Radiation Evaluation of the Texas Instruments TPS7H4001-SP 18 Amps Buck Converter

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Abstract

Total Ionizing dose (TID) and Heavy-ion single-event effect (SEE) performance of the TPS7H4001-SP synchronous buck converter is presented. Production devices were demonstrated to TID = 100 krad(Si) and shown to be ELDRS-free. DSEE load voltage and LET_{EFF} dependency was characterized across 37 devices at T≈125°C and 25°C. SET performance at worst case of 7-V and typical rail voltage of 5-V is discussed.

Introduction

Point-of-Load (POL) power distribution is very popular in satellite systems to provide optimized voltage regulation. POL typically refers to DC-DC converters and Linear Regulators. Today's FPGAs with increasingly complex digital cores demand more current, efficiency, reliability and tight regulation requiring the usage of POL's DC-DC converters for many of their power rails. Such DC-DC converters require increased radiation robustness and tolerance. Uninterrupted power delivery with minimal output transients under heavy ions irradiation are the primary features of a space rated DC-DC converter. Fig. 1 shows a typical power distribution for a space rated FPGA based on TI's space rated power solutions. Fig. 2 shows the block functional block diagram of the TPS7H4001-SP.

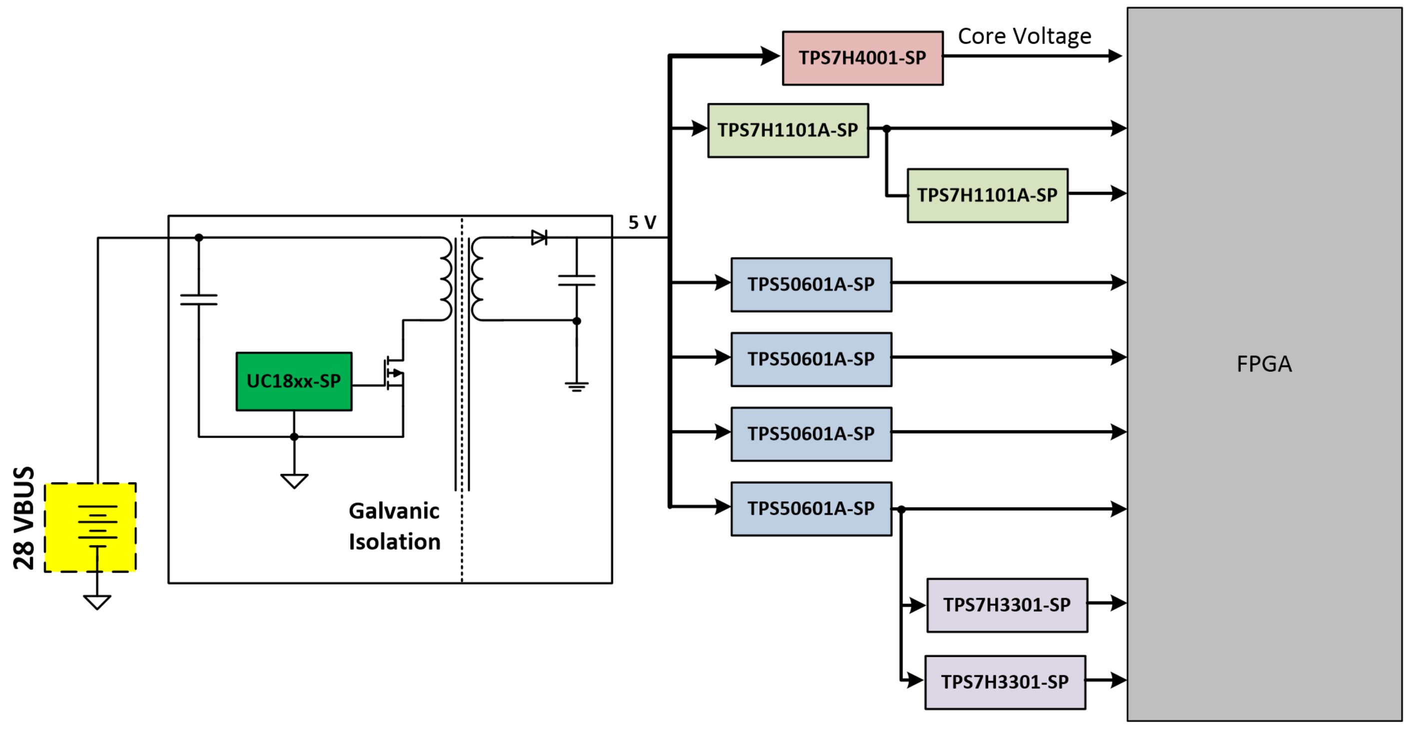

Fig. 1 *Typical power distribution for a space rated FPGA, the TPS7H4001-SP for core voltage and TI space grade power solution*

