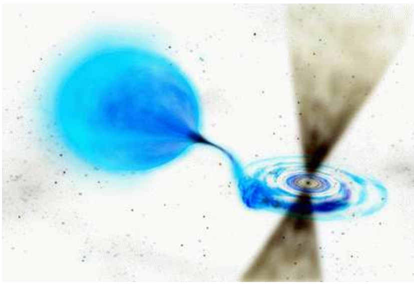

CICADA Note #4

Event Capture α First Light

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Abstract

The Event Capture α data acquisition system, based on the U.C. Berkeley IBOB/ADC hardware, has been completed. We present first astronomical tests of the Event Capture system, using the 43m telescope. These observations were carried out at 900 $\pm$64 MHz. This note summarizes observations made between 16:00 UTC on July 8, and 13:00 UTC on July 9, towards the Crab pulsar, the galactic center, the Moon and two test observations while the 43m was pointed at Zenith (straight up).

Change Record

Revision	Date	Author	Sections/Pages Affected
	Remarks		
1.0	2007-July-24	G. Langston	All
	Initial version in preparation for β design		
1.1	2007-July-25	G. Langston	All
	Add transient events and spectra		
1.1	2007-August-7	G. Langston	All
	Add acknowledgements		

Introduction

This document describes first astronomical observations using the Event Capture α, FPGA based, data acquisition system. The Event Capture α project plan was described in CICADA notes 2 and 3, by Langston, McCullough, Ford, Rumberg and Brandt. The design uses hardware developed by the CASPER[1] group at the University of California at Berkeley.

The purpose of these observations was to prove that the Event Capture α design could detect astronomical short term events, and also determine the background number of events found at high significance ($> 10\sigma$) short term events.

The Radio Frequency Interference (RFI) in this frequency range was known to be strong, but the rate of short term bursts was not known. These observations place the first constraints on this type of interference in this frequency range.

The Crab Pulsar is an ideal first source for observations using the design, as the crab pulsar is known to produce short term, intense bursts. The galactic center is known to harbor a large number of pulsars, but the dispersion in this direction is large, possibly preventing detection of short term bursts, by stretching them over such a long duration that they fall below the detection threshold. Also the galactic radio emission is also strong, nearly doubling the 43m system temperature in this frequency range.

The Moon is a primary target for future science with the Event Capture designs, as there is great current interest in detecting short term pulses of emission that may be produced when very high energy neutrinos interact with the lunar surface.

Finally, we observed the zenith, where no astronomical source is expected, so as to determine the background number of transient events. Some of the background events may be due to astronomical sources, but the majority are believed to be due to terrestrial RFI.

Observing setup

These observations used the 43m telescope and the MIT/LL wide-band, 150 to 1700 MHz feed. The dual linear polarization RF signals were transmitted from the 43m control room to the Jansky lab via fiber modems. In the 500 to 1000 MHz frequency range the effective system temperature is approximately 90 K.

In the Jansky lab, a 128 MHz wide selection of the RF signal at 900 MHz was up-converted, filtered and down converted to a center IF frequency of 684 MHz.

The dual polarization IF signals were fed to the IBOB ADC boards, and sampled at 800 MHz clock

[1] Center for Astronomy Signal Processing and Electronics Research, documentation at http://casper.berkeley.edu/

Object Name	Start Time (UTC)	Duration (hours)	Short Events	Long Events
Crab	16:00	6.5	87	36
Zenith	22:30	4.5	26	6
Sgr A	03:00	4.0	1	0
Moon	07:00	4.0	21	9
Zenith	11:00	2.0	2	0

Table 1: Objects observed during these initial tests, the start time and duration of the observations of each object. The counts of the number of short duration ($<$ 320 nano-seconds) and long duration events are listed.

rate. The interval between samples was 1.25 nano-seconds. The sampled signals were processed by the Event Capture α design.

The Event Capture α design records both polarization samples when a significantly strong pulse of IF power is found in the average signal level over a short time interval. For these observations the averaging interval was 20 samples, or 25 nano-seconds.

Transient Events

The Event capture data was analyzed using the program `eventFft`, which reads event data, identifies events, discards weak transient events, divides events into long ($\tau > 320$ nano-seconds) and short events. The spectral profile of the data before the events and of the events are computed as well as the average spectra of all input events.

We discarded all events with a peak power level less than 10σ of the background noise level. The system temperature in this band is approximately 90 K. For the 43m gain of ∼0.5 K per Jy, a 10 σ transient corresponds to a transient event brightness of ∼1800 Jy. The transient event data were buffered so that data before and after the event could be recorded. A total of 4800 samples were recorded each event, half the samples coming before the event. The number 4800 was chosen so that there would be 2048 samples free of short term event signals, so that an event-free reference spectrum was obtained before each event.

The events are divide into short and long, in order to distinguish communication based RFI from astronomical short duration pulses. (This division was only partially successful as occasionally pairs of short term transients will be counted as a single long term event.)

We assume all events detected while at zenith are due to the RFI background. The zenith observations had a total duration of 6.5 hours and had short duration event rate of 4.3±0.8 events per hour. The long duration event rate was less, 0.9± 0.4 events per hour.

Crab Pulsar

The largest detected transient event rate was towards the Crab Pulsar. These observations were carried out on Saturday afternoon, when GBT construction was on-going. Potentially a larger fraction of these events are due to RFI than events detected at other times. The pulsar short duration event rate was 13.4± 1.4 events/hour, This event rate towards the Crab Pulsar was significantly greater (5.6σ) than the background rate. The long duration event rate was also larger than the background rate, 5.5±1.1 events/hour, but the statistical significance is less (4σ).

Figure 1 (top) shows the full time series of a single short term transient event and figure 1 (bottom) shows a zoom in on the time of the event. Figure 2 (top) shows the spectrum produces from the Fourier transform of the first 2048 samples of the time series in figure 1. The spectral band bandwidth is 400 MHz and the resulting spectrum has 1024 channels. No weighting was applied to the samples before the Fourier transform. Figure 2 (bottom) shows the spectrum produced from 256 samples including the transient event. All spectra from short duration events were produced from 256 samples, regardless of the event duration.

