

Single-Event Effects (SEE) Radiation Report of the LMX2624-SP



Abstract

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the LMX2624-SP. Heavy-ions with LET_{EFF} of 2.76, 7.5, 16, 27, 45, 56, 70 and 83 MeV $\times$ cm²/mg were used to irradiate 4 production devices. Flux of 1×10^3 - 1×10^5 ions/cm²/s and fluence of 8×10^4 - 1×10^7 ions/cm² per run were used for the characterization and evaluation. The results demonstrated that the LMX2624-SP is SEL-free up to 83 MeV $\times$ cm²/mg at T = 125°C. SET transients performance of output frequencies are within $\pm 1\%$ of intended frequency from device configuration. LMX2624-SP is SEFI free up to 83 MeV $\times$ cm²/mg.

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1 Introduction

The LMX2624-SP is high performance wideband phase-locked loop (PLL) with integrated voltage controlled oscillator (VCO). It is capable of outputting any frequency from 5MHz to 30GHz. The VCO on this device covers an entire octave resulting in complete frequency coverage down to 5MHz. The high performance PLL used in LMX2624-SP has a figure of merit of -236 dBc/Hz and high phase detector frequency which can attain very low in-band noise and integrated jitter.

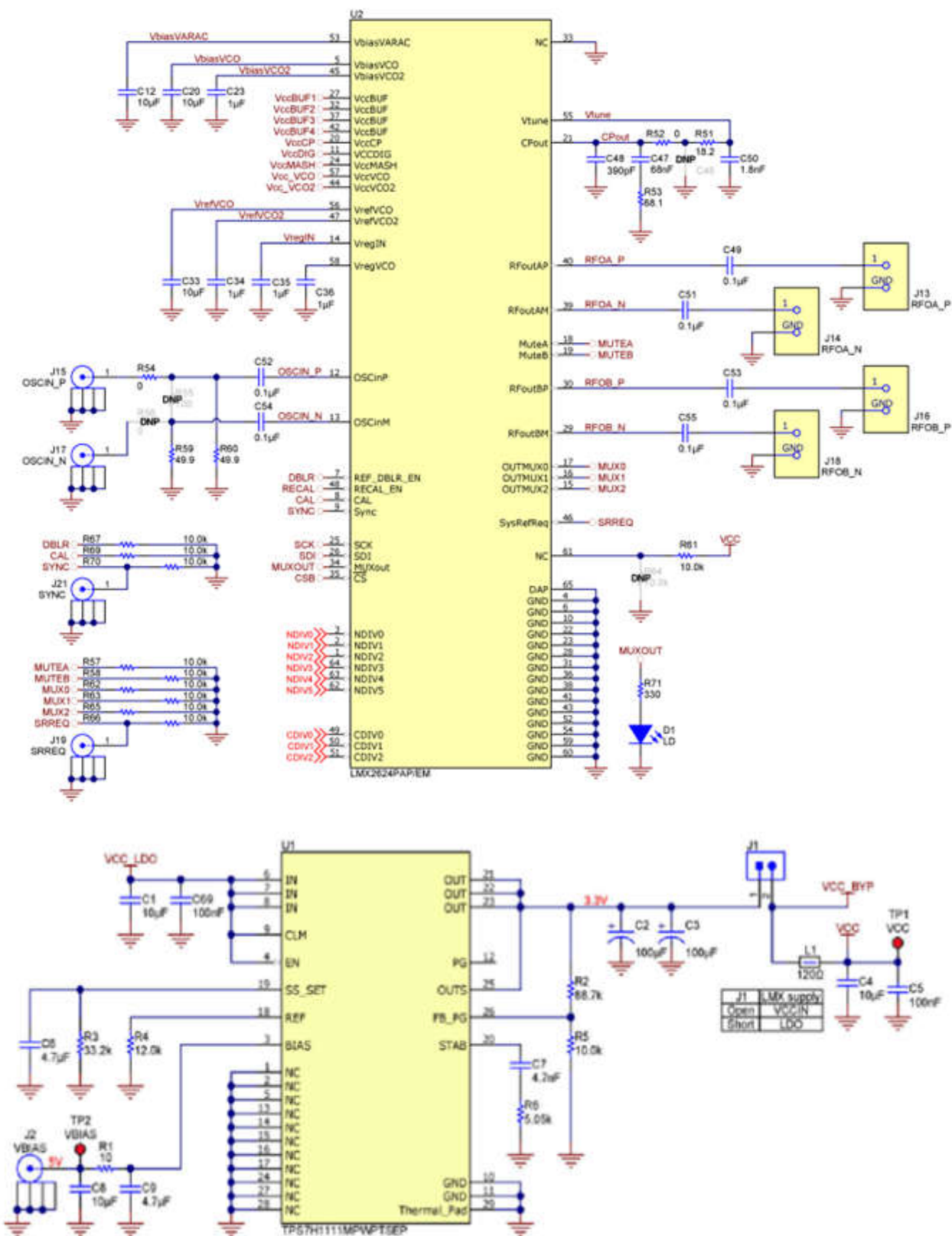
LMX2624-SP allows users to synchronize the output of multiple instances of the device. This means that deterministic phase can be obtained from a device in use cases including the one with fractional engine or output divider enabled. This device also adds support for either generating or repeating SYSREF (compliant to JESD204B/C standard), making the device designed for low-noise clock source for high-speed data converters

The device is offered in a 64-pin HTQFP plastic package. General device information and test conditions are listed in the overview information table. For more detailed technical specifications, user-guides, and application notes please go to [device product page](#).

Table 1-1. Overview Information

DESCRIPTION ⁽¹⁾	DEVICE INFORMATION
TI Part Number	LMX2624-SP
Orderable Part Number	5962R2321001PXE
VID/SMD Number	5962R2321001PXE
Device Function	Wideband Synthesizer with Phase Synchronization
Technology	BiCMOS
Exposure Facility	Facility for Rare Isotope Beams, K500 Cyclotron (KSEE), Michigan State University (19.5MeV/nucleon) and Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15MeV/nucleon)
Heavy Ion Fluence per Run	$1.00 \times 10^5 - 1.00 \times 10^7$ ions/cm ²
Irradiation Temperature	25°C (for SET and SEFI testing) and 125°C (for SEL and SEFI testing)

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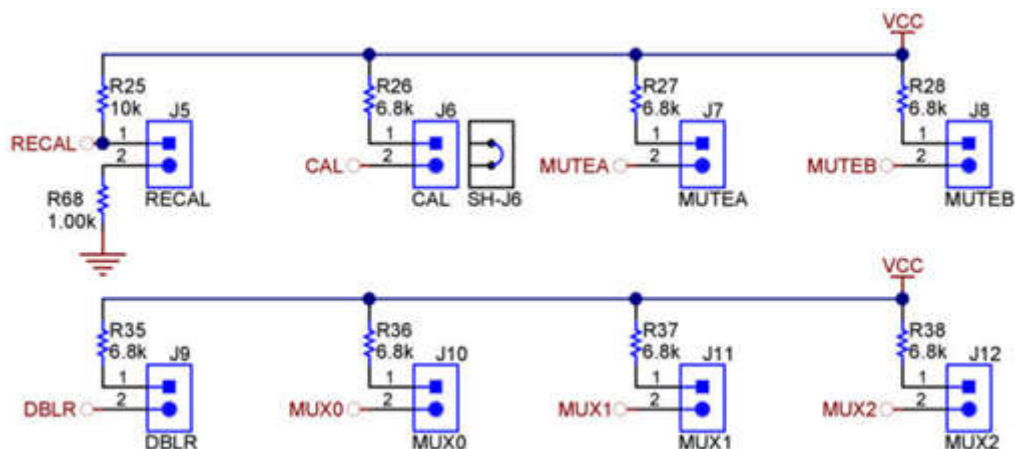


Figure 2-3. LMX2624EVM Schematics

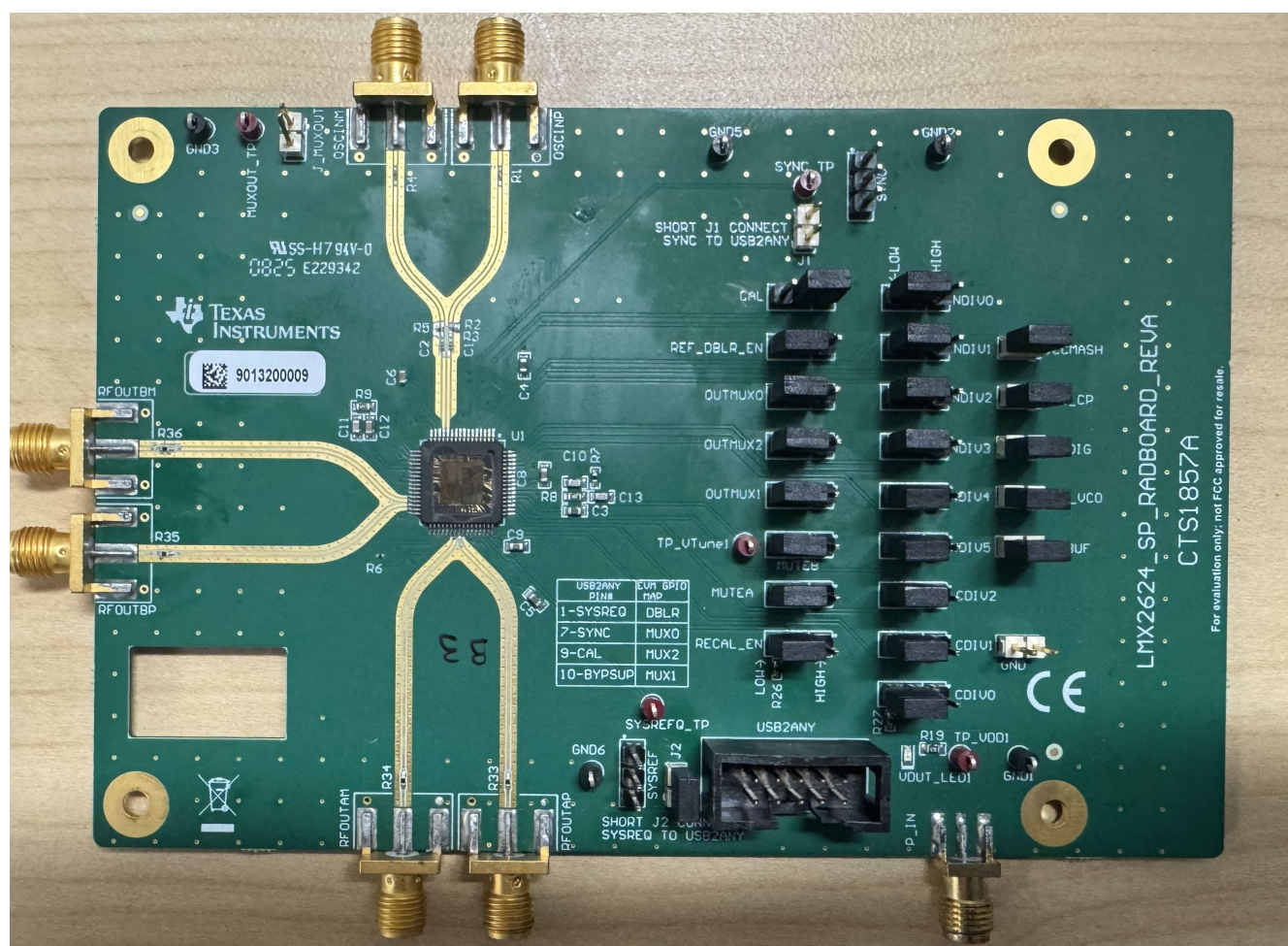


Figure 2-4. LMX2624 Rad Board Top View

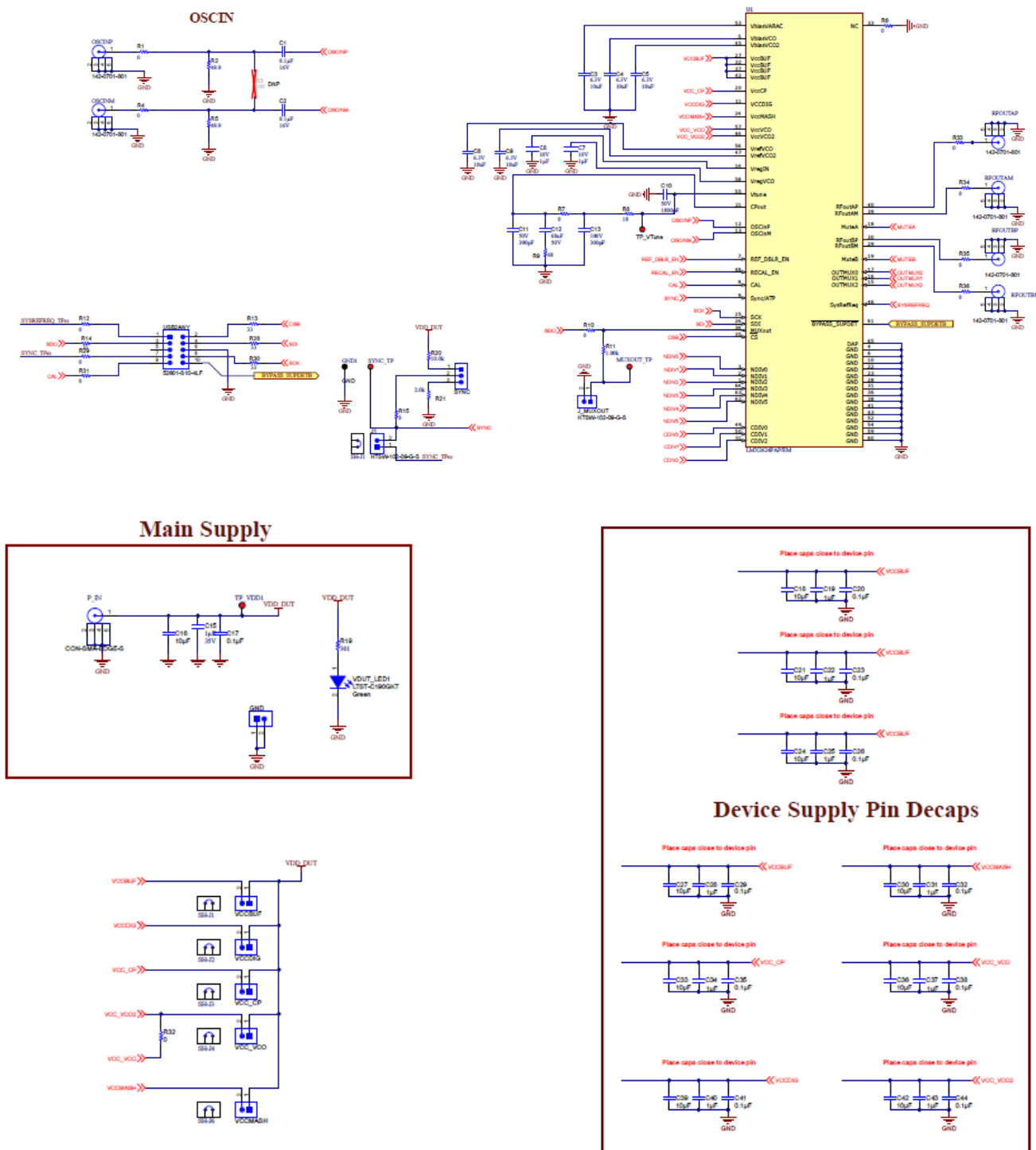


Figure 2-5. LMX2624 Rad Board Schematics

3 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by Michigan State University (MSU) Facility for Rare Isotope Beams (FRIB) using a K500 superconducting cyclotron (KSEE) and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity as the beam is collimated to a maximum of 40mm × 40mm square cross-sectional area for the in-air and vacuum scintillators. Uniformity is achieved by scattering on a Cu foil and then performing magnetic de focusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of $1 \times 10^3 - 1 \times 10^5$ ions/cm²/s was used to provide heavy-ion fluences of $8 \times 10^4 - 1 \times 10^7$ ions/cm². The KSEE facility uses a beam port that has a 3-mil polyethylene naphthalate (PEN) window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained between 40 mm for all runs.