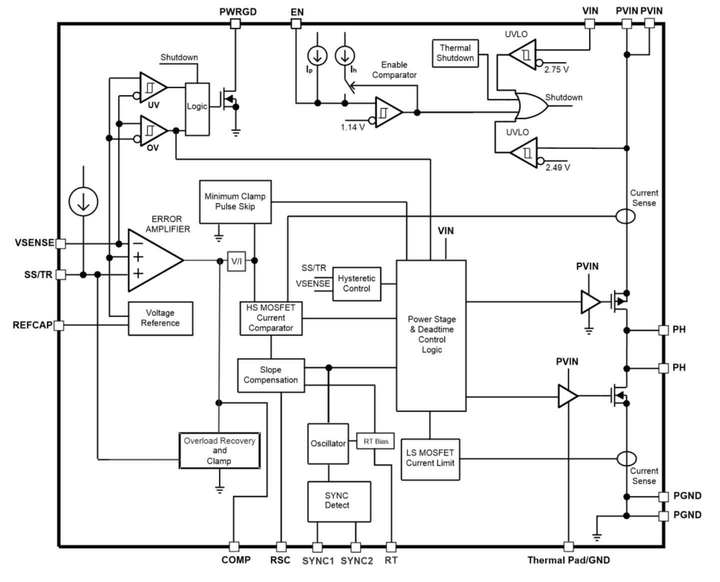

Fig. 2 TPS7H4001-SP functional block diagram.

Experimental Procedure

The SEE characterization was conducted using the TPS7H4001EVM-CVAL. Heavy-ions cocktail was provided by the Texas A&M cyclotron facility using the 15MeV/amu line. Table 1 shows the calculated Range and LET_{EFF} for the heavy-ions used during the test campaign. The numbers were calculated using a custom application based on the latest SRIM-2013 [1] models.

A picture of the device in front of the beam port is shown on Fig. 3. Power was provided to the TPS7H4001-SP using a N6766A Power Supply (PS) module mounted on a N6705C PS Rack, in a 4-wire configuration. P_{VIN} and V_{IN} were tied together at all times. For most of the test campaign a discrete power resistor of 55mΩ, dissipating 18 A was used. The only instances were it was not used, was during Destructive-Single-Events-Effects (DSEE) load dependency sweep. For which a Chroma load model: 63360-80-80 replaced the discrete resistor. With the exception of the DPO digital oscilloscope, all equipment was controlled and monitored using a custom developed LabVIEW® program (PXI-RadTest) running on a NI-PXIe-8135 Controller. The DPO was operated using the fast frame mode. When operated on this mode, the dead time is 20µs. A block diagram of the test setup used for SEE characterization of the TPS7H4001-SP is illustrated in Fig. 4. The device was heated using a convection heat gun and cool-down using a Vortex Tube. The external heat elements were aimed at the die, and a K-type thermocouple attached to the thermal pad vias with thermal paste was used to monitored the temperature. The PS current and the +5V from TAMU were monitored at all times.

Table 1 Ion, angles, and calculated LET_{EFFf}, range, and depth in silicon as calculated by RADsim-IONS (based on SRIM 2013 models)

Ion Type	Air Distance (mm)	Angle of Incidence (°)	Depth in Silicon (µm)	Range in Silicon (µm)	LET_{EFF} (MeV·cm²/mg)
^{109}Ag	40	0	84.1	84.1	49.3
^{109}Ag	40	25	75	82.7	54.8
^{141}Pr	40	0	89.4	89.4	66.37
^{141}Pr	40	27.3	77.9	87.7	74.95
^{165}Ho	30	0	93.9	93.9	75.82