Figure 3 (top) shows a time series from a long duration transient event and the bottom plot shows the intensity versus frequency spectrum for this event. Note the dominant source of power is from a narrow frequency source, probably terrestrial interference.

Figure 4 (top) shows the average spectrum from all detected events for the crab pulsar. This spectrum is produced from samples *before* the event, so shows the system gain and interference background. Figure 4 (bottom) shows the spectrum obtained while observing the short term transient events. Notice the increased power at lower frequencies, expected for pulses from the Crab pulsar.

Figure 5 shows the average spectrum produced from all long duration events. This spectrum contains strong RFI at 895.3 MHz.

Zenith

The observations of the Zenith for 6.5 hours were our reference for determining the terrestrial background of events. The average zenith spectra are shown in figures 6 and 7.

Galactic Center

Only 1 short duration event was found at the 10σ level towards the galactic center. Partially this is due to the much higher background level towards the galactic center, which doubles the system temperature from 90 K to approximately 200 K. The transient event detection threshold was $\sim$ 4000 Jy. The galactic event is shown in figures 8 and 9.

Moon

The Lunar transient short duration event rate 5.25 ± 1.1 is not significantly different than the background, zenith rate. The long duration event rate, 2.2 ± 0.8 per hour is also consistent with the background rate.

We note a significant spectral difference in the spectral signature of the short duration spectrum of the lunar events. The short duration event spectrum shows a peak at 962.8 MHz. The long duration event spectrum shows a peak at 895.9 MHz. See figures 10 and 11.

Summary

We have shown the Event Capture α data acquisition system is able to capture transient events in the IF signal from the 43m telescope. In this frequency range, there is a strong transient background, due to terrestrially generated Radio Frequency Interference (RFI).

A statistically significant number of short and long duration transient events are detected towards the Crab pulsar. We did not detect statistically significant number of events from neither the Moon nor the Galactic center.

Additional data validation techniques are required to distinguish astronomically generated events from local RFI.

REFERENCES

Hankins, T. H.; Ekers, R. D.; O'Sullivan, J. D., (1996), *A search for lunar radio Cerenkov emission from high-energy neutrinos*, *MNRAS*, **283**, 1072.

Langston, G., McCullough, R., Ford, J., Rumberg, B., Brandt, P. (2007) *Cicada Note 2: Event capture α Project Plan NRAO* `https://wikio.nrao.edu/bin/view/CICADA/CicadaNotes`

Langston, G., McCullough, R., Ford, J., Rumberg, B., Brandt, P. (2007) *Cicada Note 3: Event capture α Project Review NRAO* `https://wikio.nrao.edu/bin/view/CICADA/CicadaNotes`

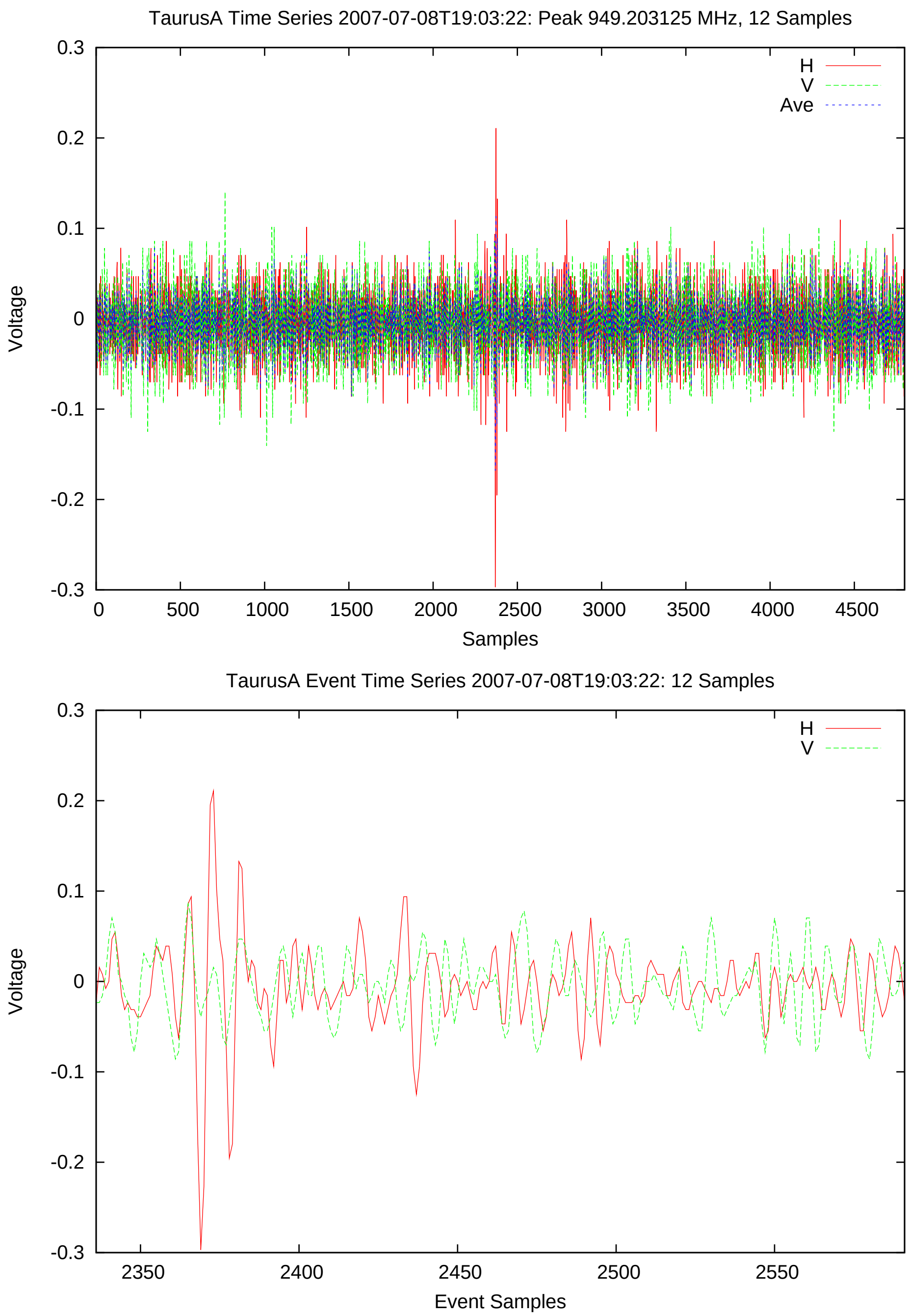

Fig. 1.— **Top:** Plot of Voltage versus time for an example short duration Crab Pulsar event captured in these tests. The data extends $\pm$ 3 μ-seconds of the event time. **Bottom:** Same data as above, except zoomed in on the captured event.

