Debuncher Transverse Cooling Measurements of October 17 & November 1, 2006.

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During this study measurements of signal to noise and cooling rate were performed on all transverse cooling bands and sub-bands. The measurement data is summarized in this memo.

Signal to Noise Measurements

The signal to noise ratio (SNR) was measured at the TRI signal point of each system as well as the FIL signal point for bands 1 and 2. The tables below give the SNR from band power measurements on spectrum analyzer 1.

Horizontal SNR Measurements

System	Measured Band Power (dBm) Beam	No Beam	Int. BW (GHz)	SNR (dB)
HB1L	-20.0	-30.1	1.2	10.1
HB1U	-18.8	-28.3	1.2	9.5
HB1 Both	-16.4	-26.1	2.0	9.7
HB1 FIL	-38.8	-48.1	2.0	9.3
HB2L	-21.5	-32.2	1.2	10.7
HB2U	-24.1	-33.5	1.2	9.4
HB2 Both	-19.8	-29.7	2.0	9.9
HB2 FIL	-42.5	-52.4	2.0	9.9
HB3L	-16.4	-20.6	1.7	4.2
HB3U	-17.0	-23.3	1.7	6.3
HB3 Both	-13.8	-18.6	2.5	4.8
HB4L	-29.4	-35.8	2.0	6.4
HB4U	-26.2	-30.4	2.0	4.2
HB4 Both	-24.4	-29.2	2.5	4.8

Vertical SNR Measurements

System	Measured Band Power (dBm) Beam	No Beam	Int. BW (GHz)	SNR (dB)
VB1L	-25.6	-33.6	1.2	8.2
VB1U	-21.5	-31.6	1.2	10.1
VB1 Both	-19.9	-29.4	1.7	9.5
VB1 FIL	-43.7	-51.7	2.0	8.0
VB2L	-28.6	-39.1	1.2	10.5
VB2U	-24.3	-34.3	1.2	10.0
VB2 Both	-23.1	-33.0	2.0	9.9
VB2 FIL	-45.0	-53.5	2.0	8.5
VB3L	-19.1	-23.6	1.7	4.5
VB3U	-19.3	-26.4	1.7	7.1
VB3 Both	-16.1	-21.6	2.5	5.5
VB4L	-29.8	-34.9	2.0	5.1
VB4U	-26.5	-30.0	2.0	3.5
VB4 Both	-24.7	-28.7	2.5	4.0

The horizontal data is given in figures 1 and 2. Horizontal band 1 TWT #2 was out of commission for these measurements. The SNR for bands 3 and 4 is 5 dB or more below that of bands 1 and 2.

The vertical data is given in figures 3 and 4. Vertical band 2 TWT #3 was out of commission for these measurements. Again, the SNR for vertical bands 3 and 4 is markedly lower than that of bands 1 and 2.

When both upper and lower sub bands of each band are measured together the ragged lobes in HB1L and VB3L disappear. See figures 5 and 6 below.

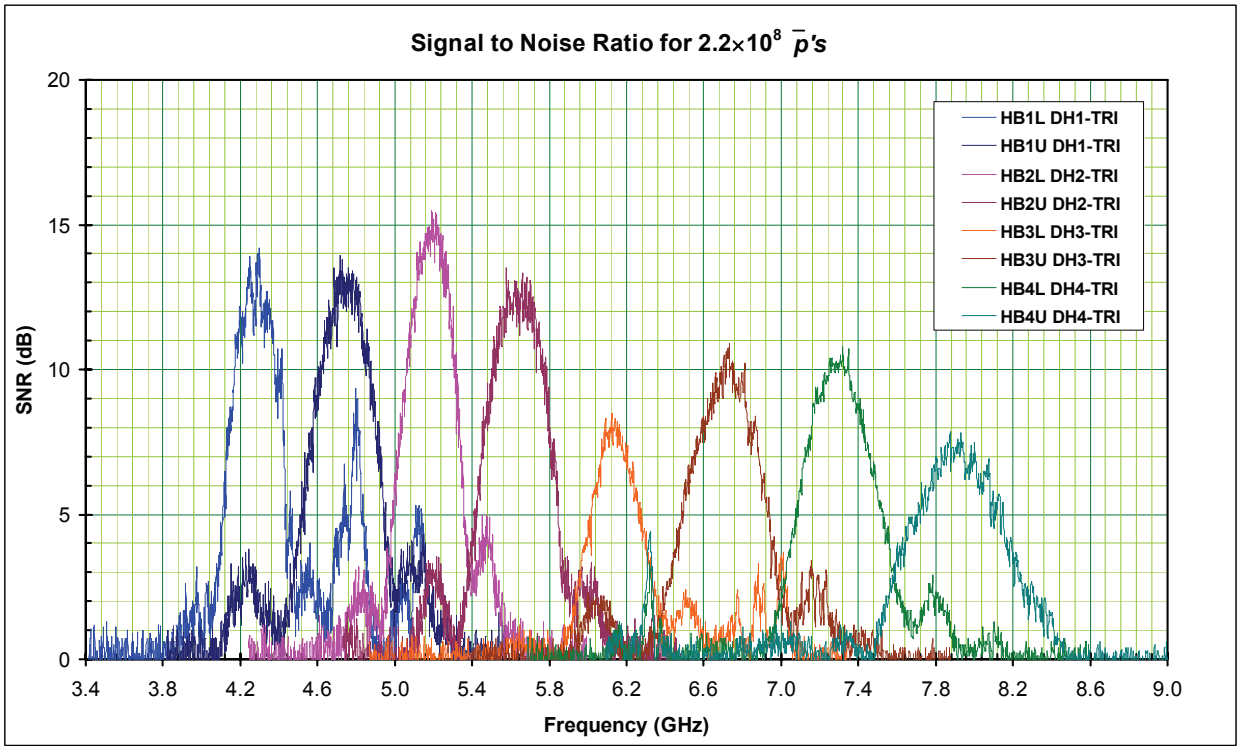


Figure 1 Horizontal SNR calculated from beam and no-beam response spectra. The raw data for this calculation is given in Figure 2.

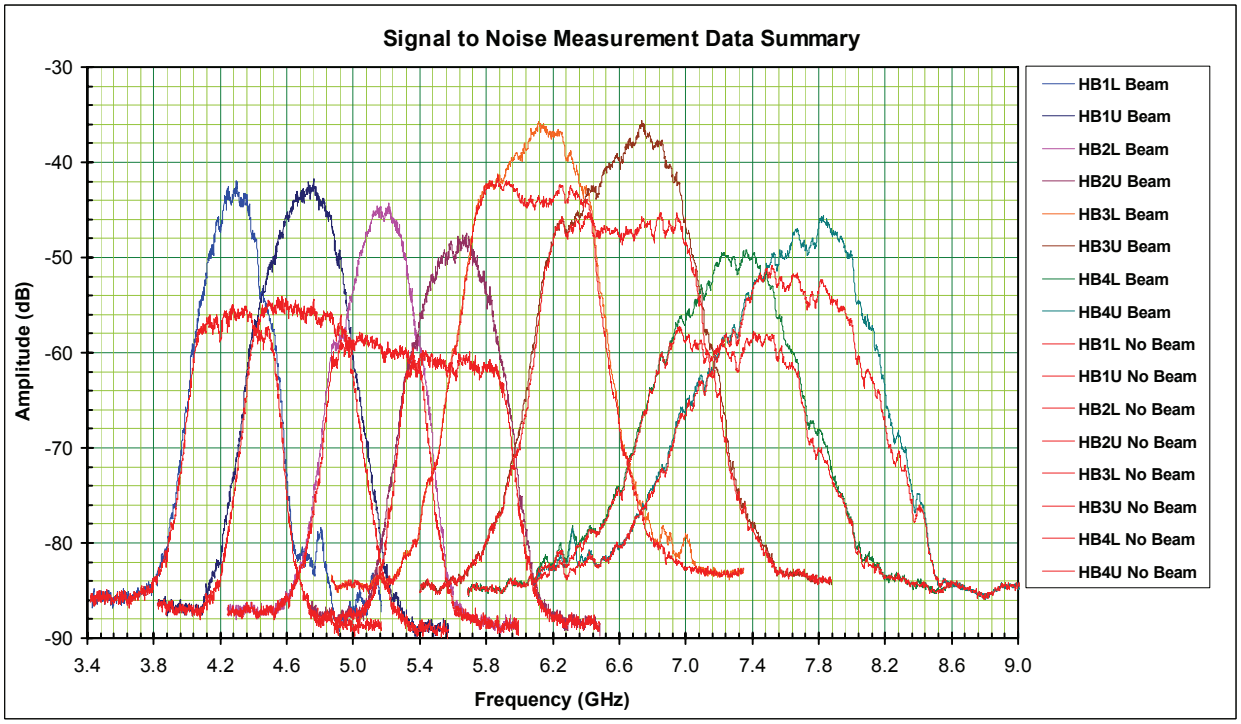


Figure 2 Horizontal raw data for the SNR calculation of Figure 1.

