Radiation Report

LMX1906-SP Single-Event Effects Report

ABSTRACT

The LMX1906-SP (5962R2320201PXE) was tested under heavy ions at a linear energy transfer (LET) up to 88.9MeV-cm^2 / mg and monitored for various Single-Event Effects (SEE). No incidences of Single-Event Latchup (SEL) were detected. SEL testing was performed at the highest operating voltage (2.6V) and temperature (125°C). No incidences of Single-Event Functional Interrupt (SEFI) were detected. Single-Event Upsets (SEU) were characterized.

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1 Product Description

The LMX1906-SP[1] is a radiation hardened low noise, high frequency JESD buffer, multiplier or divider. LMX1906-SP is the generic part number (GPN) for the product. The flight grade orderable part number is 5962R2320201PXE[2]. A prototype, which does not receive full space grade processing and testing, LMX1906PAP/EM, can be ordered for engineering evaluation. The flight grade part is available in a HTQFP package and is qualified per the QML-P flow of MIL-PRF-38535.

A block diagram of the LMX1906-SP is shown in Figure 1-1. Each of the four high frequency clock outputs and additional LOGICLK output with a wider divider range, is paired with a SYSREF output clock signal. The SYSREF signal for JESD interfaces can either be internally generated or passed in as an input and re-clocked to the device clocks. The main clock outputs are all the same frequency. This frequency can be the same, divided, or multiplied relative to the input clock. Each of these clock outputs has programmable power level. The LOGICLK output frequency is independent and typically lower frequency than the other four main clocks and has programmable output format (CML, LVDS, LVPECL) and power level. The part has a state machine clock (SMCLK) that needs to be enabled during operation.

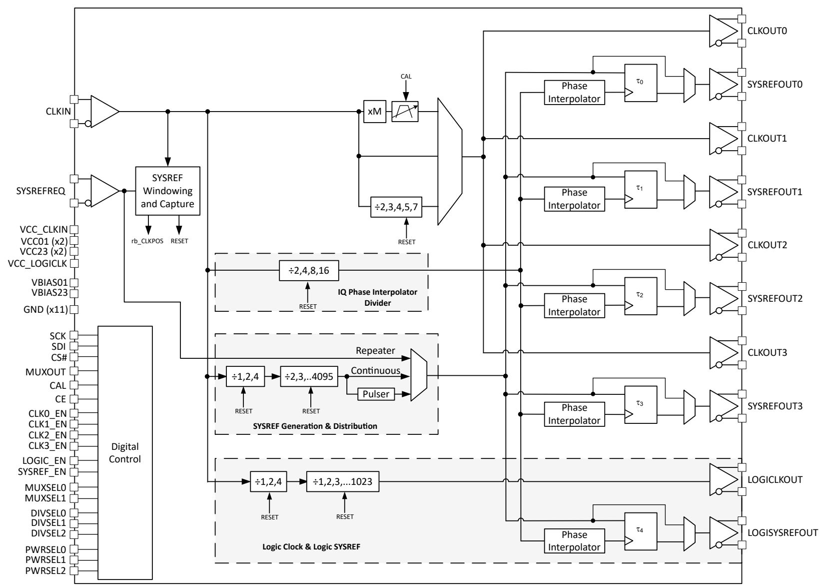

Figure 1-1. LMX1906-SP Block Diagram

The LMX1906-SP can be configured with control pins with a limited number of configuration options. The part can also be programmed through a Serial Peripheral Interface (SPI) with an expanded range of configuration options. In SPI mode, the programmed configuration is held in registers which can be read out.

The operating voltage of the LMX1906-SP is 2.4 to 2.6V.

The LMX1906-SP is manufactured on a TI BiCMOS process with SiGe npn bipolar transistors.

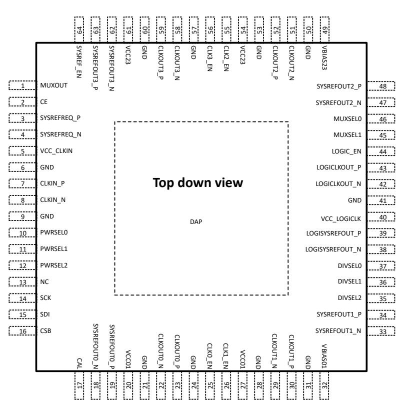

Figure 1-2. LMX1906-SP Pinout

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2 Test Setup

The LMX1906-SP was monitored for Single-Event Latchup (SEL), Single-Event Functional Interrupt (SEFI) and Single-Event Upset (SEU).

2.1 Test Board

The device under test (DUT) was soldered to a custom evaluation board similar to the LMX1906EVM evaluation board (Figure 2-1)([3]). The DUT was delidded by a chemical process to expose the die surface to the ion beam.

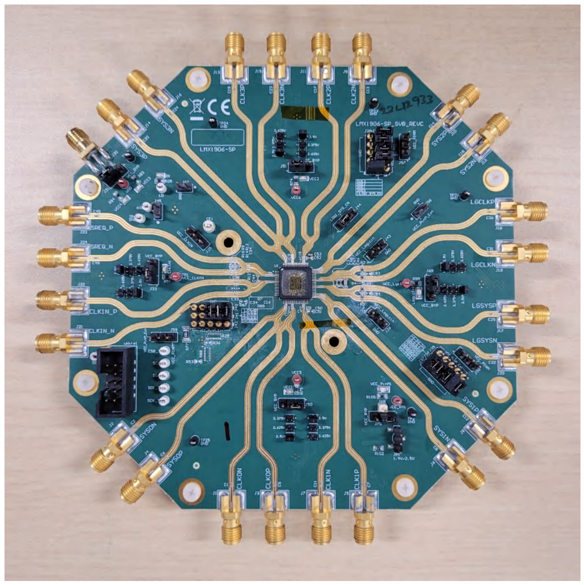

Figure 2-1. LMX1906 Custom Evaluation Board

During all testing, the current to DUT was supplied and monitored by a NI-PXIe controller using a custom Lab View® GUI (PXI Rad Test) developed by Texas Instruments for SEE testing. The current from each supply is recorded every second. The voltage was set to 2.6V as measured at the DUT board.