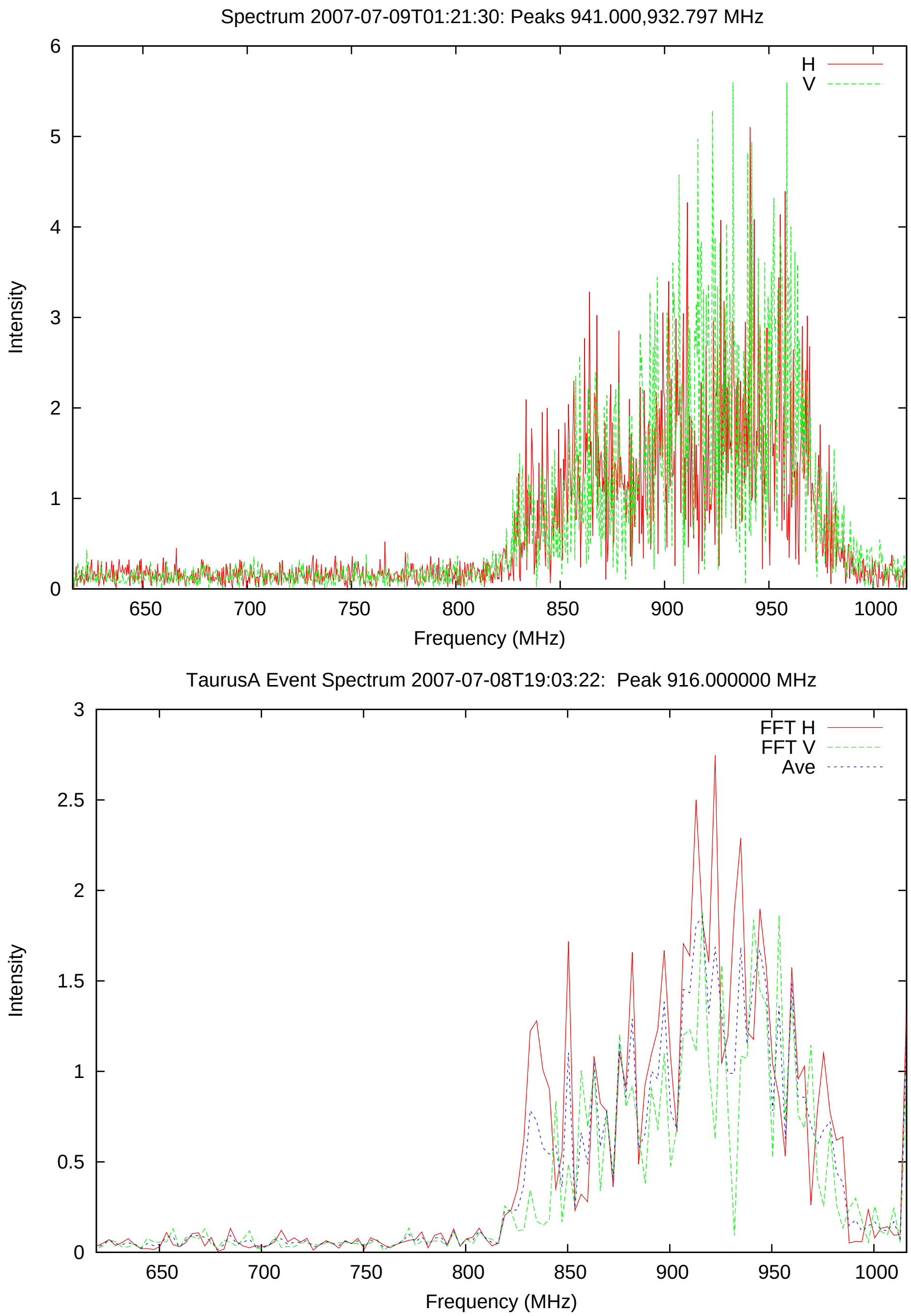

Fig. 2.— **Top:** Plot of intensity versus frequency for the initial 2048 samples before the captured event shown in the previous plot. The band pass spectrum provides a baseline for comparison with the spectrum of the captured event. The spectrum has 1024 channels and a spectral resolution of 0.390963 MHz. **Bottom:** Spectrum of 256 samples of the event time series show in the previous plot. The spectrum has 128 channels and a spectral resolution of 3.125 MHz.