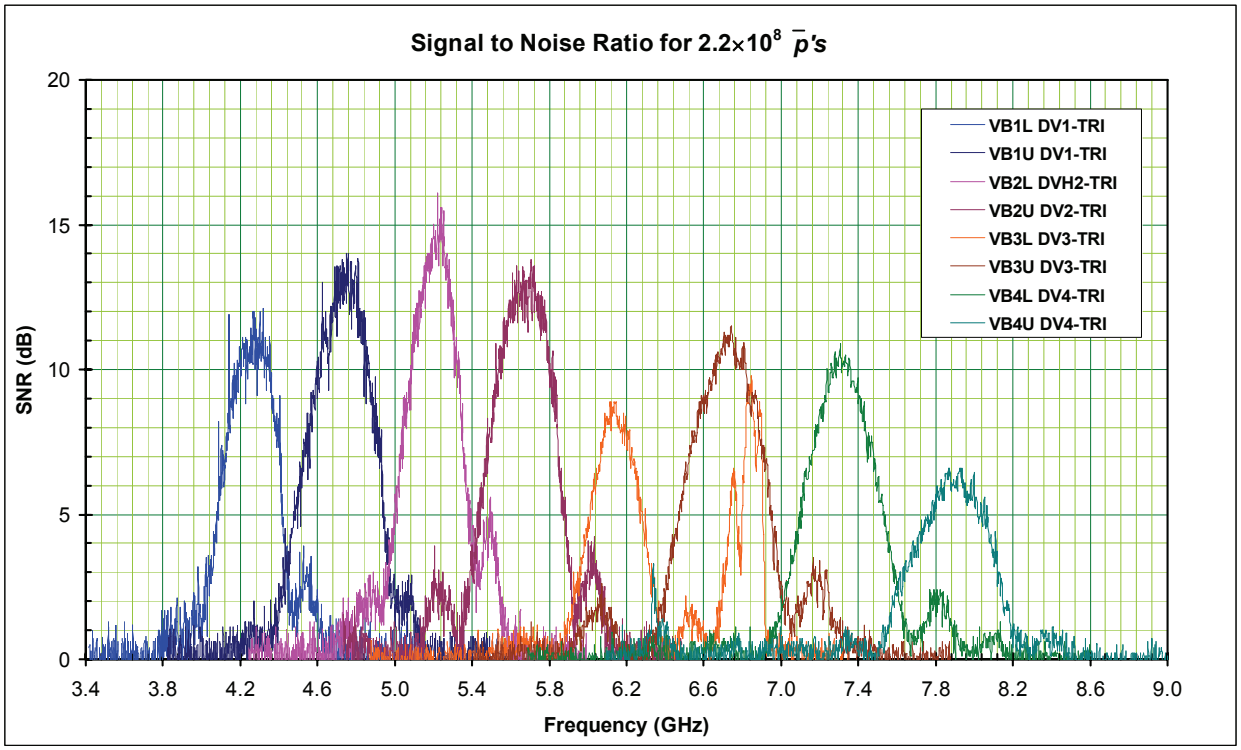


Figure 3 Vertical SNR calculated from beam and no-beam response spectra. The raw data for this calculation is given in Figure 4.

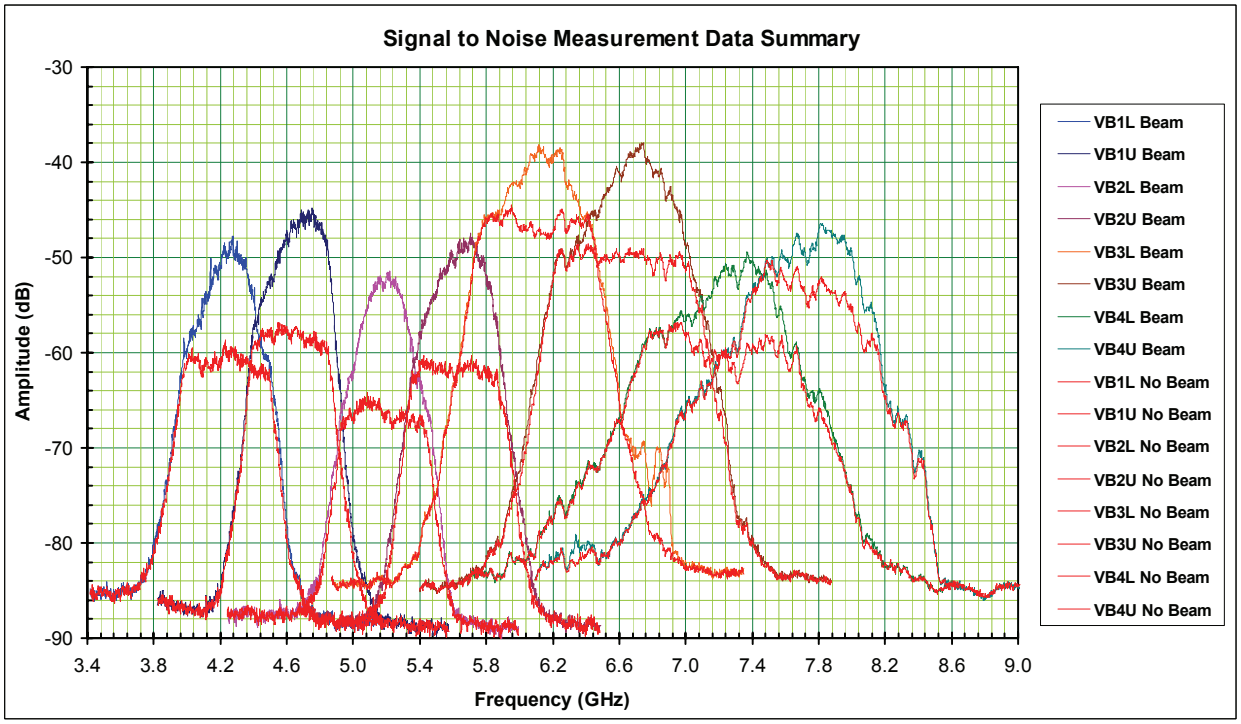


Figure 4 Vertical raw data for the SNR calculation of Figure 3.

