Final Report on Laser SET Testing of the OSD15-5T Photodiode, the RHFL4913A Voltage Regulator and the G8340-MAX3268 Photodiode & Amplifier

COO2 of ESA ESTEC Contract C22333/09/NL/Sfe

MBDA ESA Bidder No. 27027

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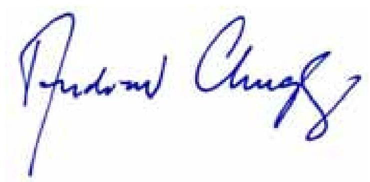

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CHANGE RECORDS SHEET

Issue No.	Date	Summary of Change	Amended by
1	29/11/13	Initial issue	Andrew Chugg
2	12/2/14	ESA comments responses	Andrew Chugg

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SUMMARY

This document is the Final Report under COO2 of ESTEC Contract No. C22333/09/NL/Sfe on the subject of Laser SET Testing of Analog Devices. It successively describes: a) Laser SET testing of the Centronic OSD15-5T photodiode; b) laser SET testing of the ST RHFL4913A Voltage Regulator; c) Laser SET testing of the Hamamatsu G8340-22 InGaAs PIN photodiode (with preamplifier) and the MAX3268 Amplifier in combination.

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LIST OF ACRONYMS AND ABBREVIATIONS

COO	Call Off Order
EMC	Electromagnetic Compatibility
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
FPGA	Field Programmable Gate Array
fs	Femtosecond
GUI	Graphical User Interface
HIF	Heavy Ion Facility (Louvain la Neuve)
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
InGaAs	Indium Gallium Arsenide
IR	Infrared
LET	Linear Energy Transfer
LSB	Least Significant Bit
MBU	Multiple Bit Upset
MOSFET	Metal-Oxide-Silicon Field Effect Transistor
NSREC	Nuclear and Space Radiation Effects Conference
PSI	Paul Scherrer Institute
PWM	Pulse Width Monitor
QMS	Quality Management System
RADECS	RADiation and its Effects on Components and Systems
RADEF	Finnish heavy ion and proton component radiation facility
SEB	Single Event Burnout
SEE	Single Event Effect
SEFI	Single Event Functional Interrupt
SEL	Single Event Latchup
SEGR	Single Event Gate Rupture
SEREEL	Single Event Radiation Effects in Electronics Laser
SET	Single Event Transient
SEU	Single Event Upset
SPDDE	Single Particle Displacement Damage Effect
SRAM	Static Random Access Memory
STREAM	System for Testing for Radiation Effects in Advanced Memories
THG	Third Harmonic Generator
TPA	Two Photon Absorption
TSL	Theodor Svedberg Laboratory
UV	Ultraviolet

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CONTENTS

FIGURES

1 INTRODUCTION

1.1 Background

1.1.1 This document is the Final Report under COO2 of ESTEC Contract No. C22333/09/NL/Sfe on the subject of Laser SET Testing of Analog Devices in accordance with the MBDA Proposal and the ESTEC Statement of Work (refs 1 & 2). It successively describes: a) Laser SET testing of the Centronic OSD15-5T photodiode; b) laser SET testing of the ST RHFL4913A Voltage Regulator; c) Laser SET testing of the Hamamatsu G8340-22 InGaAs PIN photodiode (with preamplifier) and the MAX3268 Amplifier in combination.

1.1.2 The special purpose of the testing of the Centronic OSD15-5T photodiode is comparison with parallel testing at other laser SEE facilities: cf. ref. [10], "Comparison of Single Event Transients Generated at Four Pulsed-Laser Test Facilities - NRL, IMS, EADS, JPL", RADECS 2011 Proceedings.

1.1.3 This research specifically involves the application of MBDA's Single Event Radiation Effects in Electronics Laser facility (SEREEL2). A recent photo of this facility is shown in Fig. 1.1-1 and a diagram of the overall configuration of the SEREEL2 system is shown in Fig. 1.1-2.