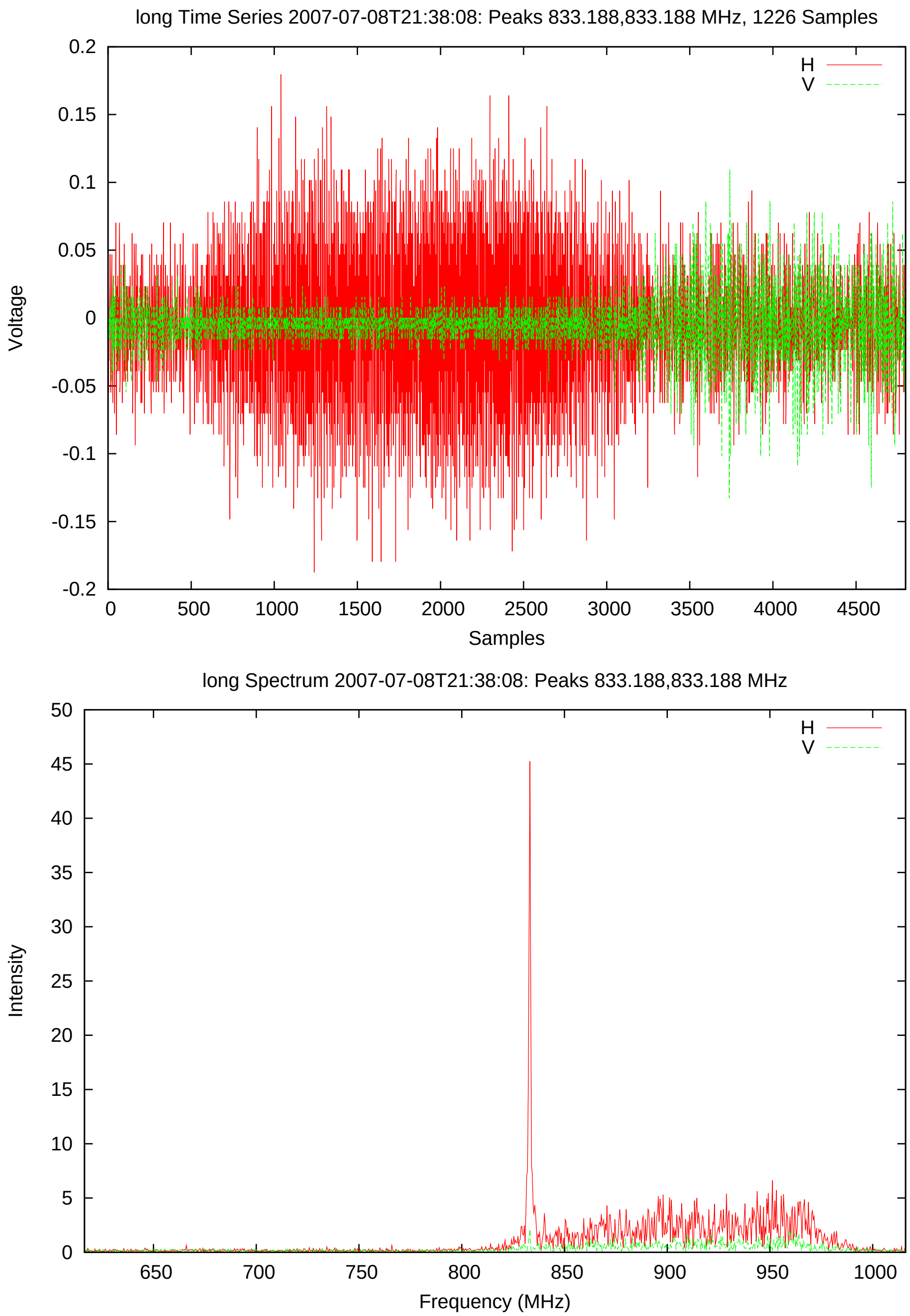

Fig. 3.— **Top:** Plot of Voltage versus time for an example long duration Crab Pulsar event captured in these tests. The data extends ± 3 μ-seconds of the event time. **Bottom:** The Fourier transform of the 2048 time samples around the start of the event. The spectrum has 1024 channels covering 400 MHz. This is an example of how RFI can be identified in captured events.

