MRM-LANL Proton Radiation Test Report on Switching Point-of-Load Converters

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Introduction

On 21 August 2008, we tested three different point-of-load (POL) DC-to-DC converter chips for their response to proton radiation and to estimate their total ionizing dose performance. The three POL converters were the Enpirion EN5360, the Enpirion EN5365, and a Peregrine PE99150. The EN5360 and EN5365 are commercial converters that were brought to our attention through our relationship with CERN while the PE99150 is an alpha version of a converter being created for the space market. The experiments were carried out using the cyclotron at UC Davis's Crocker Nuclear Laboratory (CNL).

Experimental Setup

The experimental setup was fairly equivalent for all three converters. Each converter was irradiated while operating under a load. The input current and voltage for each converter was sampled at one second intervals to record any trends in power consumption and current draw due to total ionizing dose effects. The following table provides the operating parameters for each POL converter.

Table 1 Circuit Operating Parameters

Device	Supply Voltage	Over Current Protection Limit	Output Voltage	Load
EN5360	5 V	1 A	1.2 V	1 Ω
EN5365	5 V	1.25 A	1.2 V	0.4 Ω
PE99150	5 V	1.5 A	2.58 V	3 Ω

In addition to the current draw of the circuits, we captured the input voltages and output voltages of each POL converter before irradiation and at various points during the test. This data was collected as screen captures for a Tektronix DPO7254 Oscilloscope. Each screen capture shows the input voltage, the output voltage, and their ripple. In addition, we watched for output transients exceeding 80 mV in amplitude in either direction (positive or negative) for each beam run. The only transients of this size that were observed were when the outputs of the EN5365's dropped to effectively zero.

The physical setup for the experiment is illustrated in Figure 1. Coaxial cable was used to supply the power to the converter circuits and to measure both the input and output voltages. For convenience, we used the pre-existing coaxial cable patch panels provided by CNL to connect the oscilloscope to the input (Vin) and output (Vout) voltages of the converter circuits. As a rough estimate, the length of coaxial cable between the oscilloscope and the POL converter was approximately 60 feet. The length of cable, of course, contributes to some error in the measurements, but should be reasonable for our purposes.

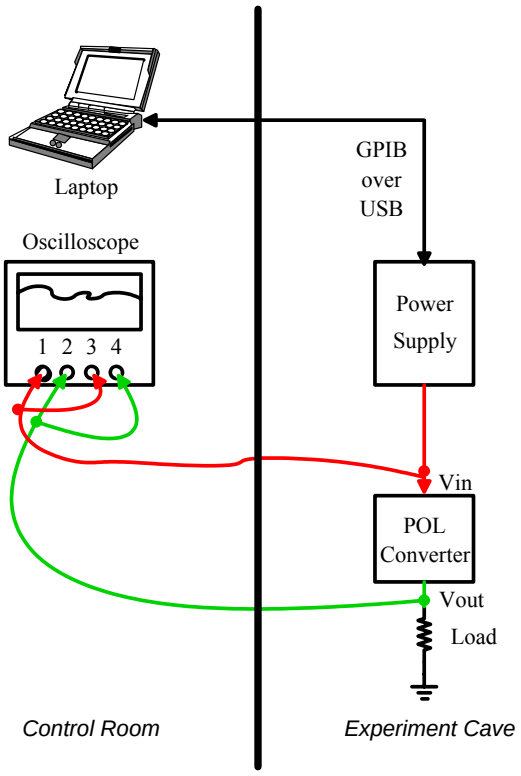

Figure 1 Equipment Setup

We used the following setup for the oscilloscope:

- Channel 1: Vin, 1 M Ω input impedance, AC Coupled, 20 MHz bandwidth
- Channel 2: Vout, 1 M Ω input impedance, AC Coupled, 20 MHz bandwidth
- Channel 3: Vin, 50 Ω input impedance, DC Coupled, 20 MHz bandwidth
- Channel 4: Vout, 50 Ω input impedance, DC Coupled, 20 MHz bandwidth
- Trigger: 80 mV positive or negative going glitches

A Tektronix PS2125G power supply was used to provide power to the converter circuits. The power supply was controlled and the current was monitored over GPIB using custom software. The power supply setup is given in Table 1 (above).

For these tests, only the Peregrine POL had been irradiated before. The rest were chips that had been delidded by Analytical Solutions in Albuquerque, but had not been used in previous radiation tests.

Enpirion EN5360 Results

For the EN5360, we had two samples, identified as Board 6 and Board 7 due to the PCB on which they were mounted. Both samples continued to function through 200 krad of dose. Figure 2 and Figure 3 illustrate the current draw versus the accumulated dose for BD 6 and BD 7, respectively. Notice that for the BD 7 plot that there is a gap of data at the end. This is due to a recording issue where we turned on logging at the end of the final run. The final value is plotted to show the general trend toward the end. It is quite consistent with the rest of the data.