1.1.4 The PowerChip NanoLaser (silver unit in the foreground of Fig. 1.1-1 and on the right hand side of Fig. 1.1-2) was used for this research. It operates at 1064nm wavelength with a 400ps pulse duration and gives a focused spot diameter of ~1.5µm. This laser is more consistent in its output than the Integra laser (1ps pulse duration), so it is to be preferred for research where its pulse duration is satisfactory as is generally the case for laser-induced SETs in analog parts.

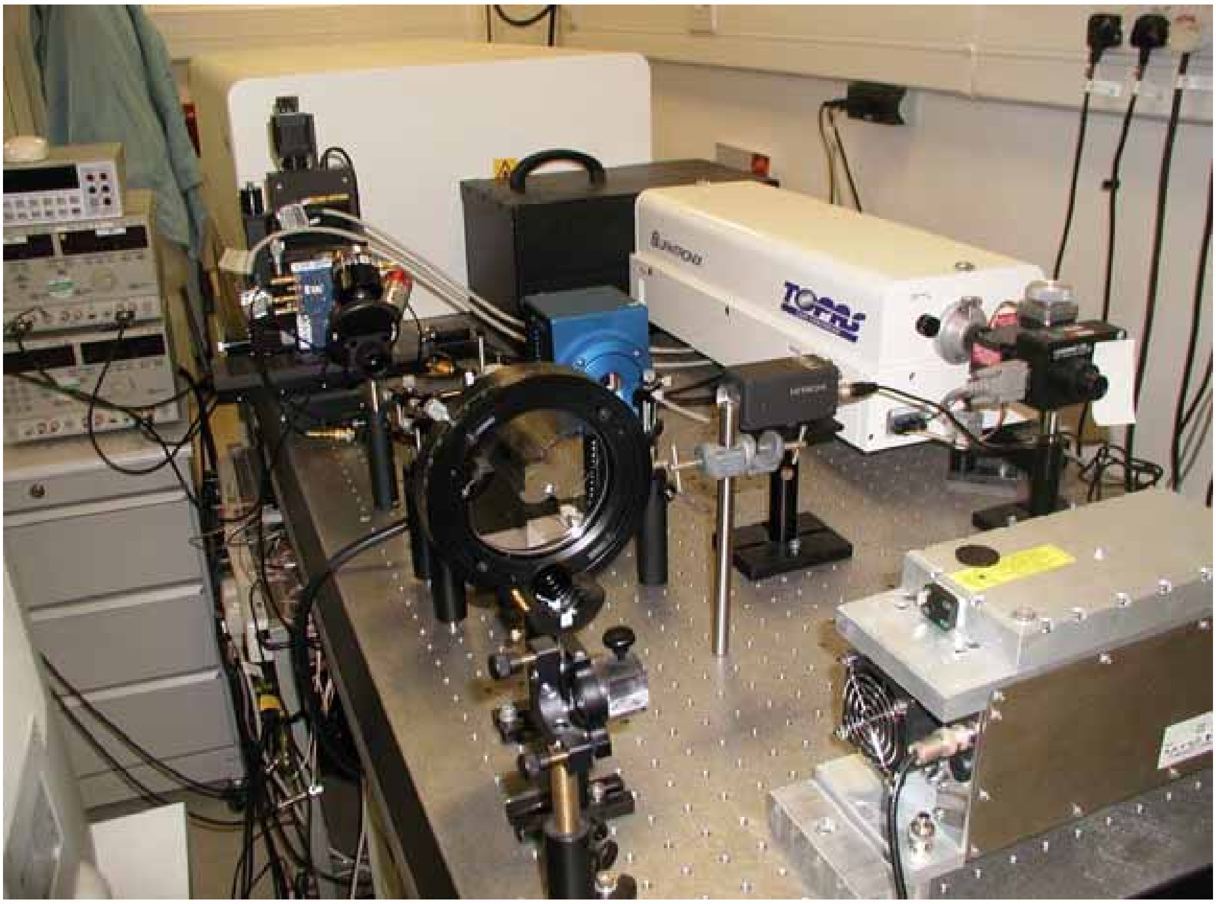


Figure 1.1-1: SEREEL2 with the new PowerChip laser incorporated in the foreground