Depending upon the test facility, a 384.4 or 400MHz signal was supplied to the CKLIN input using a Rohde & Schwarz® signal generator when the DUT was tested in repeater mode. When the DUT was tested in divider mode, the input frequency was set at 768MHz. Two to three outputs were monitored with an oscilloscope during all ion runs. The scope trigger was set on width mode so that if the falling edge of the output clock was outside the expected time window, an error is counted and the clock output is captured, as shown in Figure 2-2. On different ion runs the different outputs (CLKOUT, SYSREFOUT and LOGICLKOUT) were used to trigger the scope.

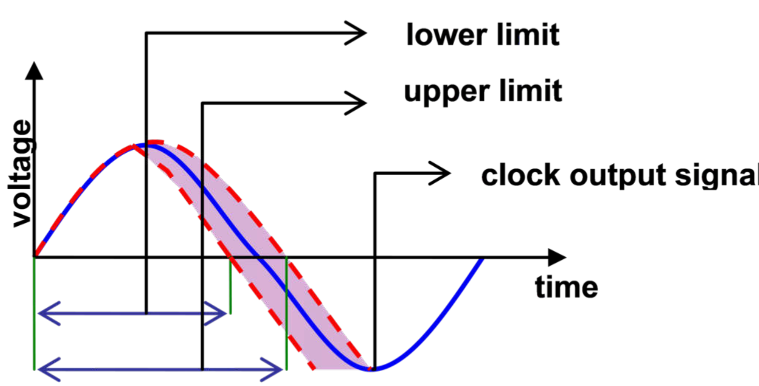

Figure 2-2. Window Trigger

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The registers were written and read back using Texas Instruments USB2ANY PC interface and TICS PRO software[3]. For most ion runs, the DUT was tested in divider mode, but a few ion runs were done with the DUT in divide by 2 mode. On most ion runs, the SYSREFOUT signal came from CLKIN and was divided down. On three ion runs, the SYSREFOUT signal came directly from the SYSREFREQ and was supplied by the 10MHz reference signal from the signal generator. On all ion runs, SMCLK_EN = 1.

2.2 Test Facility

Heavy ion irradiation was performed at the Texas A&M University Cyclotron Institute Radiation Effects Facility[4].using the 15AMeV cocktail and K500 beam line, at the Berkeley Accelerator Space Effects (BASE) Facility at the Lawrence Berkeley National Lab (LBNL)[5], using the 16AMeV cocktail with the DUT board in air and at the Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) FRIB Single Event Effects (FSEE) Facility[6]. At MSU the ion energy was dependent upon the ion.

A different DUT and DUT board was tested at each facility.

3 Results

3.1 SEL Results

No incidences of SEL were detected during the testing on any ion runs. At each facility ion runs were done with the DUT at 125°C and the supply voltage at 2.6V. The logged current changes were under 0.5mA. The results are summarized in Table 3-1.

At TAMU, a quad power supply was used to individually supply the four different power inputs of the DUT, VCC_CLKIN, VCC_LOGIC, VCC01 and VCC23.

The DUT was heated with a heat gun to 125°C as read by the IR sensor set up at TAMU for two ion runs using the Ag ion for an LET of 88.9MeV-cm ^{2} / mg. The LET was calculated at the surface of the silicon using TI's RADSim software, which adjusts LET based on the thickness of the layers passivation and metal on top of the silicon surface. The surface assumes all material on the silicon is either oxide or aluminum.

Each ion run was taken to a fluence 1×10^{7} ions/cm ^{2} . For ion run 4, the DUT was in divide by 2 mode and for ion run 5 the DUT was in repeater (buffer) mode. The maximum current change seen from one data point to the next was under 0.3mA. The currents for are plotted in Figure 3-1and Figure 3-2.