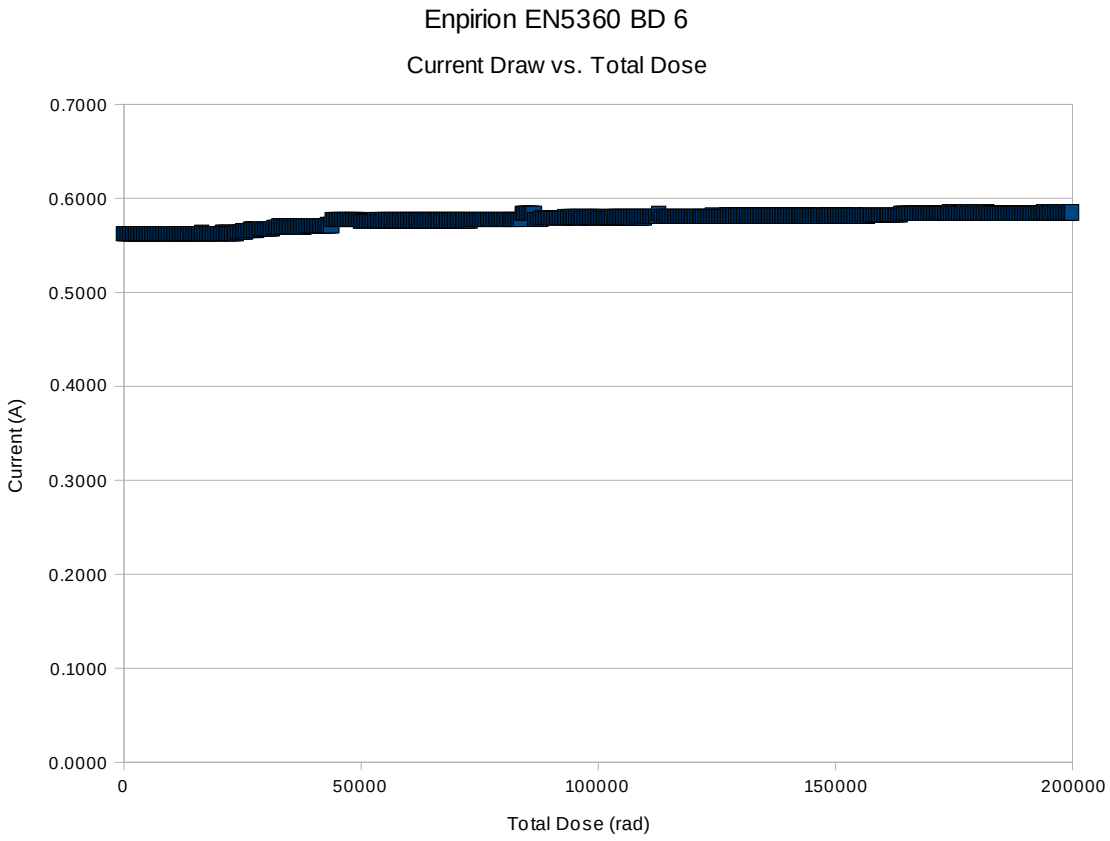

Figure 2 Enpirion EN5360 BD 6: Current Draw Vs. Total Dose

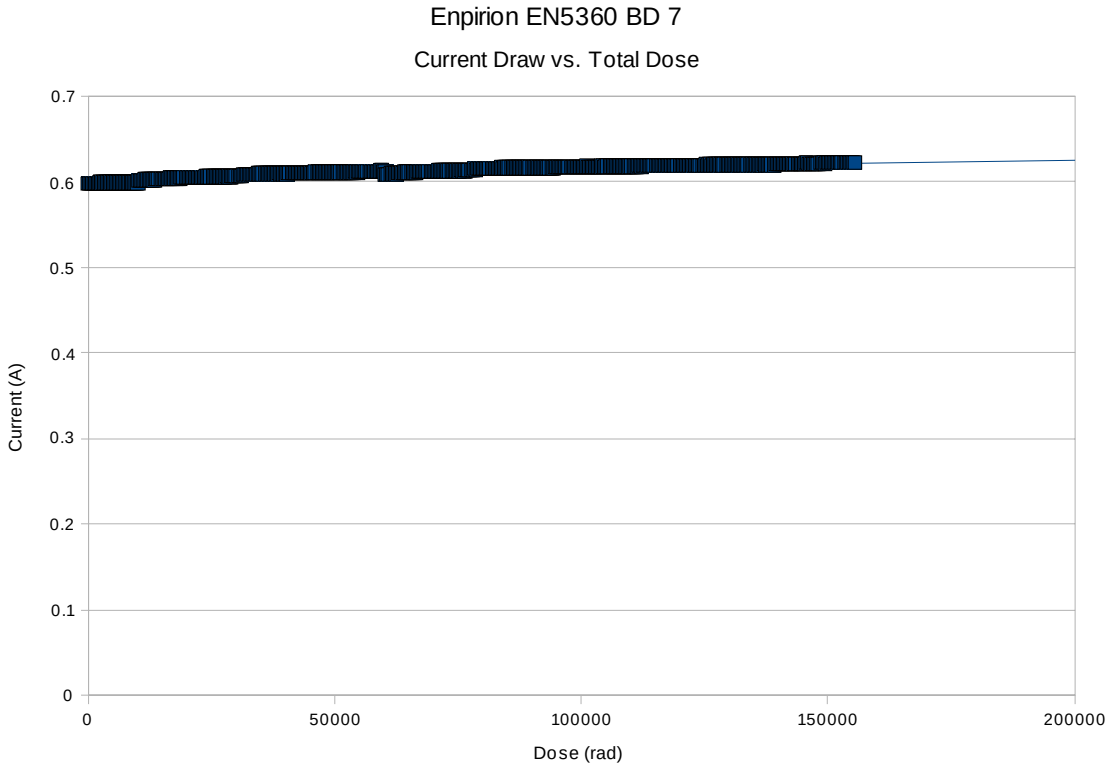

Figure 3 Enpirion EN5360 BD 7: Current Draw vs. Total Dose

The following figures are screen captures of the voltage inputs (Vin) and outputs (Vout) collected using the oscilloscope. The channel configuration was given in the previous section. The EN5360 BD 7 was the first part tested, so the intervals for the data captures are a little unusual. The rest of the devices tested were sampled at intervals of either 25 or 50 krad.

With regard to output voltage, both BD 6 and BD 7 demonstrated a slight dip in output voltage over time. For BD 6, the average output voltage was about 1.127 V (as measured by the scope itself) and this decreased to 1.125 V by the end of the test at 200 krads. For BD 7, the initial average output voltage was 1.136 V and the final average output voltage was 1.133 V by the end of the test at 200 krads. Since we didn't record the temperature of the device, it is hard to say whether or not these affects were due to irradiation.

As for the output ripple, BD 6 started with about 26 mV of output ripple (peak to peak) at about 4.81 MHz and finished the test at 200 krads with an output ripple of approximately the same magnitude and frequency (26 mV @ 4.73 MHz). BD 7 started with 28 mV of ripple at 4.65 MHz and ended with 28 mV of ripple at 4.69 MHz after 200 krads.

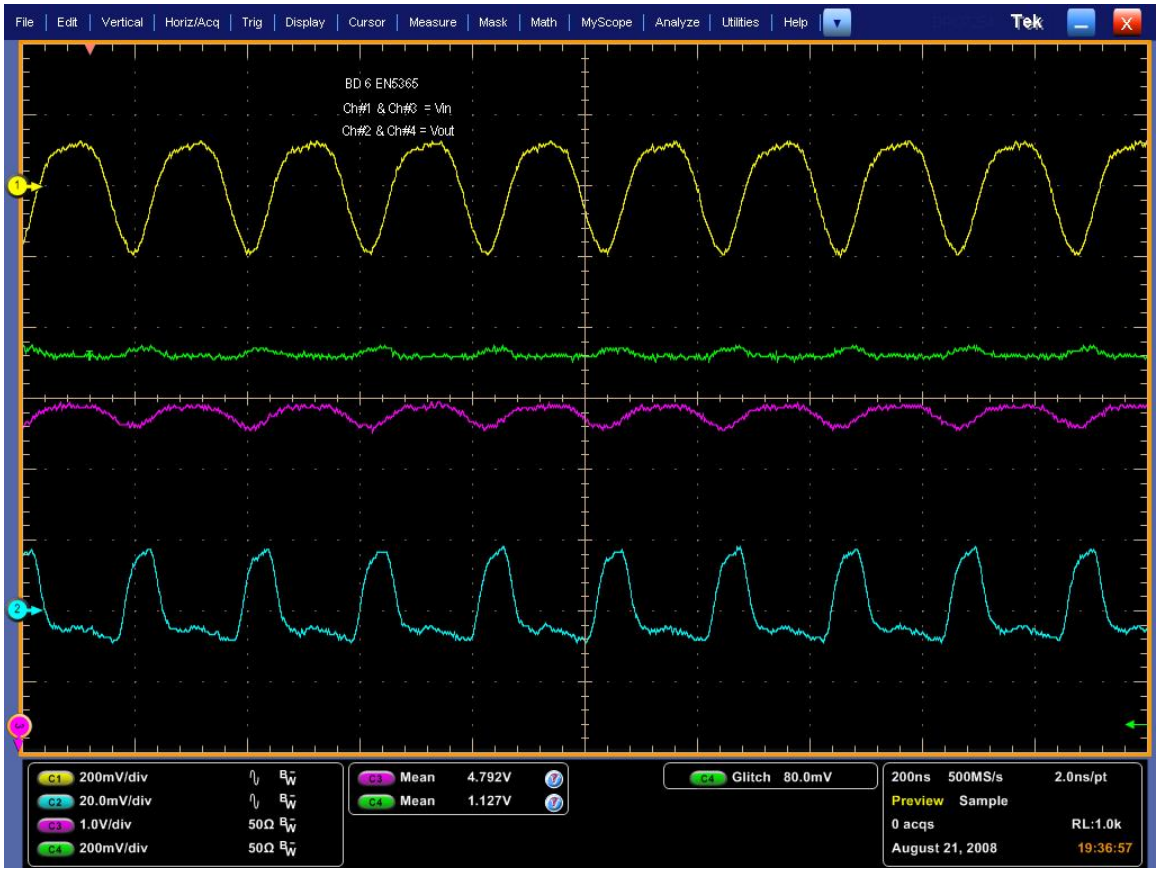

Figure 4 Enpirion EN5360 BD 6 Input and Output Voltages: Pre-Irradiation

Figure 5 Enpirion EN5360 BD 6 Input and Output Voltages: 50 krads of Accumulated Dose