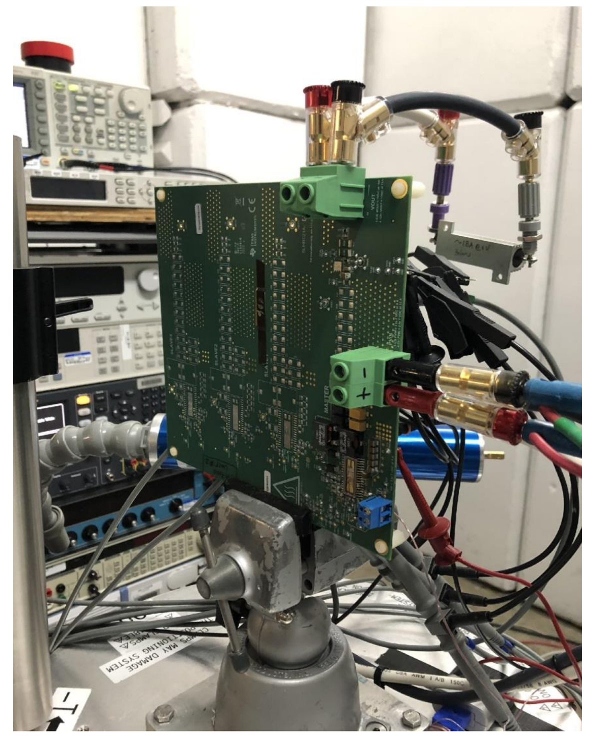

***Fig. 3**. Photograph of the TPS7H4001-SP mounted on the TPS7H4001EVM-CVAL in front of the heavy-ion beam port exit at the TAMU cyclotron facility.*

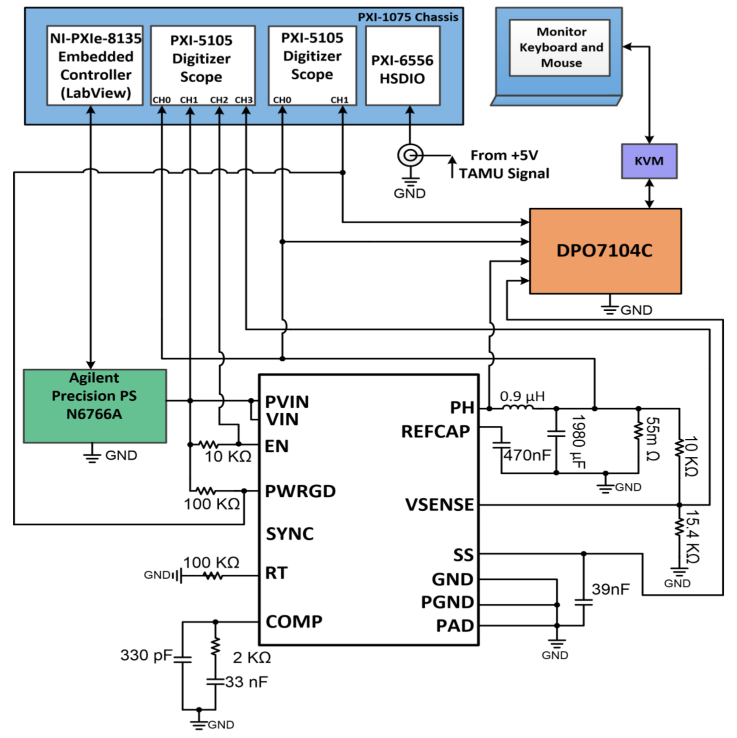

***Fig. 4**. Block diagram of the setup used for the SEE testing at the TAMU cyclotron facilities.*

Destructive Single-Event Effects (DSEE)

Many TPS7H4001-SP devices were characterized across voltage, load current, and LET_{EFF} by sweeping the variables. The purpose of this experiments was to determined the values at which destructive effects were observed, when controlling the Voltage, Load and LET_{EFF}. During the testing, only one variable was changed (sweep) at a time while the other remain constant at the maximum permissible values. When collecting data for the DSEE of the TPS7H4001-SP, it was observed that the probability of damaging a device was greater at higher temperatures, consequently most of the DSEE data was collected at this temperature.

Destructive Single-Event Effects (cont.)