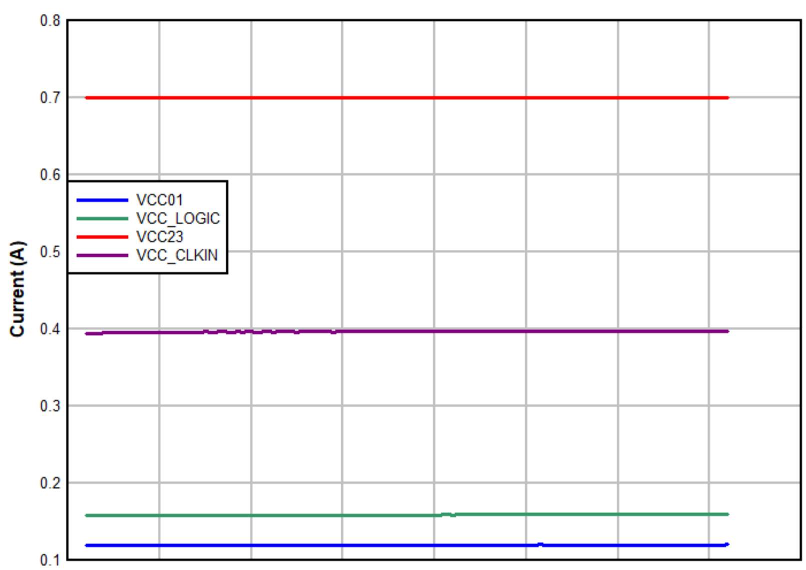

Figure 3-1. Supply Currents During Ion Run 4 in Divide by 2 Mode

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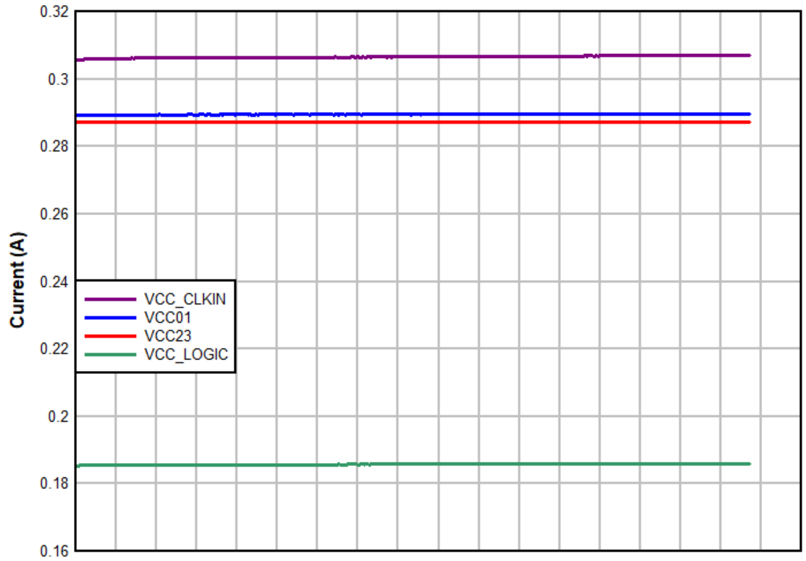

Figure 3-2. Supply Currents During Ion run 5 in Repeater Mode

At LNBL, a single power supply was used, connected to all the DUT power inputs. The DUT was heated to a junction temperature of 125°C using a hot air gun, and the DUT board temperature was monitored using a thermistor epoxied to the board. The LMX1906-SP has an on chip temperature diode that is accessed through a register read out using TICSPro software. The thermistor temperature was correlated to the chip temperature diode.

SEL testing was done with the Xe ion at a 44º incident angle for LETeff of 85MeV-cm^2/ mg. The effective linear energy transfer (LETeff) of each ion was calculated at the silicon surface of the die using the SEUSS GUI from Texas A&M University[(7)]. The calculations were based on the 2mil Mylar window used at LBNL and the metal and passivation stack above the silicon on the die. The LMX1906-SP has W through plugs. In calculating the metal stack, a 50% coverage of W was assumed.

The DUT was tested in repeater mode. No SEL (sudden current increase greater than 0.5mA) was detected to an effective fluence of 1x10^7 ions/cm^2.

At MSU, a single power supply was used, connected to all the DUT power inputs. The DUT was heated to a junction temperature greater than 125°C using a cool touch heat gun. The DUT junction temperature was monitored with the on chip temperature diode and monitored with the TICSPro software.

SEL testing was done with Tm ion with an energy of 20.3MeV/u. The LET at the surface of the die as provided by MSU was 75.0 MeV-cm^2 / mg. The DUT was at a 31° angle for an LETeff of 87MeV-cm^2 / mg. The LET provided by MSU is at the surface of the die and does not take in the effect of the metal and passivation stack on top of the silicon. The LETeff at the silicon surface is higher than reported.

The DUT was tested in repeater mode. No SEL (sudden current increase greater than 1mA) was detected to a fluence of 1 × 10^7 ions / cm^2 and an effective fluence of 8.5 × 10^6 ions / cm^2.

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Table 3-1. SEL Test Conditions and Results

DUT	DUT1	DUT1	DUT2	DUT3
Mode	Divide by 2	Repeater	Repeater	Repeater
Facility	TAMU	TAMU	LBNL	MSU
Ion	Au	Au	Xe	Tm
LET (MeV-cm2/mg)	88.9	88.9	59.1	75.0
Angle (degrees)	0	0	44	31
LETeff (MeV-cm^2/mg)	88.9	88.9	85.0	87.0
Fluence (ions/cm^2)	1×10^7	1×10^7	1.4×10^7	1×10^7
Eff Fluence (ions/cm^2)	1×10^7	1×10^7	1×10^7	8.5×10^6
SEL Detected	No	No	No	No

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3.2 SEFI Results

No incidences of SEFIs were seen on any ion run in divide by 2 or repeater mode.

Two or more outputs were monitored on every ion run. During an ion run the outputs can be momentarily upset from ion strike but they always recovered to the programmed frequency and power. The DUT operated properly after each ion run and the registers did not need to be rewritten.

In repeater mode, the CLKOUT always recovers in phase, while the SYSREFOUT can recover out of phase. In divider mode, CLKOUT can recover in phase or out of phase.