Figure 6 Enpirion EN5360 BD 6 Input and Output Voltages: 100 krads of Accumulated Dose

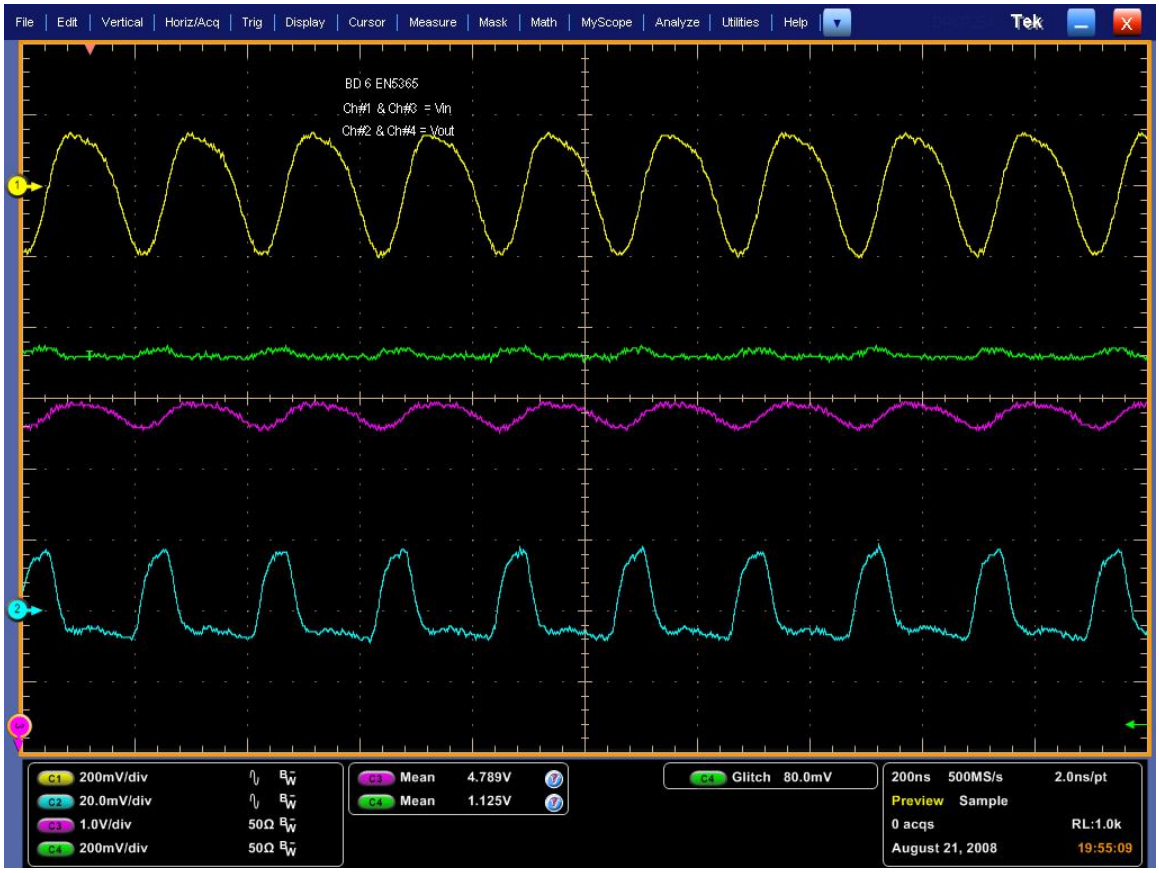

Figure 7 Enpirion EN5360 BD 6 Input and Output Voltages: 150 krads of Accumulated Dose

Figure 8 Enpirion EN5360 BD 6 Input and Output Voltages: 200 krads of Accumulated Dose

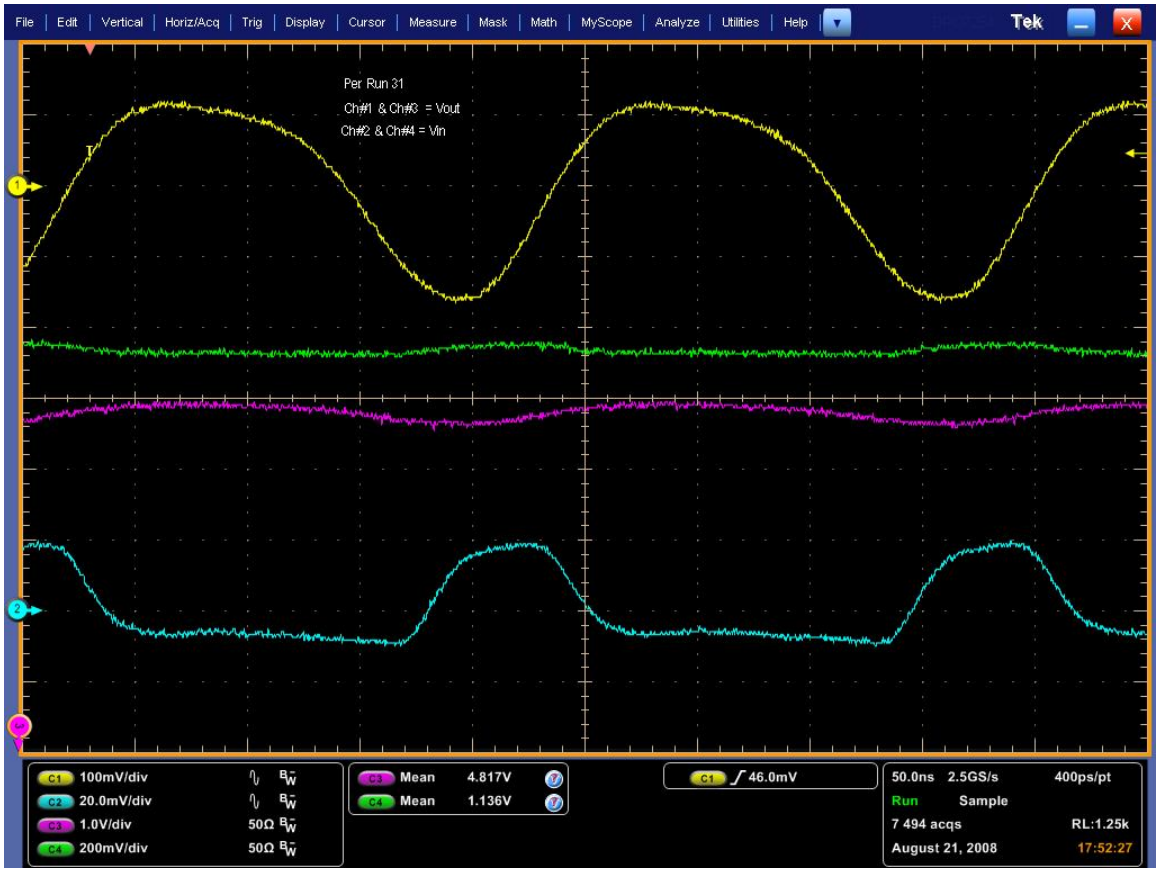

Figure 9 Enpirion EN5360 BD7 Input and Output Voltages: Pre-Irradiation (Note: Chronologically this was the very first capture taken. This figure and Figure 10 are using a different time scale than all of the other screen shots.)