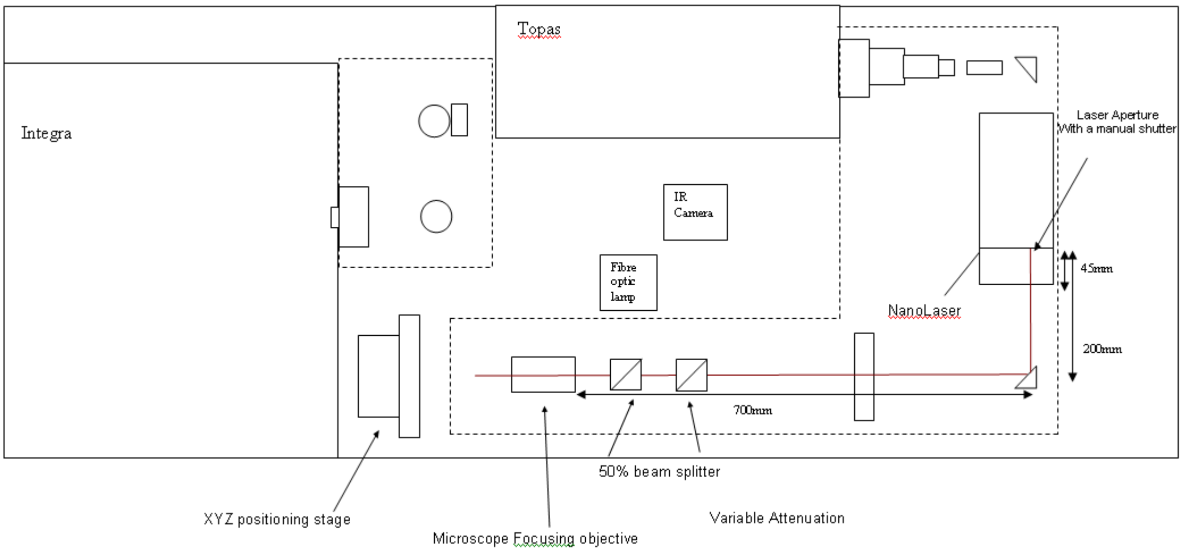


Figure 1.1-2: SEREEL2 System Configuration with PowerChip Laser Incorporated

2 LASER SET TESTING OF THE CENTRONIC OSD15-5T PHOTODIODE

2.1 Introduction

2.1.1 Under the MBDA Proposal (ref 1) and the ESTEC Statement of Work (ref 2) it is specified that the Centronic OSD15-5T be tested with the objective of comparison with parallel testing at other laser SEE facilities: cf. ref [10], "Comparison of Single Event Transients Generated at Four Pulsed-Laser Test Facilities - NRL, IMS, EADS, JPL", RADECS 2011 Proceedings.

2.2 Laser SET Trial

2.2.1 The MBDA Nd-YAG SEE laser was used to evaluate the single event transient (SET) responses of the Centronic OSD15-5T, (15 mm^2) silicon photodetector (nominally rated for a 430 to 900 nm wavelength range). The output from the work has provided SET amplitude verses duration (width) plots; charge generation (Q value) plots plus examples of worst case output behaviour transients for a number of test conditions. The OSD15-5T was tested at four voltage bias conditions. Since the device is a single large area diode only a single spiral of 122 pulses was delivered for each bias test condition at any given laser energy value.