Texas A&M University (TAMU) Cyclotron Radiation Effects Facility using a K500 superconducting cyclotron and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity over a 1-in diameter circular cross-sectional area for the in-air station. Uniformity is achieved by magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of $1 \times 10^3 - 1 \times 10^5$ ions/cm²/s was used to provide heavy-ion fluences of $8 \times 10^4 - 1 \times 10^7$ ions/cm². The TAMU facility uses a beam port that has a 1-mil Aramica window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 40mm for all runs.

For the experiments conducted on this report, there were 7 ions used ²⁰Ne, ⁴⁰Ar, ⁵⁹Co, ⁸⁴Kr, ¹⁰⁹Ag, ¹²⁹Xe, ¹⁶⁹Tm and ¹⁹⁴Au. ²⁰Ne was used to obtain LET_{EFF} of 2.76MeV×cm²/mg. ⁴⁰Ar was used to obtain LET_{EFF} of 7.5MeV×cm²/mg. ⁵⁹Co was used to obtain LET_{EFF} of 16MeV×cm²/mg. ⁸⁴Kr was used to obtain LET_{EFF} of 27MeV×cm²/mg. ¹⁰⁹Ag was used to obtain LET_{EFF} of 45MeV×cm²/mg. ¹²⁹Xe was used to obtain LET_{EFF} of 56MeV×cm²/mg. ¹⁶⁹Tm was used to obtain LET_{EFF} of 70MeV×cm²/mg. ¹⁹⁴Au was used to obtain LET_{EFF} of 83MeV×cm²/mg. The total kinetic energy for each of the ions were:

- ²⁰Ne = 0.3GeV (15MeV/nucleon)
 - Ion uniformity for these experiments was between 97% and 98%
- ⁴⁰Ar = 0.799GeV (19.5MeV/nucleon)
 - Ion uniformity for these experiments was between 95% and 96%
- ⁵⁹Co = 1.149GeV (19.5MeV/nucleon)
 - Ion uniformity for these experiments was between 89% and 90%
- ⁸⁴Kr = 1.636GeV (19.5MeV/nucleon)
 - Ion uniformity for these experiments was between 94% and 95%
- ¹⁰⁹Ag = 2.143GeV (19.5MeV/nucleon)
 - Ion uniformity for these experiments was between 92% and 93%
- ¹²⁹Xe = 2.513GeV (19.5MeV/nucleon)
 - Ion uniformity for these experiments was between 90% and 91%
- ¹⁶⁹Tm = 3.294GeV (19.5MeV/nucleon)
 - Ion uniformity for these experiments was between 88% and 89%
- ¹⁹⁴Au = 3.840GeV (19.5MeV/nucleon)
 - Ion uniformity for these experiments was between 92% and 93%

Figure 3-1 shows the LMX2624EVM in front of the beam line at the MSU K500 superconducting cyclotron facility. Figure 3-2 shows the LMX2624 Rad Board in front of the beam line at the MSU K500 superconducting cyclotron facility.

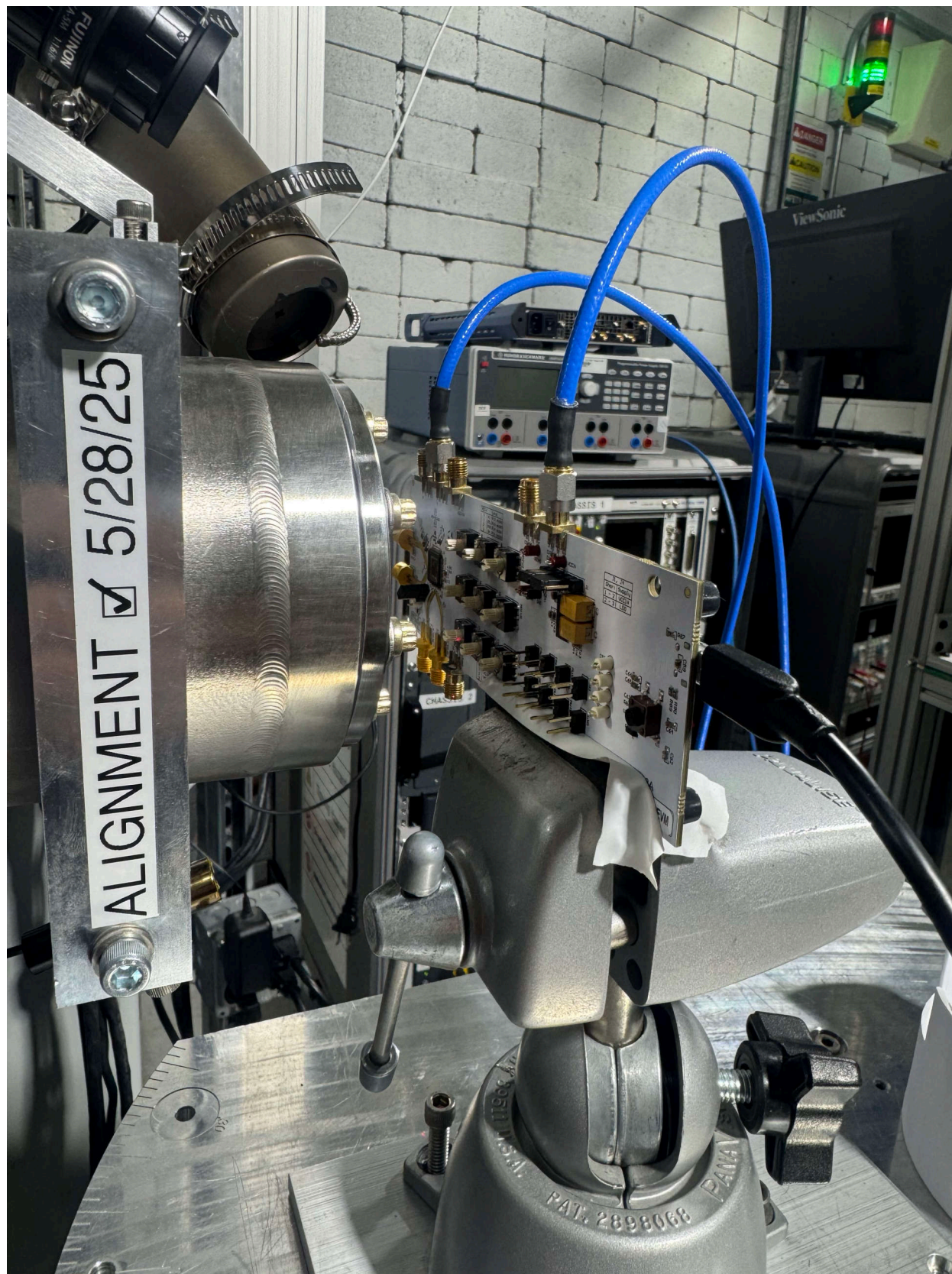


Figure 3-1. LMX2624EVM in Front of the Heavy-Ion Beam Exit Port at K500 Superconducting Cyclotron at Michigan State University

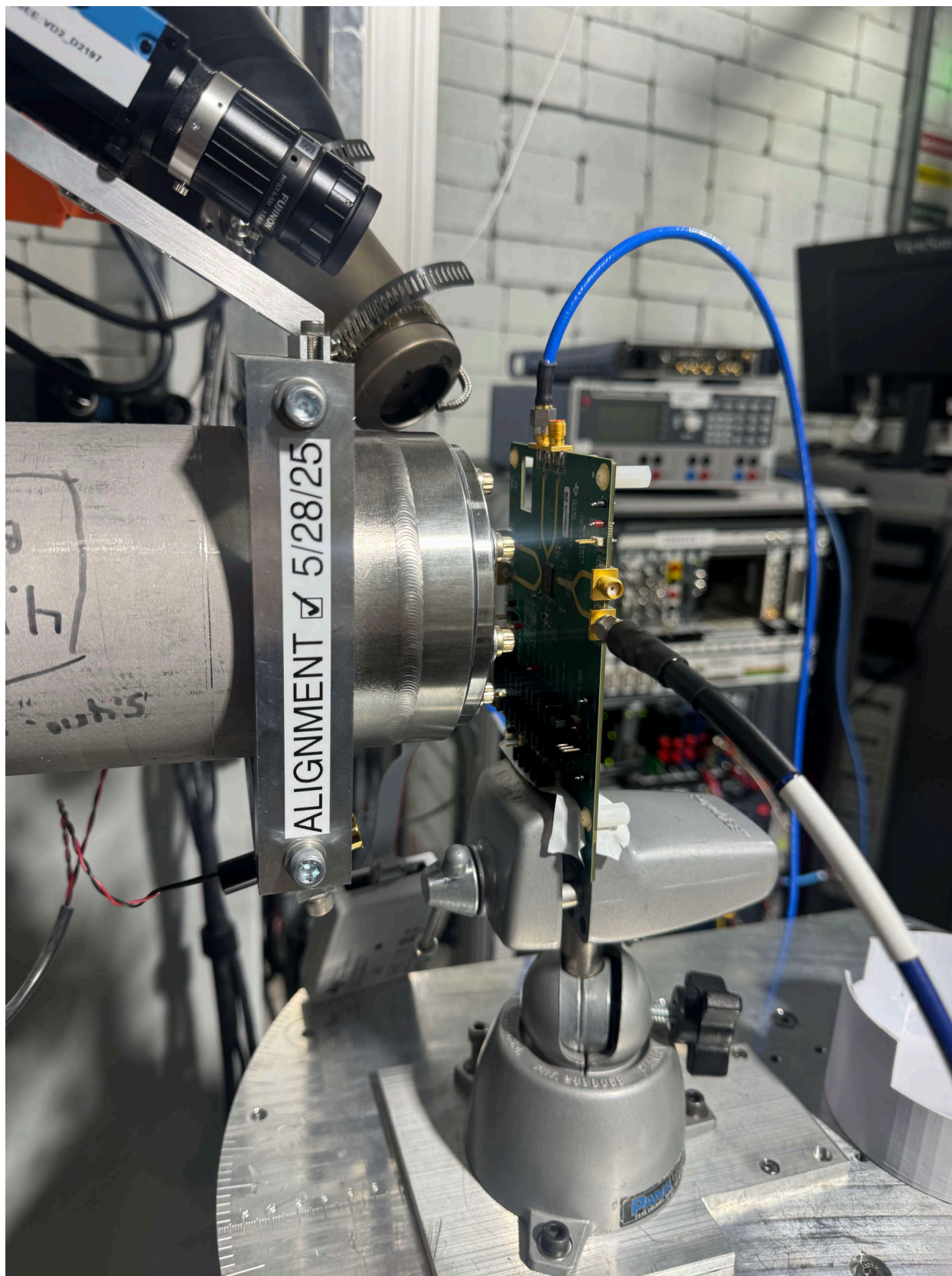


Figure 3-2. LMX2624 Rad Board in Front of the Heavy-Ion Beam Exit Port at K500 superconducting cyclotron at Michigan State University

4 LET_{EFF} and Range Calculation

Backend Film Stack

Passivation
TiN+Ti barrier
Metal 8
TiN+Ti barrier
ILD 8
TiN+Ti barrier
Metal 7
TiN+Ti barrier
ILD 7
TiN+Ti barrier
Metal 6
TiN+Ti barrier
ILD 6
TiN+Ti barrier
Metal 5
TiN+Ti barrier
ILD 5
TiN+Ti barrier
Metal 4
TiN+Ti barrier
ILD 4
TiN+Ti barrier
Metal 3
TiN+Ti barrier
ILD 3
TiN+Ti barrier
Metal 2
TiN+Ti barrier
ILD 2
TiN+Ti barrier
Metal 1
TiN+Ti barrier
ILD 1
Silicon

Figure 4-1. Generalized Cross-Section of the BiCMOS13 Technology BEOL Stack on the LMX2624-SP

The LMX2624-SP is fabricated in the TI Bipolar CMOS process with a back-end-of-line (BEOL) stack consisting of 13 layers of standard thickness aluminum. The total stack height from the surface of the passivation to the silicon surface is 13 μm based on nominal layer thickness as shown in Figure 4-1.

Accounting for energy loss through the degrader, copper foil, beam port window, air gap, and the BEOL stack of the LMX2624-SP, the effective LET (LET_{EFF}) at the surface of the silicon substrate and the range was determined with:

- SEUSS 2024 software (provided by TAMU and based on the latest SRIM-2013 [7] models)
- MSU Stack-Up Calculator (provided by MSU FRIB and based on the latest SRIM-2013 [7] models)

The results are shown in [Ion LET_{EFF} and Range in Silicon](#).

Table 4-1. Ion LET_{EFF} and Range in Silicon

Facility	Beam Energy (MeV/nucleon)	Ion Type	Degrader Steps (#)	Degrader Angle (°)	Copper Foil Width (μm)	Beam Port Window	Air Gap (mm)	Angle of Incidence	LET _{EFF} (MeV $\times\text{cm}^2/\text{mg}$)	Range (μm)
TAMU	15	²⁰ Ne	0	0	-	1-mil Aramica	40	0	2.76	274
KSEE - MSU	19.5	⁴⁰ Ar	0	0	5	3-mil PEN	40	0	7.5	241
KSEE - MSU	19.5	⁵⁹ Co	0	0	5	3-mil PEN	40	0	15.3	176
KSEE - MSU	19.5	⁸⁴ Kr	0	0	5	3-mil PEN	40	0	27.4	144
KSEE - MSU	19.5	¹⁰⁹ Ag	0	0	5	3-mil PEN	40	0	44.7	112
KSEE - MSU	19.5	¹²⁹ Xe	0	0	5	3-mil PEN	40	0	56.6	105
KSEE - MSU	19.5	¹⁶⁹ Tm	0	0	5	3-mil PEN	40	0	70.8	116
KSEE - MSU	19.5	¹²⁹ Xe	0	0	5	3-mil PEN	40	30	83.0	105

Table 4-1. Ion LET_{EFF} and Range in Silicon (continued)

Facility	Beam Energy (MeV/ nucleon)	Ion Type	Degrader Steps (#)	Degrader Angle (°)	Copper Foil Width (μm)	Beam Port Window	Air Gap (mm)	Angle of Incidence	LET_{EFF} (MeV×cm ² /mg)	Range (μm)
KSEE - MSU	19.5	¹⁹⁷ Au	0	0	5	3-mil PEN	40	40	83.0	122

5 Test Setup and Procedures

A decapped LMX2624-SP device was soldered onto the LMX2624EVM board for SEL testing. There was a single board input supply used to power the LMX2624EVM which provided $V_{CC_{VCO1}}$, $V_{CC_{VCO2}}$, $V_{CC_{BUF1}}$, $V_{CC_{BUF2}}$, $V_{CC_{BUF3}}$, $V_{CC_{BUF4}}$, $V_{CC_{DIG}}$, $V_{CC_{CP}}$ and $V_{CC_{MASH}}$. The supply for the device was provided via channel 1 of an N6705C power module. The supply was connected to V_{CCIN} SMA port on the board then was then split out through the board to the respective pins for the LMX2624-SP device. The input frequency used for this device was 100MHz at 10dBm. This was attached to OSCIN_P pin through a SMA cable located on the EVM board. The input frequency of 100MHz was provided by Rhode and Schwartz SME03 Signal Generator

All equipment was controlled and monitored using a custom-developed LabVIEW™ program (PXI-RadTest) running on a HP-Z4 desktop computer. The computer communicates with the PXI chassis via an MXI controller and NI PXIe-8381 remote control module.