At MSU, the registers were readout before and after an ion run at 87MeV-cm^2/ mg taken to a fluence of 8.7 × 10^6 ions/cm^2 at room temperature. The register readings were compared using Beyond Compare software (Figure 3-3). None of the programmable registers changed during the ion run. Changes were seen on R11, R12 and R24. R24 is the temperature diode readout and small variations in the temperature can occur during an ion run, resulting in different register readings. R11 and R12 measure the delay between the CLKIN and SYSREF rising edges. Since SYSREF can sometimes recover out of phase from an ion strike, the value of these registers can change during an ion run.

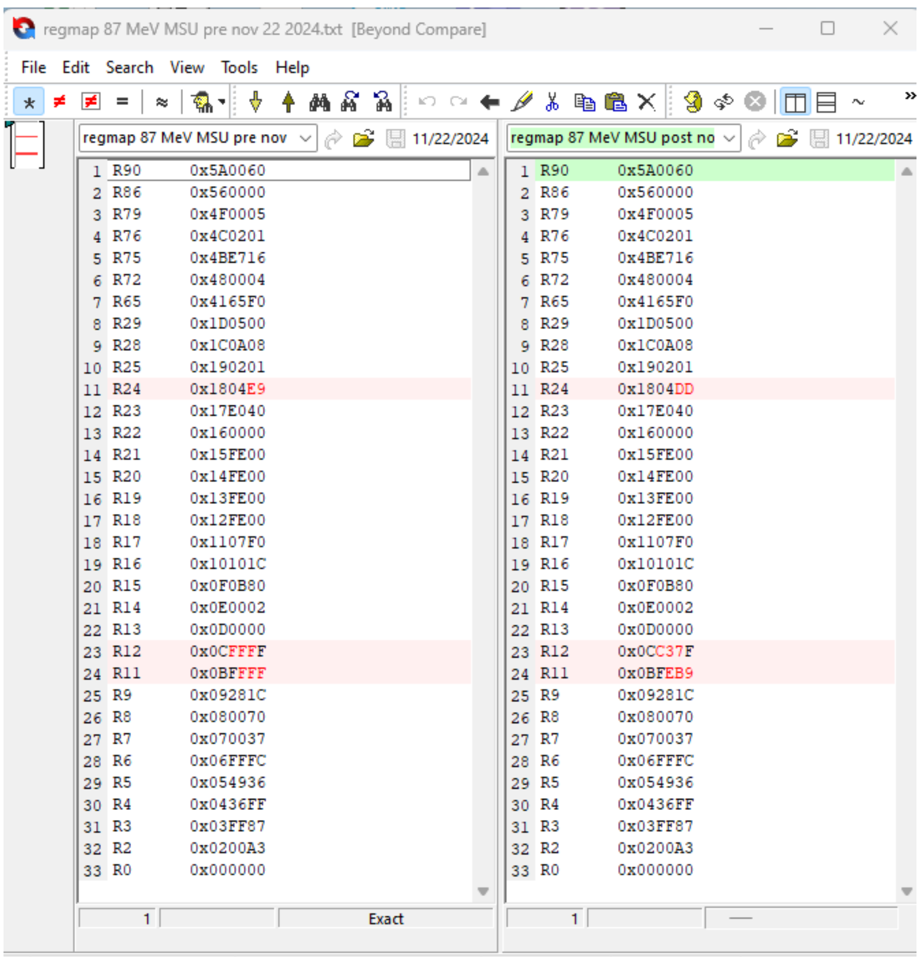

Figure 3-3. Screen Capture of Beyond Compare Comparing Registers Pre- and Post an Ion Run

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3.3 SEU Results

A summary of SEU results is shown in Table 3-2.

When CLKOUT was used to trigger the scope, two SEU signatures of the outputs were seen, one where the output can begin to recover within one or two clock cycles (Figure 3-4) and one where the event lasted multiple clock cycles (Figure 3-5). An SEU that occurred on multiple cycles can take up to 800ns to recover. When SYSREFOUT was used as the scope trigger, an additional SEU signature was seen where the SYSREFOUT pulse can broaden or shorten (Figure 3-6). When SYSREFOUT was used as the scope trigger, the SEUs that were captured can take as long as 22μs to recover. During a long event, all three outputs took the same amount of time to recover. Between 25% to 41% of the events were under 10ns, depending upon the output monitored. When an event was triggered on one channel, the other two channels can also be upset between 43% to 95% of the time as listed in Table 3-3.

In repeater mode, CLKOUT always recovered in phase with the output prior to the ion strike. In divider mode, the CLKOUT can recover out of phase on the long SEUs. When SYSREFOUT was divided down from the CLKIN signal, the SYSREFOUT output can sometimes recover out of phase.

Table 3-2. SEU Results

Trigger	Facility	Ion	LET	Angle	LETeff	Events	Fluence	Cross Section
			(MeV-cm^2/mg)	°	(MeV-cm^2/mg)	#	(ions/cm^2)	(cm^2)
Repeater Mode								
CLKOUT	LBNL	Ar	8.9	0	8.9	0	1×10^7	0
	LBNL	V	13.7	0	13.7	61	2×10^7	3.1×10^{-6}
	LBNL	Cu	22	0	22	61	1.0×10^7	6.1×10^{-6}
	LBNL	Kr	33.4	0	33.4	200	1.8×10^7	1.1×10^{-5}
	LBNL	Xe	59.1	0	59.1	100	3.9×10^6	2.5×10^{-5}
	TAMU	Au	88.9	0	87.0	208	3.4×10^6	6.0×10^{-5}
SYSREFOUT	MSU	Xe	50.5	0	50.5	300	4.2×10^6	7.2×10^{-5}
	LBNL	Xe	59.1	0	59.1	100	2.6×10^6	3.8×10^{-5}
	MSU	Tm	75	31	87	300	1.6×10^6	1.9×10^{-4}
	TAMU	Au	88.9	0	88.9	102	1.6×10^6	6.2×10^{-5}
LOGICCLKOUT	TAMU	Au	88.9	0	88.9	328	7.2×10^6	4.5×10^{-5}
Divider Mode								
CLKOUT	TAMU	Au	88.9	0	88.9	133	1.4×10^6	9.4×10^{-5}

