in Table 1, 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 curve 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. Again, the bold section of each curve identifies the specified 6-10 GHz IF band. The maximum gain slope specification is shown by the green dashed lines at 4 dB.

Gain slope over the entire IF band, formally spanning 6-10 GHz[3], is calculated by subtracting the absolute values of the maximum and minimum gains over this 4 GHz bandwidth. This produces a single gain slope number for each LO frequency as shown by black points in the gain slope graphs. The corresponding gain slope specification for the entire IF band is shown as the black dashed line in the graphs.

## 3. Total Power Calculations

Total power for the specified bandwidth was calculated for at LO frequency using the following equation:

$$P_{tot} = kB \sum_{f=10GHz}^{f=6GHz} \left[300 + T_{Rx}(f)\right] G(f)$$

Where: $P_{tot}$ = total receiver noise power (W) at cartridge output when observing 300K load

$T_{Rx}(f)$ = receiver noise temperature (K) at the measured IF

$G(f)$ = receiver gain at the measured IF

k = Boltzmann's constant ($1.38 \times 10^{-23}$ W/K-Hz)

B = equivalent noise bandwidth (approx. 100 MHz)

300 = receiver input temperature given in total power specification (K).

A similar calculation yields total power over the entire 4-12 GHz band. It is important to note that gain above 12 GHz and below 4 GHz exists for the Band 6 cartridge but is not included in these calculations. Future lab measurements will quantify the out-of-band power and validate the calculations in this report.

## 4. Equalizer Calculations

To predict gain and gain slope when equalizers are built into the warm IF amplifiers, the gain contribution of the warm IF amplifiers installed on the Warm Cartridge Assembly (WCA) was removed from the measured cartridge gain data and the gain of an ideal amplifier with slope correction was added. Table 2 identifies the warm IF amplifiers used with WCA 001, and because s-parameters were measured for all warm IF amplifiers, the corresponding $s_{21}$ could be subtracted from the overall cartridge gain for each receiver channel. Afterwards, the gain of an identical ideal amplifier with gain slope correction was added to each receiver channel. The optimum slope value was determined by minimizing the largest 2-GHz and 4-GHz gain slopes for both polarizations and all intermediate frequencies from 6-10 GHz.

[3] Reduced performance is available from 4-12 GHz.

The amplifier that minimizes cartridge gain slope has 12 dB of gain slope from 4 to 12 GHz and exhibits the following gain/frequency parameters:

Gain at 4 GHz = 28 dB,
Gain at 12 GHz = 40 dB.

**Table 2: Warm IF Amps Installed in WCA 001**

| Polarization | Sideband | Serial Number |
|---|---|---|
| 0 | USB | 0438-104 |
| | LSB | 0517-108 |
| 1 | USB | 0523-109 |
| | LSB | 0521-110 |

## 5. Results

Gain *vs*. intermediate frequency for Cartridge 001, polarization 0 is shown in Figure 1. The IF response from each LO is plotted as overlapping lines in the figures. The darkened lines show gain over the specified 6-10 GHz IF. Figure 2 shows the predicted gain response using a perfect IF amplifier that includes the equalization discussed immediately above. Similar results are shown in Figure 3 and Figure 4 for polarization 1. Note that the actual warm IF amplifiers installed in polarization 0 differ in overall gain by about 3 dB. That gain difference is removed when ideal amps are used as shown by the overlapping curves for each sideband in Figure 2.

Gain slopes of Cartridge 001, polarization 0 are plotted in Figure 5 and corresponding slopes with equalizers are shown in Figure 6. Both 2-GHz and 4-GHz gain slopes meet specifications for this polarization, as shown in Figure 6. Figure 7 and Figure 8, gain slopes for polarization 1, show some frequencies where the gain slopes continue to exceed specifications, although improvement is significant compared to no equalization.

Gain slopes of a second Band 6 Cartridge, SN 003, both without and with the same equalizer are shown in Figure 9, Figure 10, Figure 11, and Figure 12. Measurements of that cartridge are limited to course IF frequency spacing, but improvement is similar to the finer-spaced data measured in Cartridge 001.

Total output power is calculated for each polarization in Figure 13 and Figure 15 for Cartridge 001 using the existing warm IF amplifiers with no equalization. The overall gain of the ideal warm IF amplifiers was adjusted to provide 1-2 dB of margin above minimum gain specifications as shown in Figure 14 and Figure 16. Excess gain can always be removed with attenuators.