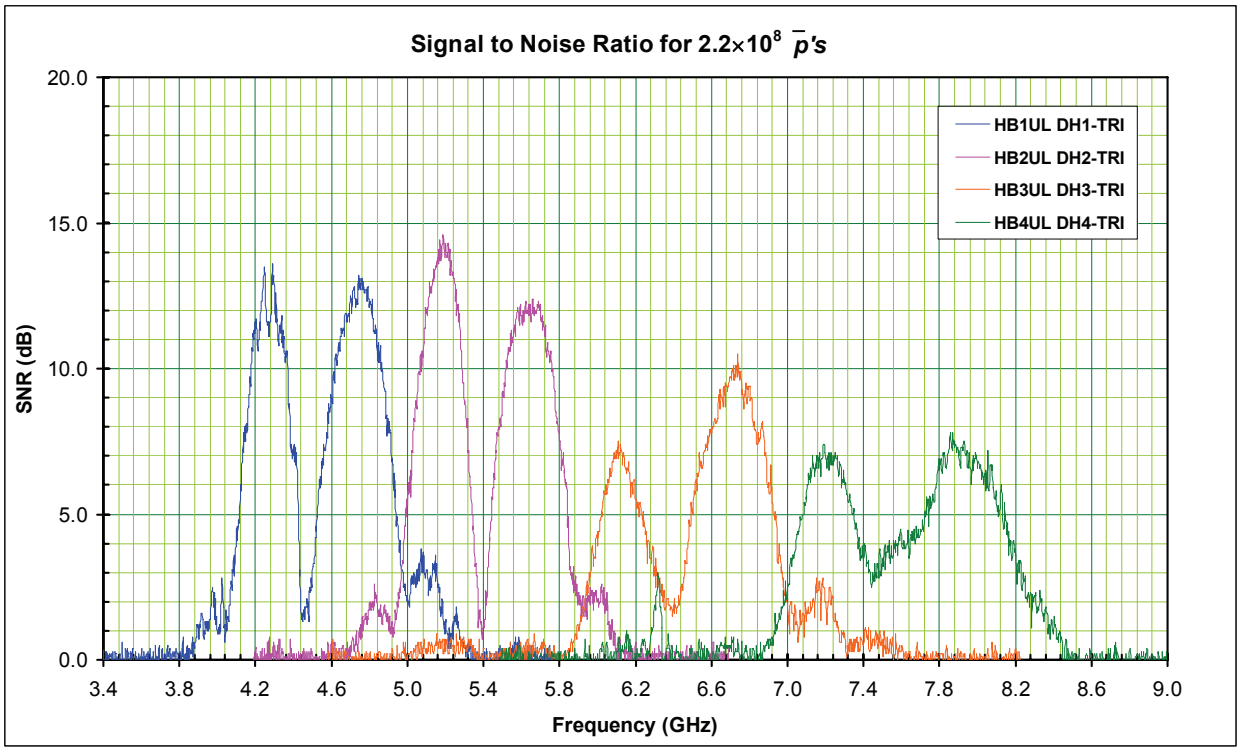


Figure 5 SNR for all horizontal bands. The upper and lower sub bands were both on for each measurement.

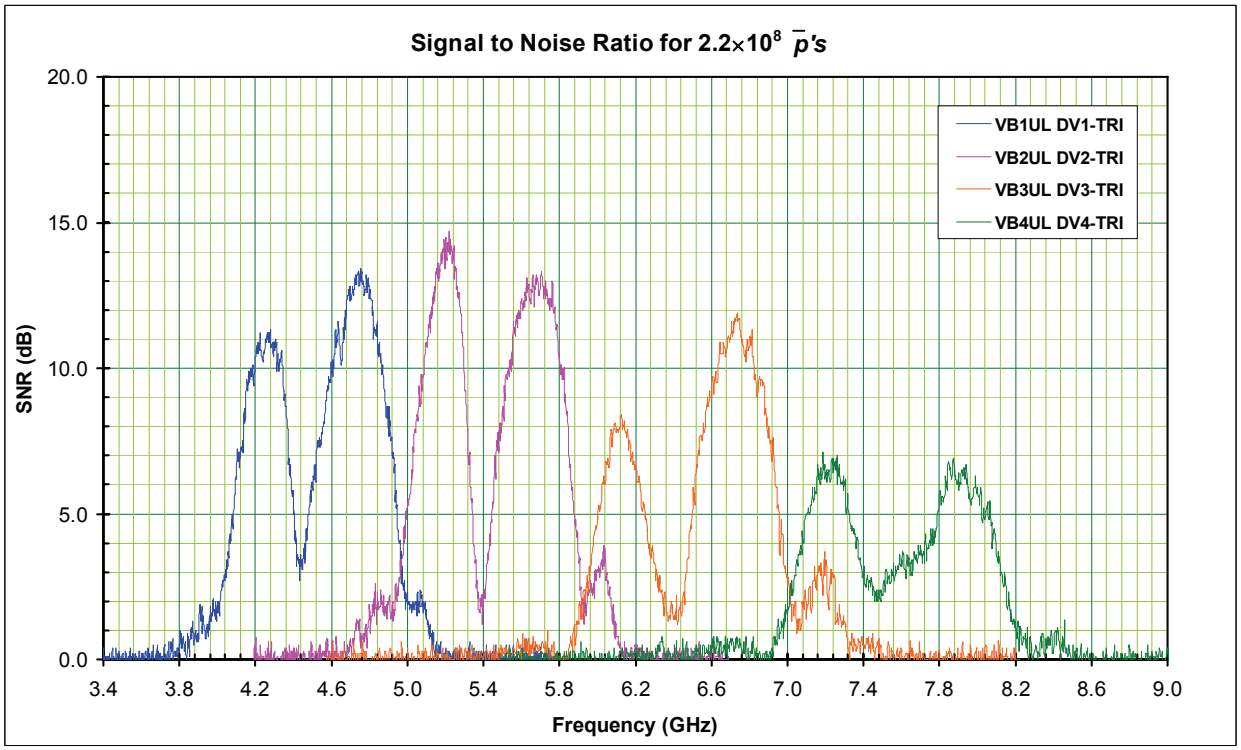


Figure 6 SNR for all vertical bands. The upper and lower sub bands were both on for each measurement.

SNR downstream of filters

The signal to noise ratio downstream of the notch filter in bands 1 and 2 was also measured. The results are shown in figures 7 through 10.

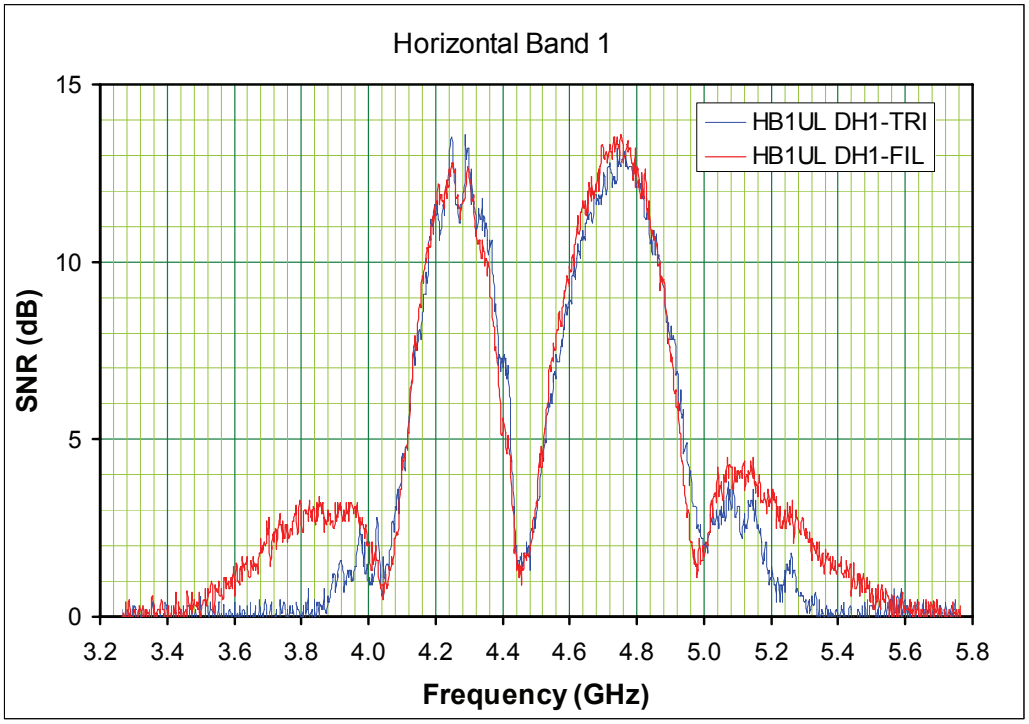


Figure 7 Horizontal band 1. Comparison of SNR upstream and downstream of the notch filter.