A cross-conduction test was conducted to determine if this was the root cause of the observed damage of the devices under heavy-ions. The test was conducted by monitoring the High Side FET (using a High BW, differential probe, from P_{VIN} to Phase), and the Low Side FET (using a Passive Probe from Phase to GND). These signals were ultimately monitored with the DPO7104C and trigger with an "AND" using a V_{IH}=500mV. **During the testing not a single capture was observed indicating the TPS7H4001-SP does not suffer from cross conduction problems**. Fig. 5 encapsulates the results in which damage during the SEE testing was observed, defining the safe-operating-area (SOA). A typical current plot *at T≈125°C for a non destructive and destructive runs are shown on Fig. 6 and 7, respectively.*

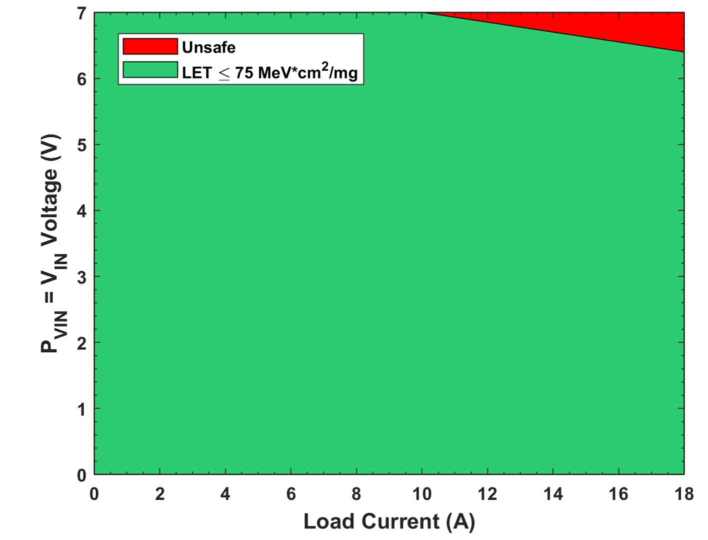

Fig. 5 SOA Curve of the TPS7H4001-SP

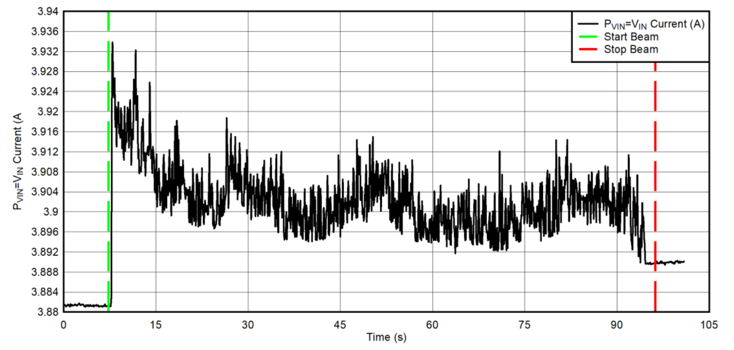

***Fig. 6**. Typical Current vs Time Plot for a Non-destructive Run of the TPS7H4001-SP at T= 125 C.*

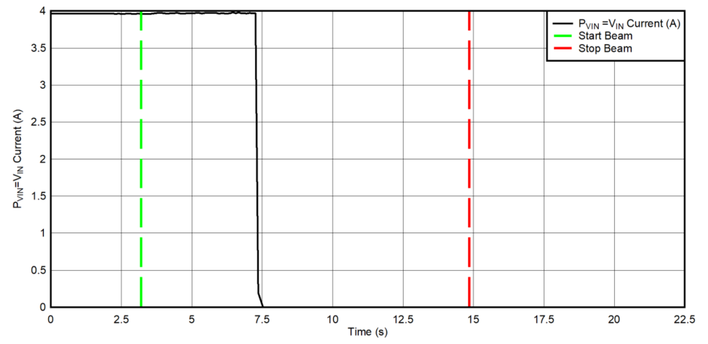

***Fig. 7**. Typical Current vs Time Plot for a destructive Run of the TPS7H4001-SP at T= 125 C.*

Single Event Transients (SET)

SET are defined as heavy-ion-induced transients upsets on the V_{OUT}, SS, and the PWRGD flag of theTPS7H4001-SP. PWRGD SET's were fast and temporary False indication of a non stale output voltage. SET testing was conducted at room temperature. V_{OUT} SET's were characterize using a window trigger of 3% (30 mV) around the nominal output voltage (1 V). Common P_{VIN}=V_{IN} rail of 5 and 7-V (worst case) were used for the data collection. **Not a single SET was observed at P_{VIN}=V_{IN}= 5-V**.For all SET's runs the device was loaded to 18-A (using the discrete power resistor). During two runs the trigger signal on the DPO was changed from V_{OUT} to SS. **Not a single SS_{SET} was observed**. During this runs the trigger was set to 600mV using an Edge/Negative trigger. PWRGD SET's were characterize using a an Edge/Negative at half the V_{IN} voltage. Since PWRGD SET's were fast on time, as a proof of concept an Low-Pass filter (LPF) was installed on the PWRGD flag. Table 2 summarizes the SET results for the TPS7H4001-SP. Histograms summarizing V_{OUT} SET's at P_{VIN}=V_{IN}=7-V are shown on Fig. 8 and 9. As can be observed on Fig. 10, the use of LPF is a viable option to mitigate PWRGD false triggers.