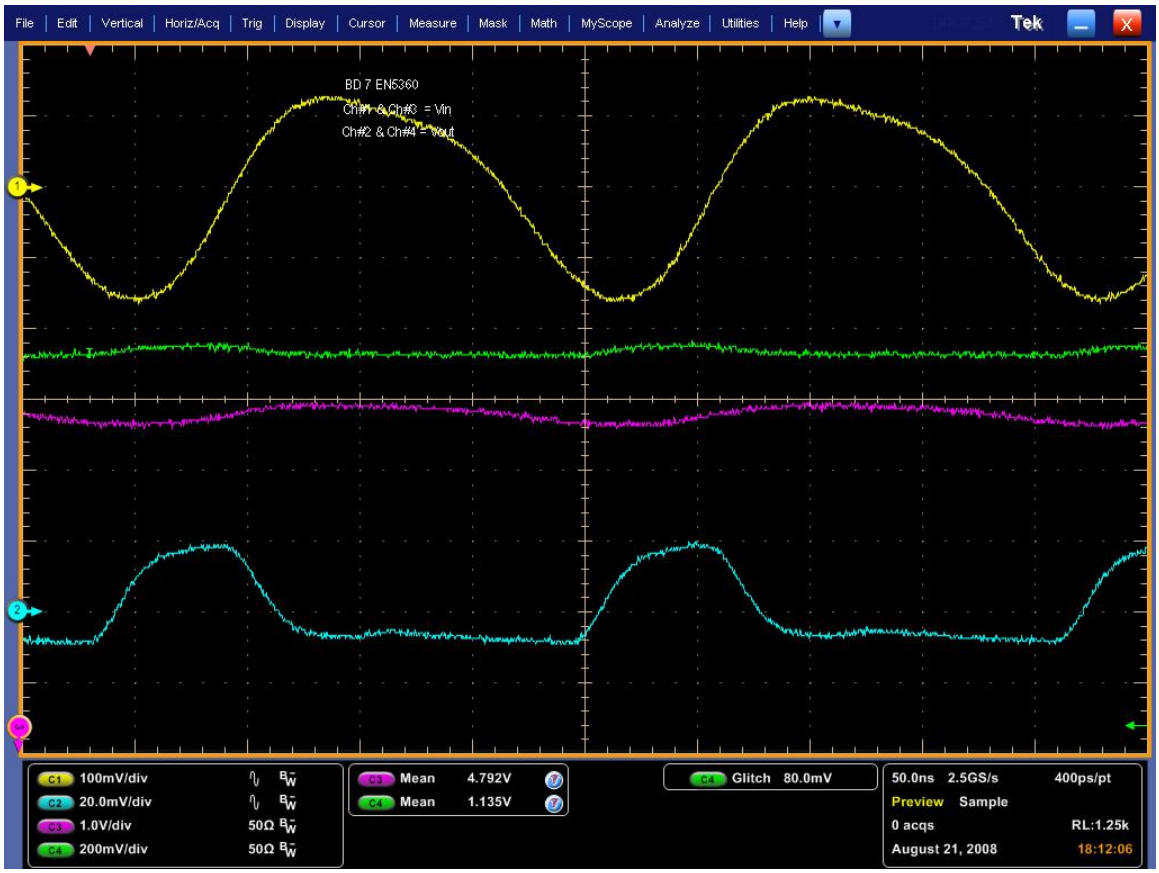

Figure 10 Enpirion EN5360 BD 7 Input and Output Voltages: 60 krads of Accumulated Dose (See note from Figure 9.)

Figure 11 Enpirion EN5360 BD 7 Input and Output Voltages: 102 krads of Accumulated Dose (Note: Time scale was changed after this point to better show frequency of ripple)

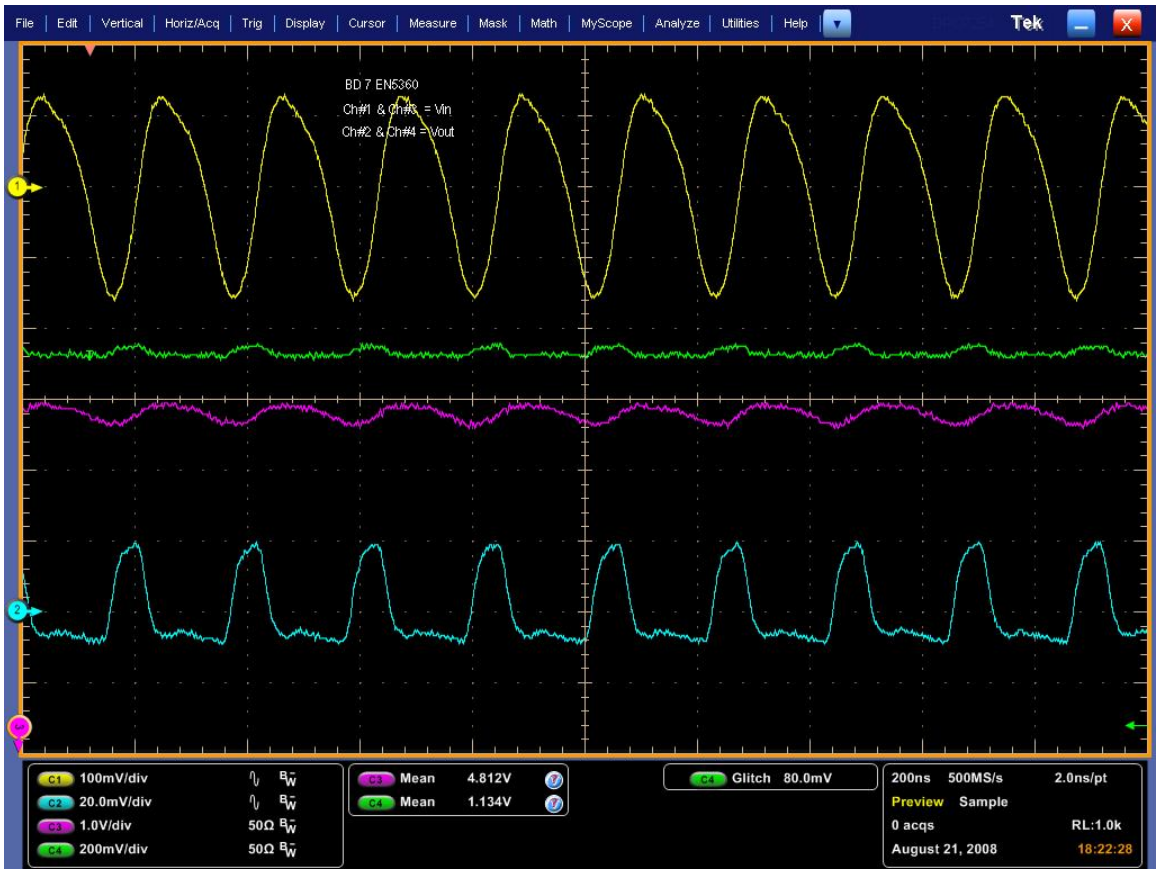

Figure 12 Enpirion EN5360 BD 7 Input and Output Voltages: 155 krads of Accumulated Dose

Figure 13 Enpirion EN5360 BD 7 Input and Output Voltages: 200 krads of Accumulated Dose

Enpirion EN5365 Results

As with the EN5360's, we tested two samples of the Enpirion EN5365, each labeled BD 6 and BD 7 as before. Both EN5365 devices failed at an accumulated dose of about 165 krads (BD 7 at about 166 krads and BD 6 at about 164 krads). As mentioned above in the Experimental Setup section, overcurrent protection (OCP) was used for all of the POL converters and OCP was not tripped when the EN5365's failed, suggesting that they did not fail by causing a short.