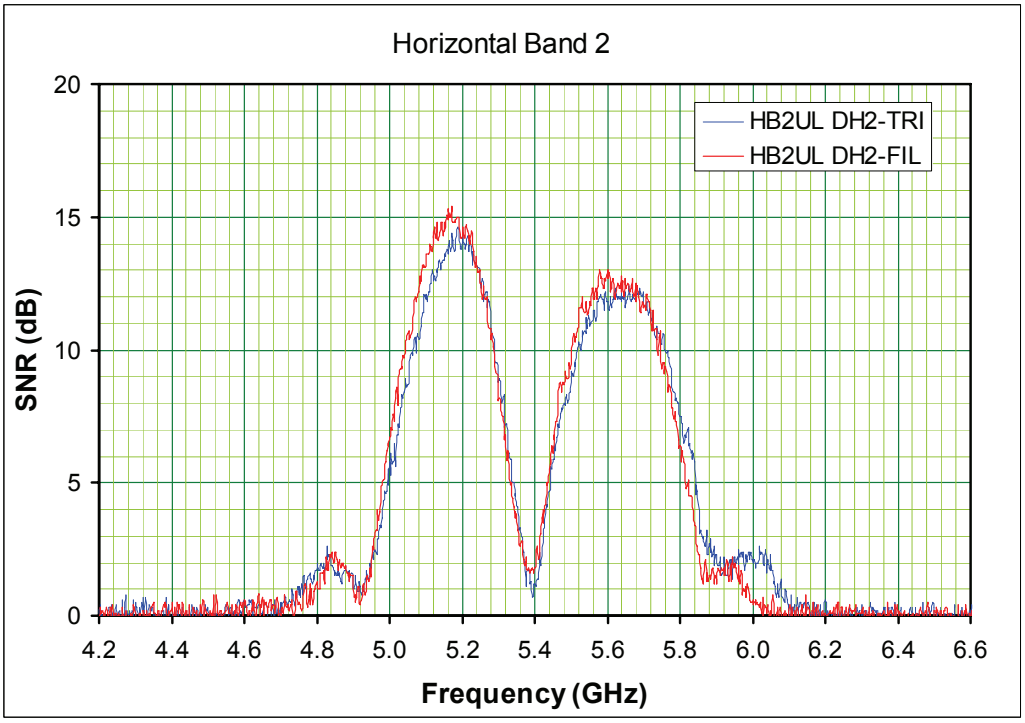


Figure 8 Horizontal band 2. Comparison of SNR upstream and downstream of the notch filter.

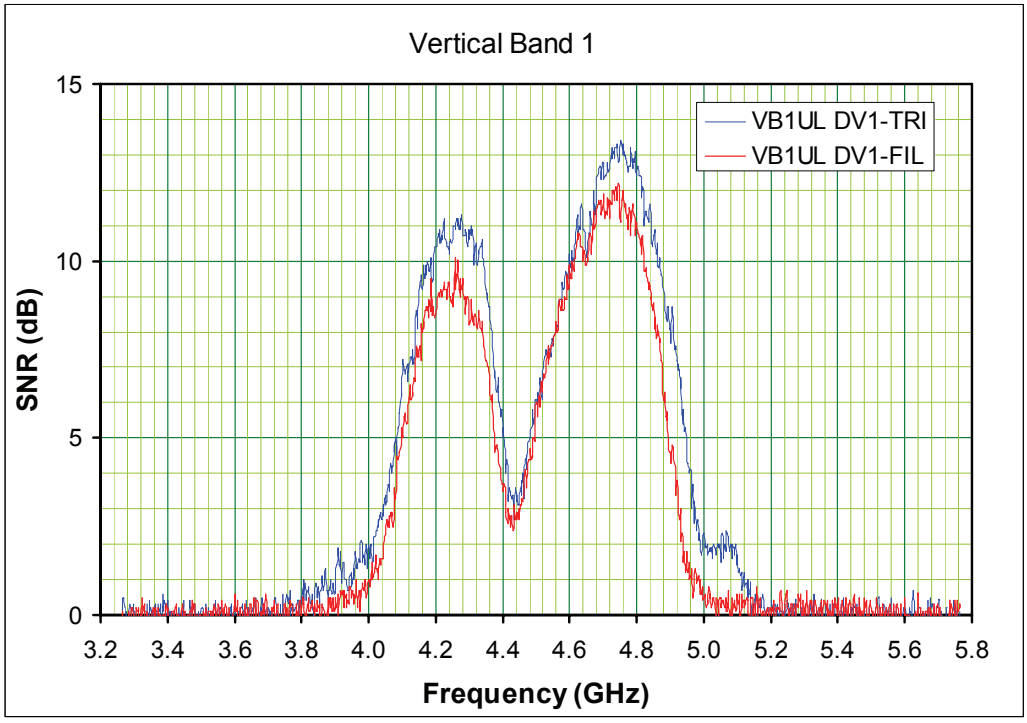


Figure 9 Vertical Band 1. Comparison of SNR upstream and downstream of the notch filter.

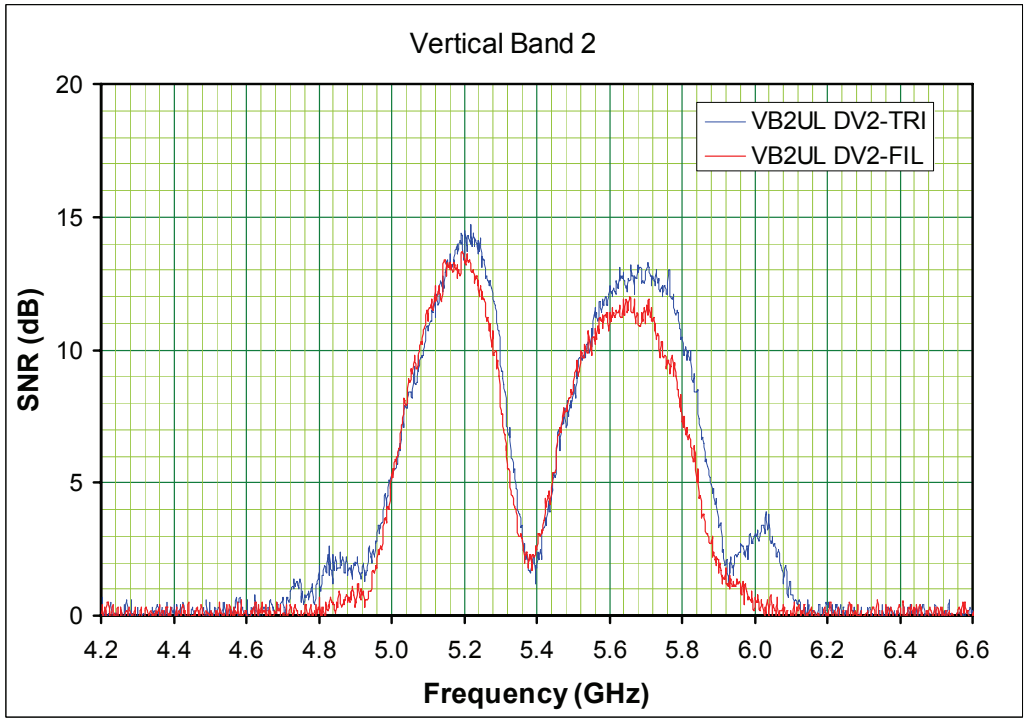


Figure 10 Vertical band 2. Comparison of SNR upstream and downstream of the notch filter.