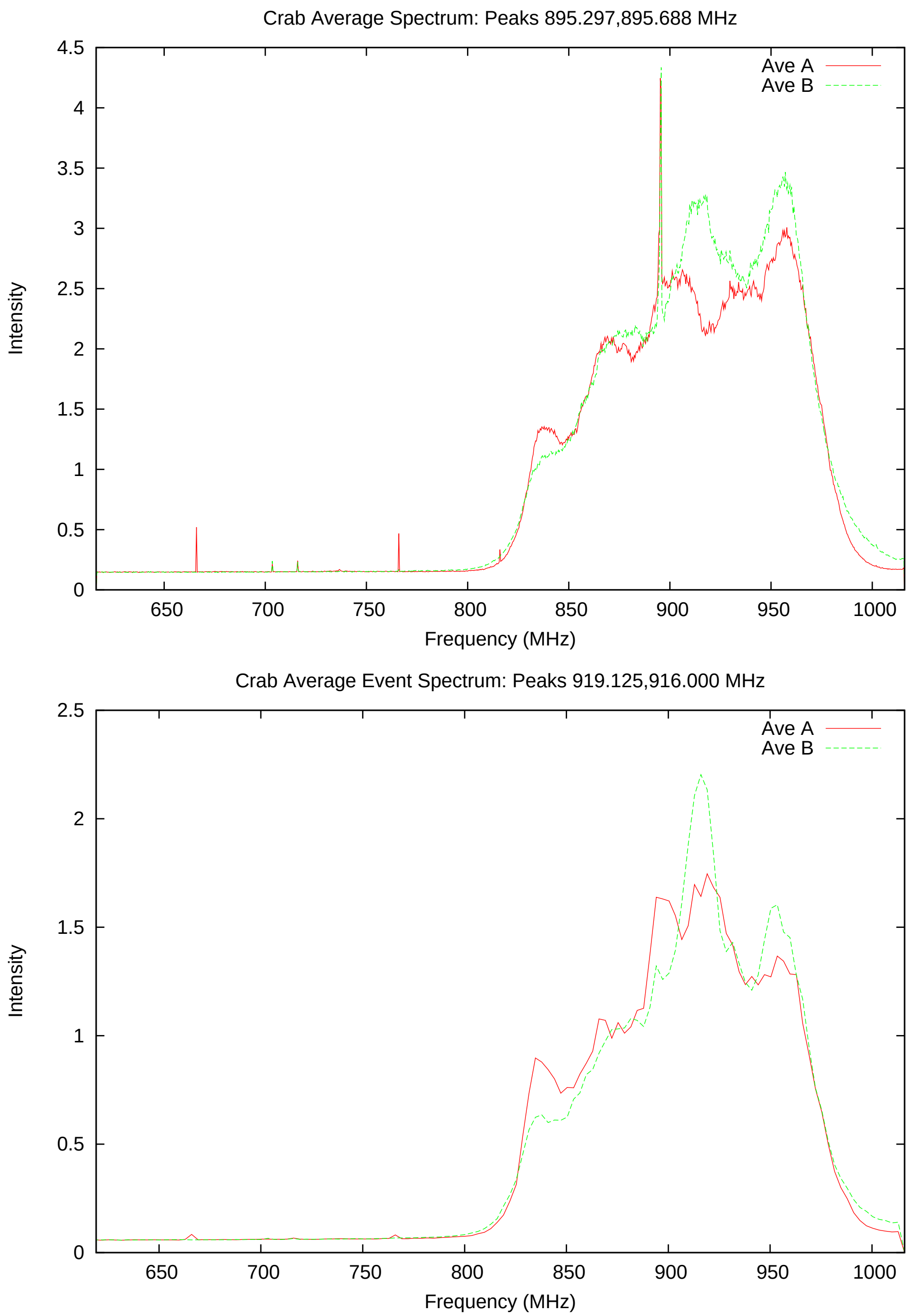

Fig. 4.— **Top:** Plot of intensity versus frequency for average of all band pass spectra of the time range before the captured Crab Pulsar events. **Bottom:** Spectrum of 256 samples of the average of all short duration events. The spectrum has 128 channels and a channel spacing of 3.125 MHz.

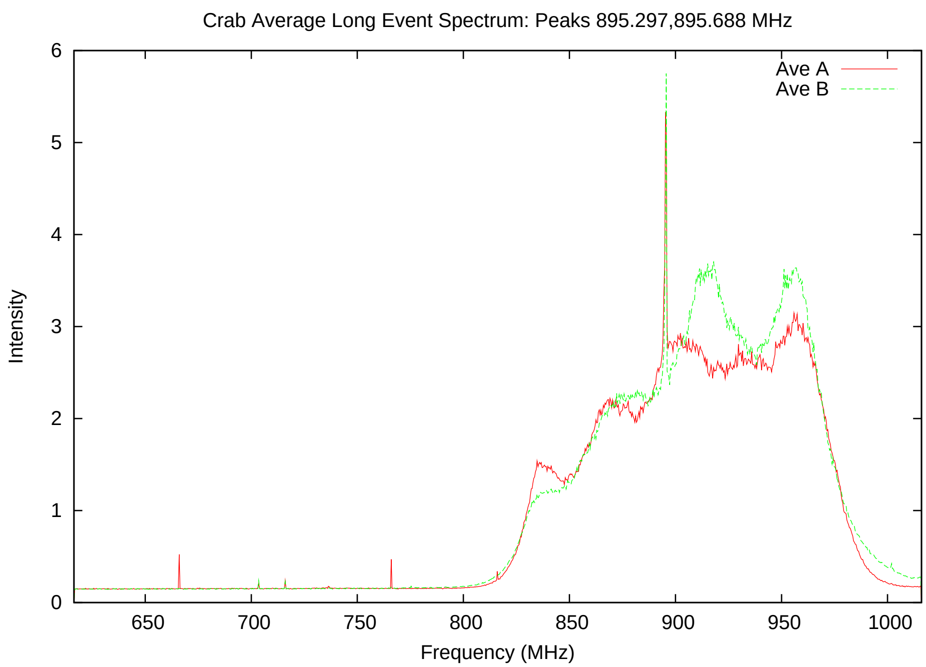

Fig. 5.— Spectrum of 2048 samples of the average of all long duration Crab pulsar events. The spectrum has 1024 channels and a channel spacing of 0.39 MHz.