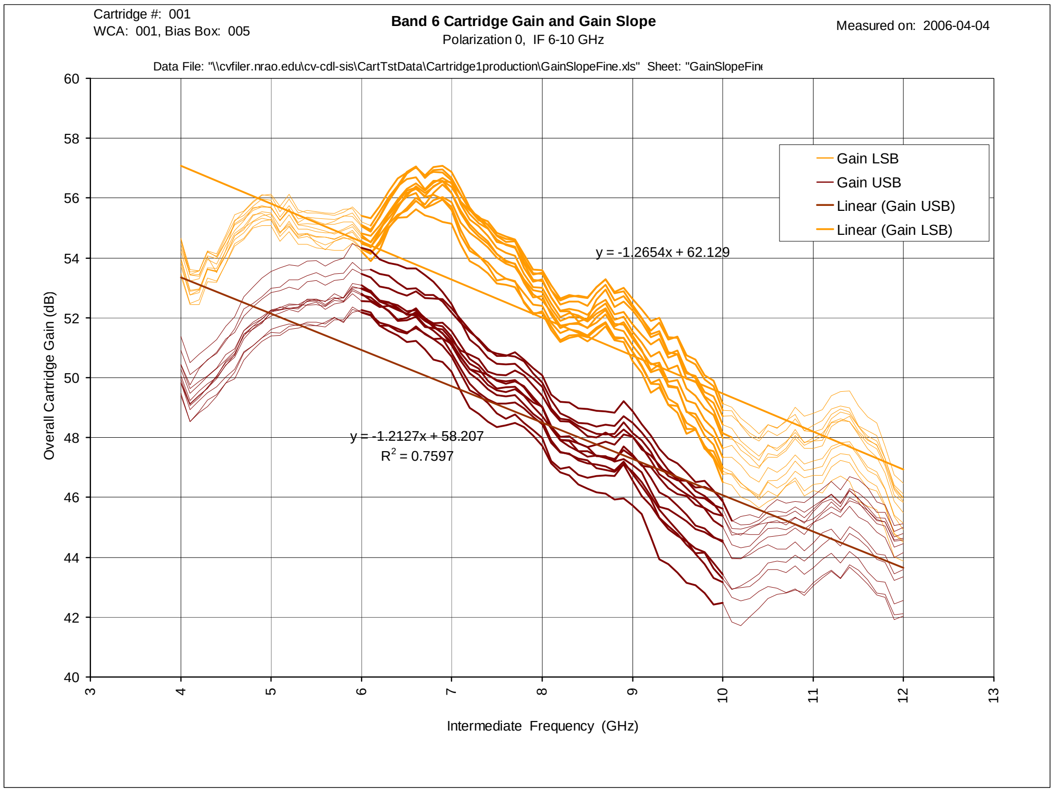


**Figure 1: Gain vs. IF, Cartridge 001, Polarization 0 (dark lines are spec bandwidth)**

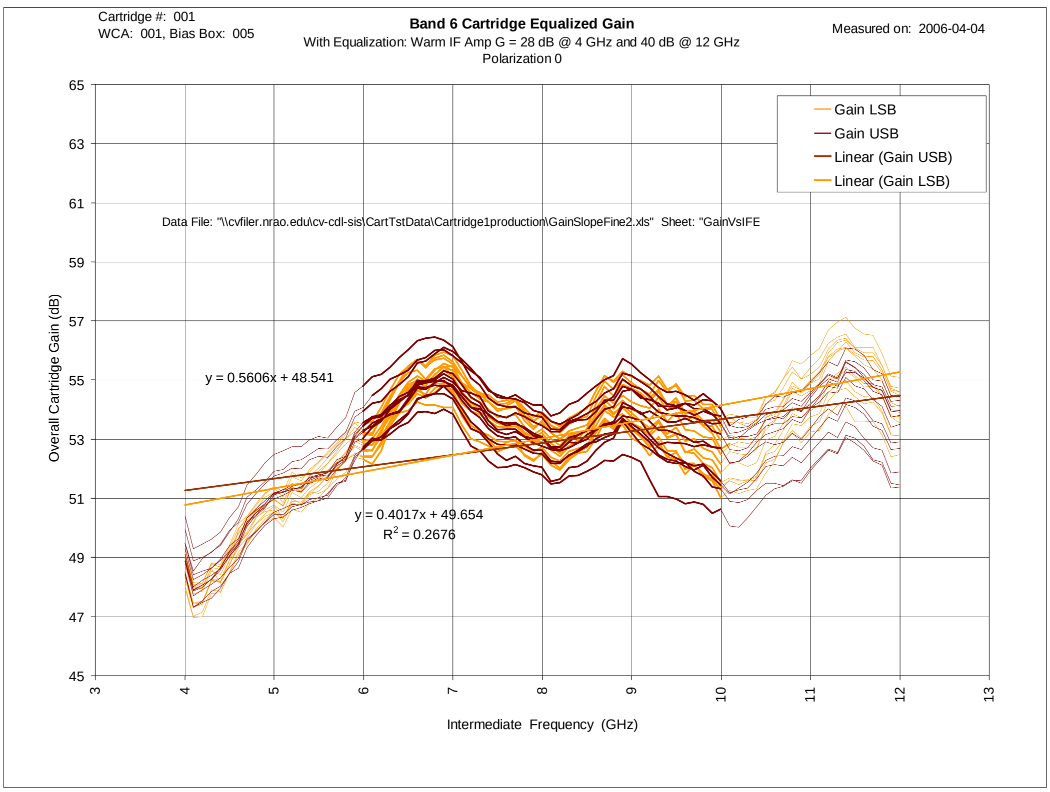


**Figure 2: Gain vs. IF with Equalizer, Cartridge 001, Pol 0**

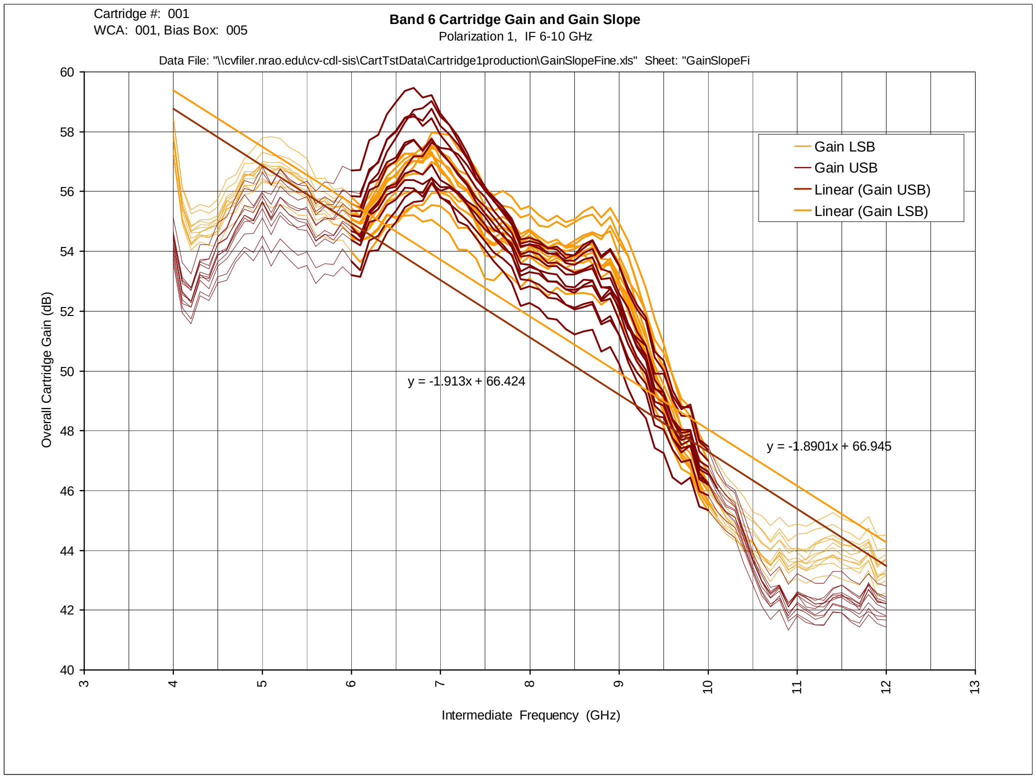