Table 2 Upper Bound Cross Section for V_{OUT} and PWRGD at 95 % confidence interval

LET_{EFF} (MeV·cm² /mg)	P_{VIN}=V_{IN} (V)	UB V_{OUT} Cross Section for ≥ |3%| [cm²/device]	PWRGD Cross-Section (≤ VIN / 2) [cm²/device]
66.37	5	9.21×10^{-8}	2.6×10^{-6}
75	5	5.27×10^{-8}	1.86×10^{-6}
66.37	7	1.03×10^{-6}	9.47×10^{-7}
75	7	3.48×10^{-6}	5.21×10^{-7}

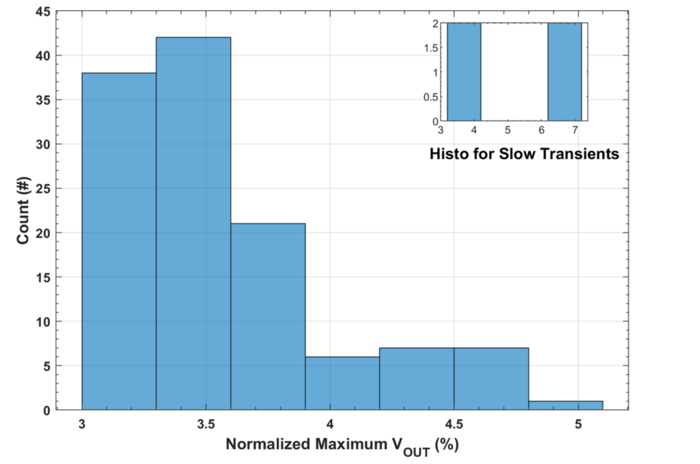

***Fig. 8**. Histogram of the SET's Normalized Maximum Deviation.*

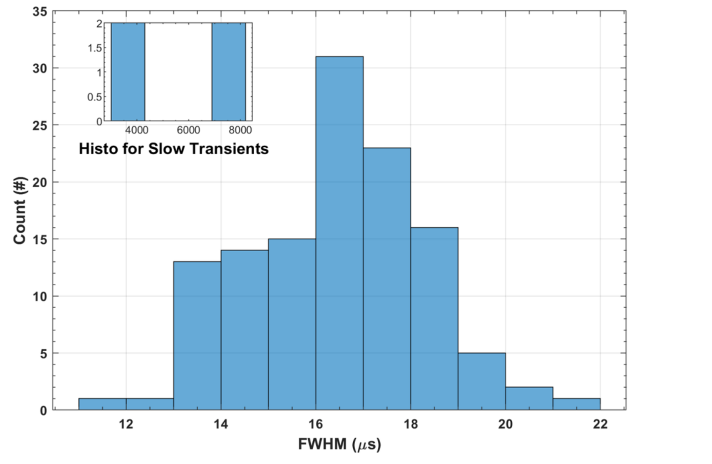

***Fig. 9**. Histogram of the SET's Transient Time.*

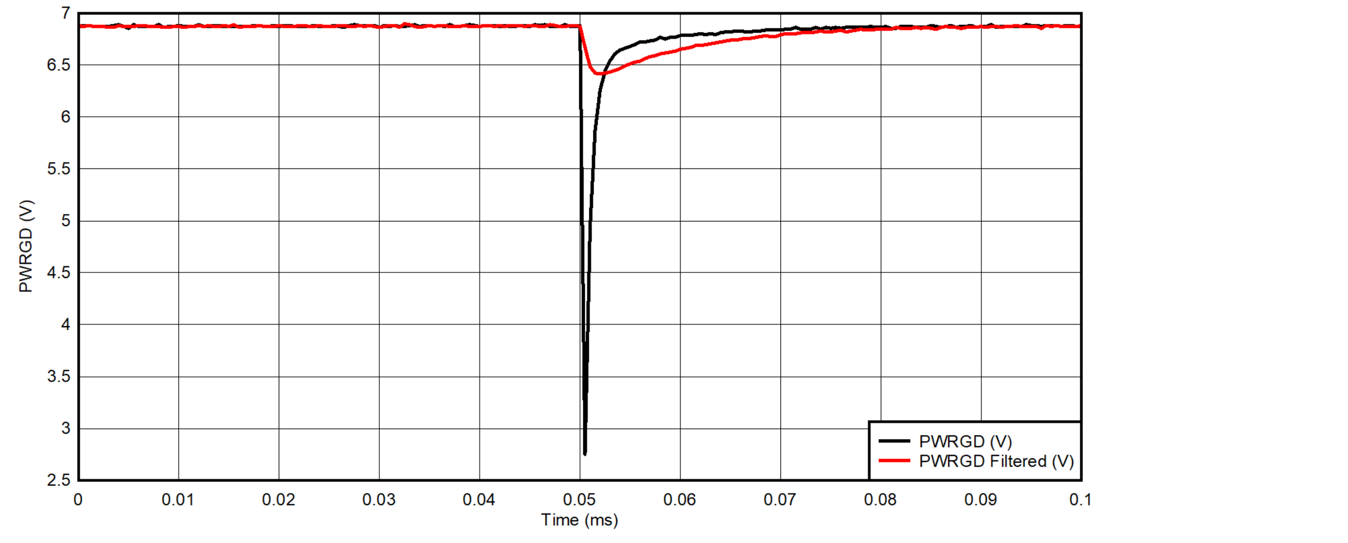

***Fig. 10**. Typical PWRGD Upset With and Without Filtering.*

Total Ionizing Dose (TID)

The TPS7H4001-SP was tested according to MIL-STD-883, Test Method 1019.9 Conditions A and D. For this test, the product was irradiated up to the target radiation level of 100 krad (Si) and then put through full electrical parametric testing on the production Automated Test Equipment (ATE). The device was functional and passed all parametric tests.