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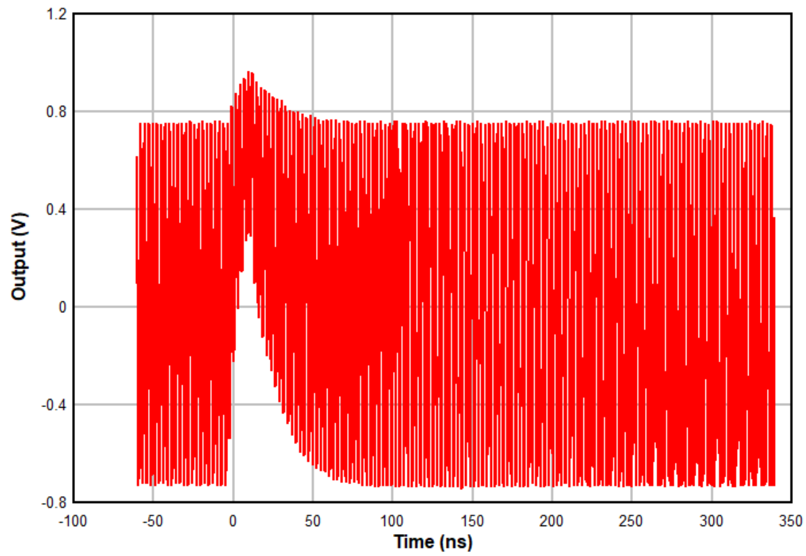

Figure 3-4. SEU on CLKOUT0 that Began to Recover in 10ns

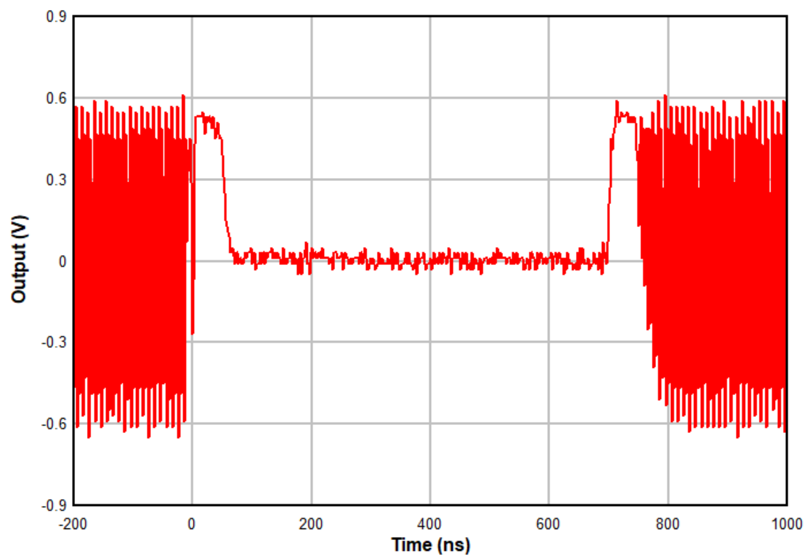

Figure 3-5. Long SEU on CLKOUT0

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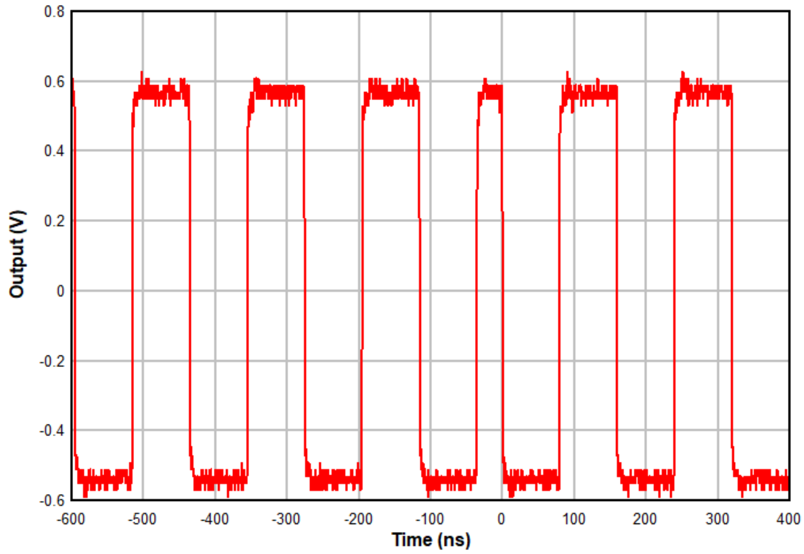

Figure 3-6. SEU on SYSREFOUT1 where the Pulse Shortened

At TAMU, a 384.4MHz signal was put on CLKIN. For most of the testing, the DUT was in repeater mode and configured so that CLKOUT and LOGICOUT was 384.4MHz and SYSREFOUT was 3MHz. CLKOUT0, SYSREFOUT1 and LOGICLKOUT outputs were monitored on every ion run. Three separate ion runs were done, with the oscilloscope set to trigger on one of the three monitored outputs. All testing was done at an LET of 88.9MeV-cm^2/ mg. The results are summarized in Table 3-3. The SEUs were categorized as those recovering in less than 10ns and those lasting longer than 10ns. For the testing at TAMU, the maximum length of an SEU was not determined because the scope window was not set wide enough to capture the whole event.