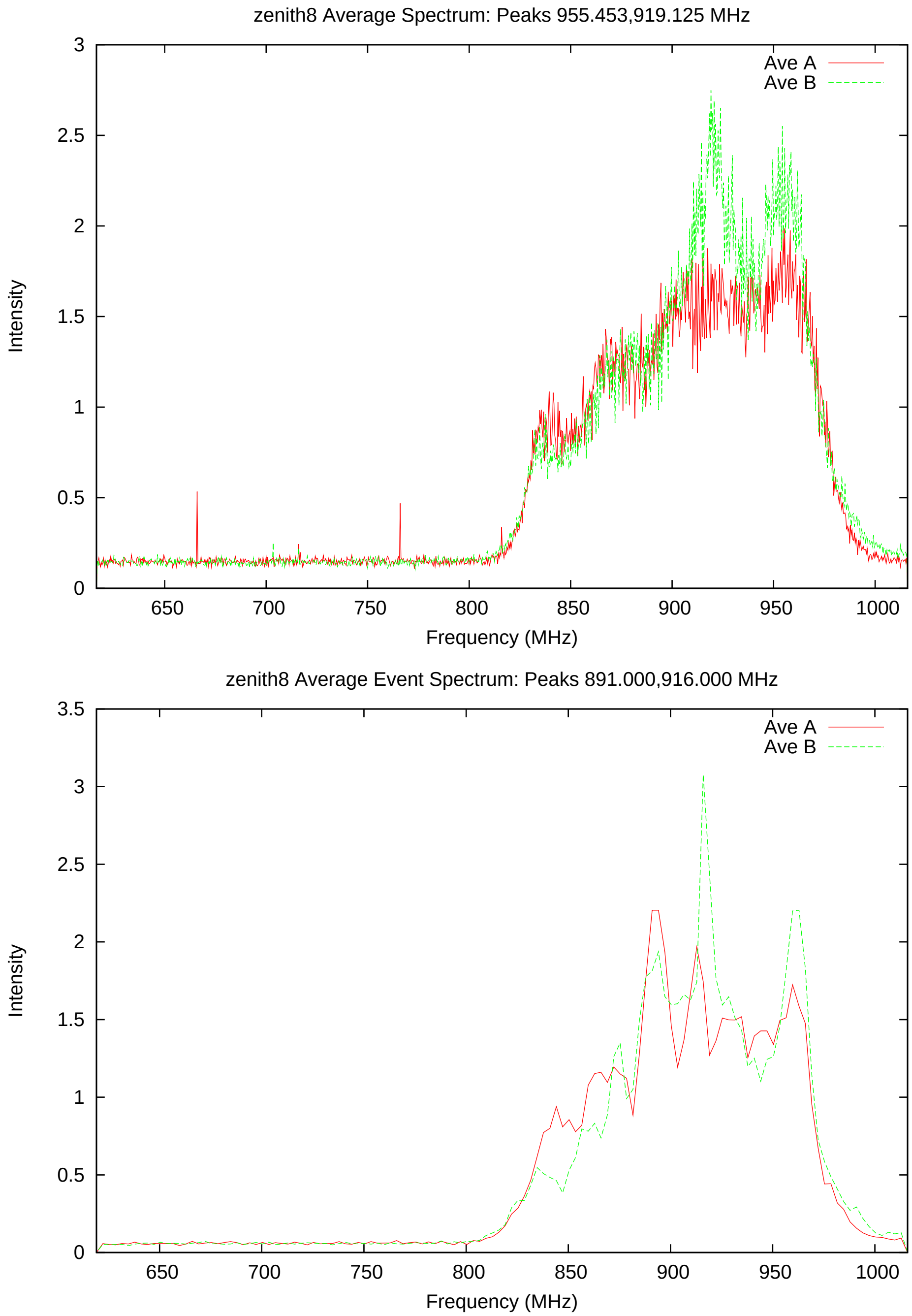

Fig. 6.— **Top:** Plot of intensity versus frequency for average of all band pass spectra of the time range before the captured Zenith (background) events. **Bottom:** Spectrum of 256 samples of the average of all short duration events. The spectrum has 128 channels and a spectral resolution of 3.125 MHz.

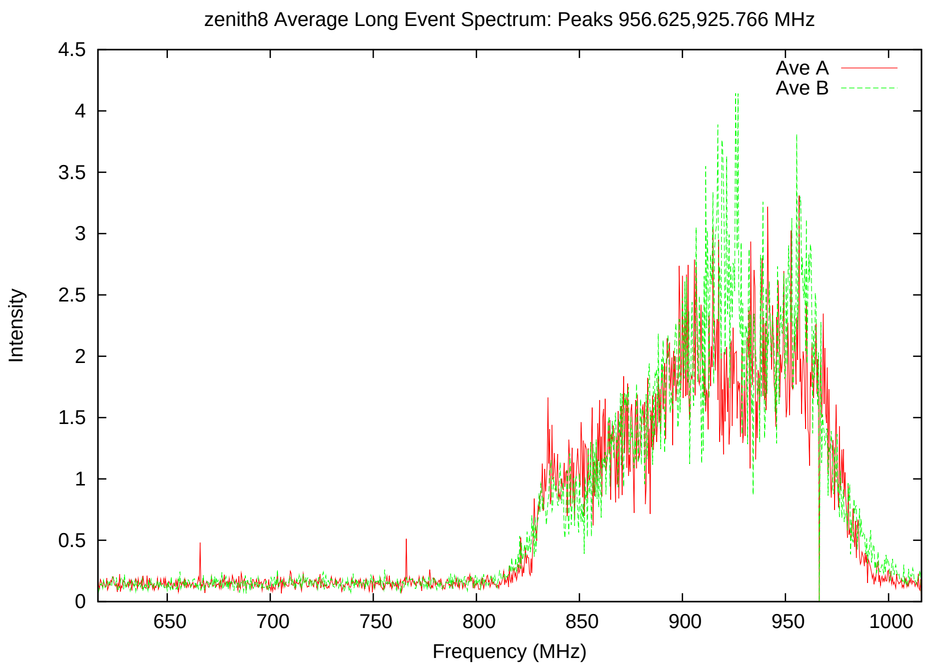

Fig. 7.— Spectrum of 2048 samples of the average of all long duration Zenith (background) events. The spectrum has 1024 channels and a channel spacing of 0.39 MHz.