**Figure 3: Gain vs. IF, Cartridge 001 Polarization 1**

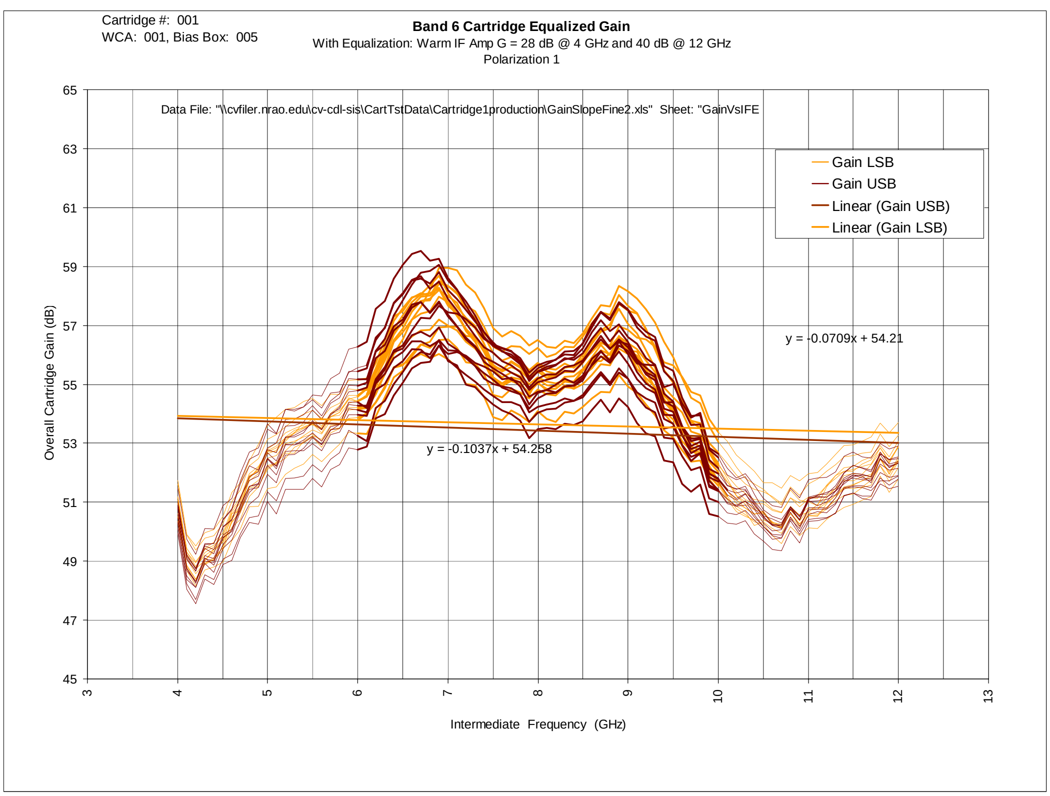


**Figure 4: Gain vs. IF with Equalizer, Cartridge 001, Pol 1**

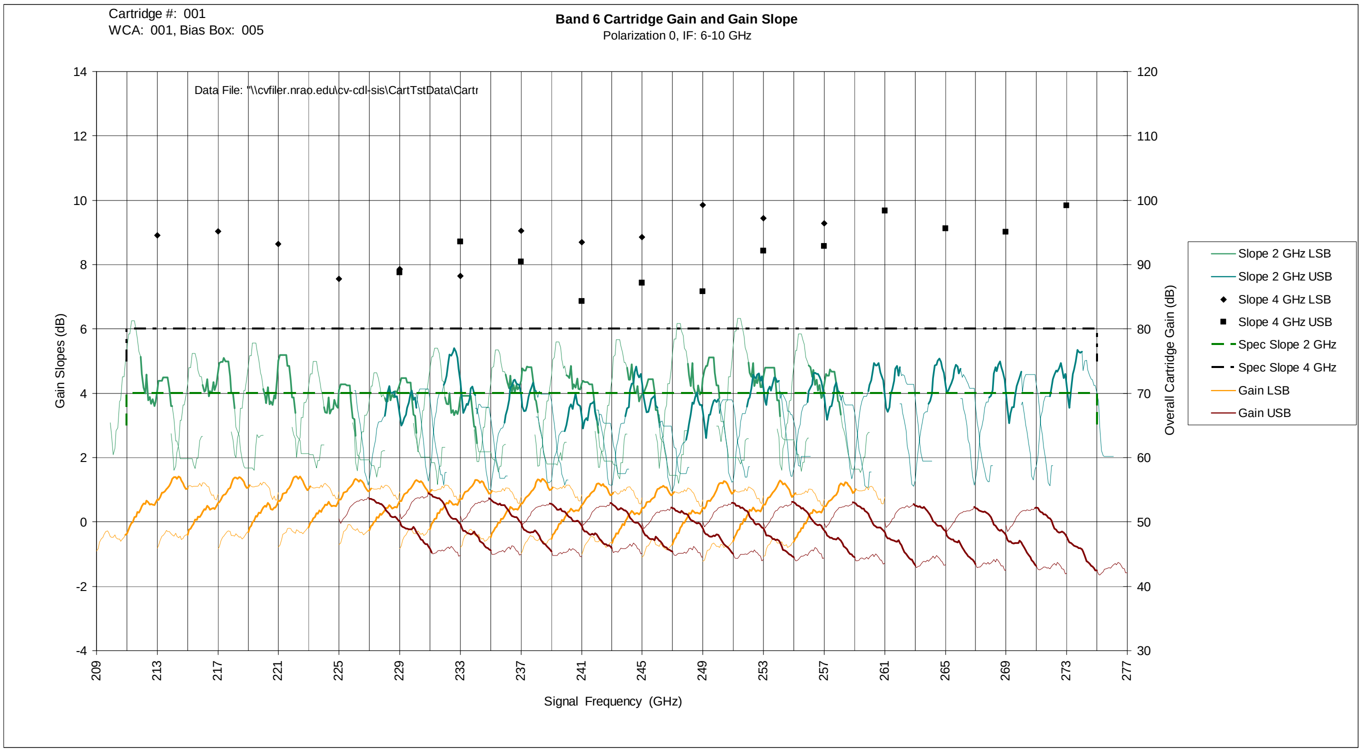