Cooling Rate Measurements

The cooling rate was measured for each sub-band by connecting spectrum analyzer 1 to the SCH signal points of HB1L and VB1L and tuning it to a betatron sideband near the center of these sub-bands. The spectrum analyzer is then set to zero-span with a resolution bandwidth that is wider than the betatron sideband being observed. These measurements were made while stacking with a very long cycle time. The table below describes the timing of these measurements.

Stacking cycle time	30 sec
Sweep time	25 sec
Δp cooling on time	\$80 + 1.03 sec
Δp cooling off time	\$80 + 1.01 sec
Transverse cooling on time	\$80 + 2.03 sec
Transverse cooling off time	\$80 + 1.01 sec
SA 1 external trigger	\$80 + 1.03 sec

The transverse cooling comes on 1.00 sec after the spectrum analyzer sweep starts and 1.00 sec after the momentum cooling is gated on. The last 24 seconds of each trace were fit to an exponential. The resulting cooling times are given in the table below.

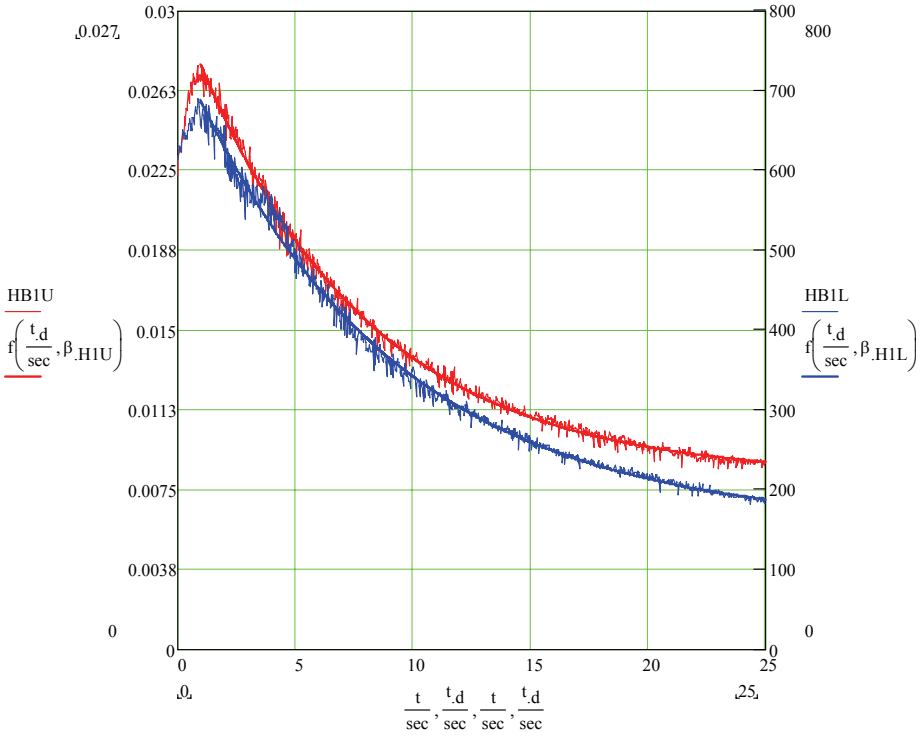
Transverse Cooling Times

Band	**Horizontal**	**Vertical**
1 Lower[†]	8.601 sec	6.575 sec
1 Upper[†]	7.254 sec	6.609 sec
2 Lower	12.318 sec	12.648 sec
2 Upper	8.906 sec	8.593 sec
3 Lower	14.663 sec	13.062 sec
3 Upper	10.101 sec	12.186 sec
4 Lower	12.205 sec	16.021 sec
4 Upper	22.556 sec	15.067 sec

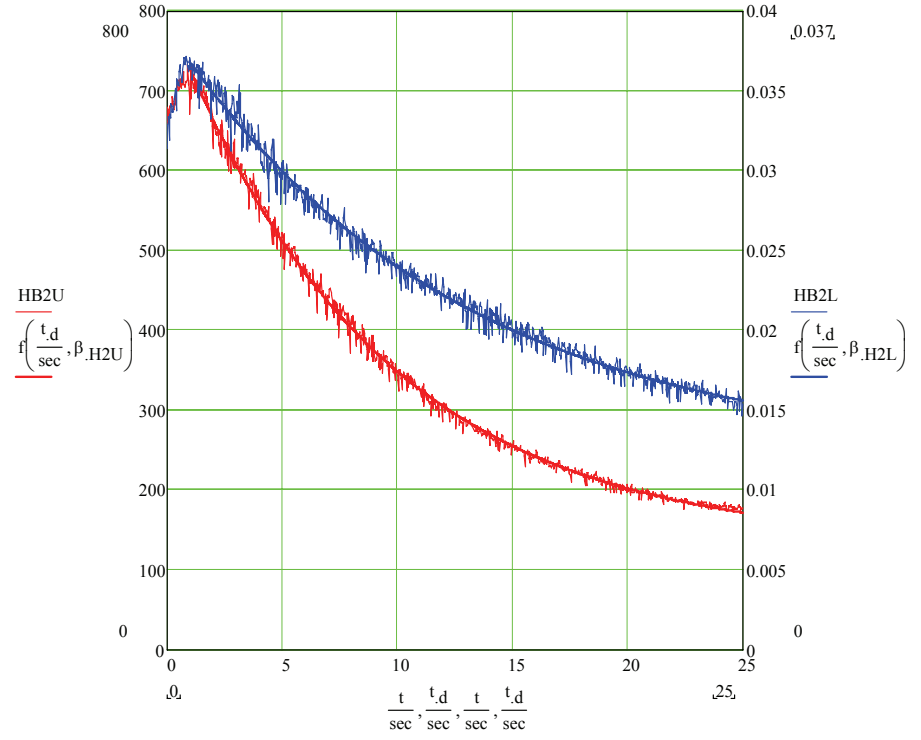
The fits are shown in the plots below.

[†] Measured using the B2L pickup tuned near the center of B2L.