In Figure 14 and Figure 15, we have plotted the current draw of the devices versus the accumulated dose for BD 6 and BD 7, respectively. In both graphs, there is a noticeable upward inflection in current draw around 100 krads. When they failed, both chips were only drawing about 0.11 A.

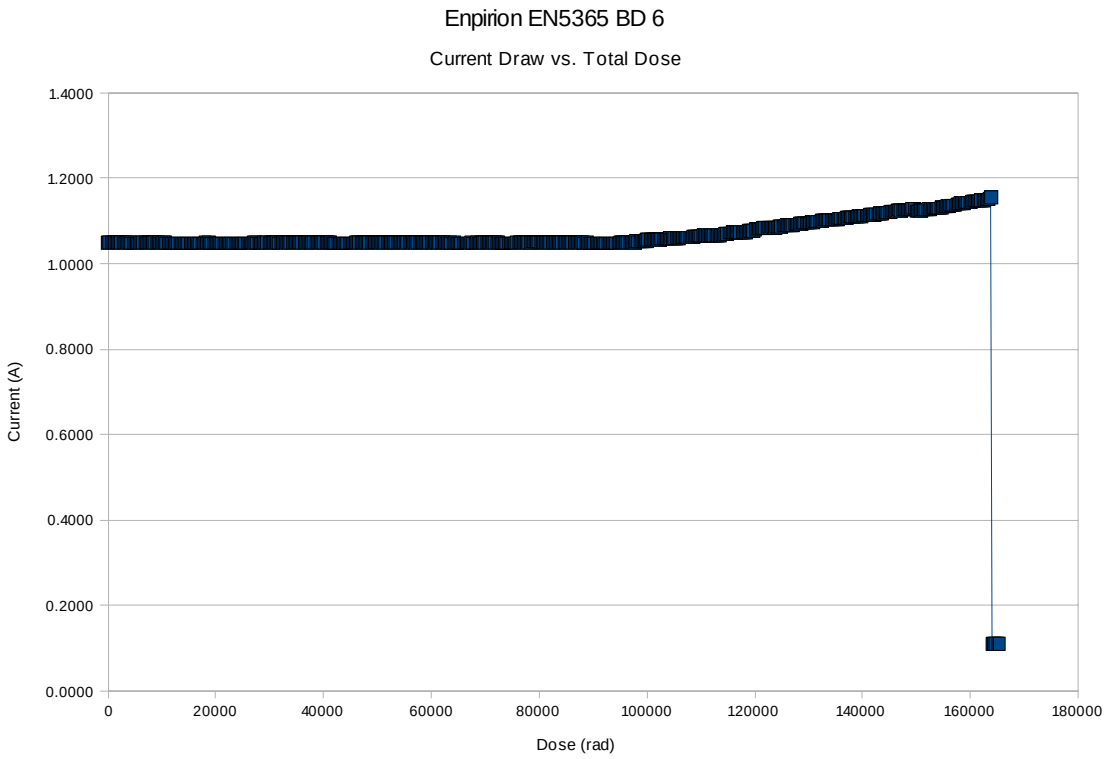

Figure 14 Enpirion EN5365 BD 6: Current Draw vs. Accumulated Dose

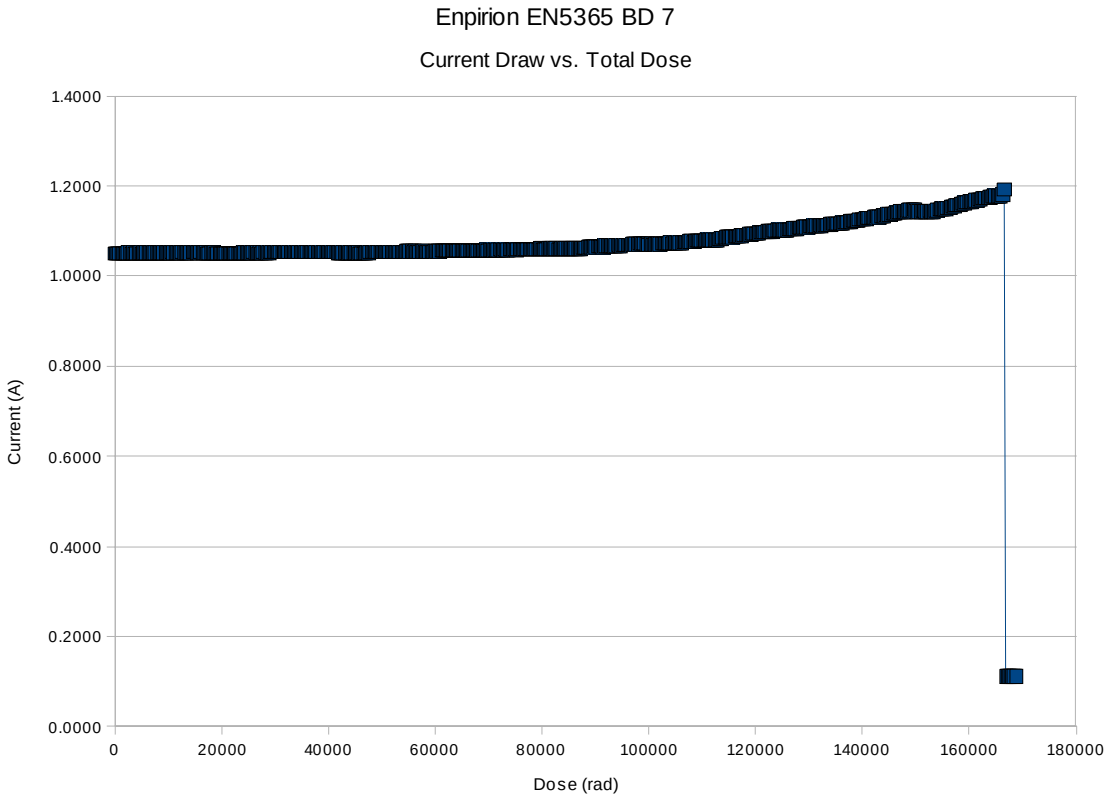

Figure 15 Enpirion EN5365 BD 7: Current Draw vs. Accumulated Dose

The following are screen captures from the oscilloscope for the two samples taken at intervals of 25 or 50 krads (depending on who close we were to the failure region). Notice that the output voltage appears to be effectively 0 V for BD 7 when it failed (see Figure 26). For BD 6, it appears that the output voltage was about 40 mV (see Figure 21). It is also interesting that Input 2 is off the scale of the screen capture, which may be the case since

this was probably taken at the moment of failure so the AC-coupled sampled output likely had an amplitude that was significantly larger than normal.

As for the output of the two samples, there was a slight increase in average output voltage over the 0 to 150 krad range. For BD 6 pre-irradiation, the output voltage average was about 1.122 V (based on the scope's on measurement). At 150 krads, the output voltage average rose to about 1.127 V, a very small change. For BD 7, the average output voltage was measure to be 1.125 V before irradiation and rose to 1.139 V at 150 krads, a slight be more pronounced drift. Since we didn't measure the temperature of the chips, it is hard to argue that this is a result of irradiation alone, but it may have been a factor.

As for the dose effects on the output ripple, we observed very little change on the range from 0 to 150 krads of accumulated dose. The frequency of the ripple is about 5 MHz, as expected from EN5365. Before the irradiation, the ripple for both the input and the output voltages appears to be about 5.15 MHz (7 cycles in 1.36 microseconds) for BD 6. After 150 krads of accumulated dose, the frequency of the ripple appears to be about the same (about 5.11 MHz or 9 cycles in 1.76 microseconds). For BD 7, the pre-irradiation ripple appears to be about 5.26 MHz (8 cycles in 1.52 microseconds) and is about the same after 150 krads (5.30 MHz or 7 cycles in 1.32 microseconds). The output ripple magnitude was approximately 60 mV peak to peak for both samples and did not change significantly over the range of 0 to 150 krads.