**Figure 5: Gain Slope, Cartridge 001, Polarization 0 (Dark curves are spec bandwidth)**

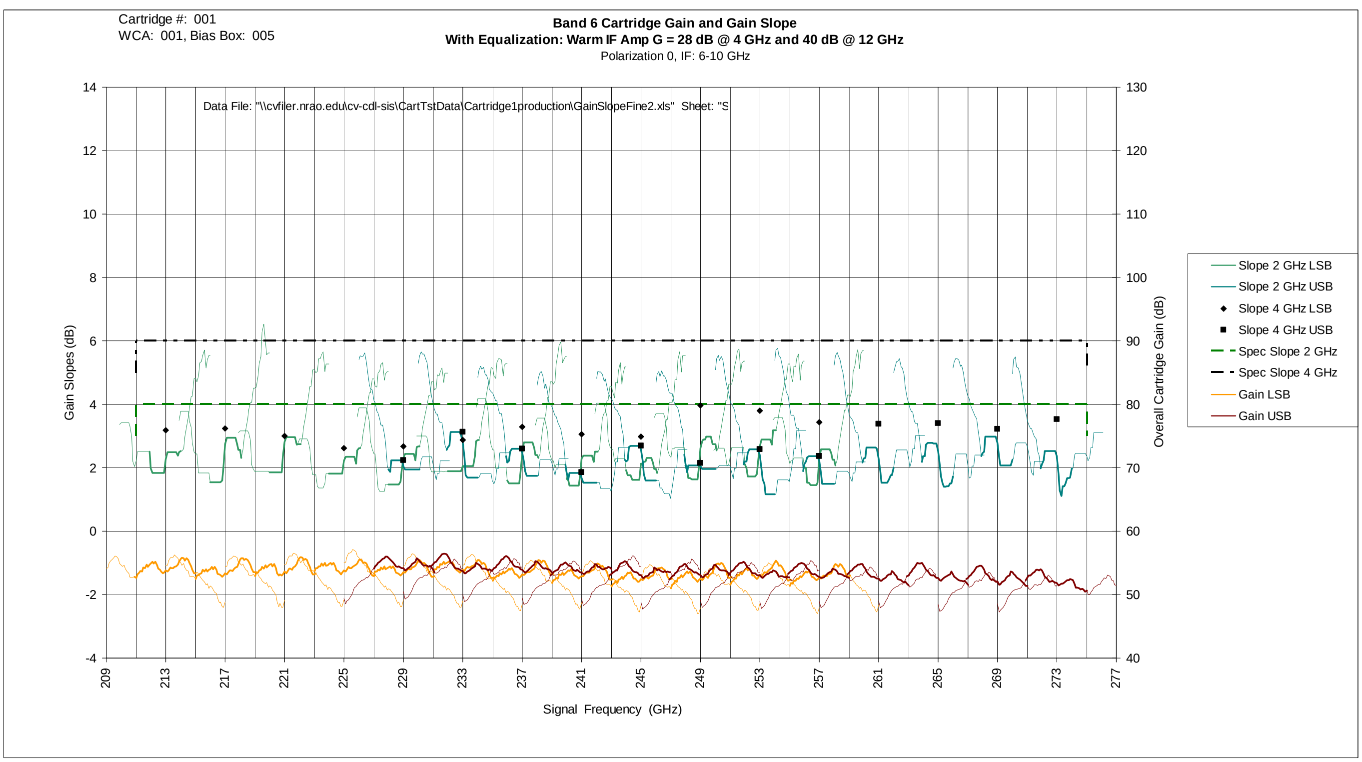


**Figure 6: Gain Slope with Equalizer, Cartridge 001, Polarization 0**

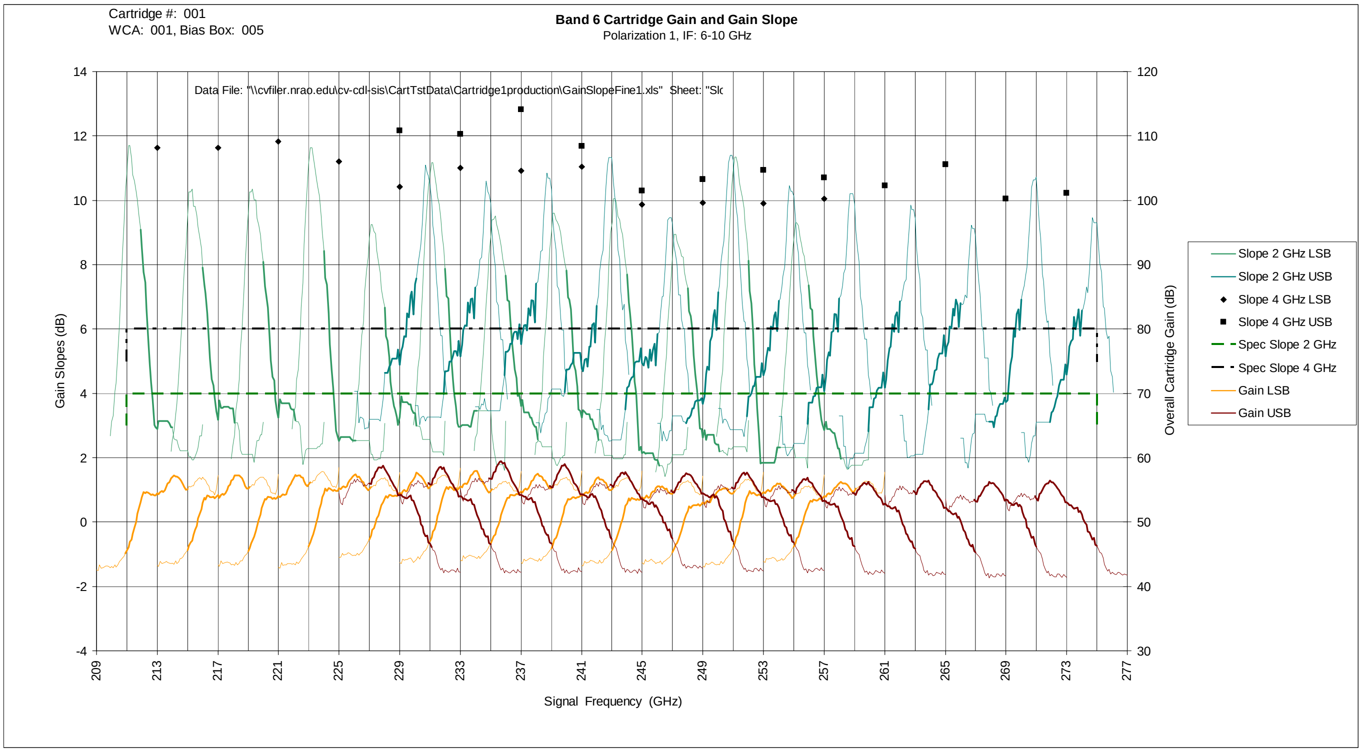


**Figure 7: Gain Slope, Cartridge 001, Polarization 