[Equipment Settings and Parameters Used During the SEL Testing of the LMX2624EVM Board](#) shows the connections, limits, and compliance values used during the testing. [Figure 5-1](#) shows a block diagram of the setup used for SEL testing of the LMX2624-SP on the LMX2624EVM.

Table 5-1. Equipment Settings and Parameters Used During the SEL Testing of the LMX2624EVM Board

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
$V_{CC_{VCO1}}$	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
$V_{CC_{VCO2}}$	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
$V_{CC_{BUF1}}$	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
$V_{CC_{BUF2}}$	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
$V_{CC_{BUF3}}$	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
$V_{CC_{BUF4}}$	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
$V_{CC_{DIG}}$	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
$V_{CC_{MASH}}$	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
OSCIN_P	R&S SME03	5kHz to 2.2GHz	-	100MHz at 10dBm

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to ensure that the test system was stable under all bias and load conditions prior to being taken to the test facility. During the heavy-ion testing, the LabVIEW control program powered up the LMX2624-SP device and set the external sourcing and monitoring functions of the external equipment. After functionality and stability was confirmed, the beam shutter was opened to expose the device to the heavy-ion beam. The shutter remained open until the target fluence was achieved (determined by external detectors and counters). No sudden increases in current were observed (outside of normal fluctuations) on any of the test runs and indicated that no SEL events occurred during any of the tests.

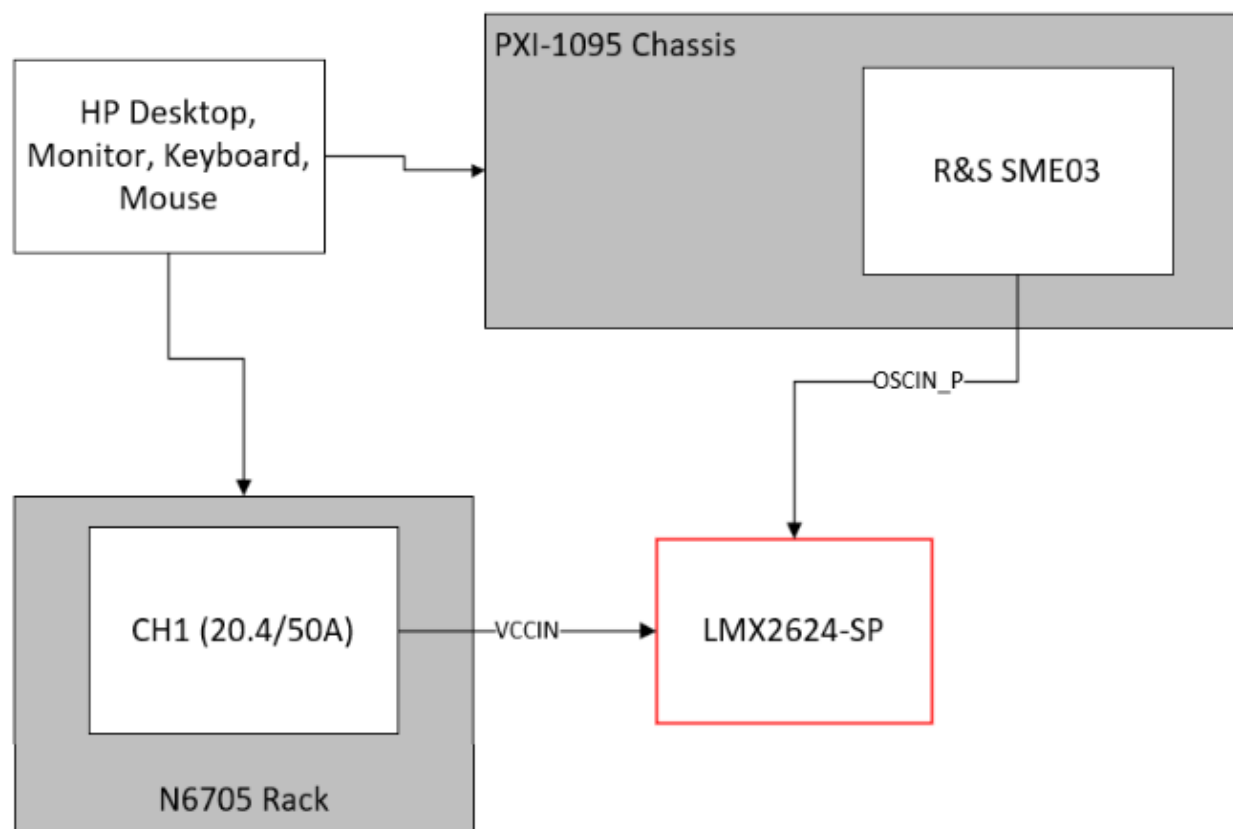


Figure 5-1. Block Diagram of the SEL Test Setup for the LMX2624EVM

LMX2624 Rad Board Setup and Procedures

A decapped LMX2624-SP device was soldered LMX2624 Rad board for SET testing. There was a single input supply used to power the LMX2624Rad Board which provided VCC_{VCO1} , VCC_{VCO2} , VCC_{BUF1} , VCC_{BUF2} , VCC_{BUF3} , VCC_{BUF4} , VCC_{DIG} , VCC_{CP} and VCC_{MASH} . The supply for the device was provided via Ch. 1 of an N6705C power module. The supply was connected to VCCIN SMA port on the board then was then split out through the board to the respective pins for the LMX2624-SP device. The input frequency used for this device was 100MHz at 10dBm. This was attached to OSCIN_P pin through a SMA cable located on the Rad board. The input frequency of 100MHz was provided by Rhode & Schwartz SME03 Signal Generator. Single Event Transients were measured and captured with a Tektronix® MSO68B oscilloscope. This was connected to the RFOUT_AP and RFOUT_BP outputs on Rad board to characterize device configuration. RFOUT_AP and RFOUT_BP pins were routed through Rad board and connected to oscilloscope through SMA cables.

Input power supply was controlled and monitored using a custom-developed LabVIEW program (PXi-RadTest) running on a HP-Z4 desktop computer. The computer communicates with the PXI chassis via an MXI controller and NI PXIe-8381 remote control module. The MSO68B oscilloscope was controlled externally and monitored during experiment.

[Equipment Settings and Parameters Used During the SEL Testing of the LMX2624EVM Board](#) shows the connections, limits, and compliance values used during the testing. [Figure 5-1](#) shows a block diagram of the setup used for SET testing of the LMX2624-SP on the LMX2624EVM.

Table 5-2. Equipment Settings and Parameters Used During the SET Testing of the LMX2624 Rad Board

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
VCC_{VCO1}	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
VCC_{VCO2}	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V

Table 5-2. Equipment Settings and Parameters Used During the SET Testing of the LMX2624 Rad Board (continued)

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
VCC _{BUF1}	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
VCC _{BUF2}	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
VCC _{BUF3}	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
VCC _{BUF4}	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
VCC _{DIG}	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
VCC _{MASH}	N6705C (CH # 1)	20.4V, 50A	1.5A	3.1 to 3.8V
OSCIN_P	R&S SME03	5kHz to 2.2GHz	-	100MHz at 10dBm
RFOUT_AP	Tektronix MSO68B	1GHz Analog BW and 50 GS/S	-	50 GS/s
RFOUT_BP	Tektronix MSO68B	1GHz Analog BW and 50 GS/S	-	50 GS/s

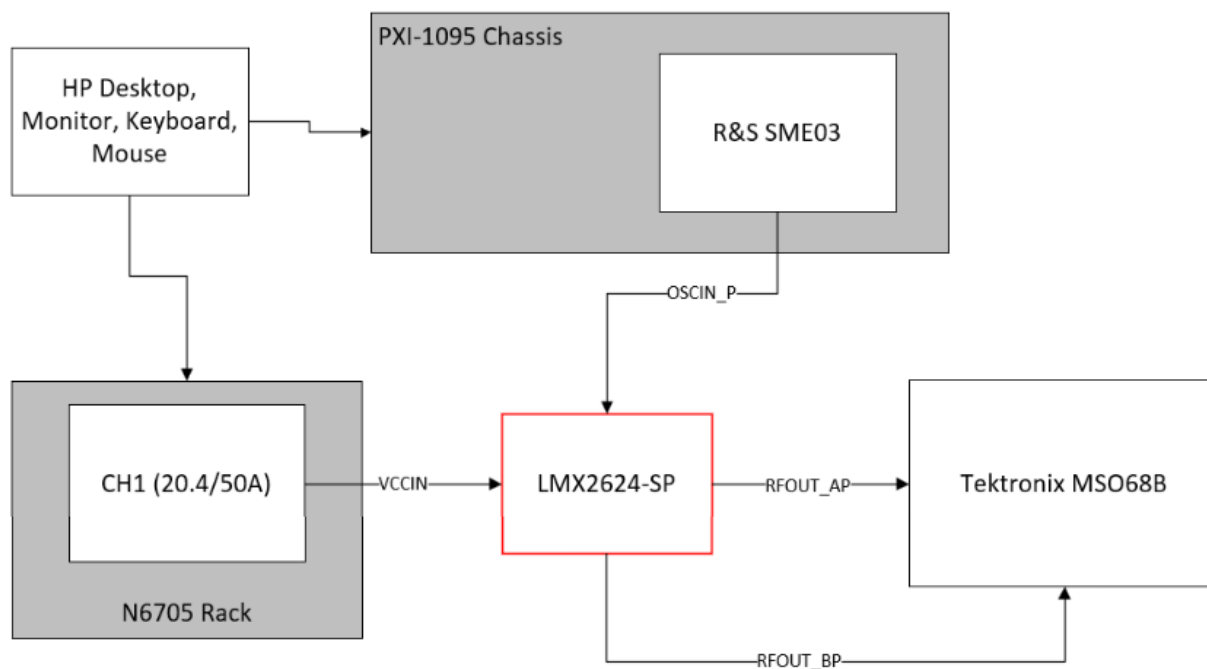


Figure 5-2. Block Diagram of the SET Test Setup for the LMX2624 Rad Board

6 Destructive Single-Event Effects (DSEE)

6.1 Single-Event Latch-up (SEL) Results

During the SEL testing the device was heated to 125°C by using a Closed-Loop PID controlled heat gun (MISTRAL 6 System [120V, 2400W]). The die temperature was verified using a standalone FLIR thermal camera prior to exposure to heavy ions at KSEE.

The species used for SEL testing was ^{129}Xe at 19.5MeV/nucleon with an angle of incidence of 30°. (for more details refer to [Ion LET_{EFF} and Range in Silicon](#)). Flux of approximately 1×10^5 ions/cm²/s and a fluence of approximately 1×10^7 ions/cm² per run was used. Run duration to achieve this fluence was approximately two minutes. The three devices were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 3.45V. No SEL events were observed during all runs, indicating that the LMX2624-SP is SEL-free up to 83MeV×cm²/mg. [Table 6-1](#) shows the SEL test conditions and results. [Figure 6-1](#) shows a plot of the current versus time for run #1.

Table 6-1. Summary of LMX2624-SP SEL Test Condition and Results

Run #	Unit #	Facility	Ion	Angle of Incidence (Deg)	LET _{EFF} (MeV×cm ² /mg)	Flux (ions/cm ² /s)	Fluence (ions/cm ²)	RFOUT_AP Output	RFOUT_BP Output	Configured with Pin/SPI	V _{cc} (V)	Input Frequency (MHz)	SEL (# Events)
1	1	KSEE-MSU	^{129}Xe	30	83	1.01×10^5	1.5×10^7	Doubler	CHDIV	SPI	3.45	100	0
2	1	KSEE-MSU	^{129}Xe	30	83	1.00×10^5	1×10^7	CHDIV	VCO	SPI	3.45	100	0
3	1	KSEE-MSU	^{129}Xe	30	83	1.02×10^5	1×10^7	VCO	Doubler	SPI	3.45	100	0
4	1	KSEE-MSU	^{129}Xe	30	83	1.03×10^5	1×10^7	VCO	CHDIV	Pin	3.45	100	0
5	1	KSEE-MSU	^{129}Xe	30	83	1.01×10^5	1×10^7	VCO	CHDIV	SPI	3.45	100	0
6	2	KSEE-MSU	^{129}Xe	30	83	1.00×10^5	1×10^7	Doubler	CHDIV	SPI	3.45	100	0
7	2	KSEE-MSU	^{129}Xe	30	83	1.00×10^5	1×10^7	CHDIV	VCO	SPI	3.45	100	0
8	2	KSEE-MSU	^{129}Xe	30	83	1.00×10^5	1.5×10^7	VCO	Doubler	SPI	3.45	100	0
9	2	KSEE-MSU	^{129}Xe	30	83	1.02×10^5	1×10^7	VCO	CHDIV	Pin	3.45	100	0
10	2	KSEE-MSU	^{129}Xe	30	83	1.01×10^5	1×10^7	VCO	CHDIV	SPI	3.45	100	0
11	3	KSEE-MSU	^{129}Xe	30	83	1.00×10^5	1×10^7	Doubler	CHDIV	SPI	3.45	100	0
12	3	KSEE-MSU	^{129}Xe	30	83	1.00×10^5	1×10^7	CHDIV	VCO	SPI	3.45	100	0
13	3	KSEE-MSU	^{129}Xe	30	83	1.00×10^5	1×10^7	VCO	Doubler	SPI	3.45	100	0
14	3	KSEE-MSU	^{129}Xe	30	83	1.02×10^5	1.5×10^7	VCO	CHDIV	Pin	3.45	100	0
15	3	KSEE-MSU	^{129}Xe	30	83	1.01×10^5	1×10^7	VCO	CHDIV	SPI	3.45	100	0

Using the MFTF method described in [Single-Event Effects \(SEE\) Confidence Interval Calculations application report](#) and combining (or summing) the fluences of the fifteen runs at 125°C (15×10^7 ions/cm²), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{\text{SEL}} \leq 8.11 \times 10^{-8} \text{ cm}^2/\text{device for LET}_{\text{EFF}} = 83\text{MeV}\times\text{cm}^2/\text{mg and } T = 125^\circ\text{C}.$$

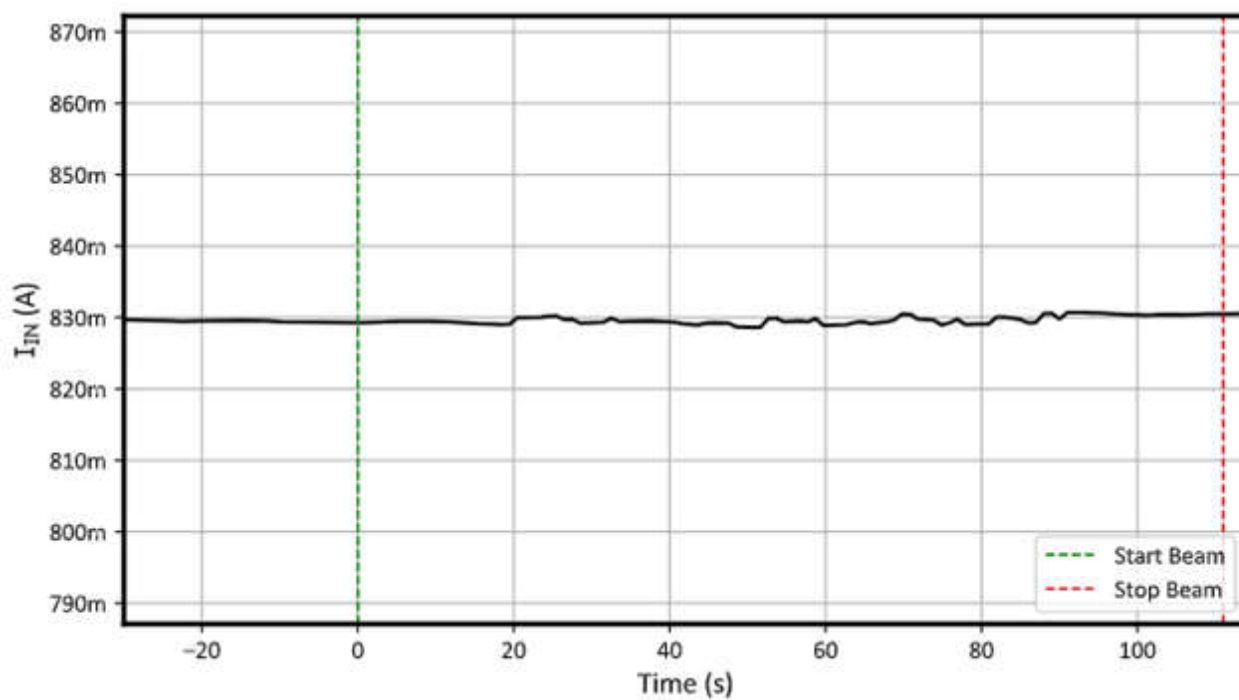


Figure 6-1. Current versus Time for Run #1 (SEL) of the LMX2624-SP at $T = 125^{\circ}\text{C}$ (RFOUT_AP = Doubler and RFOUT_BP = CHDIV - 23GHz)