LDR exposure was performed on biased and unbiased devices in a Co-60 gamma cell under a 10-mrad(Si)/s exposure rate. For the LDR (10 mrad(Si)/s) exposure, the test box was positioned approximately 2 m from the source. The TPS7H4001-SP HDR exposure was performed on biased and unbiased devices in a Co-60 gamma cell at TI SVA facility in Santa Clara, CA. The un-attenuated dose rate of this cell is 63.68 rad(Si)/s. After exposure, the devices were packed in dry ice (per MIL-STD-883 Method 1019.9 section 3.10) and returned to TI Dallas for a full post radiation electrical evaluation using Texas Instruments Automated Test Equipment (ATE). Fig. 9 show the V_{REF} drift at V_{IN}=3V.

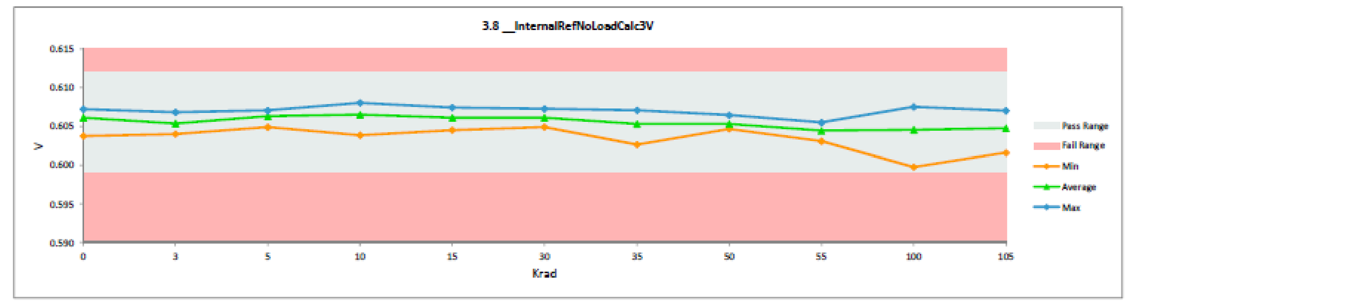

***Fig. 11**. TPS7H4001-SP VREF drift up to 100 krad(Si) at PVIN=VIN=3 V.*

Summary

- **TID = 100 krad(Si) LDR and HDR**
- **DSEE-free at LET_{EFF} ≤ 75 MeV-cm²/mg @ 6.4 and 10-A**
- **V_{OUT} SET-free at P_{VIN}=V_{IN}=5V for deviations ≥ |3%| and characterize at 7-V.**

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