Horizontal Band 1



Horizontal Band 2



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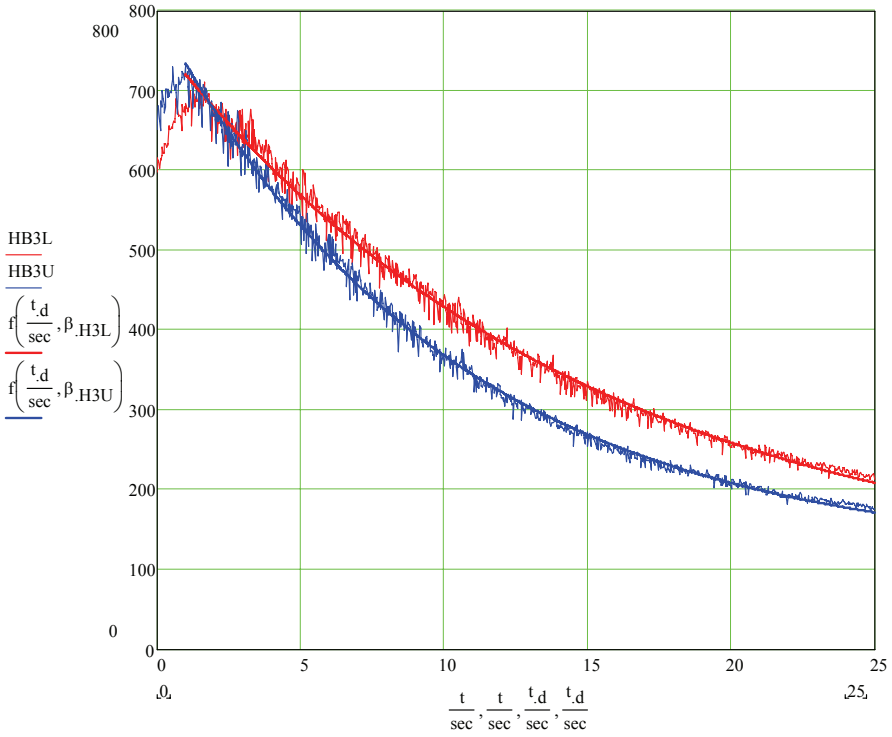
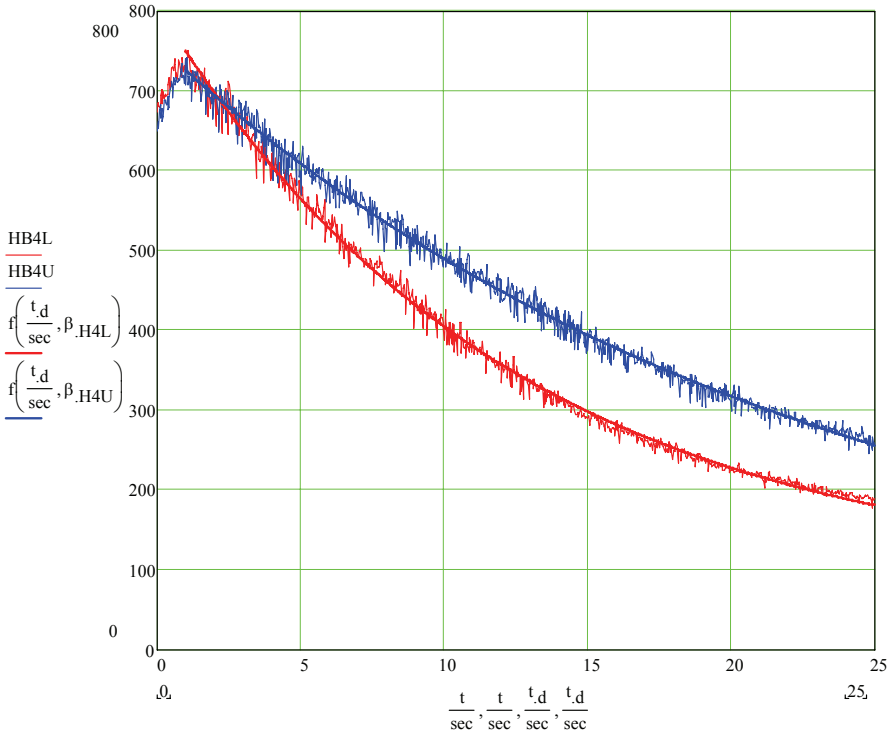
Horizontal Band 3



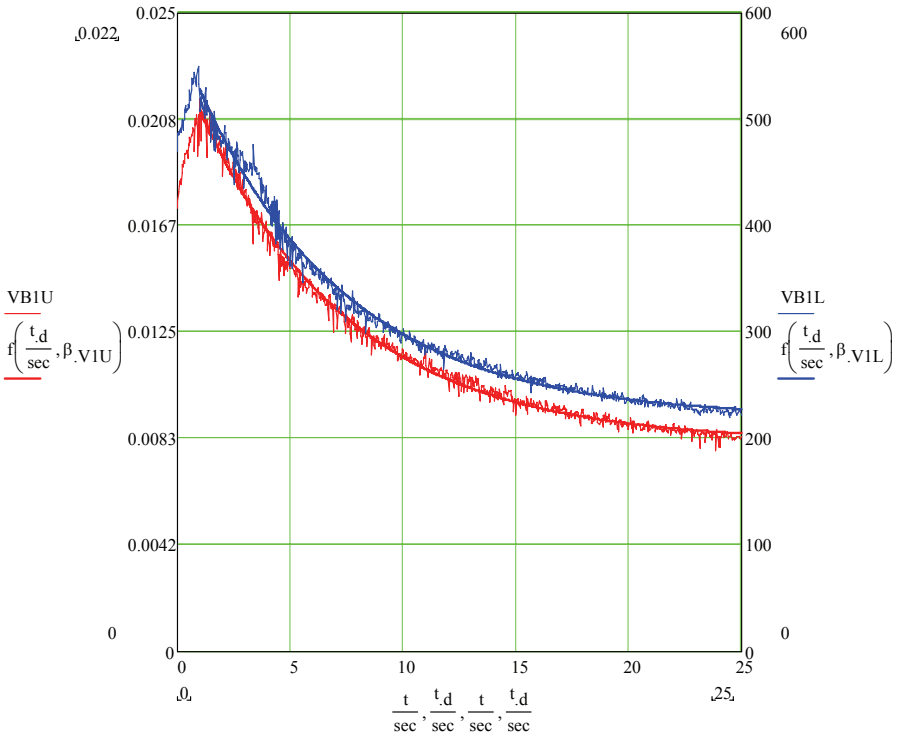
Time (sec)

Horizontal Band 4



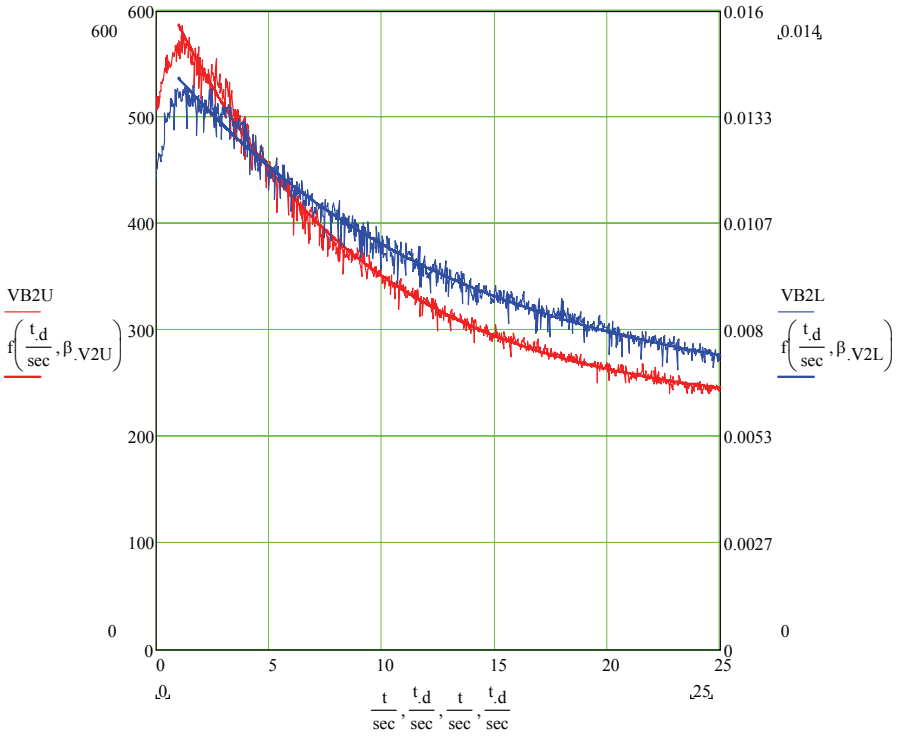
Time (sec)

Vertical Band 1



Time (sec)

Vertical Band 2



Time (sec)