7 Single-Event Transients (SET)

SETs are defined as heavy-ion induced transients upsets on the RFOUT_AP and RFOUT_BP outputs of the LMX2624-SP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for SET testing was ^{20}Ne at 15MeV/nucleon, ^{40}Ar at 19.5MeV/nucleon, ^{59}Co at 19.5MeV/nucleon, ^{84}Kr at 19.5MeV/nucleon, ^{109}Ag at 19.5MeV/nucleon, ^{129}Xe at 19.5MeV/nucleon, ^{169}Tm at 19.5MeV/nucleon and ^{197}Au for a LET_{EFF} at 19.5MeV/nucleon; of 7.5, 16, 27, 45, 56, 70, 83 MeV $\times$ cm ^{2} /mg, for more details refer to [Ion LET_{EFF} and Range in Silicon](#). Flux of 1×10^3 - 1×10^5 ions/cm ^{2} /s and a fluence of 8×10^4 - 1×10^6 ions/cm ^{2} , per run were used for the SET characterization discussed on this chapter. This section is separated into the LMX2624-SP modes used for SET. In different device modes, the trigger needed to be set with respect to the device mode. The specific trigger used for each mode will be stated in each section.

Runs with LET_{EFF} range of 83 - 7.5MeV $\times$ cm ^{2} /mg were preformed at Michigan State University (MSU) Facility for Rare Isotope Beams (FRIB) using a K500 superconducting cyclotron (KSEE). Runs with $\text{LET}_{\text{EFF}} = 2.76$ MeV $\times$ cm ^{2} /mg were preformed at Texas A&M University (TAMU) Cyclotron Radiation Effects Facility using a K500 superconducting cyclotron.

Waveform size, sample rate, trigger type, value, and signal for all scopes used is presented on [Table 7-1](#). From limitations of the Tektronix MSO68B oscilloscope, there are outputs from LMX2624-SP modes that are not characterized, these outputs are presented in [Table 7-1](#)

Table 7-1. Scope and Device Settings

Scope Model	Trigger Type	Device Configuration	RFOUT_AP Output	RFOUT_BP Output	Configured by SPI/Pin	PLL	Characterization of RFOUT_AP	Characterization of RFOUT_BP
Tektronix MSO68B	Pulse Width Trigger	1	CHDIV	SYSREF Continuous	SPI	Integer	Included	Included
		2	CHDIV	SYSREF Continuous	SPI	Fractional	Included	Included
		3	CHDIV	VCO	SPI	Fractional	Included	Not Included
		4	VCO	CHDIV	SPI	Integer	Not Included	Included
		5	Doubler	CHDIV	SPI	Integer	Not Included	Included

7.1 Single Event Transients (SET)

Device Configuration 1

For $V_{\text{CC}} = 3.3$ V (Nominal) 1 unit was characterized from 83MeV down to 2.76MeV. ^{20}Ne was used to obtain LET_{EFF} of 2.76MeV $\times$ cm ^{2} /mg. ^{40}Ar was used to obtain LET_{EFF} of 7.5MeV $\times$ cm ^{2} /mg. ^{59}Co was used to obtain LET_{EFF} of 16MeV $\times$ cm ^{2} /mg. ^{84}Kr was used to obtain LET_{EFF} of 27MeV $\times$ cm ^{2} /mg. ^{109}Ag was used to obtain LET_{EFF} of 45MeV $\times$ cm ^{2} /mg. ^{129}Xe was used to obtain LET_{EFF} of 56MeV $\times$ cm ^{2} /mg. ^{169}Tm was used to obtain LET_{EFF} of 70MeV $\times$ cm ^{2} /mg. ^{197}Au was used to obtain LET_{EFF} of 83MeV $\times$ cm ^{2} /mg. In this device configuration, the output frequency for RFOUT_AP = 206.25MHz and RFOUT_BP = 68.75MHz. RFOUT_AP output is the main divided down low noise clock and RFOUT_BP is SYSREF. Both outputs are characterized below. The Tektronix MSO68B oscilloscope was used to monitor RFOUT_AP and RFOUT_BP signals of the LMX2624-SP with the respective signal triggering off a 1% window. A trigger of 4.8ns was used for RFOUT_AP outputs in this section. Also, a trigger of 14.5 ns was used for RFOUT_BP outputs in this section. [Table 7-2](#) summarizes the events seen in this mode on RFOUT_AP Output. [Table 7-3](#) summarizes the events seen in this mode on RFOUT_BP.

Table 7-2. Summary of LMX2624-SP in Device Configuration 1 - RFOUT_AP Output

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
3	Au	0	83	4.84E+06	5.64E+04	1	RFOUT_A P	Pulse Width	1%	210
4	Au	0	83	5.04E+06	5.85E+04	2	RFOUT_A P	Pulse Width	1%	182
20	Tm	0	70	1.00E+04	5.00E+04	1	RFOUT_A P	Pulse Width	1%	150

Table 7-2. Summary of LMX2624-SP in Device Configuration 1 - RFOUT_AP Output (continued)

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
21	Tm	0	70	2.77E+06	5.25E+04	2	RFOUT_A P	Pulse Width	1%	154
51	Xe	0	56	5.00E+06	4.88E+04	1	RFOUT_A P	Pulse Width	1%	135
53	Xe	0	56	4.95E+06	3.94E+04	2	RFOUT_A P	Pulse Width	1%	104
70	Ag	0	45	3.42E+06	5.12E+04	1	RFOUT_A P	Pulse Width	1%	111
72	Ag	0	45	2.78E+06	5.11E+06	2	RFOUT_A P	Pulse Width	1%	117
86	Kr	0	27	5.00E+06	4.98E+04	1	RFOUT_A P	Pulse Width	1%	92
87	Kr	0	27	5.00E+06	4.98E+04	2	RFOUT_A P	Pulse Width	1%	90
100	Co	0	16	5.01E+06	5.39E+04	1	RFOUT_A P	Pulse Width	1%	52
101	Co	0	16	5.00E+06	5.50E+04	2	RFOUT_A P	Pulse Width	1%	37
115	Ar	0	7.5	5.01E+06	4.91E+04	1	RFOUT_A P	Pulse Width	1%	9
116	Ar	0	7.5	5.01E+06	5.18E+04	2	RFOUT_A P	Pulse Width	1%	10
1	Ne	0	2.76	5.00E+06	5.00E+04	1	RFOUT_A P	Pulse Width	1%	0
2	Ne	0	2.76	5.01E+06	5.05E+04	2	RFOUT_A P	Pulse Width	1%	0

Table 7-3. Summary of LMX2624-SP in Device Configuration 1 - RFOUT_BP Output

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
5	Au	0	83	5.00E+06	5.88E+06	1	RFOUT_B P	Pulse Width	1%	176
6	Au	0	83	5.03E+06	6.21E+04	2	RFOUT_B P	Pulse Width	1%	151
23	Tm	0	70	4.52E+06	4.52E+04	1	RFOUT_B P	Pulse Width	1%	142
24	Tm	0	70	4.67E+06	4.07E+04	2	RFOUT_B P	Pulse Width	1%	141
55	Xe	0	56	5.06E+06	7.31E+04	1	RFOUT_B P	Pulse Width	1%	141
56	Xe	0	56	5.02E+06	6.13E+04	2	RFOUT_B P	Pulse Width	1%	128
73	Ag	0	45	4.02E+06	5.09E+04	1	RFOUT_B P	Pulse Width	1%	107
74	Ag	0	45	3.95E+06	5.17E+04	2	RFOUT_B P	Pulse Width	1%	114
88	Kr	0	27	5.05E+06	5.15E+04	1	RFOUT_B P	Pulse Width	1%	59
89	Kr	0	27	5.05E+06	5.26E+04	2	RFOUT_B P	Pulse Width	1%	53
102	Co	0	16	5.00E+06	5.40E+04	1	RFOUT_B P	Pulse Width	1%	19

Table 7-3. Summary of LMX2624-SP in Device Configuration 1 - RFOUT_BP Output (continued)

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
103	Co	0	16	5.00E+06	5.37E+04	2	RFOUT_BP	Pulse Width	1%	19
117	Ar	0	7.5	5.03E+06	5.23E+04	1	RFOUT_BP	Pulse Width	1%	4
118	Ar	0	7.5	5.03E+06	5.34E+04	2	RFOUT_BP	Pulse Width	1%	6
3	Ne	0	2.76	5.01E+06	5.13E+04	1	RFOUT_BP	Pulse Width	1%	0
4	Ne	0	2.76	5.03E+06	5.02E+04	2	RFOUT_BP	Pulse Width	1%	0

A Weibull fit using the events and fluence from [Table 7-2](#) can be seen below.

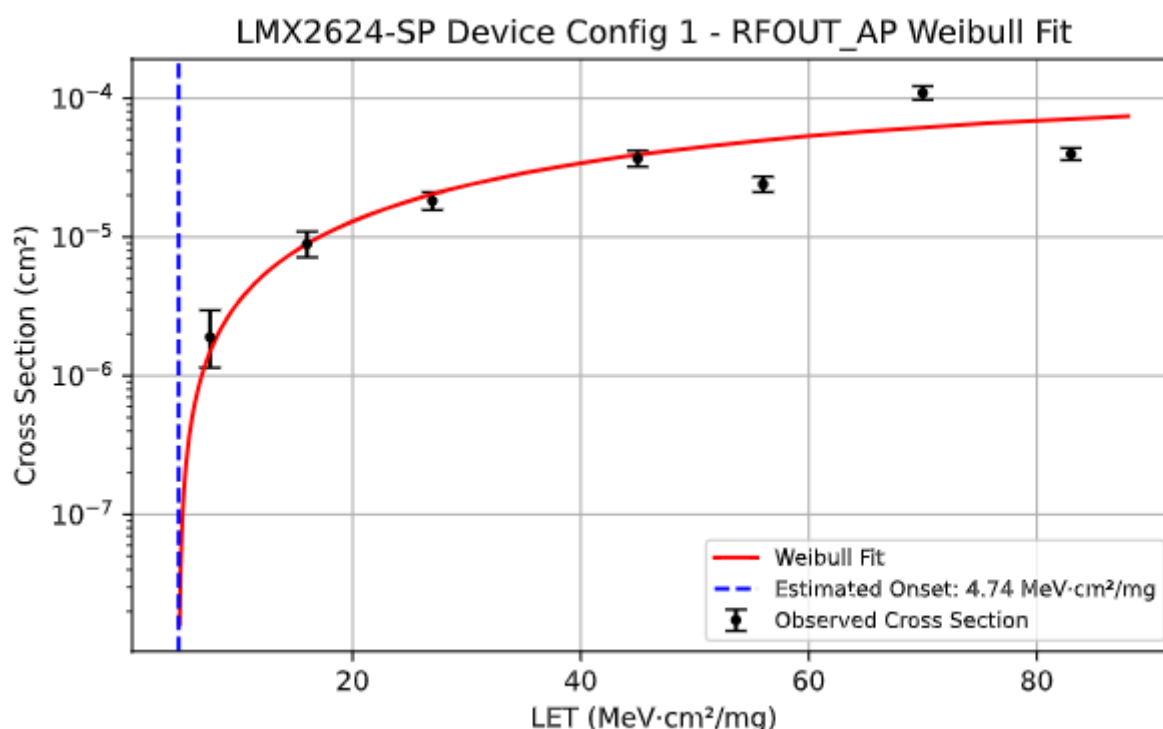


Figure 7-1. Weibull Fit for LMX2624-SP Device Configuration 1 - RFOUT_AP Output

Table 7-4. Weibull Fit Parameters for LMX2624-SP Device Configuration 1 - RFOUT_AP output

Parameters	Values
Cross Section (cm ²)	1.09 × 10 ⁻⁴
Onset (MeV×cm ² /mg)	4.74
W (MeV×cm ² /mg)	75.34
S	1.30

A Weibull fit using the events and fluence from [Table 7-3](#) can be seen below.

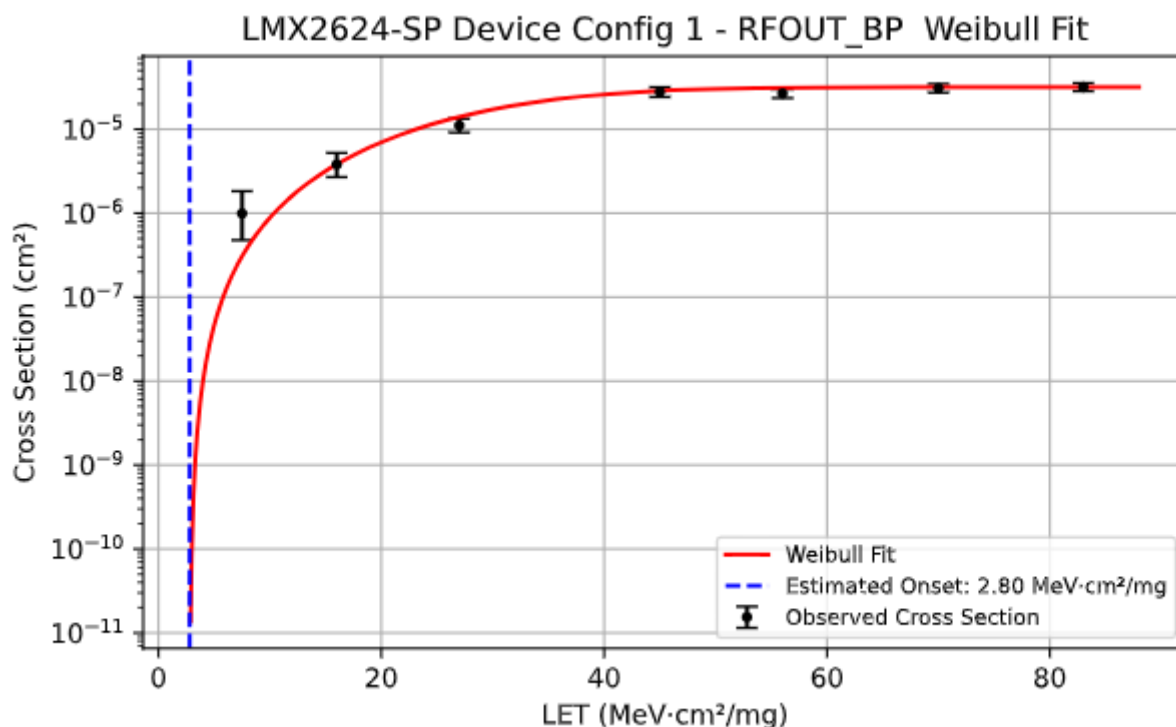


Figure 7-2. Weibull Fit for LMX2624-SP Device Configuration 1 - RFOUT_BP Output

Table 7-5. Weibull Fit Parameters for LMX2624-SP Device Configuration 1 - RFOUT_BP output

Parameters	Values
Cross Section (cm ²)	3.17×10^{-5}
Onset (MeV×cm ² /mg)	2.80
W (MeV×cm ² /mg)	30.00
S	2.50

Device Configuration 2

For $V_{CC} = 3.3V$ (Nominal) 1 unit was characterized from 83MeV down to 2.76MeV. ^{20}Ne was used to obtain LET_{EFF} of 2.76MeV×cm²/mg. ^{40}Ar was used to obtain LET_{EFF} of 7.5MeV×cm²/mg. ^{59}Co was used to obtain LET_{EFF} of 16MeV×cm²/mg. ^{84}Kr was used to obtain LET_{EFF} of 27MeV×cm²/mg. ^{109}Ag was used to obtain LET_{EFF} of 45MeV×cm²/mg. ^{129}Xe was used to obtain LET_{EFF} of 56MeV×cm²/mg. ^{169}Tm was used to obtain LET_{EFF} of 70MeV×cm²/mg. ^{197}Au was used to obtain LET_{EFF} of 83MeV×cm²/mg. In this device configuration, the output frequency for RFOUT_AP = 207.5 MHz and RFOUT_BP = 68.75 MHz. RFOUT_AP output is the main divided down low noise clock and RFOUT_BP is SYSREF. Both outputs are characterized below. The Tektronix MSO68B oscilloscope was used to monitor RFOUT_AP and RFOUT_BP signals of the LMX2624-SP with the respective signal triggering off a 1% window. A trigger of 4.8 ns was used for RFOUT_AP outputs in this section. Also, a trigger of 14.5 ns was used for RFOUT_BP outputs in this section. [Table 7-6](#) summarizes the events seen in this mode on RFOUT_AP Output. [Table 7-7](#) summarizes the events seen in this mode on RFOUT_BP.