Table 3-3. Output SEUs at 88.9MeV-cm^2/ mg at TAMU

Ion Run	7	11	12
Trigger	CLKOUT0	LOGICLKOUT	SYSREFOUT1
Events (Number)	105	106	102
Fluence (ions/cm^2)	1.75×10^6	2.34×10^6	1.63×10^6
Cross Section (cm^2)	6.00×10^{-5}	4.53×10^{-5}	6.26×10^{-5}
Events < 10ns	26	50	42
% < 10ns	25%	47%	41%
Events on CLKOUT0 (#)		84	44
% of total events		79%	43%
Events on LOGICLKOUT (#)	100		59
% of total events	95%		58%
Events on SYSREFOUT1 (Number)	80	61	
% of total events	76%	58%	

Two ion runs at TAMU were done with the DUT in divider mode with the input at 768MHz and the CLKOUT output at 384 MHz. There were a total of 132 events at a total fluence of 1.41×10^6 ions / cm^2 for a cross section of 9.4×10^{-5} cm^2. As in repeater mode, there were events that recovered after a few clock cycles and events that lasted more than 500 ns. For testing in this mode, the scope window was not wide enough to determine the maximum length of an event. The output can recover 180° out of phase after some ion strikes (Figure 3-7).

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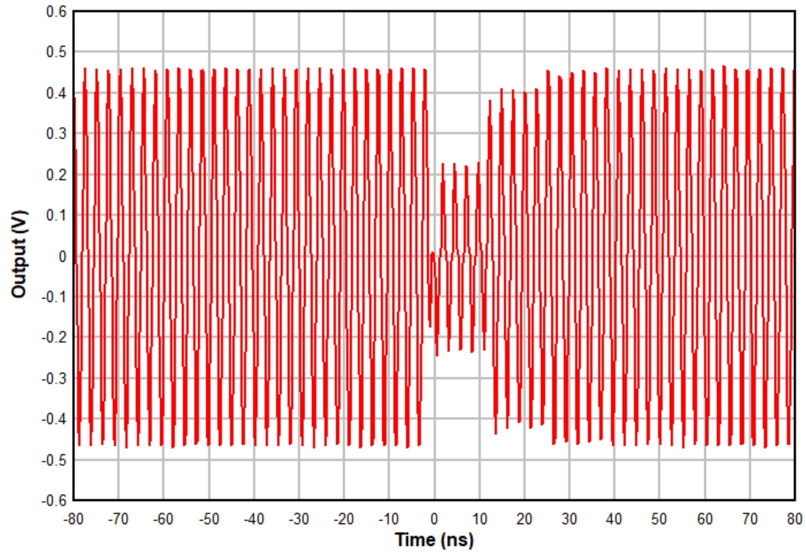

Figure 3-7. SEU in Divider Mode with CLKOUT0 Recovering 180° Out of Phase

At LNBL, all testing was done in repeater mode with input and CLKOUT at 400MHz. For most of the ion runs, the SYSREFOUT output was divided down from CLKIN and was 3.125MHz. For three ion runs, the SYSREFOUT output came directly from the SYSREFREQ input at 10MHz. Testing was done using several different ions (Table 3-2). For most of the ion runs, CLKOUT0 was used for the scope trigger.

No SEUs were detected during an ion run using Ar with an LET of 8.9MeV-cm ^{2} /mg to a fluence of 1x10^7 ions/cm ^{2} . SEUs were detected at the next highest LET tested, with V at 13.7MeV-cm^2/mg.

For one ion run with Ar (LET = 35MeV-cm^2/mg) the scope window was expanded so that maximum amount time for an SEU to recover can be determined. Several SEUs took between 780 to 790ns to recover (Figure 3-5).

When the SYSREF signal was supplied by SYSREFREQ and there was a long SEU on CLKOUT SYSREFOUT can also have a corresponding long SEU (Figure 3-8). For short SEUs on CLKOUT, SYSREROUT was not disturbed (Figure 3-9). SYSREFOUT always recovered in phase.

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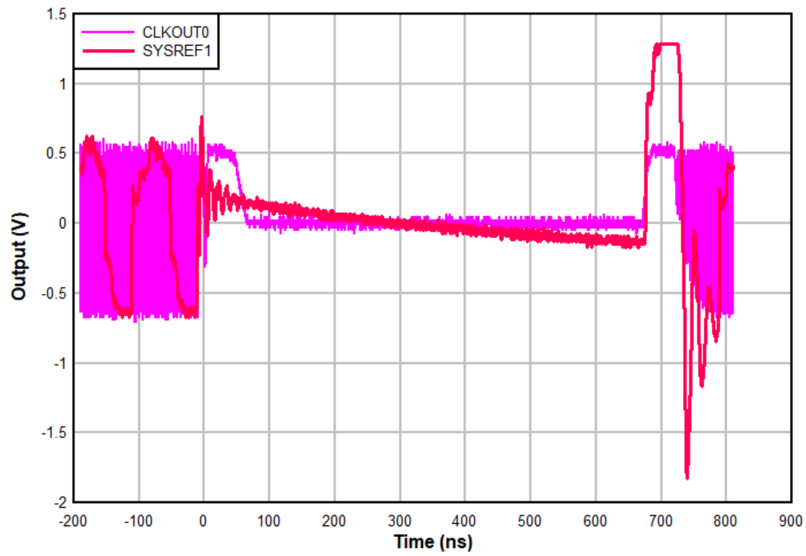