1 (Dark curves are spec bandwidth)**

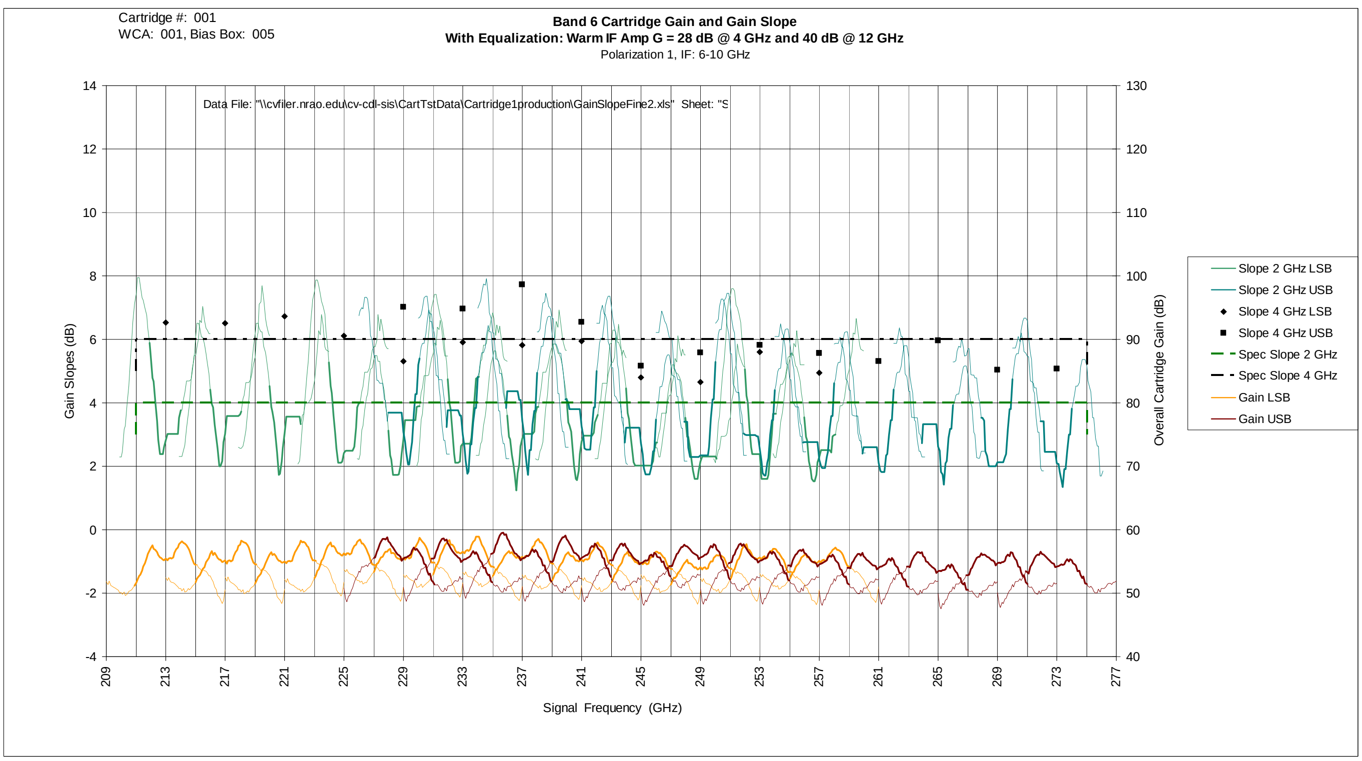


**Figure 8: Gain Slope with Equalization, Cartridge 001, Polarization 1**

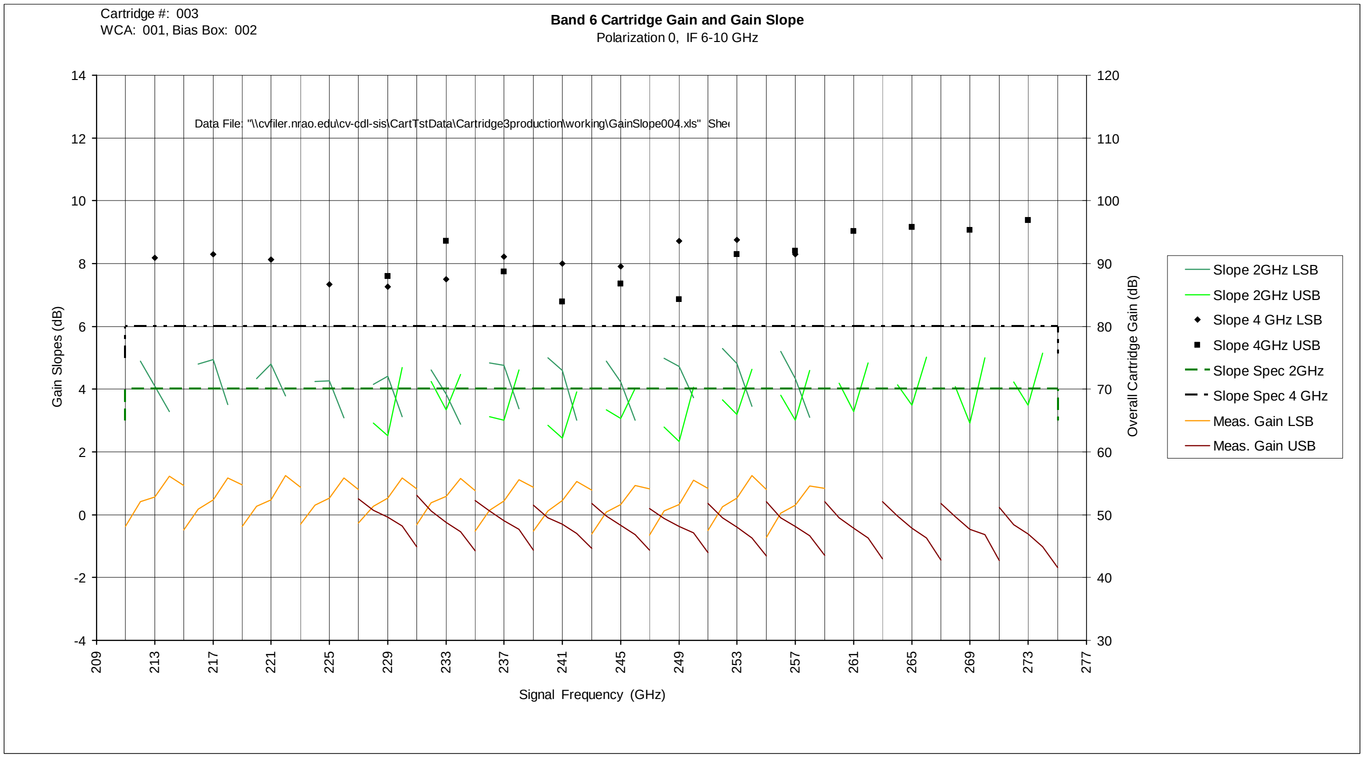


**Figure 9: Gain Slope, Cartridge 003, Polarization 0**