Table 7-6. Summary of LMX2624-SP in Device Configuration 2 - RFOUT_AP Output

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
7	Au	0	83	4.78E+06	6.20E+04	1	RFOUT_A P	Pulse Width	1%	249
8	Au	0	83	5.00E+06	6.17E+04	2	RFOUT_A P	Pulse Width	1%	213

Table 7-6. Summary of LMX2624-SP in Device Configuration 2 - RFOUT_AP Output (continued)

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
36	Tm	0	70	1.10E+06	5.21E+04	1	RFOUT_A P	Pulse Width	1%	133
37	Tm	0	70	1.60E+06	5.17E+04	2	RFOUT_A P	Pulse Width	1%	160
59	Xe	0	56	2.63E+06	4.53E+04	1	RFOUT_A P	Pulse Width	1%	126
60	Xe	0	56	1.79E+06	4.51E+04	2	RFOUT_A P	Pulse Width	1%	125
75	Ag	0	45	1.90E+06	5.06E+04	1	RFOUT_A P	Pulse Width	1%	105
76	Ag	0	45	2.31E+06	5.25E+04	2	RFOUT_A P	Pulse Width	1%	105
90	Kr	0	27	2.69E+06	5.38E+04	1	RFOUT_A P	Pulse Width	1%	89
91	Kr	0	27	2.31E+06	5.23E+04	2	RFOUT_A P	Pulse Width	1%	91
104	Co	0	16	5.00E+06	5.45E+04	1	RFOUT_A P	Pulse Width	1%	79
106	Co	0	16	5.00E+06	5.58E+04	2	RFOUT_A P	Pulse Width	1%	58
119	Ar	0	7.5	5.03E+06	5.28E+04	1	RFOUT_A P	Pulse Width	1%	12
120	Ar	0	7.5	5.03E+06	5.30E+04	2	RFOUT_A P	Pulse Width	1%	7
5	Ne	0	2.76	5.03E+06	5.01E+04	1	RFOUT_A P	Pulse Width	1%	0
6	Ne	0	2.76	5.04E+06	5.01E+04	2	RFOUT_A P	Pulse Width	1%	0

Table 7-7. Summary of LMX2624-SP in Device Configuration 2 - RFOUT_BP Output

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
9	Au	0	83	5.01E+06	6.07E+04	1	RFOUT_B P	Pulse Width	1%	173
10	Au	0	83	5.00E+06	6.03E+04	2	RFOUT_B P	Pulse Width	1%	128
38	Tm	0	70	5.05E+06	4.93E+04	1	RFOUT_B P	Pulse Width	1%	113
40	Tm	0	70	3.26E+06	5.08E+04	2	RFOUT_B P	Pulse Width	1%	103
61	Xe	0	56	5.01E+06	4.36E+04	1	RFOUT_B P	Pulse Width	1%	122
62	Xe	0	56	5.03E+06	4.63E+04	2	RFOUT_B P	Pulse Width	1%	132
77	Ag	0	45	4.90E+06	5.00E+04	1	RFOUT_B P	Pulse Width	1%	99
78	Ag	0	45	5.00E+06	5.20E+04	2	RFOUT_B P	Pulse Width	1%	96
91	Kr	0	27	5.00E+06	5.34E+04	1	RFOUT_B P	Pulse Width	1%	60
92	Kr	0	27	5.05E+06	5.23E+04	2	RFOUT_B P	Pulse Width	1%	73

Table 7-7. Summary of LMX2624-SP in Device Configuration 2 - RFOUT_BP Output (continued)

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
107	Co	0	16	5.00E+06	5.50E+04	1	RFOUT_BP	Pulse Width	1%	32
108	Co	0	16	5.00E+06	5.77E+04	2	RFOUT_BP	Pulse Width	1%	18
121	Ar	0	7.5	5.01E+06	5.27E+04	1	RFOUT_BP	Pulse Width	1%	5
122	Ar	0	7.5	5.02E+06	5.50E+04	2	RFOUT_BP	Pulse Width	1%	3
7	Ne	0	2.76	5.00E+06	5.01E+04	1	RFOUT_BP	Pulse Width	1%	0
8	Ne	0	2.76	5.01E+06	5.00E+04	2	RFOUT_BP	Pulse Width	1%	0

A Weibull fit using the events and fluences from [Table 7-6](#)

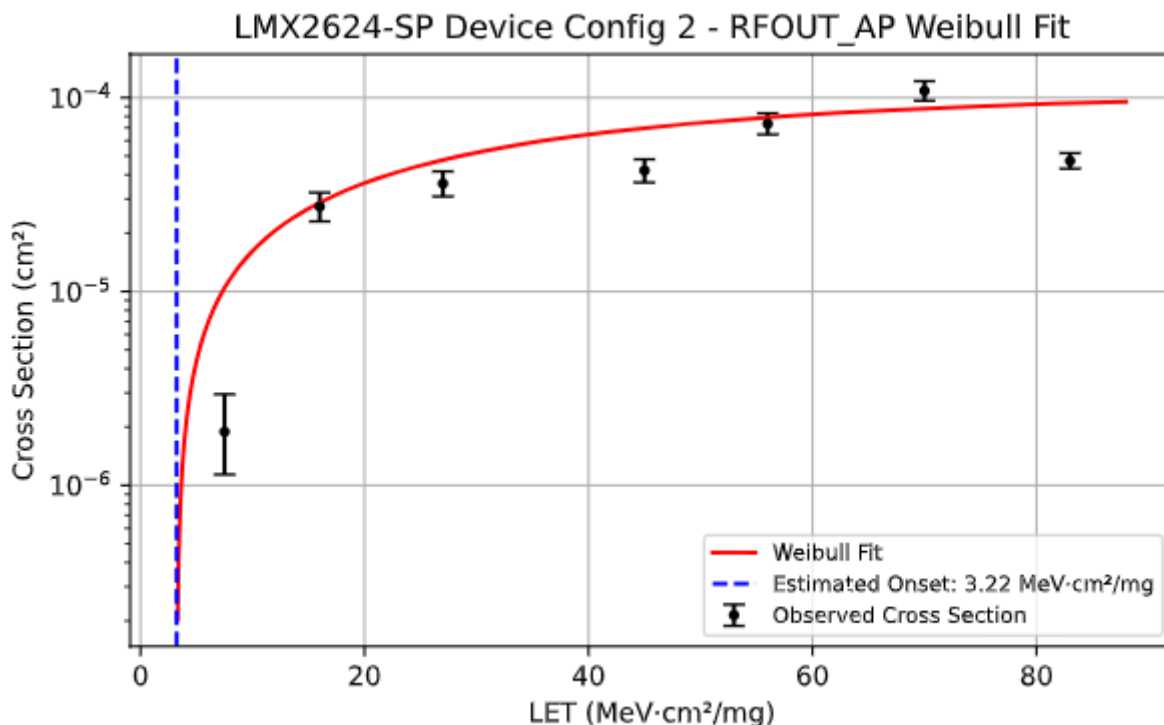


Figure 7-3. Weibull Fit for LMX2624-SP Device Configuration 2 - RFOUT_AP Output

Table 7-8. Weibull Fit Parameters for LMX2624-SP Device Configuration 2 - RFOUT_AP output

Parameters	Values
Cross Section (cm ²)	1.09×10^{-4}
Onset (MeV×cm ² /mg)	3.22
W (MeV×cm ² /mg)	54.71
S	1.02

A Weibull fit using the events and fluences from [Table 7-7](#) can be viewed below.

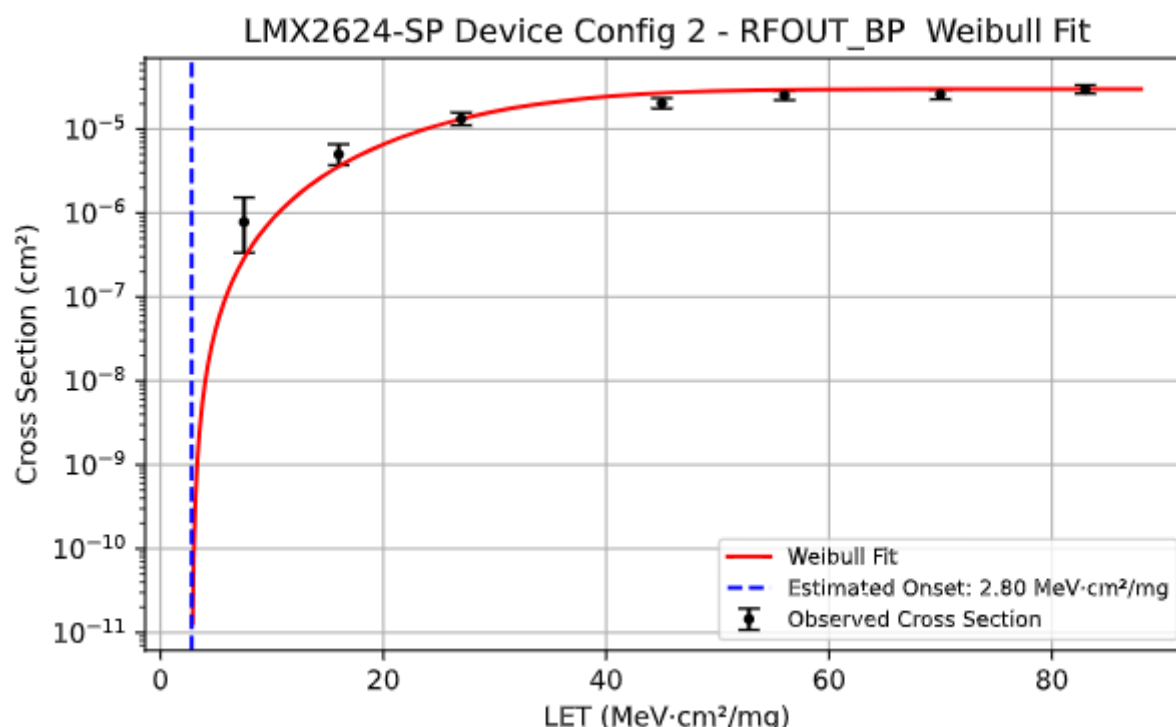


Figure 7-4. Weibull Fit for LMX2624-SP Device Configuration 2 - RFOUT_BP Output

Table 7-9. Weibull Fit Parameters for LMX2624-SP Device Configuration 2 - RFOUT_BP output

Parameters	Values
Cross Section (cm ²)	2.98×10^{-5}
Onset (MeV×cm ² /mg)	2.80
W (MeV×cm ² /mg)	30.00
S	2.50

7.2 Single Event Transients (SET) - Device Configuration 3

For $V_{CC} = 3.3V$ (Nominal) 1 unit was characterized from 83MeV down to 2.76MeV. ^{20}Ne was used to obtain LET_{EFF} of 2.76MeV×cm²/mg. ^{40}Ar was used to obtain LET_{EFF} of 7.5 MeV×cm²/mg. ^{59}Co was used to obtain LET_{EFF} of 16MeV×cm²/mg. ^{84}Kr was used to obtain LET_{EFF} of 27MeV×cm²/mg. ^{109}Ag was used to obtain LET_{EFF} of 45MeV×cm²/mg. ^{129}Xe was used to obtain LET_{EFF} of 56MeV×cm²/mg. ^{169}Tm was used to obtain LET_{EFF} of 70MeV×cm²/mg. ^{197}Au was used to obtain LET_{EFF} of 83MeV×cm²/mg. In this device configuration, the output frequency for RFOUT_AP = 191.4MHz and RFOUT_BP = 12.25GHz. Due to RFOUT_BP's high frequency, only RFOUT_AP is characterized below. The Tektronix MSO68B oscilloscope was used to monitor RFOUT_AP and RFOUT_BP signals of the LMX2624-SP with the respective signal triggering off a 1% window. A trigger of 5.2ns was used for RFOUT_AP outputs in this section. Due to oscilloscope bandwidth, only RFOUT_AP will be characterized in this section. Table 7-10 summarizes the events seen in this mode on RFOUT_AP Output.

Table 7-10. Summary of LMX2624-SP in Device Configuration 3 - RFOUT_AP Output

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
11	Au	0	83	5.05E+06	4.95E+04	1	RFOUT_A P	Pulse Width	1%	172
12	Au	0	83	5.00E+06	4.72E+04	2	RFOUT_A P	Pulse Width	1%	209
43	Tm	0	70	5.05E+06	4.90E+04	1	RFOUT_A P	Pulse Width	1%	140

Table 7-10. Summary of LMX2624-SP in Device Configuration 3 - RFOUT_AP Output (continued)

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
44	Tm	0	70	5.04E+06	5.40E+04	2	RFOUT_A P	Pulse Width	1%	112
63	Xe	0	56	3.09E+06	4.83E+04	1	RFOUT_A P	Pulse Width	1%	94
64	Xe	0	56	2.97E+06	4.80E+04	2	RFOUT_A P	Pulse Width	1%	105
79	Ag	0	45	3.55E+06	5.16E+04	1	RFOUT_A P	Pulse Width	1%	85
80	Ag	0	45	3.44E+06	5.22E+04	2	RFOUT_A P	Pulse Width	1%	88
93	Kr	0	27	5.00E+06	5.35E+04	1	RFOUT_A P	Pulse Width	1%	50
94	Kr	0	27	5.00E+06	5.45E+04	2	RFOUT_A P	Pulse Width	1%	73
109	Co	0	16	5.00E+06	5.79E+04	1	RFOUT_A P	Pulse Width	1%	26
123	Ar	0	7.5	5.04E+06	5.46E+04	1	RFOUT_A P	Pulse Width	1%	1
9	Ne	0	2.76	5.00E+06	5.06E+04	1	RFOUT_A P	Pulse Width	1%	0

A Weibull fit using these events and fluences from [Table 7-10](#) can be viewed below.