2.2.2 Device Description: the OSD15-5T is a 15 mm2 silicon photodetector - nominally rated for a 430 to 900 nm wavelength range, in TO5 package, manufactured by Centronic of the UK. The device has maximum ratings for the reverse DC voltage of 15 volts; peak DC current of 10 mA [therefore a maximum power dissipation is 0.15 watts] however the peak current is 200 mA pulse current on 1% duty cycle [i.e. power dissipation reduced to 0.03 watts]. The active area of the device is 3.8 mm x 3.8 mm and has a capacitance of 390 pF at 0 V bias and 80 pF at 12 V bias.

2.2.3 The test circuit is given in Figure 2.2-1. The output voltages were monitored on oscilloscopes using low capacitance Tektronix P6243 scope probes [1 Mohm; <1pF] into a Tektronix TDS5104B Scope [Max 5GS/s or 200 ps/point and 256 bit voltage resolution]. The voltage scales were DC coupled and set to provide the optimum resolution capability for the maximum potential voltage observed during the spiral.

2.2.4 Similarly the time base of the oscilloscopes were set to ensure the full capture of the transient durations with the optimum time resolution. The Tektronix TDS5104B Scope was set to record 5000 data points per oscilloscope trace. A signal transient having a minimum of 5 samples was therefore 1ns duration and the longest transient at the maximum sample rate setting gave a maximum transient duration of 1µs. For longer durations the time resolution of the data was reduced in proportion: thus for a 1ms trace the time resolution became 200ns / point. The configuration settings were adjusted throughout the trial for optimal capture of the results.