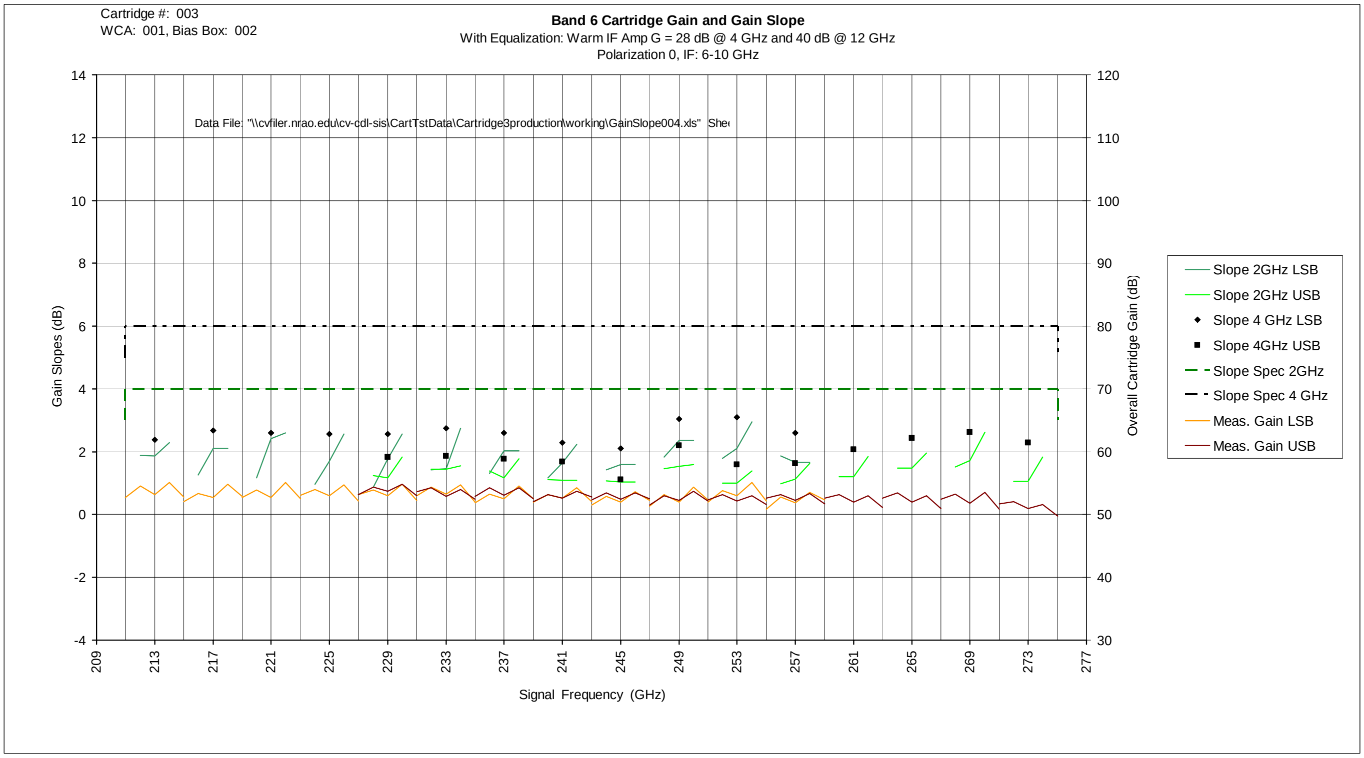


**Figure 10: Gain Slope with Equalization, Cartridge 003, Polarization 0**

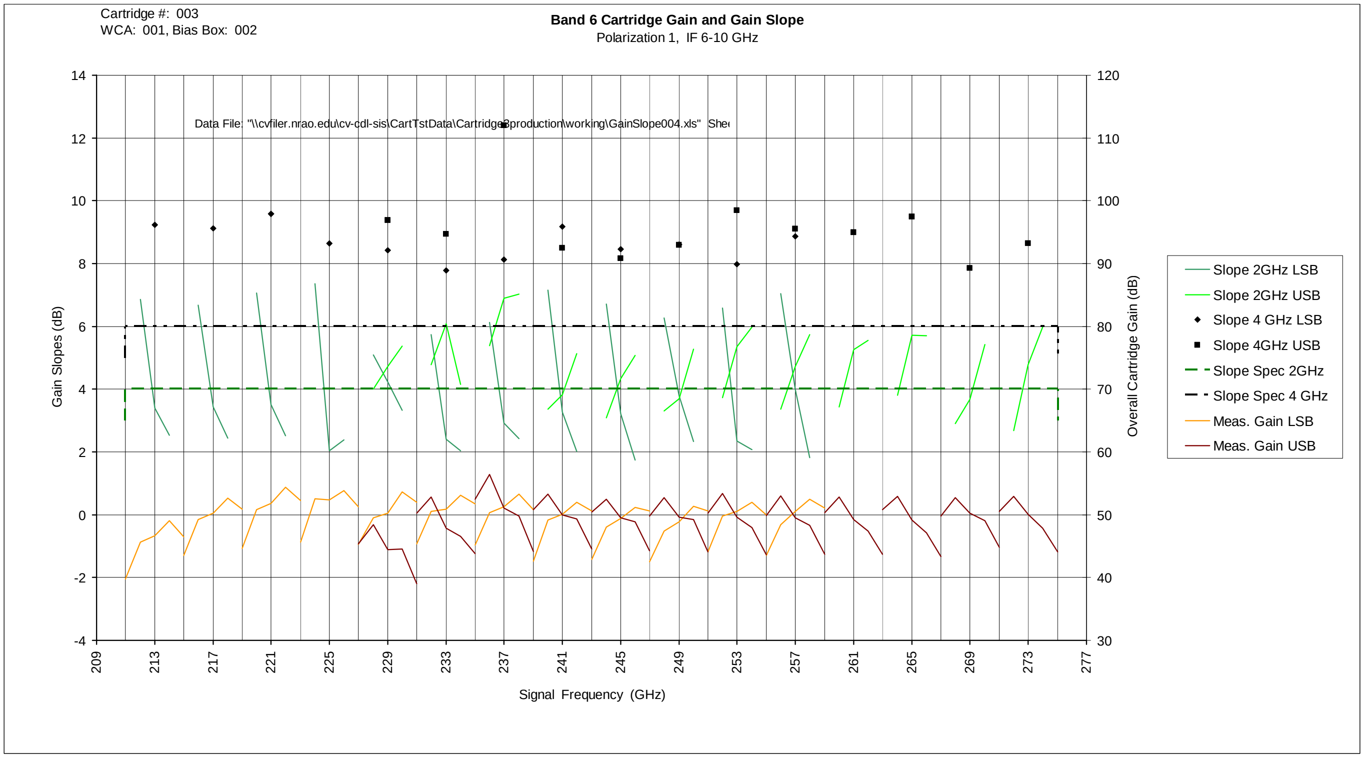


**Figure 11: Gain Slope, Cartridge 003, Polarization 1**

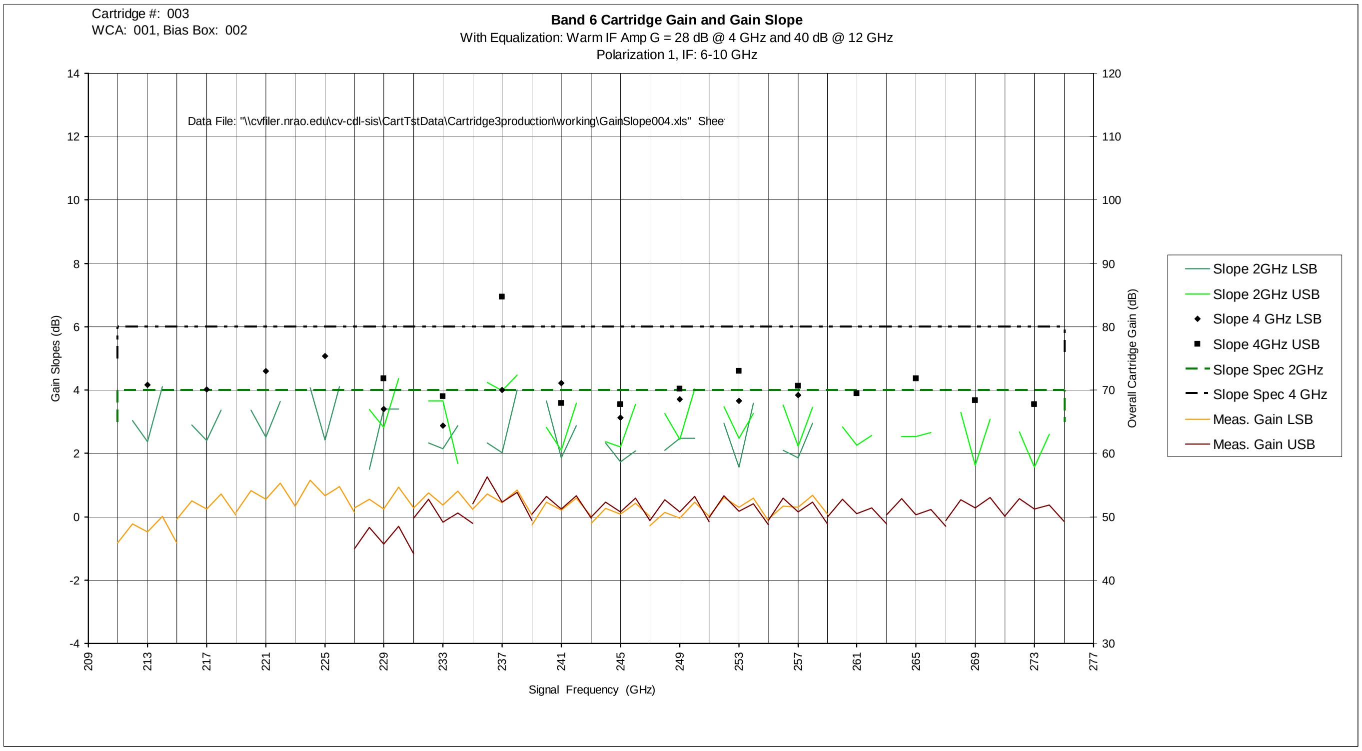