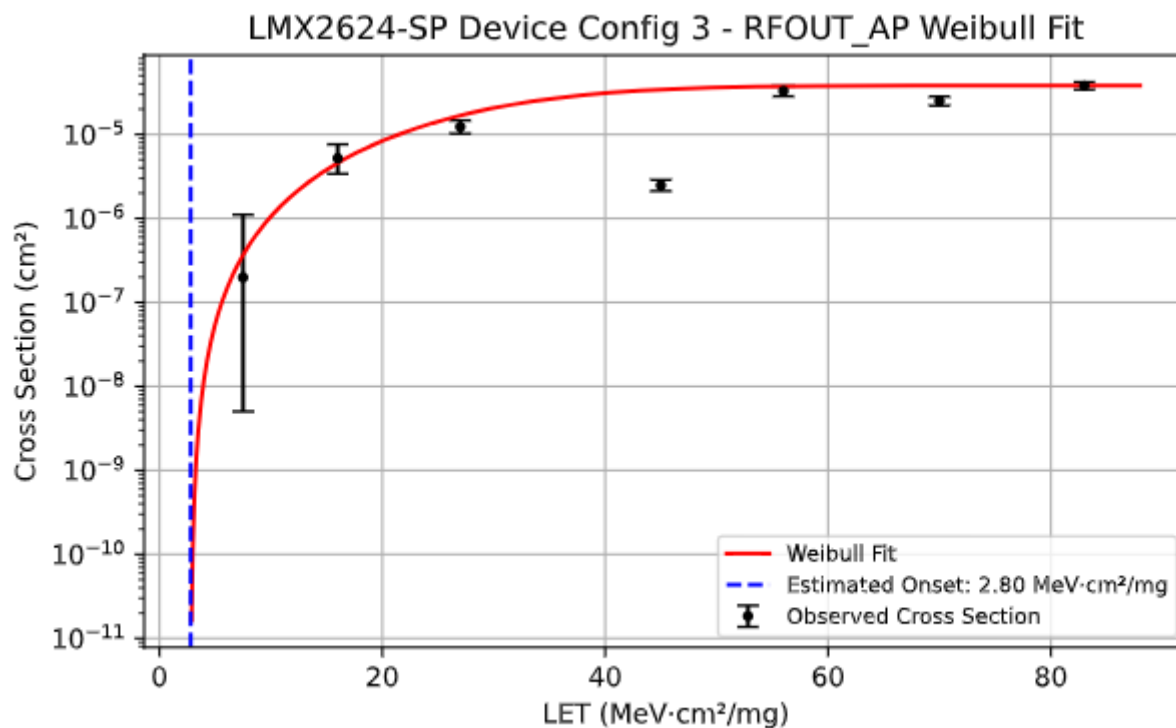


Figure 7-5. Weibull Fit for LMX2624-SP Device Configuration 3 - RFOUT_AP Output

Table 7-11. Weibull Fit Parameters for LMX2624-SP Device Configuration 3 - RFOUT_AP output

Parameters	Values
Cross Section (cm ²)	3.79×10^{-5}
Onset (MeV×cm ² /mg)	2.80

Table 7-11. Weibull Fit Parameters for LMX2624-SP Device Configuration 3 - RFOUT_AP output (continued)

Parameters	Values
W (MeV×cm ² /mg)	30.00
S	2.50

7.3 Single Event Transients (SET) - Device Configuration 4

For $V_{CC} = 3.3V$ (Nominal) 1 unit was characterized from 83MeV down to 2.76MeV. ²⁰Ne was used to obtain LET_{EFF} of 2.76MeV×cm²/mg. ⁴⁰Ar was used to obtain LET_{EFF} of 7.5MeV×cm²/mg. ⁵⁹Co was used to obtain LET_{EFF} of 16MeV×cm²/mg. ⁸⁴Kr was used to obtain LET_{EFF} of 27MeV×cm²/mg. ¹⁰⁹Ag was used to obtain LET_{EFF} of 45MeV×cm²/mg. ¹²⁹Xe was used to obtain LET_{EFF} of 56MeV×cm²/mg. ¹⁶⁹Tm was used to obtain LET_{EFF} of 70MeV×cm²/mg. ¹⁹⁷Au was used to obtain LET_{EFF} of 83MeV×cm²/mg. In this device configuration, the output frequency for RFOUT_AP = 13.5GHz and RFOUT_BP = 52.7MHz. Due to RFOUT_AP's high frequency, only RFOUT_BP is characterized below. The Tektronix MSO68B oscilloscope was used to monitor RFOUT_AP and RFOUT_BP signals of the LMX2624-SP with the respective signal triggering off a 1% window. A trigger of 19ns was used for RFOUT_BP outputs in this section. Due to oscilloscope bandwidth, only RFOUT_BP will be characterized in this section. [Table 7-12](#) summarizes the events seen in this mode on RFOUT_BP.

Table 7-12. Summary of LMX2624-SP in Device Configuration 4 - RFOUT_BP Output

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
16	Au	0	83	5.03E+06	4.23E+04	1	RFOUT_BP	Pulse Width	1%	118
17	Au	0	83	5.02E+06	4.01E+04	2	RFOUT_BP	Pulse Width	1%	149
48	Tm	0	70	5.02E+06	5.28E+04	1	RFOUT_BP	Pulse Width	1%	84
49	Tm	0	70	5.03E+06	5.44E+04	2	RFOUT_BP	Pulse Width	1%	105
67	Xe	0	56	5.02E+06	4.20E+04	1	RFOUT_BP	Pulse Width	1%	99
68	Xe	0	56	5.04E+06	5.14E+04	2	RFOUT_BP	Pulse Width	1%	94
84	Ag	0	45	5.01E+06	5.05E+04	1	RFOUT_BP	Pulse Width	1%	80
85	Ag	0	45	5.03E+06	5.27E+04	2	RFOUT_BP	Pulse Width	1%	86
97	Kr	0	27	5.05E+06	5.41E+04	1	RFOUT_BP	Pulse Width	1%	55
98	Kr	0	27	5.00E+06	6.06E+04	2	RFOUT_BP	Pulse Width	1%	45
114	Co	0	16	5.06E+06	5.91E+04	1	RFOUT_BP	Pulse Width	1%	18
126	Ar	0	7.5	5.05E+06	5.50E+04	1	RFOUT_BP	Pulse Width	1%	1
10	Ne	0	2.76	5.00E+06	5.03E+04	1	RFOUT_BP	Pulse Width	1%	0

A Weibull fit was constructed using the events and fluences from [Table 7-12](#). This can be located below

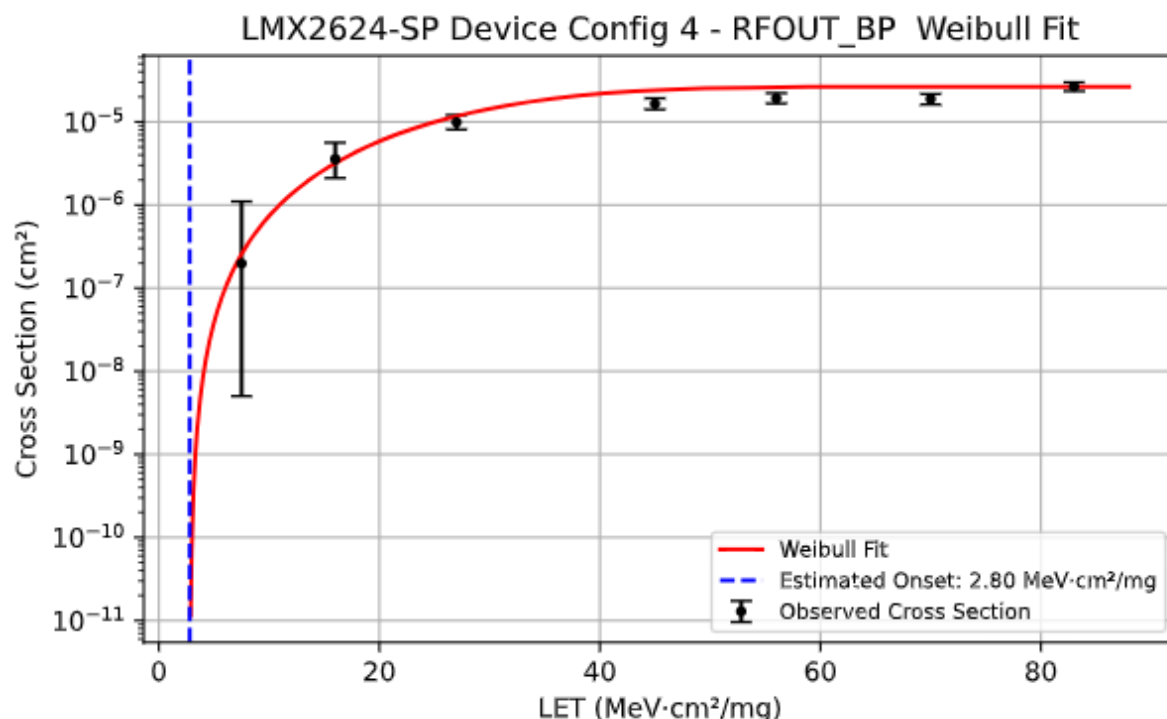


Figure 7-6. Weibull Fit for LMX2624-SP Device Configuration 4 - RFOUT_BP Output

Table 7-13. Weibull Fit Parameters for LMX2624-SP Device Configuration 4 - RFOUT_BP output

Parameters	Values
Cross Section (cm ²)	2.65 x 10 ⁻⁵
Onset (MeV·cm ² /mg)	2.80
W (MeV·cm ² /mg)	30.00
S	2.50

Single Event Transients (SET) - Device Configuration 5

For $V_{CC} = 3.3V$ (Nominal) 1 unit was characterized from 83MeV down to 2.76MeV. ^{20}Ne was used to obtain LET_{EFF} of 2.76MeV×cm²/mg. ^{40}Ar was used to obtain LET_{EFF} of 7.5 MeV×cm²/mg. ^{59}Co was used to obtain LET_{EFF} of 16MeV×cm²/mg. ^{84}Kr was used to obtain LET_{EFF} of 27MeV×cm²/mg. ^{109}Ag was used to obtain LET_{EFF} of 45MeV×cm²/mg. ^{129}Xe was used to obtain LET_{EFF} of 56MeV×cm²/mg. ^{169}Tm was used to obtain LET_{EFF} of 70MeV×cm²/mg. ^{197}Au was used to obtain LET_{EFF} of 83MeV×cm²/mg. In this device configuration, the output frequency for RFOUT_AP = 23GHz and RFOUT_BP = 119.8MHz. Due to RFOUT_AP's high frequency, only RFOUT_BP is characterized below. The Tektronix MSO68B oscilloscope was used to monitor RFOUT_AP and RFOUT_BP signals of the LMX2624-SP with the respective signal triggering off a 1% window. A trigger of 8.5ns was used for RFOUT_BP outputs in this section. Due to oscilloscope bandwidth, only RFOUT_BP will be characterized in this section.. [Table 7-14](#) summarizes the events seen in this mode on RFOUT_BP.

Table 7-14. Summary of LMX2624-SP in Device Configuration 5 - RFOUT_BP Output

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
15	Au	0	83	5.02E+06	4.25E+04	1	RFOUT_BP	Pulse Width	1%	185
14	Au	0	83	5.04E+06	4.50E+04	2	RFOUT_BP	Pulse Width	1%	209

Table 7-14. Summary of LMX2624-SP in Device Configuration 5 - RFOUT_BP Output (continued)

Run Number on Beam	Ion	Angle	Eff LET	Fluence	Flux	Run	RF Output	Trigger Type	Trigger Details (+/-)	Events
45	Tm	0	70	4.93E+06	5.53E+04	1	RFOUT_BP	Pulse Width	1%	133
46	Tm	0	70	4.24E+06	5.36E+04	2	RFOUT_BP	Pulse Width	1%	134
65	Xe	0	56	2.27E+06	4.70E+04	1	RFOUT_BP	Pulse Width	1%	94
66	Xe	0	56	2.39E+06	4.65E+04	2	RFOUT_BP	Pulse Width	1%	96
82	Ag	0	45	5.00E+06	5.31E+04	1	RFOUT_BP	Pulse Width	1%	80
83	Ag	0	45	5.03E+06	5.11E+04	2	RFOUT_BP	Pulse Width	1%	96
96	Kr	0	27	5.00E+06	5.73E+04	1	RFOUT_BP	Pulse Width	1%	51
96	Kr	0	27	5.04E+06	5.79E+04	2	RFOUT_BP	Pulse Width	1%	54
113	Co	0	16	5.03E+06	5.74E+04	1	RFOUT_BP	Pulse Width	1%	27
124	Ar	0	7.5	5.01E+06	5.44E+04	1	RFOUT_BP	Pulse Width	1%	2
11	Ne	0	2.76	5.00E+06	5.01E+04	1	RFOUT_BP	Pulse Width	1%	0

A Weibull fit was constructed using the events and fluences from [Table 7-12](#). This can be located below

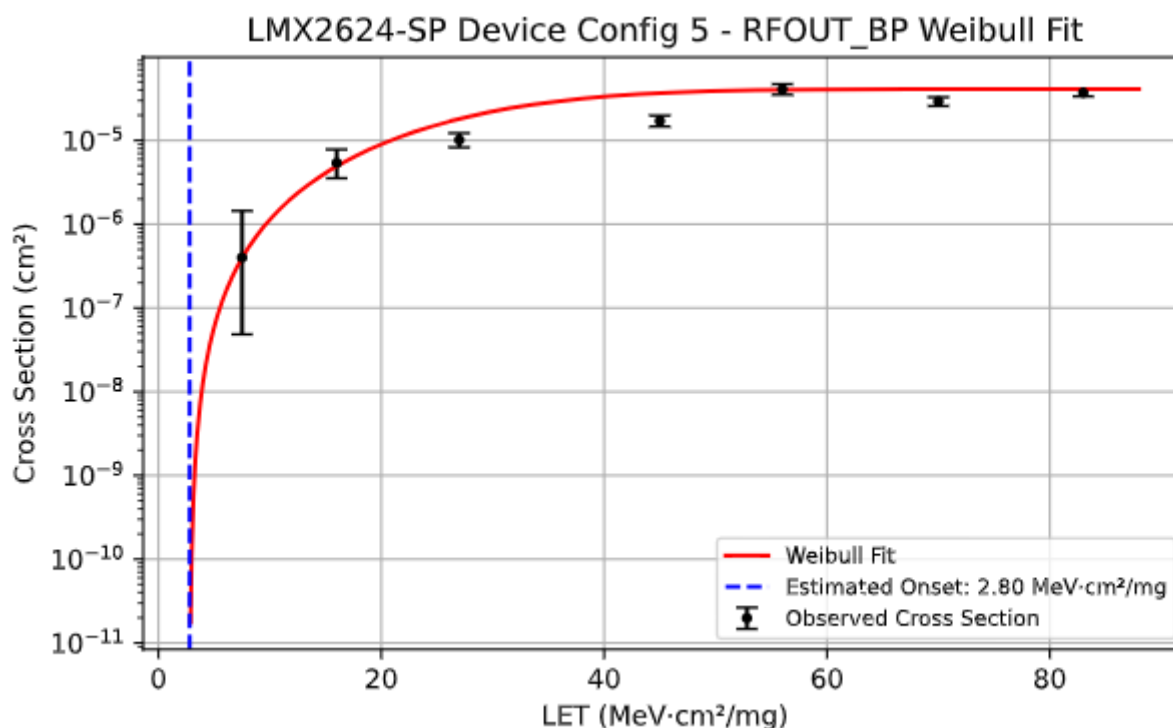


Table 7-15. Weibull Fit Parameters for LMX2624-SP Device Configuration 5 - RFOUT_BP Output

Parameters	Values
Cross Section (cm ²)	4.08×10^{-5}
Onset (MeV×cm ² /mg)	2.50
W (MeV×cm ² /mg)	30.00
S	2.50

8 Single Event Upsets Signature

In this section, the signatures of single event upsets seen are described. During testing throughout all beam energies, the signatures of SEUs were constant.. These Single Event Upsets Signatures are slightly different, depending on the device configuration. The device configurations tested are below along with Single Event profiles and distributions of event occurring, while under radiation.