Figure 16 Enpirion EN5365 BD 6 Input and Output Voltages: Pre-Irradiation

Figure 17 Enpirion 5365 BD 6 Input and Output Voltages: 50 krads of Accumulated Dose

Figure 18 Enpirion EN5365 BD 6 Input and Output Voltages: 100 krads of Accumulated Dose

Figure 19 Enpirion EN5365 BD 6 Input and Output Voltages: 125 krads of Accumulated Dose

Figure 20 Enpirion EN5365 BD 6 Input and Output Voltages: 150 krads of Accumulated Dose

Figure 21 Enpirion EN5365 BD 6 Input and Output Voltages: 165 krads of Accumulated Dose

Figure 22 Enpirion EN5365 BD 7 Input and Output Voltages: Pre-Irradiation

Figure 23 Enpirion EN5365 BD 7 Input and Output Voltages: 50 krads of Accumulated Dose

Figure 24 Enpirion EN5365 BD 7 Input and Output Voltages: 100 krads of Accumulated Dose

Figure 25 Enpirion EN5365 BD 7 Input and Output Voltages: 150 krads of Accumulated Dose

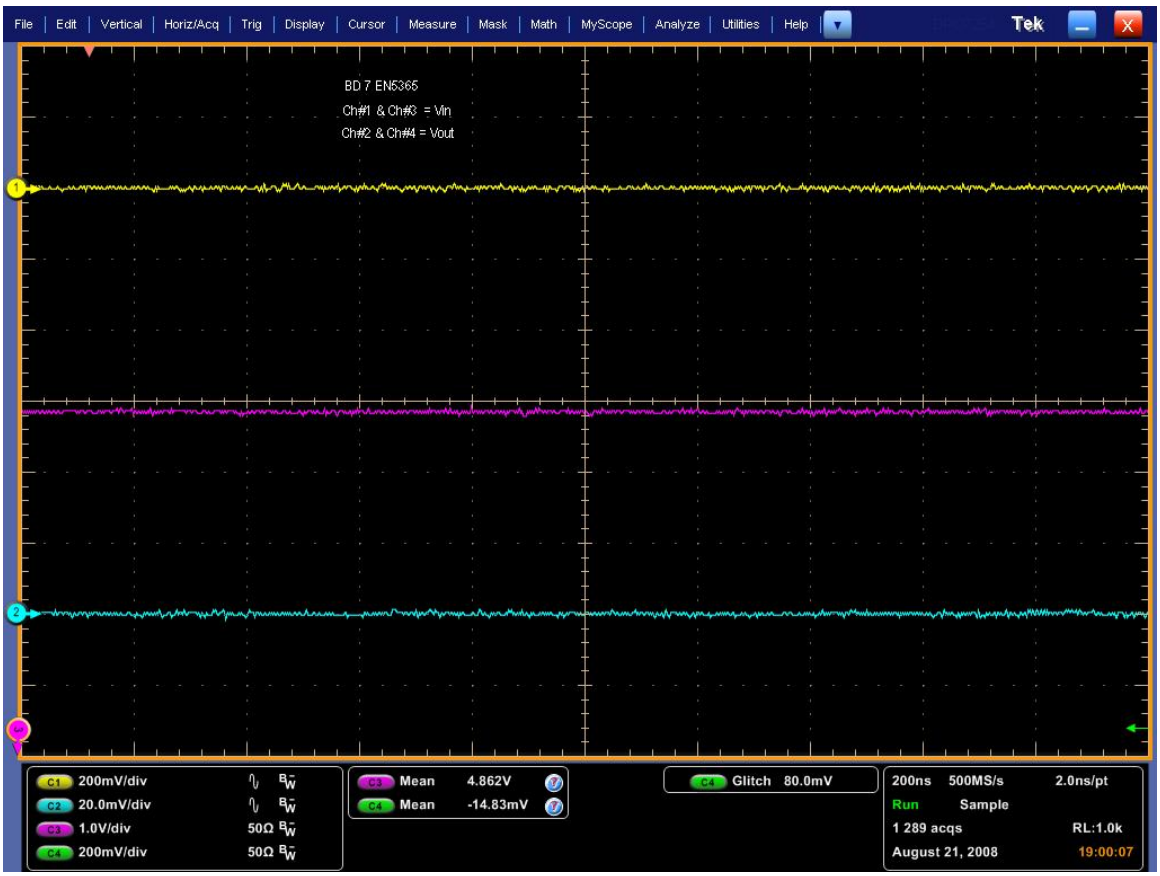

Figure 26 Enpirion 5365 BD 7 Input and Output Voltages: 169 krads of Accumulated Dose

Peregrine PE99150

We had a single sample of this part. Due to time constraints we only had time to test the device through 100 krads of proton radiation. This particular part underwent some single-event latchup (SEL) testing at Lawrence Berkeley National Laboratory (LBNL) the previous week, with XXX amount of dose. Figure 27 shows the current draw of the part versus the accumulated dose for 0 to 100 krads of proton radiation. The discontinuities may be due to some annealing or other behaviors between irradiation runs. It is not clear what happened between 25 krads and 50 rads (all contained in a single run). The overall current draw dropped over the duration of the test.