**Figure 12: Gain Slope with Equalization, Cartridge 003, Polarization 1**

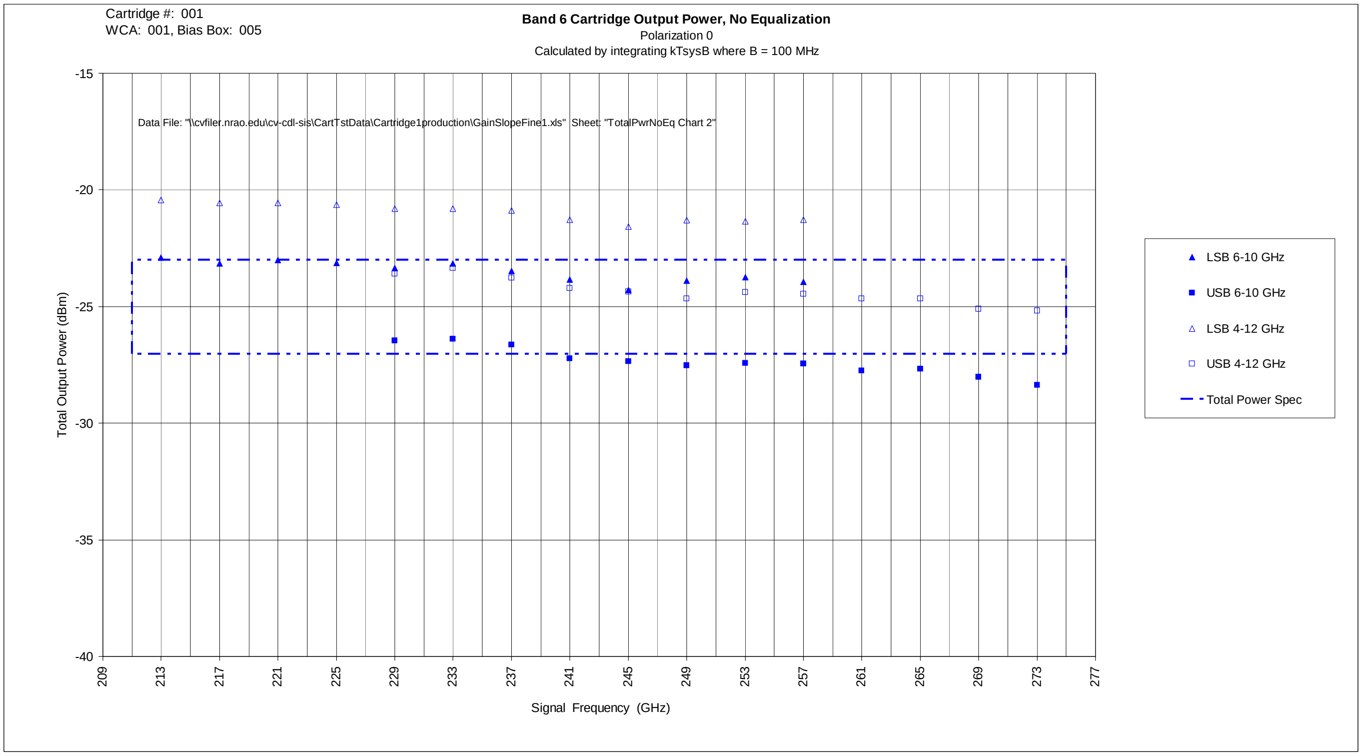


**Figure 13: Total Power Calculation, Cartridge 001, Pol 0**

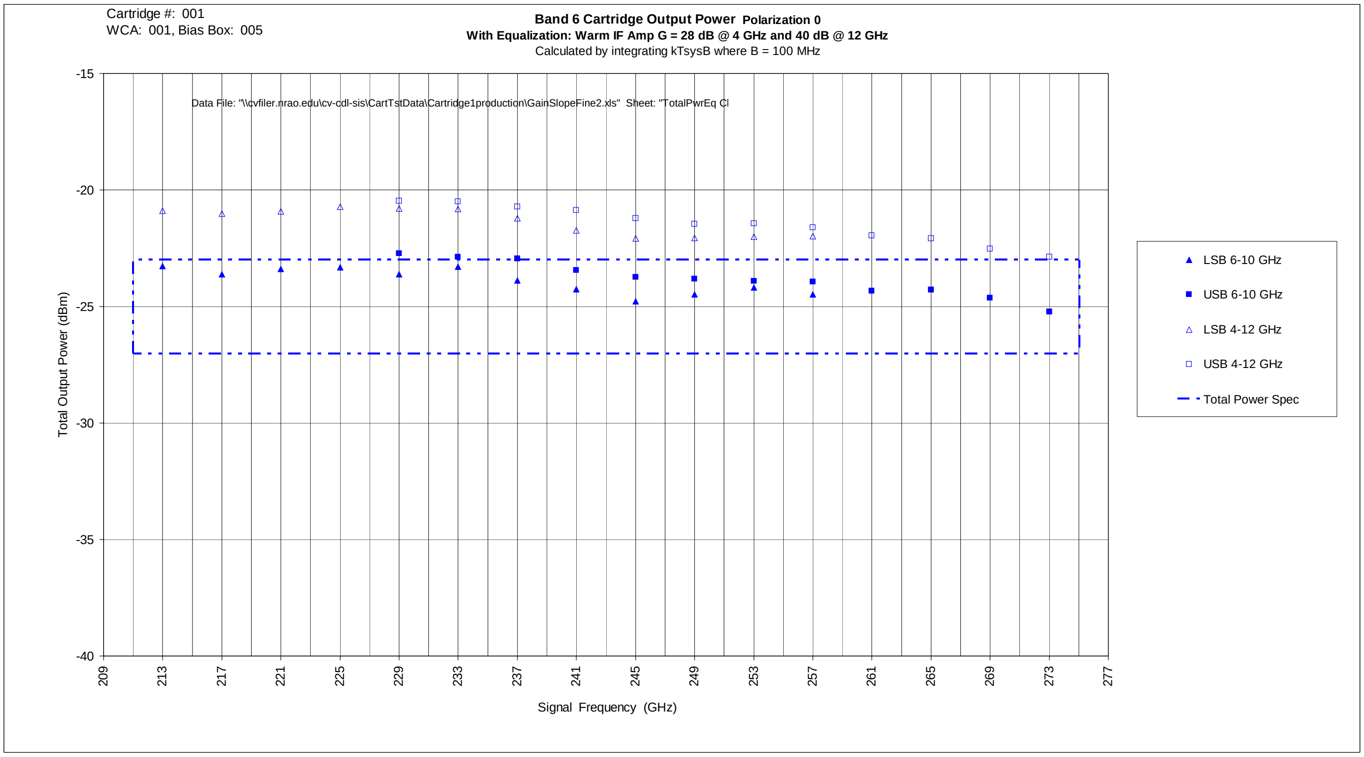