Single Event Upset Signature - Device Configuration 1

During Device Configuration 1, both outputs RFOUT_AP and RFOUT_BP we captured and analyzed. The waveforms and analysis presented during this section are Runs #21 and #24 from [Table 7-2](#) and [Table 7-3](#) respectively. [Figure 8-1](#) shows an example event from RFOUT_AP and [Figure 8-2](#) shows an example event from RFOUT_BP during testing.

For RFOUT_AP Output, [Figure 8-3](#) show the duration of each event 4 Run#21. [Figure 8-4](#) shows when each event caused the scope to trigger during Run #21. This was a collection during the full fluence of the beam run, run #21 lasted for 64 seconds.

For RFOUT_BP Output, [Figure 8-5](#) shows the duration of each event during Run #24. [Figure 8-6](#) shows when each event caused the scope to trigger during Run #24. This was a collection during the full fluence of the beam run, run #24 lasted for 115 seconds.

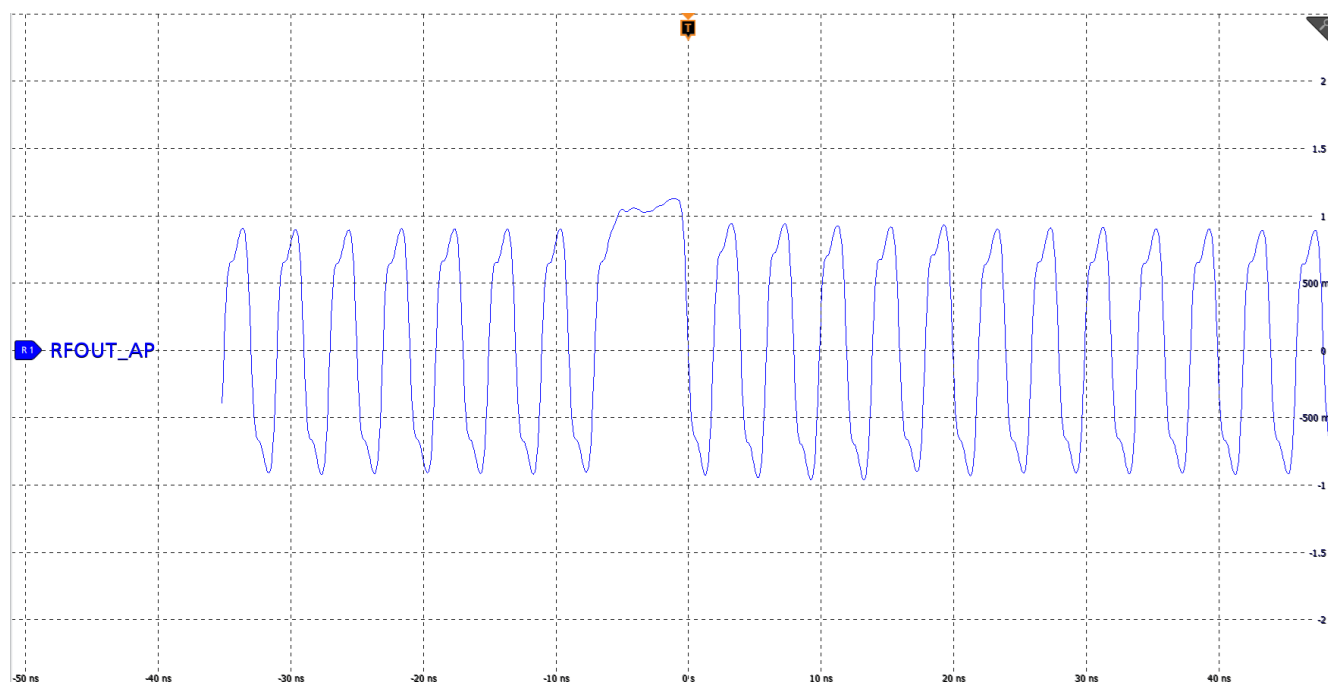


Figure 8-1. Single Event Upset Signature - Device Configuration 1 - RFOUT_AP Output

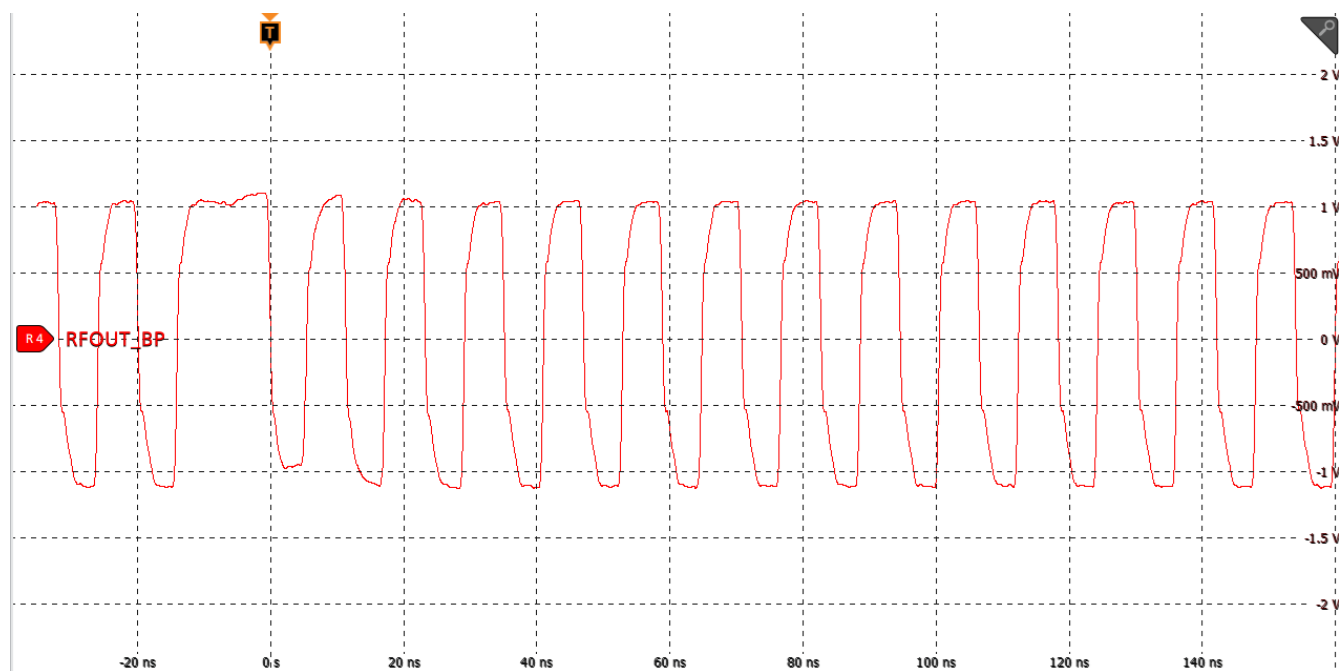


Figure 8-2. Single Event Upset Signature - Device Configuration 1 - RFOUT_BP Output

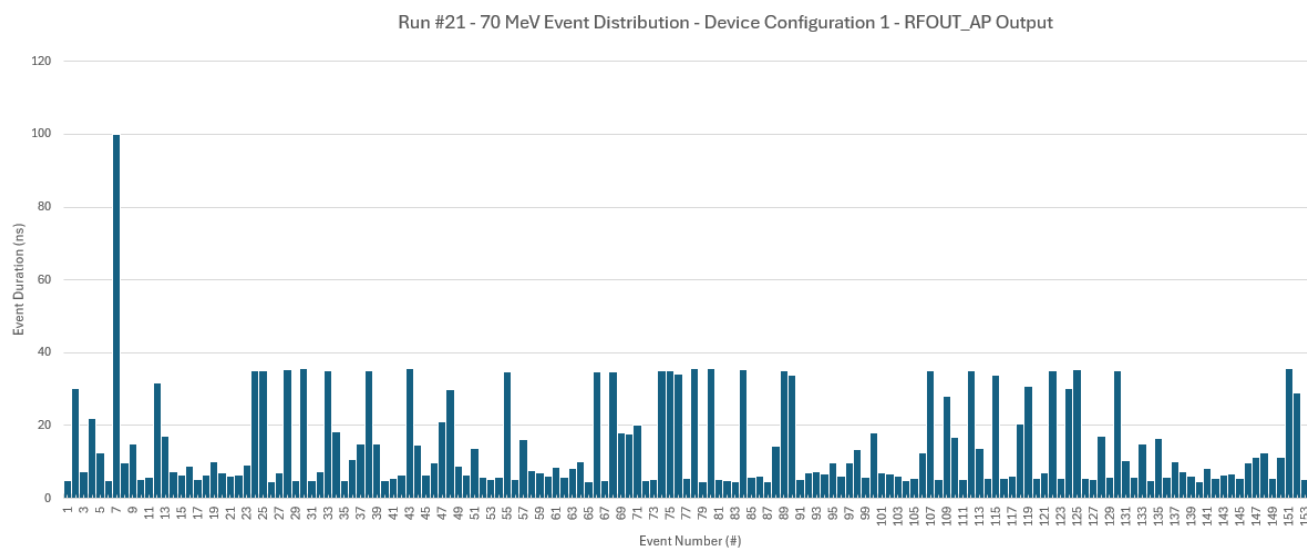


Figure 8-3. Run #21 Event Distribution - RFOUT_AP Output

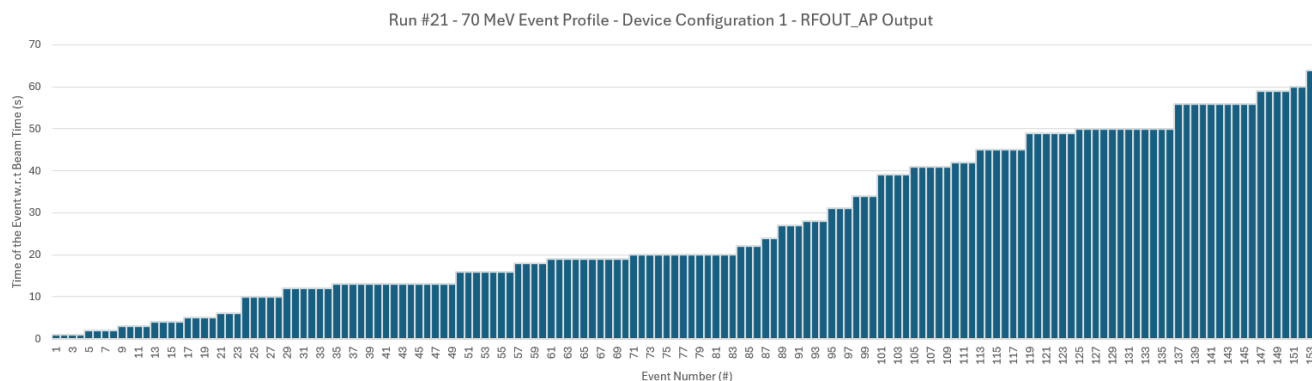


Figure 8-4. Run #21 Event Profile - RFOUT_AP Output

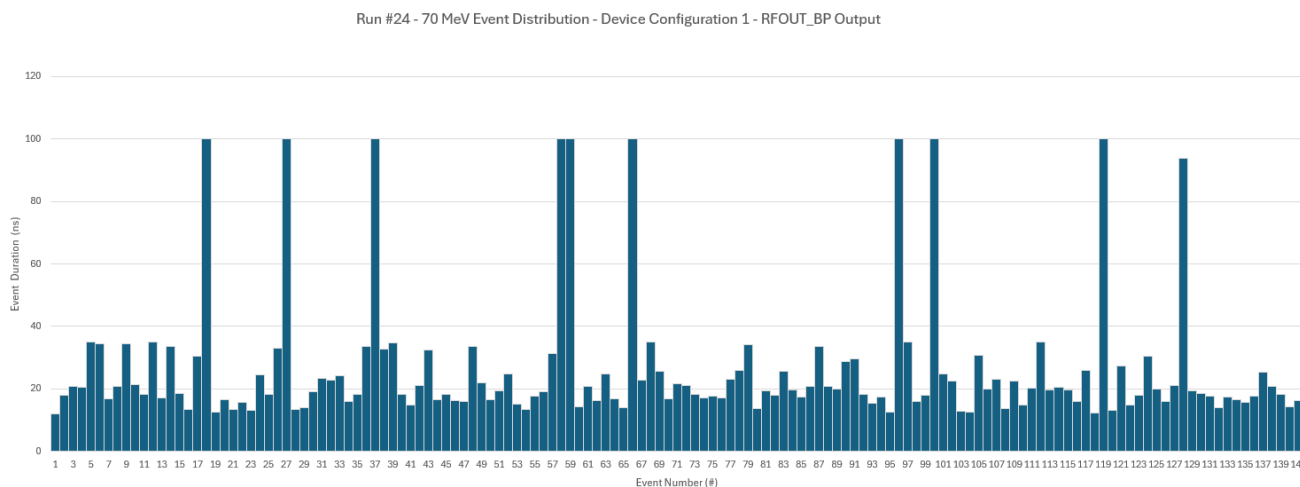


Figure 8-5. Run #24 Event Distribution - RFOUT_BP Output

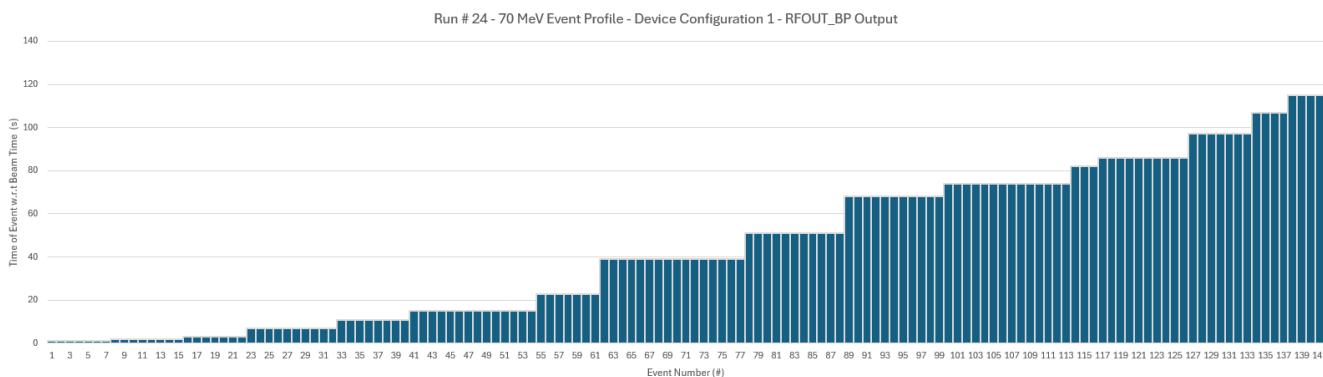


Figure 8-6. Run #24 Event Profile - RFOUT_BP Output

Single Event Upset Signature - Device Configuration 2

During Device Configuration 2, both outputs RFOUT_AP and RFOUT_BP we captured and analyzed. The waveforms and analysis presented during this section are Runs #36 and #40 from [Table 7-6](#) and [Table 7-7](#) respectively. [Figure 8-7](#) shows an example event from RFOUT_AP and [Figure 8-8](#) shows an example of events from RFOUT_BP outputs during testing.