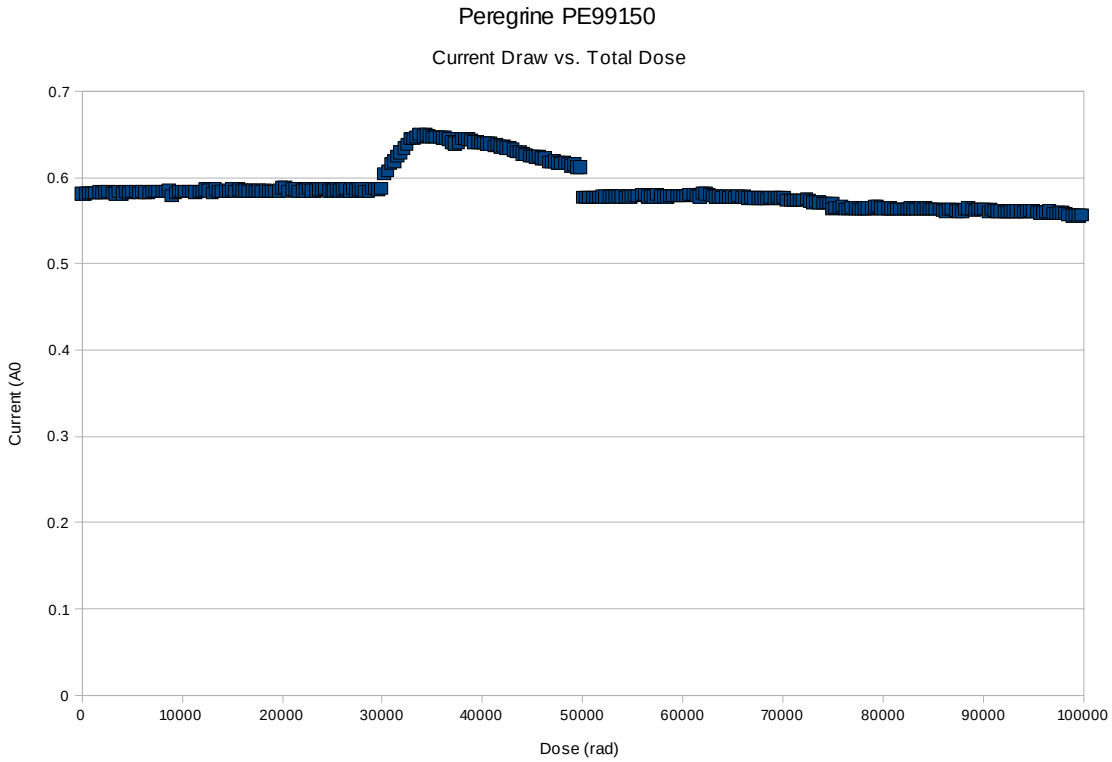

Figure 27 Peregrine PE99150: Current Draw vs. Accumulated Dose

Regarding the output voltage of the device, there was a small drift over the duration of the test. The average output voltage before irradiation was 2.311 V, as measured by the oscilloscope. After 100 krads of proton radiation, the output voltage had dropped to 2.275 V. Another significant detail to mention is the change in ripple within the first 50 krads. This also seems to be correlated with the brief increase in current draw during that range of accumulated dose. Initially the ripple had a peak-to-peak value of 120 mV. After 50 krads, the rippled dropped to 20 mV and later grew to about 50 mV by the end of the test. The initial ripple had a frequency of about 95 kHz. After 100 krads of proton radiation, a periodic waveform on the output was produced again, but at 1.28 MHz, a much higher frequency. This behavior may been a result of the SEL testing at LBNL, so it is hard to draw many conclusions from this single part and test.

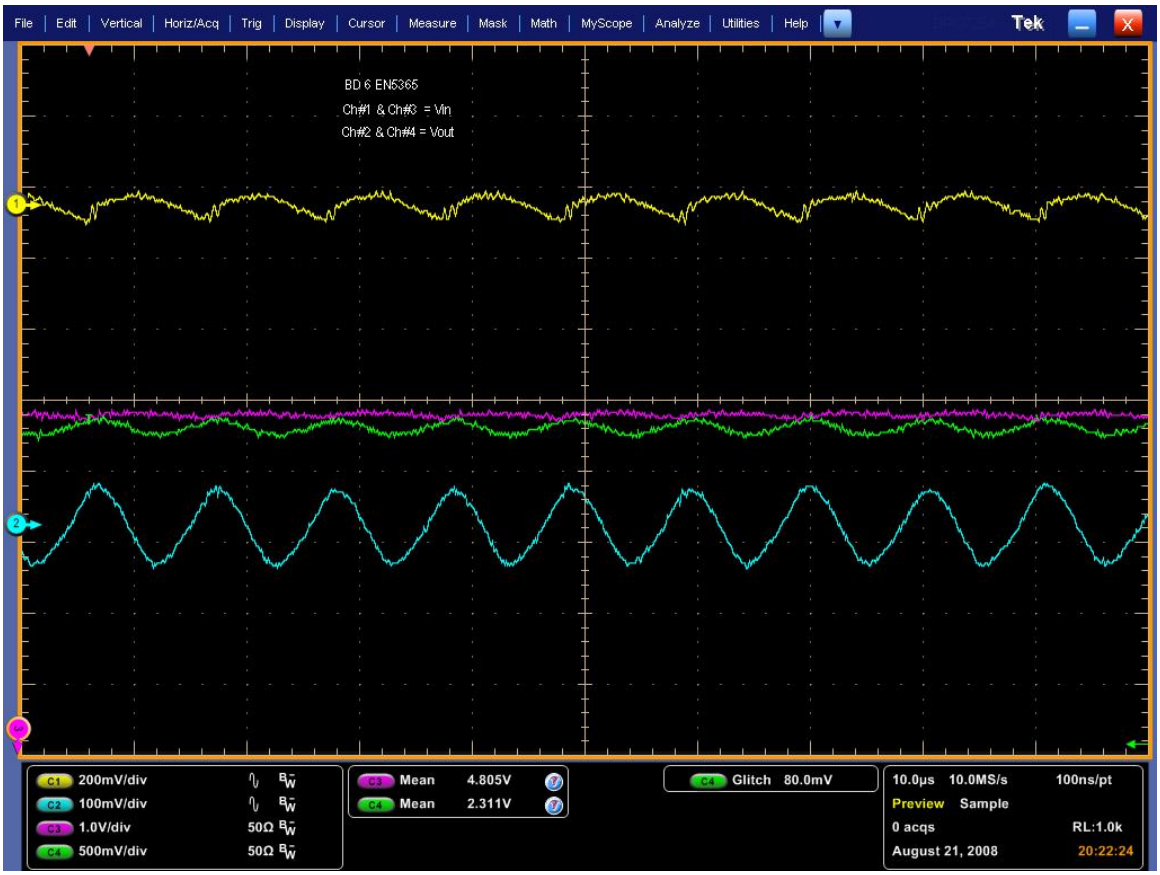

Figure 28 Peregrine PE99150 Input and Output Voltages: Pre-Irradiation

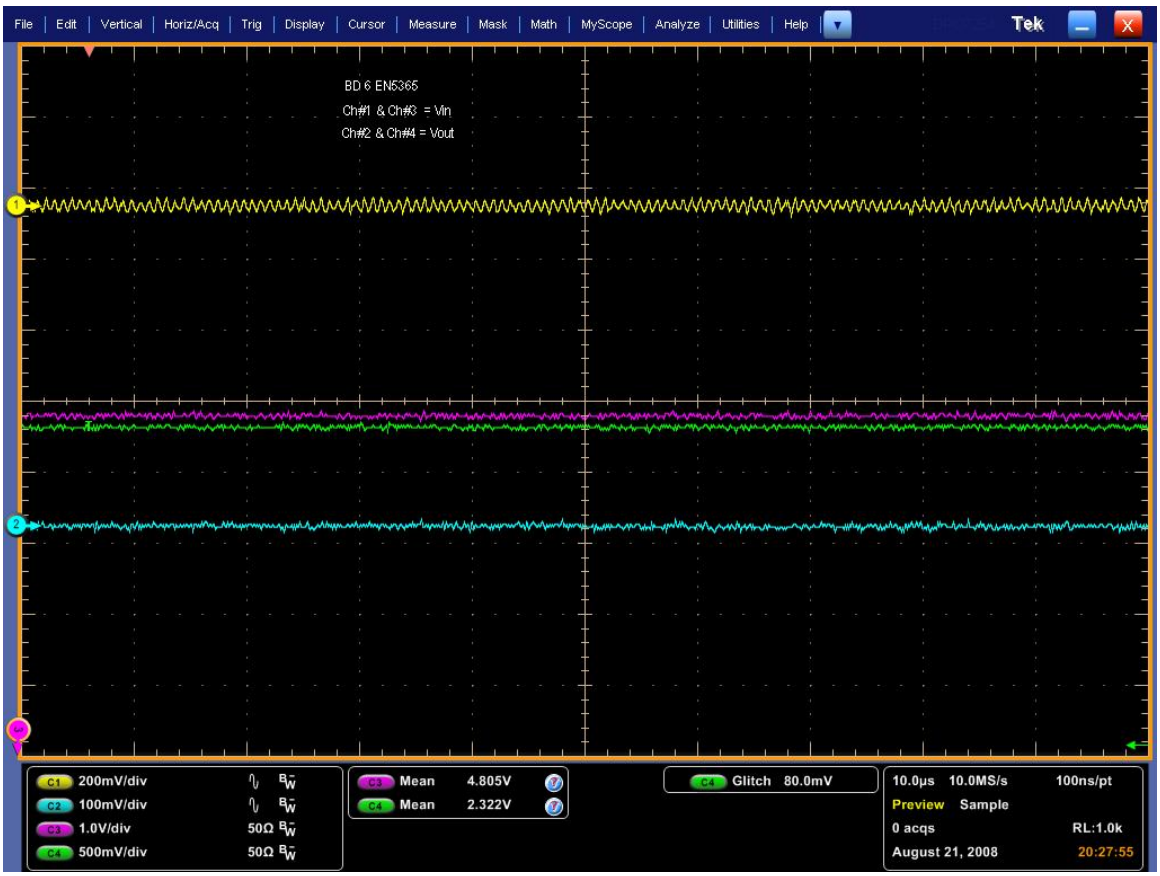

Figure 29 Peregrine PE99150 Input and Output Voltages: 50 krads of Accumulated Dose