Figure 3-8. Long SEU with SYSREF Supplied Directly from SYSREFREQ

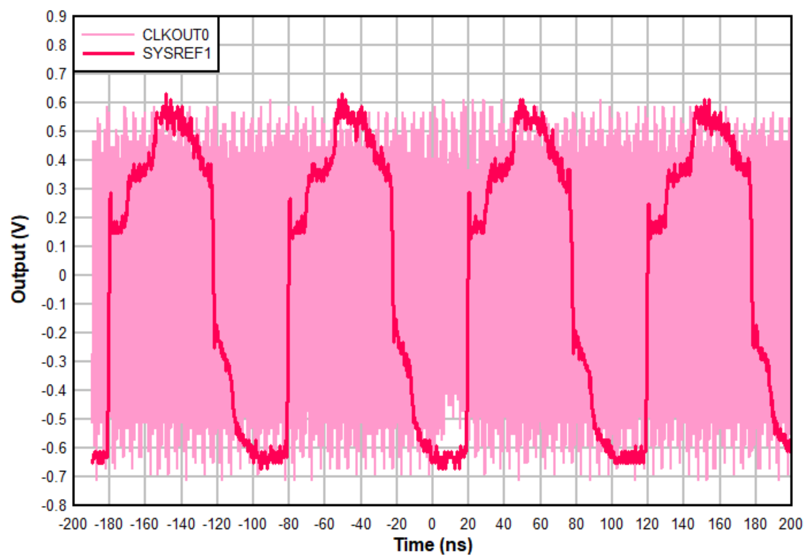

Figure 3-9. Short SEU with SYSREF supplied directly from SYSREFREQ

At MSU, all testing was done in repeater mode with input and CLKOUT at 400MHz and SYSREF divided down from CLKIN to 3.125 MHz. Only the SYSREF1 output was monitored as the scope at the facility did not have the bandwidth to capture the 400 MHz signals. Testing was done with Tm with an energy of 20.3MeV at an angle of 31° for an LETeff of 87MeV-cm^2/mg at the surface of the die and Xe with an energy of 18.4MeV for an LET of 50.5MeV-cm^2/ mg at the surface of the die. The LET is provided by MSU and is at the surface at the die and not the surface of the silicon. When accounting for the metal and passivation layers on top of the silicon, the actual LET at the surface of the die is higher. Three ion runs were done at each LET, capturing 100 events at each run.

On one run at 50.5MeV-cm^2 / mg, the scope window was expanded so that the maximum amount of time for SYSREF to recover is determined. Several SEUs took between 20 and 22µs to recover (Figure 3-10).

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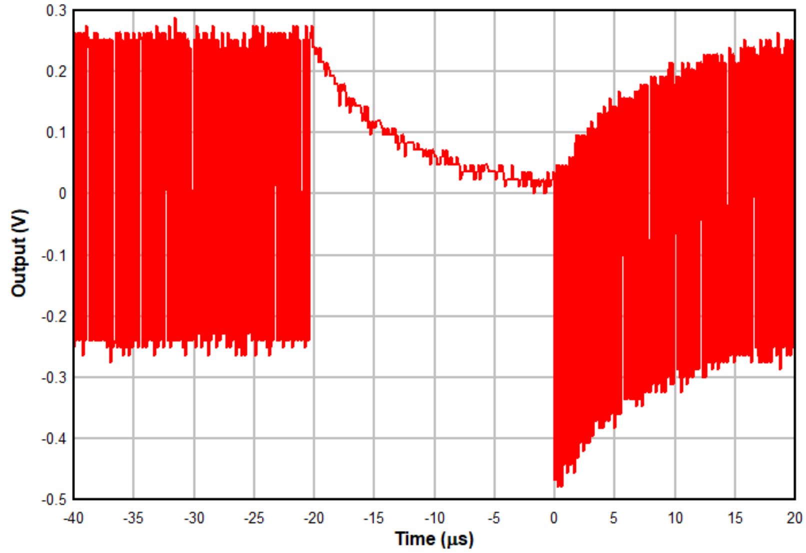

Figure 3-10. Long SYSREFOUT SEU

The SEU cross sections versus LETeff are plotted in Figure 3-11, Figure 3-12 and Figure 3-13. Two sigma error bars, representing a confidence level of approximately 95%[8] , are plotted around each data point. In Figure 3-11, a Weibull plot was fitted to the CLKOUT data. The Weibull fit parameters are listed in Table 3-4.

$$F(L) = A\left(1 - EXP\left\{-\left[{L - Lo}/{W}\right]^{s}\right\}\right); L > Lo \quad (1)$$