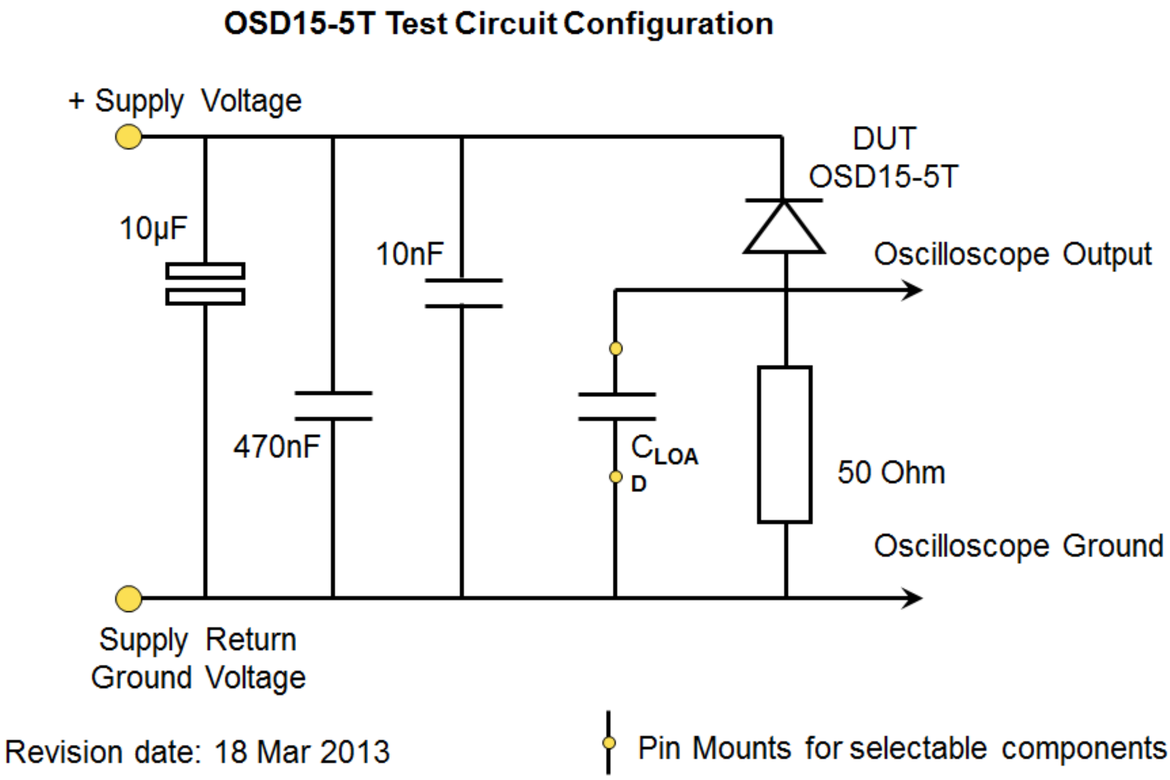


Figure 2.2-1: OSD15-5T Test Circuit Configuration

2.3 Laser SET results

2.3.1 Laser pulses were delivered across the photodiode to simulate SET events in each of three lines across the device die as shown in Figure 2.3-1.

2.3.2 A red spot in the inset of the die in all subsequent SET event traces indicates the specific location of the laser pulse for that trace.

2.3.3 Figure 2.3-2 shows the response on the centre line near the contact. MBDA saw a much faster and higher amplitude response than had been seen in the equivalent shots for other laser facilities (see inset graph and ref. [10]).

2.3.4 MBDA saw the SET amplitude decrease and its duration increase (somewhat proportionally) with increasing distance of the laser spot from the contact along the centre line (Figure 2.3-3).

2.3.5 The MBDA events were similar in amplitude and duration to those seen by other facilities at the furthest point of the centre line from the contact (Figure 2.3-4).

2.3.6 The variation in the amplitude of the SET events with distance along the centre line from the contact is plotted for two data sets in Figure 2.3-5.

2.3.7 The variations in SET event magnitude along the two trial lines orthogonal to the centre line are shown in Figure 2.3-6. The line that passed close to the contact (blue traces) showed a pronounced peak of sensitivity close to the contact. Near the centre of the device the orthogonal sensitivity variation was relatively flat (red traces).

2.3.8 The variation in peak output voltage with laser pulse energy at a point 0.1mm from the contact is shown in Figure 2.3-7 for a range of four different supply voltages. MBDA saw just over 0.1V at ~1nJ which may be compared with the range of parallel results from four other laser facilities (inset graph and ref. [10]).

2.3.9 MBDA saw about 0.1nJ of charge flow in the SET events at ~1nJ laser pulse energy (Figure 2.3-8). This is quite consistent with the integrated charge seen by other facilities at this pulse energy (inset and ref. [10]).

2.3.10 The variation in the magnitude of the response with focussing depth relative to the device surface is shown in Figure 2.3-9. These profiles were taken at the centre of the die 1.5mm from the contact. The surface of the die was at 36.609mm and larger depths moved the focus into the silicon. MBDA observed the same small notch in the depthwise sensitivity profile as had been seen by other facilities (inset graph and ref [10]).

2.3.11 Summary for the OSD15-5T Photodiode: the SETs are highly location dependent; MBDA see faster pulses/responses than previous laser SET investigations in other companies [10], but we obtain the same integrated charge generation as seen at other laser facilities.