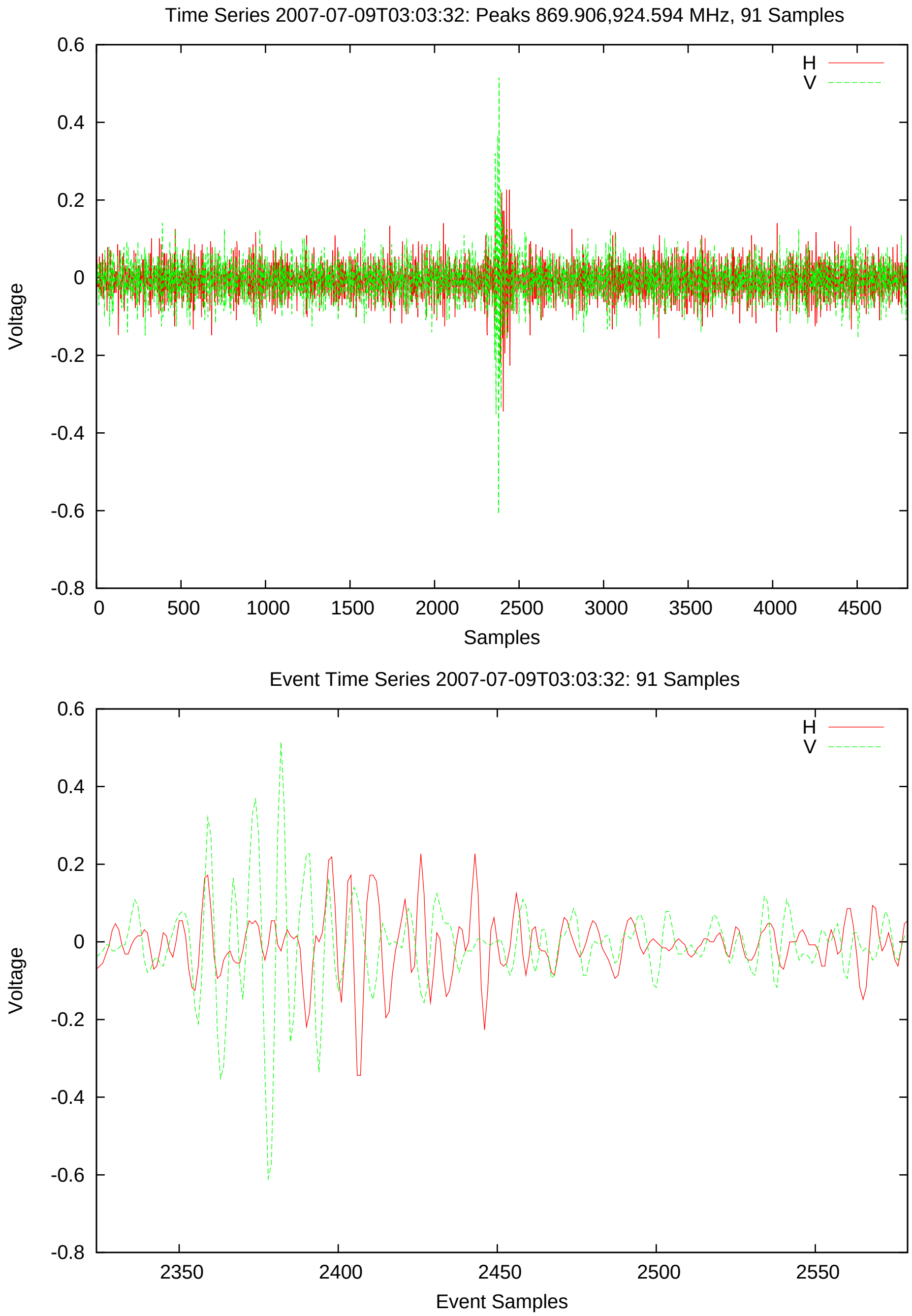

Fig. 8.— **Top:** Plot of Voltage versus time for the only Sgr A event captured in these tests. The data extends $\pm$ 3 μ-seconds of the event time. **Bottom:** Same data as above, except zoomed in on the captured event.

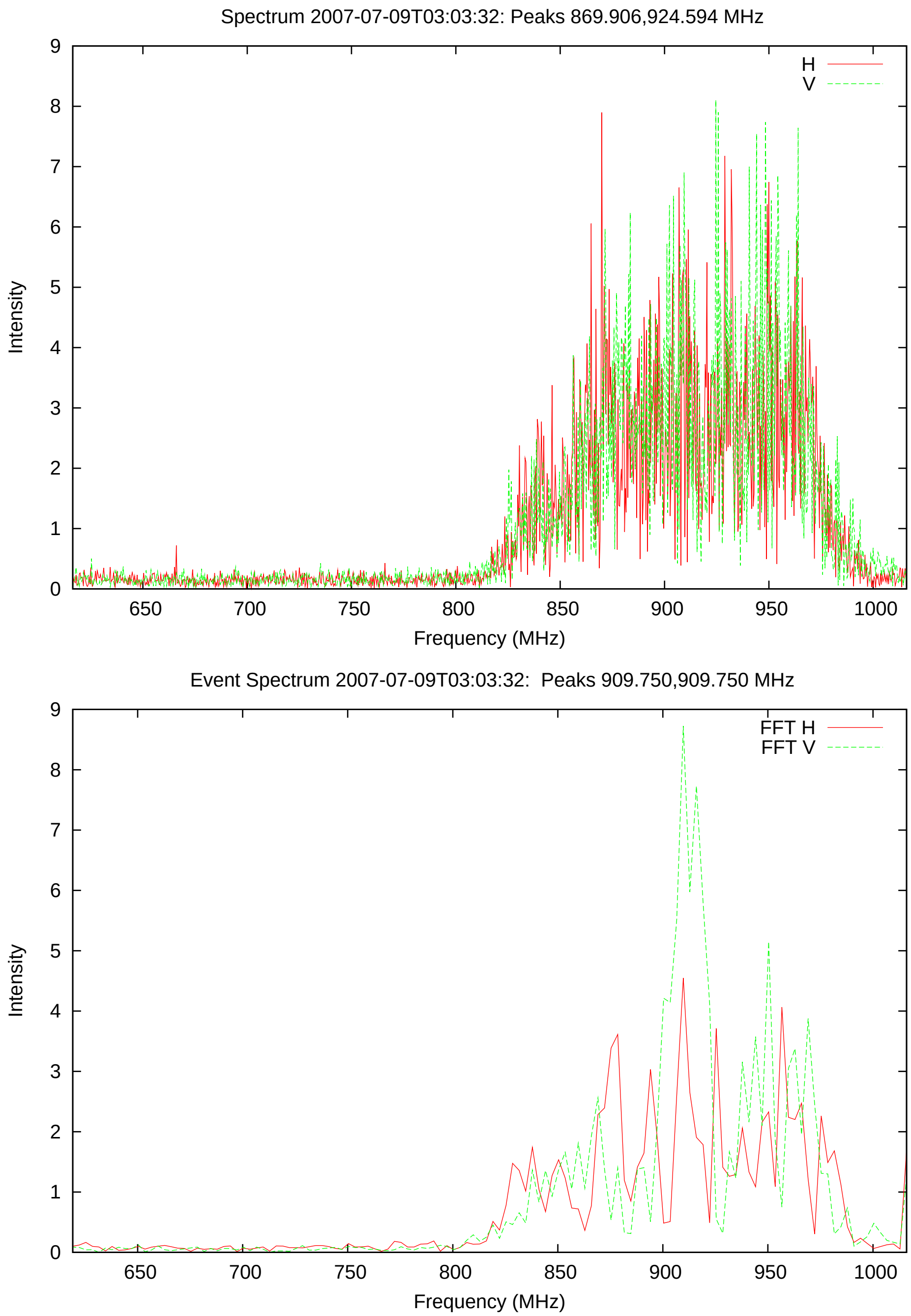

Fig. 9.— **Top:** Plot of intensity versus frequency for the initial 2048 samples before the captured event shown in the previous plot. The band pass spectrum provides a baseline for comparison with the spectrum of the captured event. The spectrum has 1024 channels and a channel spacing of 0.390963 MHz. **Bottom:** Spectrum of 256 samples of the event time series show in the previous plot. The spectrum has 128 channels and a channel spacing of 3.125 MHz.