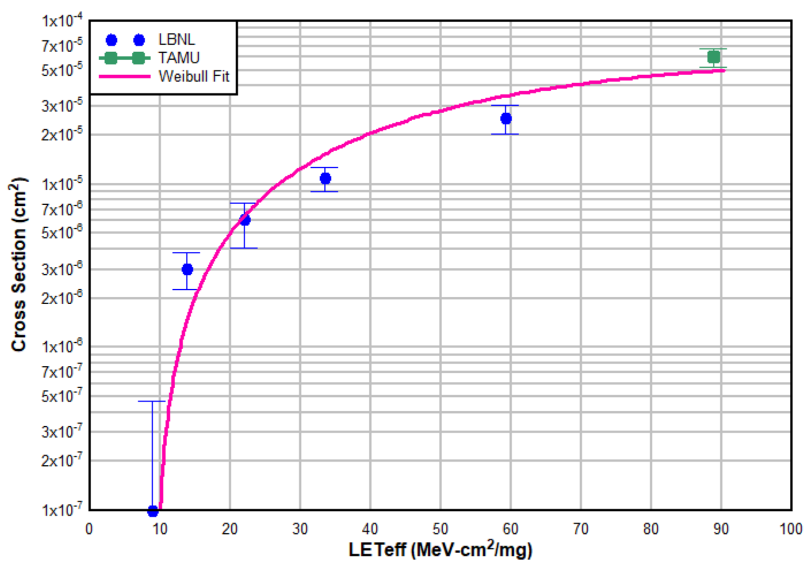

Figure 3-11. SEUs Cross Section vs. LETeff with CLKOUT0 as Scope Trigger

Table 3-4. Weibull Fit Parameters for SEUs with CLKOUT0 as Scope Trigger

A	Lo	W	s
1.89 × 10-4	9.2	60	1.2

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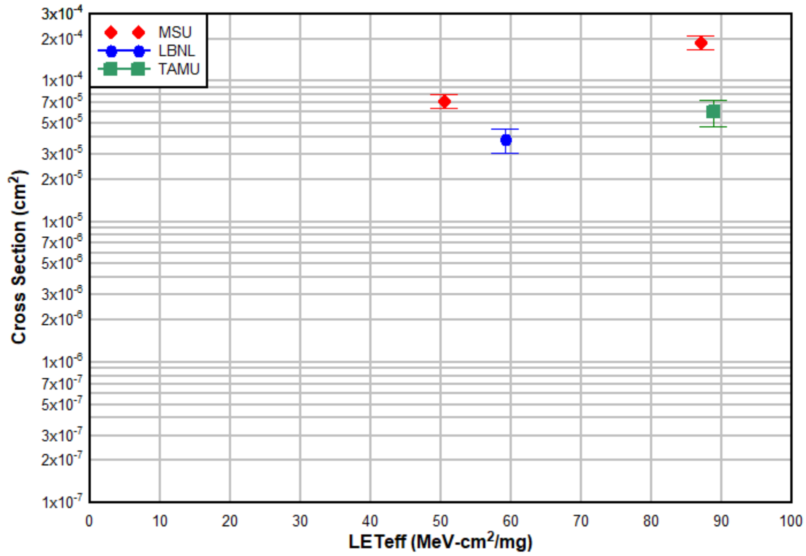

Figure 3-12. SEU Cross Section vs. LETeff with SYSREFOUT1 as Scope Trigger

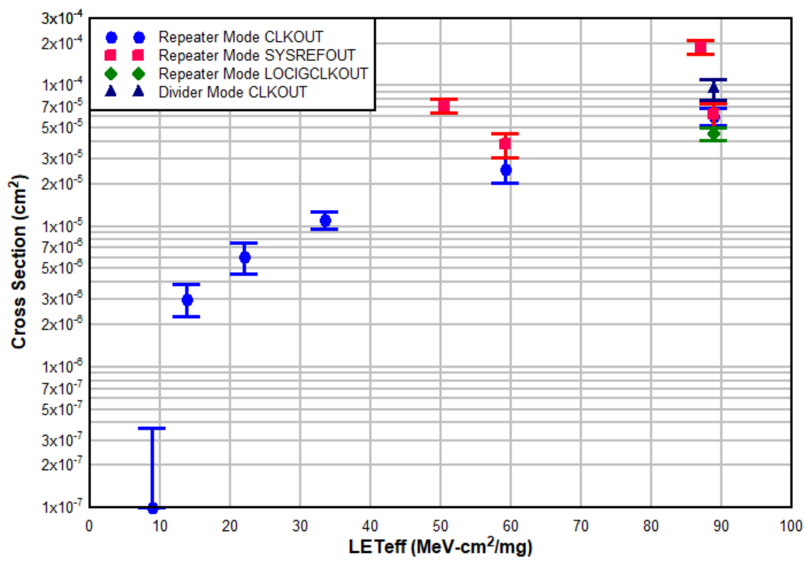

Figure 3-13. SEU Cross Section vs. LETeff for all Events with Operating Mode and Scope Trigger per the Legend

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4 Summary

Under heavy ion testing, the LMX1906-SP was found to be SEL and SEFI immune up to 88.9MeV-cm^2/ mg, the maximum LET tested. SEL testing was performed at maximum operating voltage (2.6V) and with the junction at greater than the maximum operating temperature (125°C).

SEUs were characterized. The signatures of the SEUs were different depending upon what output was used to trigger the scope. SEUs can last just a few clock cycles or as long 800ns when CLKOUT was used as the scope trigger and 22µs when SYSREFOUT was used as the scope trigger, under the conditions tested. The time to recover is likely to be based on the input frequency, with higher input frequencies recovering faster

In repeater mode, CLKOUT always recovered in phase with the output prior to the ion strike. When CLKIN is divided down, the output can recover out phase as when SYSREFOUT is divided down from CLKIN or CLKOUT when the part is in divider mode.

5 References

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