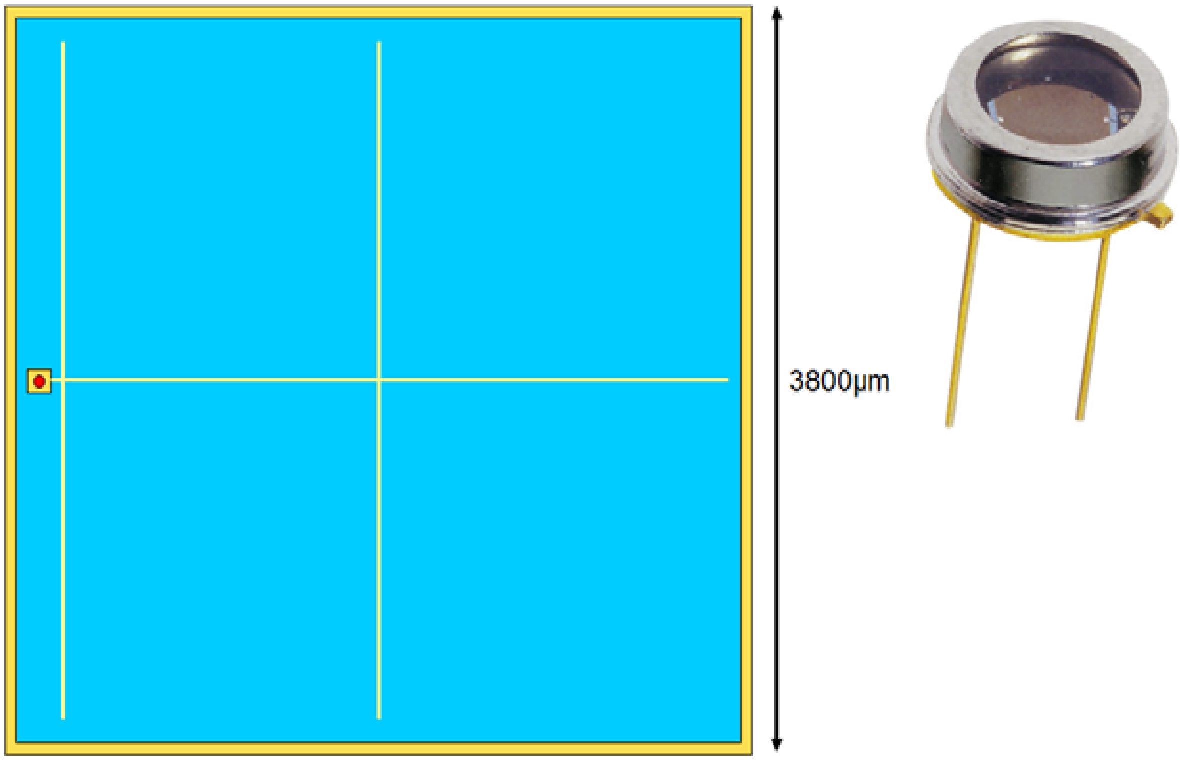


Figure 2.3-1: OSD15-5T Device Map showing lines of the 3 Scans Performed

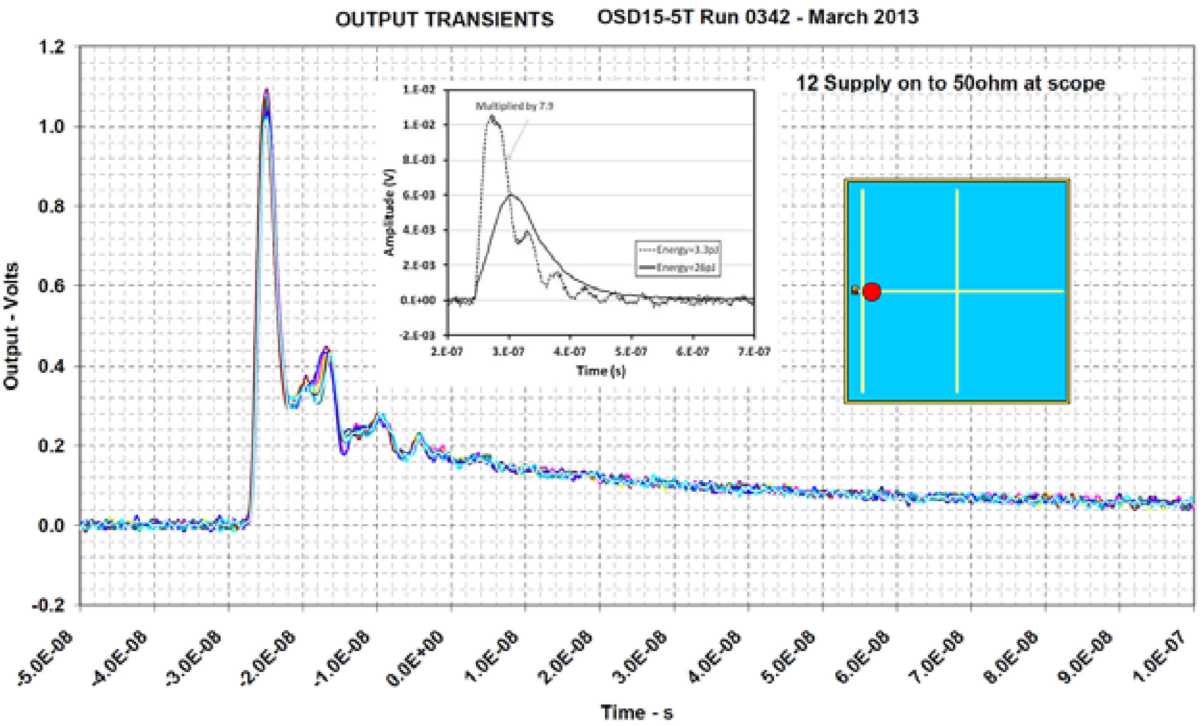


Figure 2.3-2. Laser Induced Photocurrent Trace (1) at 3nJ pulse energy - response on centre line at 100µm from contact (short time base)