For RFOUT_AP Output, [Figure 8-9](#) show the duration of each event for Run#36. [Figure 8-10](#) shows when each event caused the scope to trigger during Run #36. This was a collection during the full fluence of the beam run, run #36 lasted for 22 seconds.

For RFOUT_BP Output, [Figure 8-11](#) shows the duration of each event during Run #40. [Figure 8-12](#) shows when each event caused the scope to trigger during Run #40. This was a collection during the full fluence of the beam run, run #40 lasted for 65 seconds.

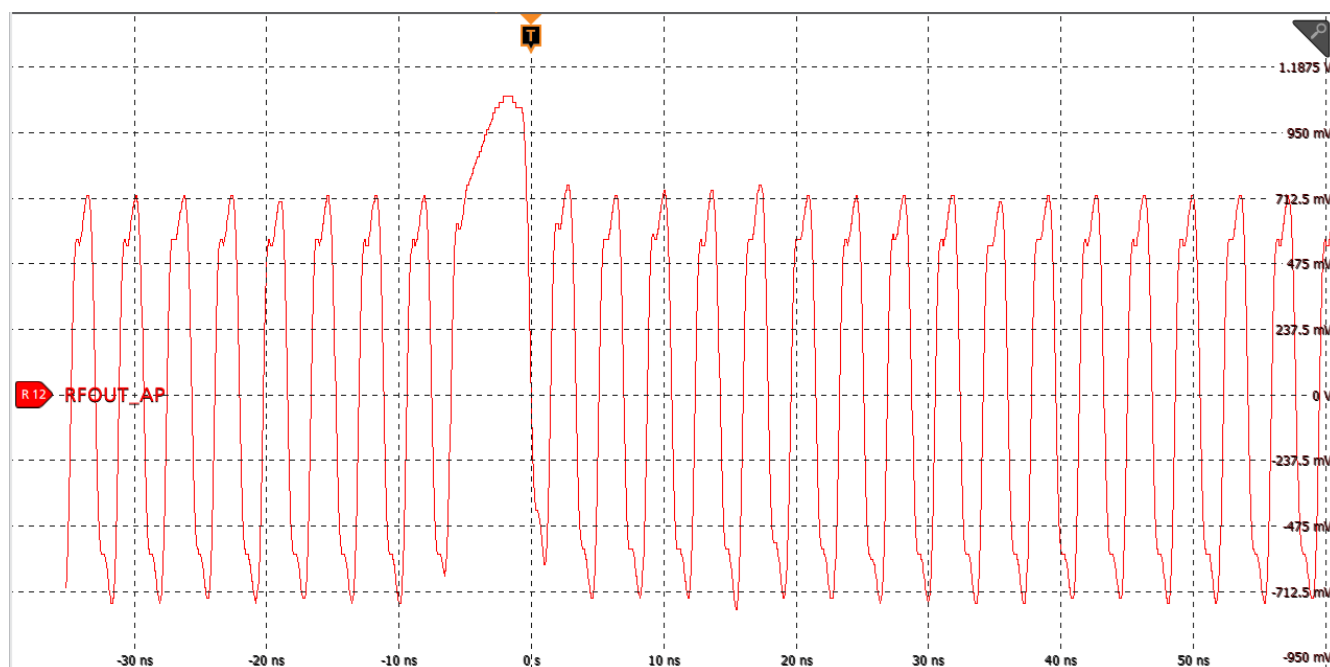


Figure 8-7. Single Event Upset Signature - Device Configuration 2 - RFOUT_AP Output

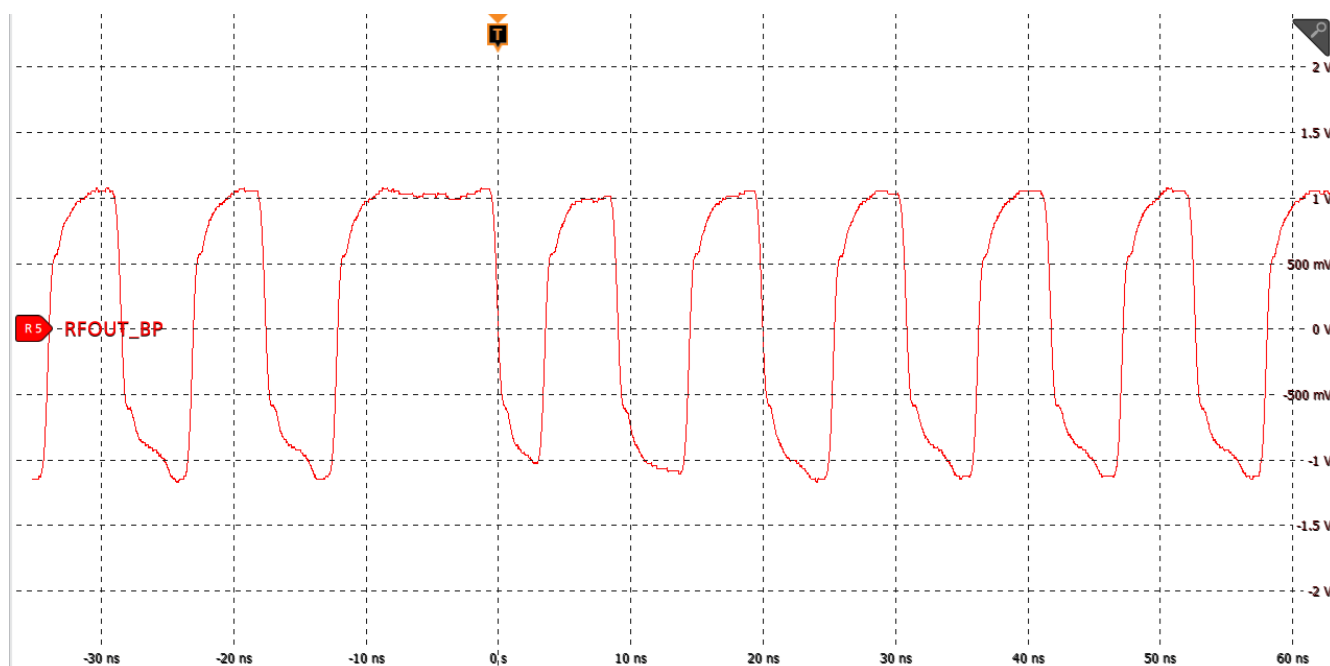


Figure 8-8. Single Event Upset Signature - Device Configuration 2 - RFOUT_BP Output

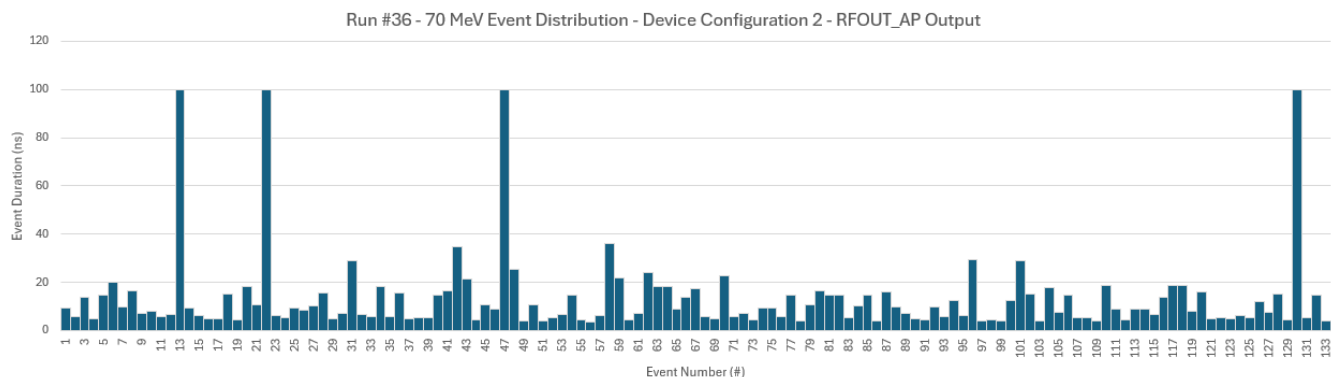


Figure 8-9. Run #36 Event Distribution - RFOUT_AP Output

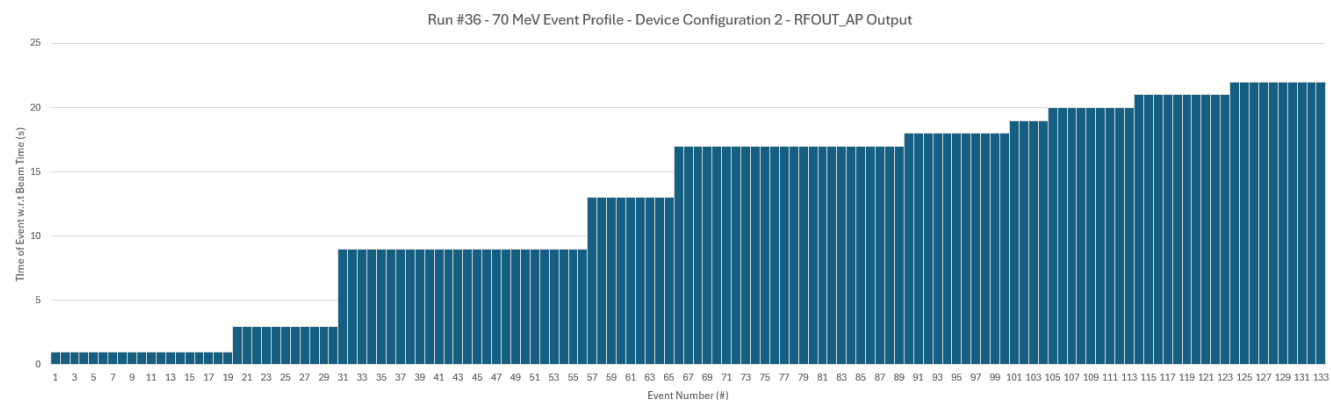


Figure 8-10. Run #36 Event Profile - RFOUT_AP Output

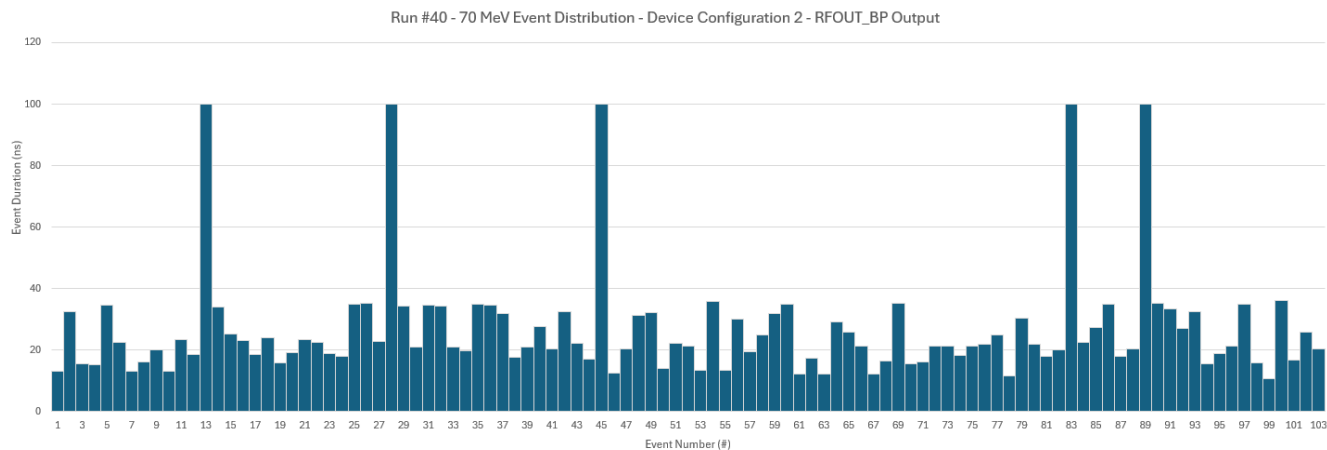


Figure 8-11. Run #40 Event Distribution - RFOUT_BP Output

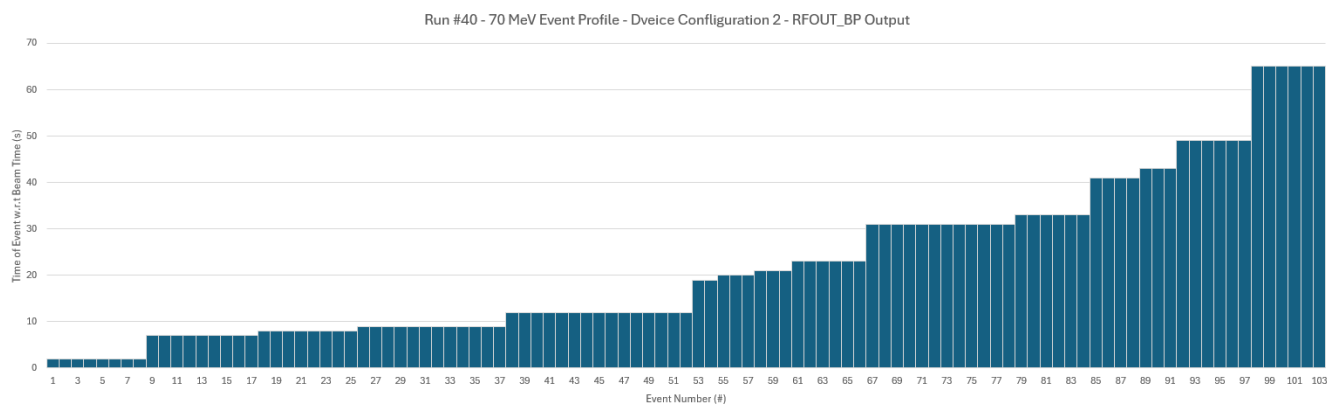


Figure 8-12. Run #40 Event Profile - RFOUT_BP Output

9 Single Event Functional Interrupt (SEFI)

During Single Event Latch Up (SEL) and Single Event Transient (SET) testing and characterization, LMX2624-SP device was continuously monitored for Single Event Functional Interrupt (SEFI). While LMX2624-SP device was testing under radiation, there was no evidence that a SEFI occurred. It can be concluded that LMX2624-SP is SEFI free up to $83 \text{ MeV} \times \text{cm}^2 / \text{mg}$.

Summary

The purpose of this study was to characterize the effect of heavy-ion irradiation on the single-event effect (SEE) performance of the LMX2624-SP high performance wideband phase-locked loop (PLL) with integrated voltage controlled oscillator (VCO) and voltage regulator. Heavy-ions with $\text{LET}_{\text{EFF}} = 2.76$ to $83 \text{ MeV} \times \text{cm}^2 / \text{mg}$ were used for the SEE characterization campaign. Flux of $\approx 10^4$ to 10^5 ions/ cm^2/s and fluences of $\approx 10^6$ to 10^7 ions/ cm^2 per run were used for the characterization. The SEE results demonstrated that the LMX2624-SP is free of destructive SEL $\text{LET}_{\text{EFF}} = 83 \text{ MeV} \times \text{cm}^2 / \text{mg}$ and across the full electrical specifications. Transients at $\text{LET}_{\text{EFF}} = 2.76$ to $75 \text{ MeV} \times \text{cm}^2 / \text{mg}$ on RFOUT_AP and RFOUT_BP are presented and discussed. LMX2624-SP is SEFI up to $83 \text{ MeV} \times \text{cm}^2 / \text{mg}$.

10 References

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