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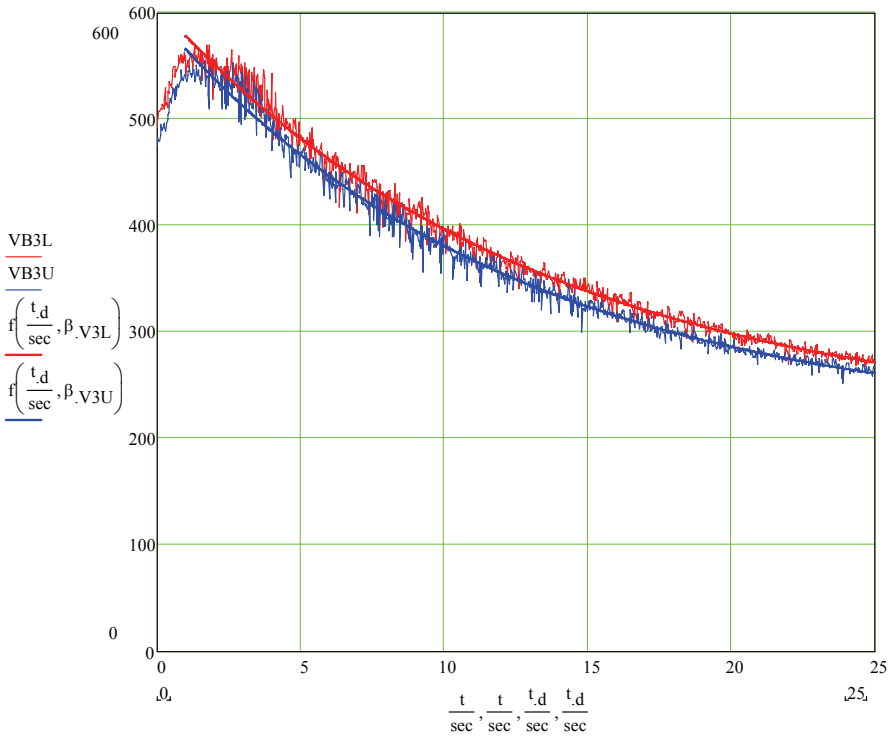
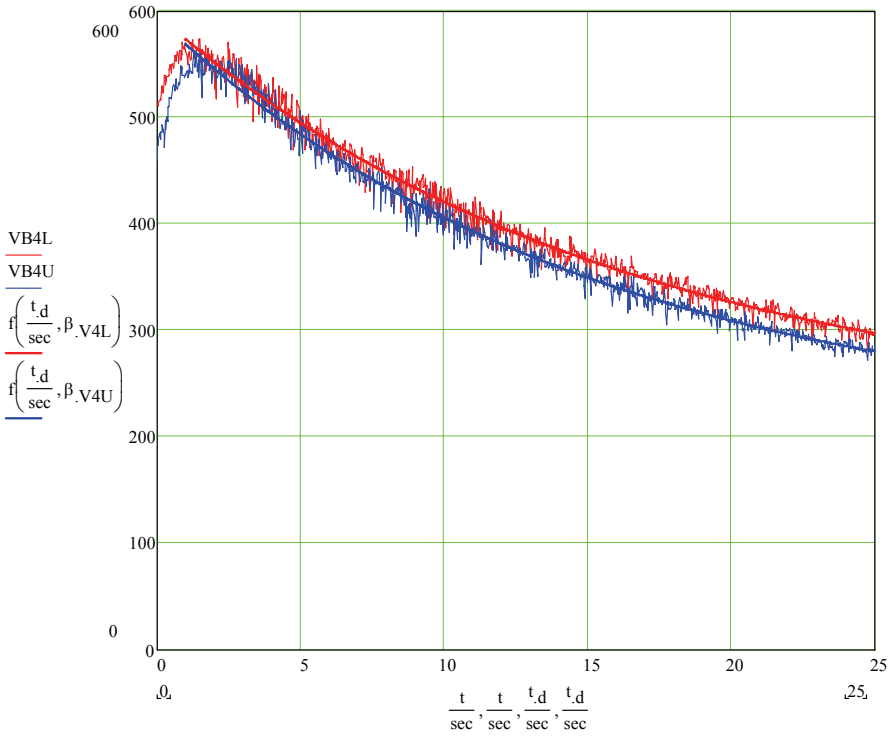
Vertical Band 3



Time (sec)

Vertical Band 4



Time (sec)

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Combined upper + lower sub band cooling rates

The cooling rate and SNR was measured for each band with both upper and lower low level sub bands on. The results are shown in the following table. The plots showing the cooling time fits are shown in figures 11 and 12 below.

System	SNR (dB)	**Int. BW (GHz)**	τ (sec)
HB1	9.7	2.0	4.631
HB2	9.9	2.0	5.580
HB3	4.8	2.5	6.641
HB4	4.8	2.5	9.886
VB1	9.5	2.0	4.398
VB2	9.9	2.0	7.270
VB3	5.5	2.5	6.922
VB4	4.0	2.5	8.778

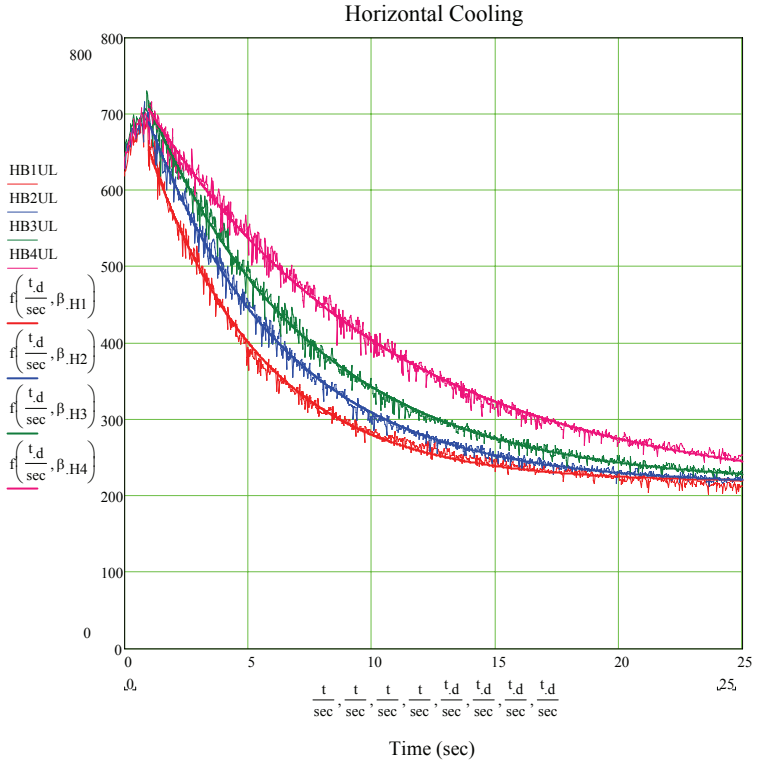

Figure 11 Exponential fits to horizontal betatron sideband power vs. time. Both low level sub-bands were on when each system was measured.

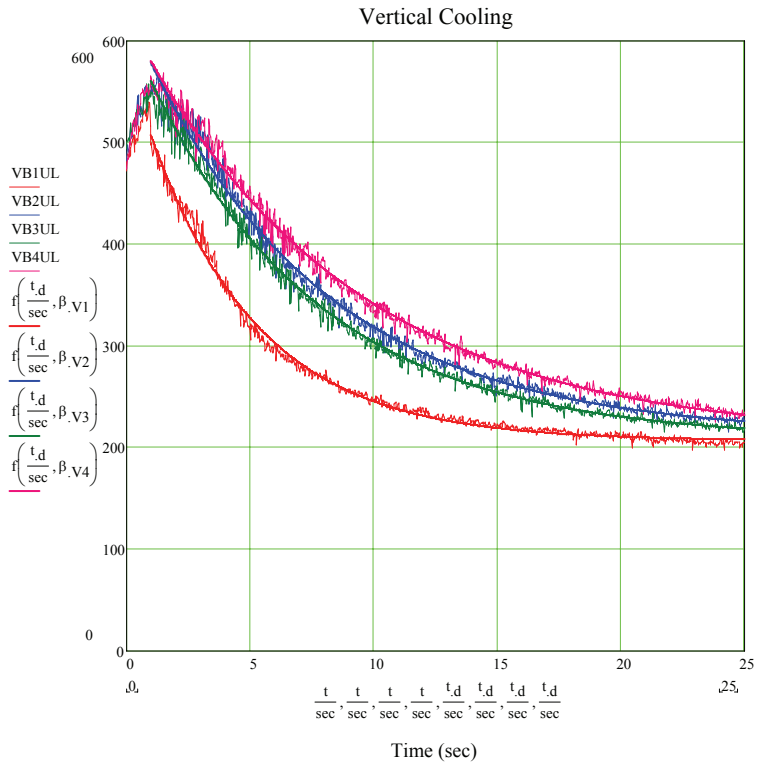

Figure 12 Exponential fits to vertical betatron sideband power vs. time. Both low level sub-bands were on when each system was measured.