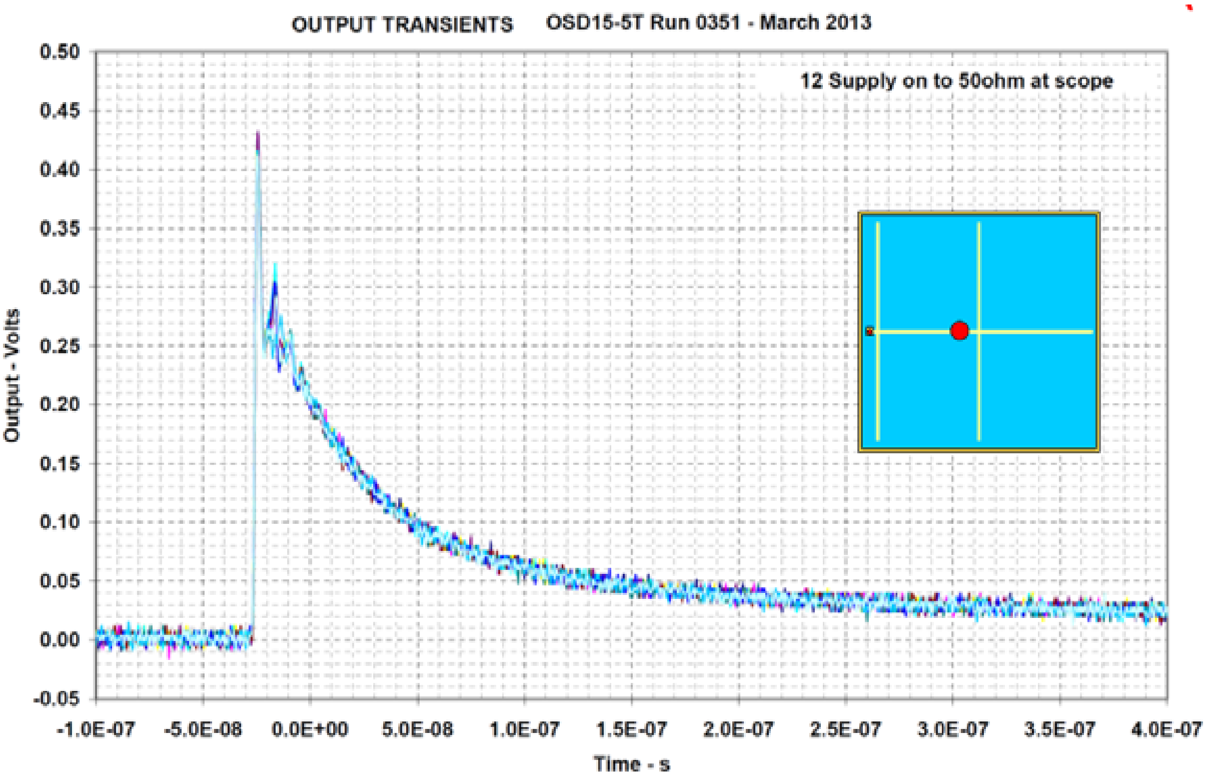


Figure 2.3-3: Laser Induced Photocurrent Trace (2) at 3nJ pulse energy - response on centre line at 1200µm from contact (longer time base)