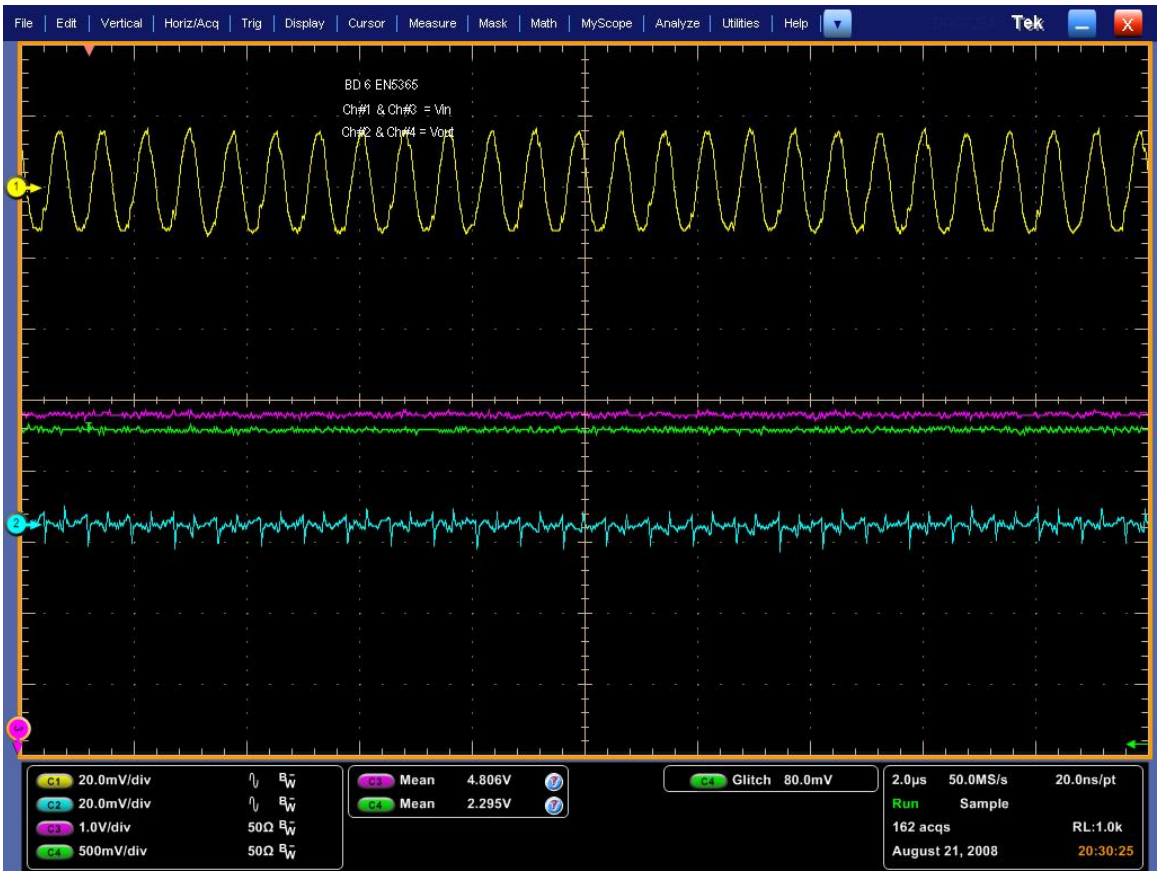

Figure 30 Peregrine PE99150 Input and Output Voltages: 75 krads of Accumulated Dose

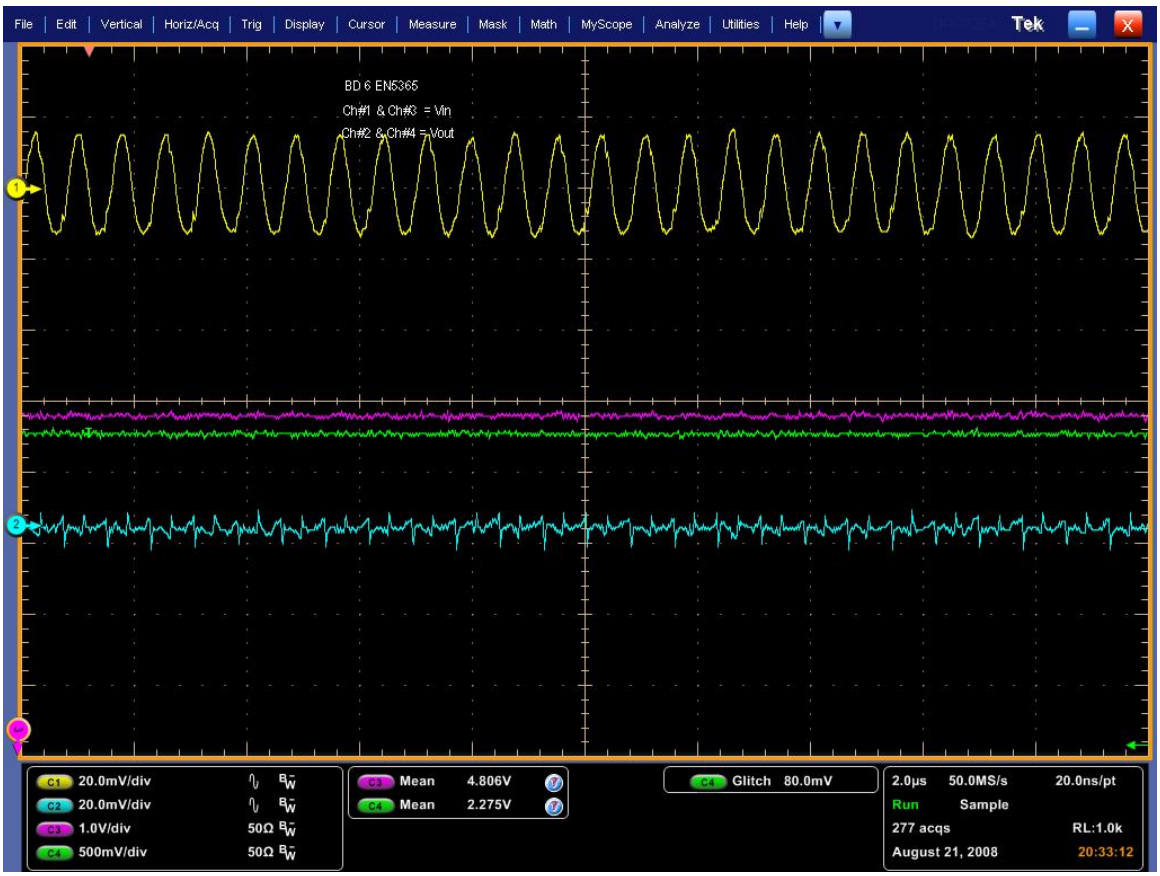

Figure 31 Peregrine PE99150 Input and Ouput Voltages: 100 krads of Accumulated Dose