**Figure 14: Total Power Calculation with Equalizer, Cartridge 001, Pol 0**

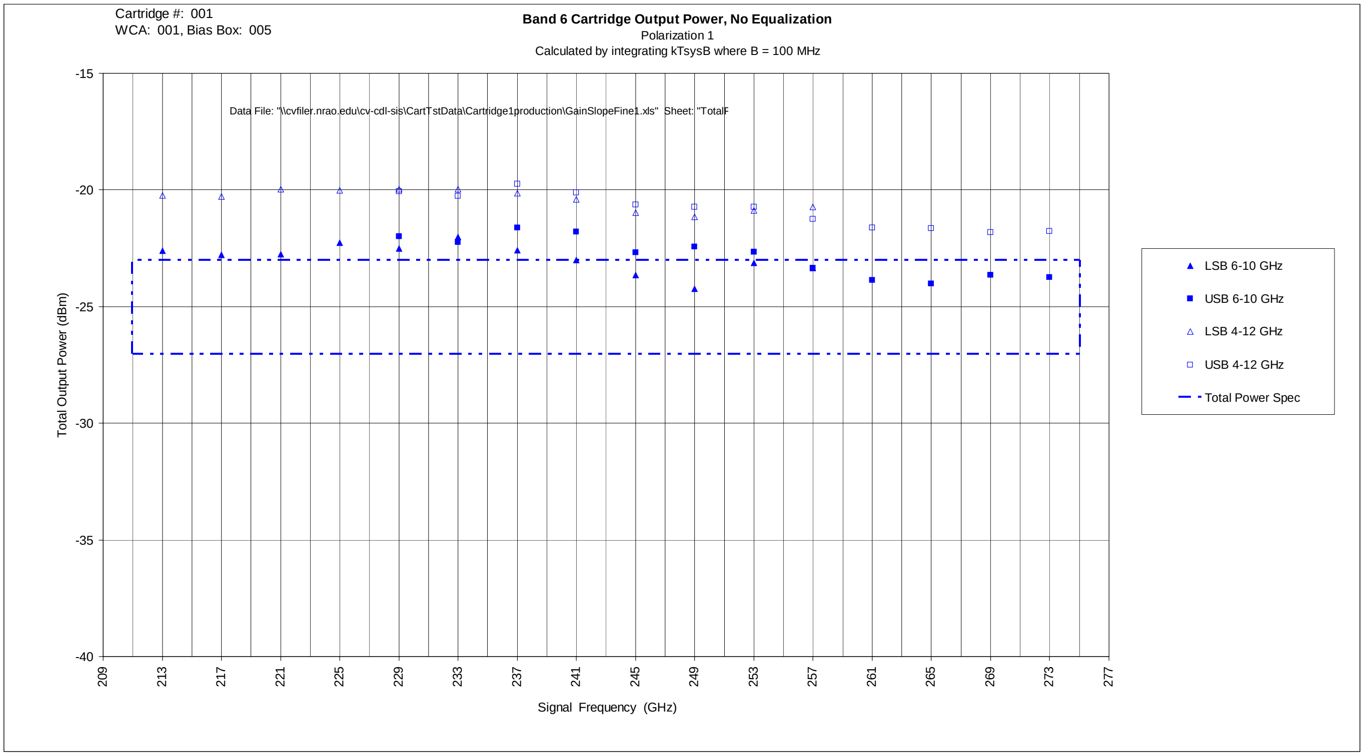


**Figure 15: Total Power Calculation, Cartridge 001, Pol 1**

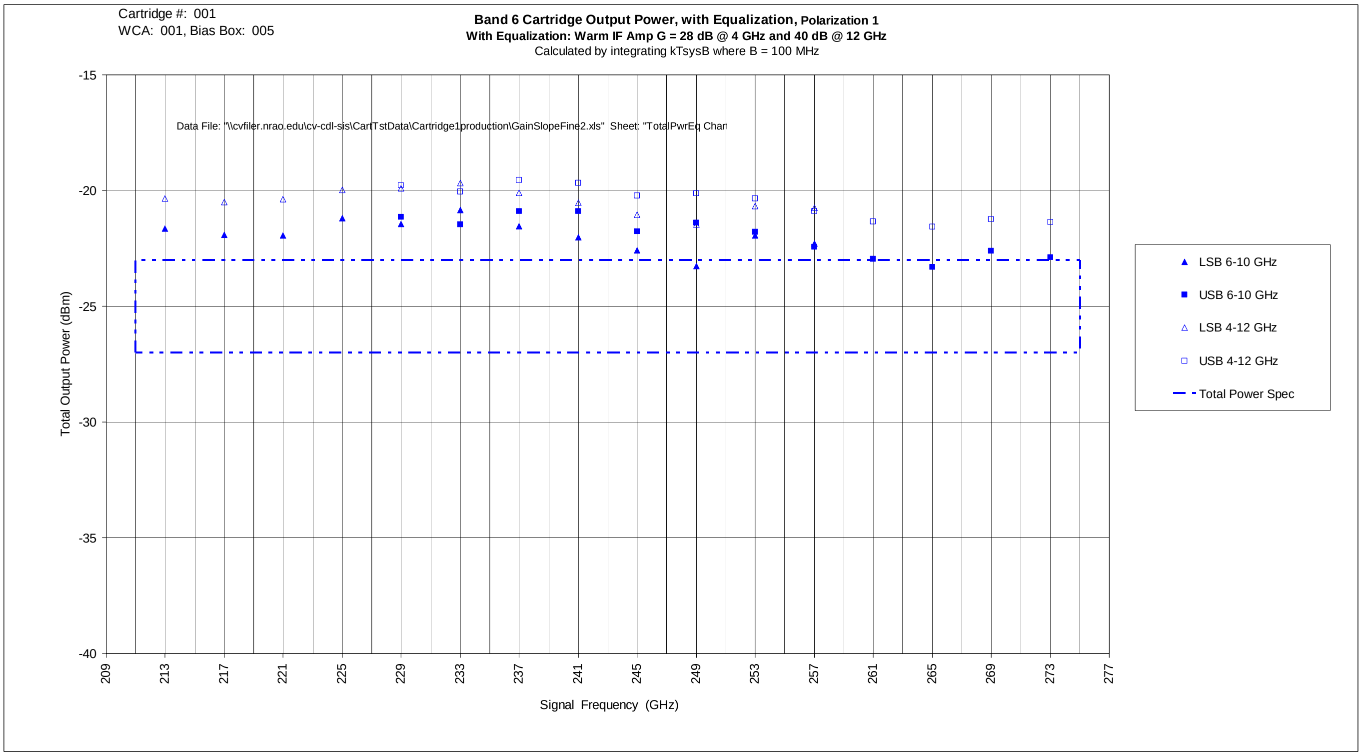


**Figure 16: Total Power Calculation with Equalizer, Cartridge 001, Pol 1**