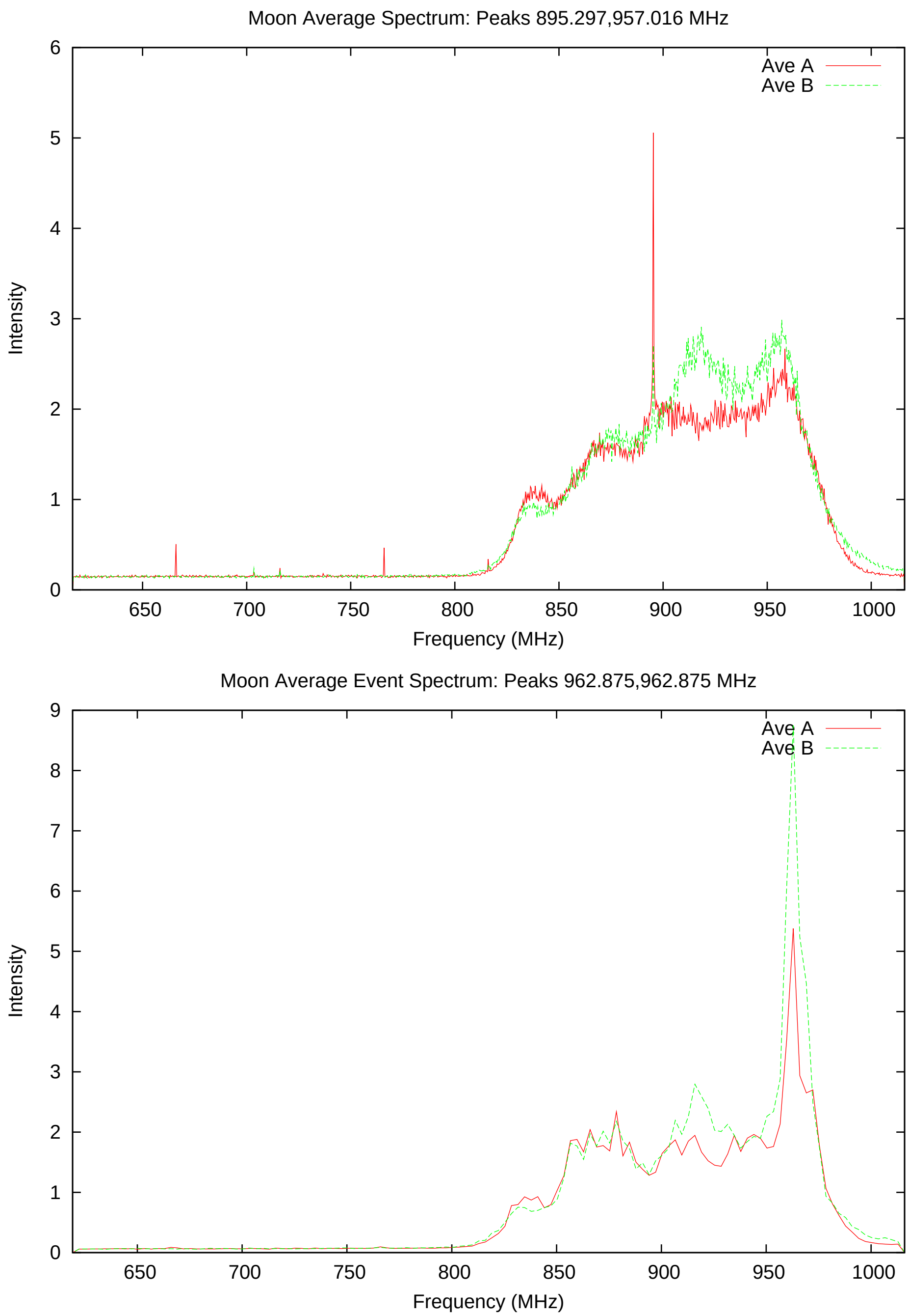

Fig. 10.— **Top:** Plot of intensity versus frequency for average of all band pass spectra of the time range before the captured Moon events. **Bottom:** Spectrum of 256 samples of the average of all short duration events. The spectrum has 128 channels and a spectral resolution of 3.125 MHz.

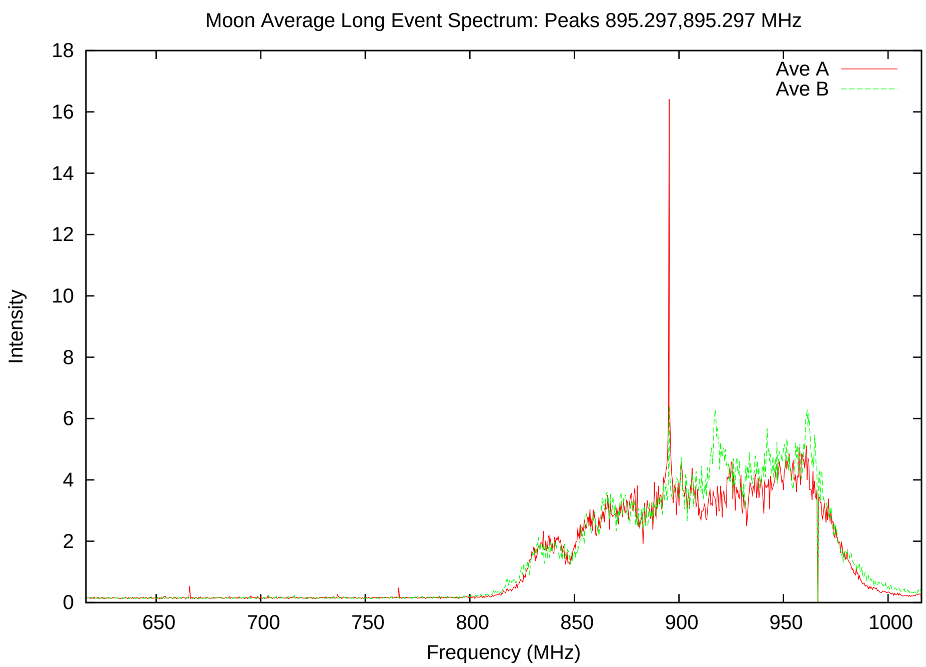

Fig. 11.— Spectrum of 2048 samples of the average of all long duration Moon events. The spectrum has 1024 channels and a channel spacing of 0.39 MHz.