Analysis

The measured cooling rates span a rather wide range. A variety of parameters were examined in an attempt to determine what causes this variation in cooling rate. The table below contains a summary of the various parameters that were studied. The red entries are quantities that are significantly different from what is expected.

System	β_{pu} (m)	β_k (m)	$\Delta\phi$ (deg)	SNR (dB)	τ (sec)
HB1L	7.72	12.03	109.5	10.1	8.601
HB1U	17.74	12.03	95.47	9.5	7.254
HB2L	11.76	10.29	94.3	10.7	12.318
HB2U	5.00	10.29	72.5	9.4	8.906
HB3L	5.90	9.15	103.8	4.2	14.663
HB3U	12.52	9.15	84.4	6.3	10.101
HB4L	8.86	6.8	110.9	6.4	12.205
HB4U	3.87	6.8	81.9	4.2	22.556
VB1L	4.12	11.83	117.4	8.2	6.575
VB1U	11.22	11.83	92.7	10.1	6.609
VB2L	10.35	8.92	136.2	10.5	12.648

System	β_{pu} (m)	β_k (m)	$\Delta\phi$ (deg)	SNR (dB)	τ (sec)
VB2U	4.01	8.92	110.0	10.0	8.593
VB3L	4.84	9.01	98.0	4.5	13.062
VB3U	14.15	9.01	77.9	7.1	12.186
VB4L	10.14	7.17	95.3	5.1	16.021
VB4U	4.32	7.17	69.8	3.5	15.067

The parameter that best correlates to slow cooling rate is SNR. The graph below plots cooling rate versus SNR. The correlation is far from perfect. Moreover, there seems to be no explanation for the anomalously long cooling time for HB2L and VB2L.

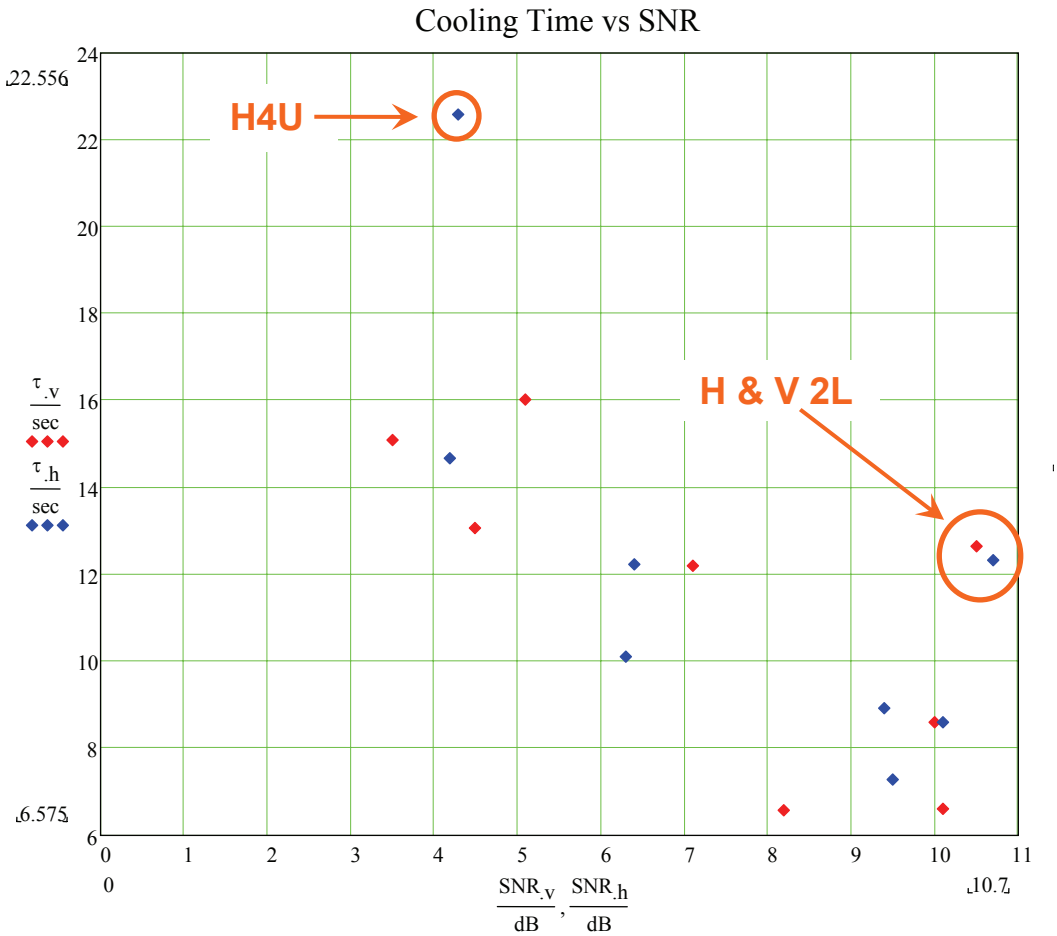

Figure 2 Exponential cooling time (τ) versus signal to noise ratio (SNR) for all cooling sub bands. ♦ is horizontal and ♦ is vertical.

Observations

1. The SNR for HB1L and VB3L shows some rather ragged lobes that are not present in when both sub bands of HB1 and VB3 are measured together. This was checked and verified during the November 1, 2006 measurements.
2. The noise level of horizontal and vertical band 3 is about 10 dB higher than the other bands – why is this?
3. The SNR for horizontal and vertical band 3 lower is relatively small. Also the band width of these bands is narrower than any other sub-band.
4. The SNR for horizontal and vertical band 4 upper is the smallest of the lot. Moreover the SNR of these sub-bands are 3-4 dB lower than the band 4 lower sub-bands. Also, the difference between band for upper and lower is not seen when both sub-bands are measured together.
5. Band 2 lower has the best SNR for both the horizontal and the vertical systems.
6. The cooling rate for horizontal and vertical band 2 lower is ~40% worse than the upper sub-band even though the lower band 2 sub bands have the best SNR – that's no fair!
7. HB4U really stinks. VB4 upper and lower smell pretty bad as well.
8. The notch filters in horizontal bands 1 and 2 do nothing to improve the SNR. The SNR is actually degraded through the notch filters of vertical bands 1 and 2.
9. The notch filters for horizontal bands 1 and 2 do very little to improve the SNR (a small fraction of a dB).
10. The SNR is actually degraded through the notch filters of vertical bands 1 and 2.

Appendix: Setup and conditions

October 17, 2006 Measurements			***November 1, 2006 Measurements***	
D:H1PA1	11.00		D:H1PA1	11.00
D:H2PA1	19.50		D:H2PA1	21.00
D:H3PA1	4.00		D:H3PA1	4.00
D:H4PA1	3.00		D:H4PA1	3.00
D:V1PA1	15.50		D:V1PA1	12.50
D:V2PA1	17.25		D:V2PA1	16.00
D:V3PA1	15.00		D:V3PA1	13.00
D:V4PA1	10.00		D:V4PA1	8.25

During the October 17 measurements D:IBEAMV = 21 μA (2.22×10^8 $\bar{p}$'s) – very consistent from pulse to pulse.

During the November 1 measurements D:IBEAMV = 17 μA (1.80×10^8 $\bar{p}$'s). The beam intensity during this time was somewhat variable. The number given is only an average.

NOTE: None of the analysis in this memo properly accounts for the gain and beam intensity differences between the October 17 measurements and the November 1 measurements.

The SNR measurements for HB1L, HB4L, VB1L, VB3L, and VB1UL were done on November 1.

The cooling rate measurements for HB1U, HB2L, VB1U, and VB2L were done on November 1.