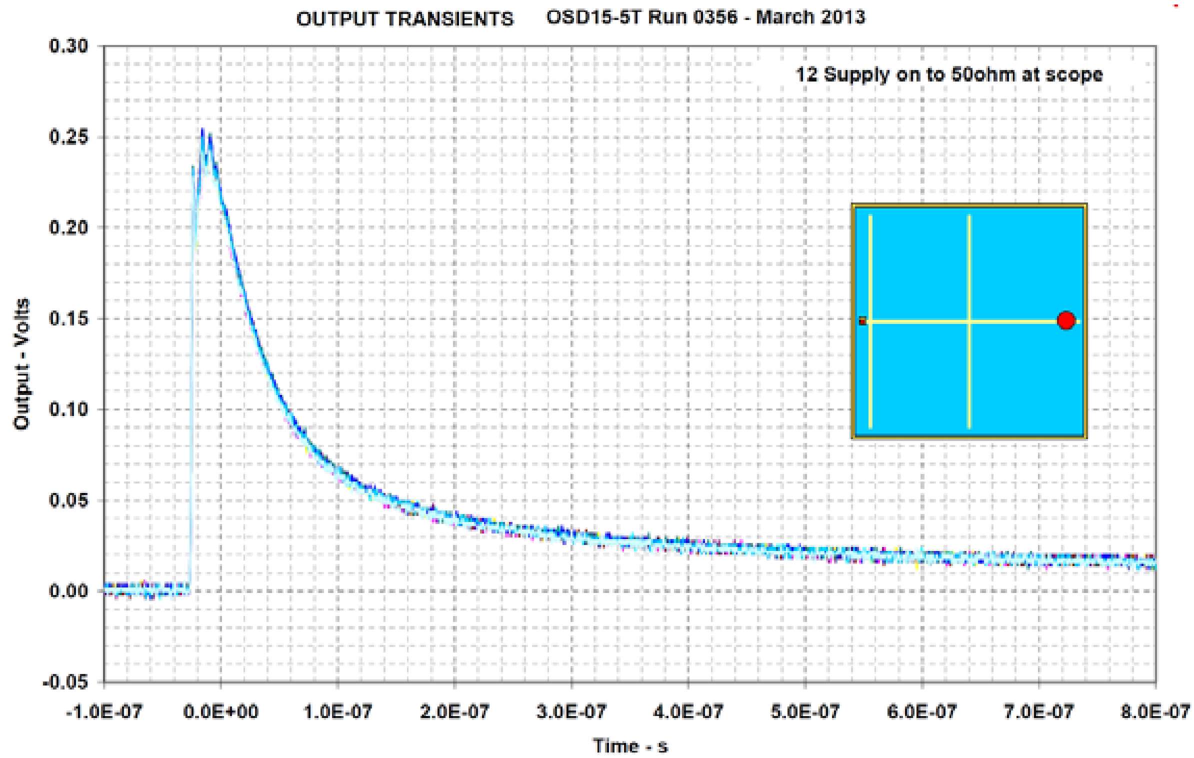


Figure 2.3-4: Laser Induced Photocurrent Trace (3) at 3nJ pulse energy - response on centre line at 2800µm from contact (yet longer time base)

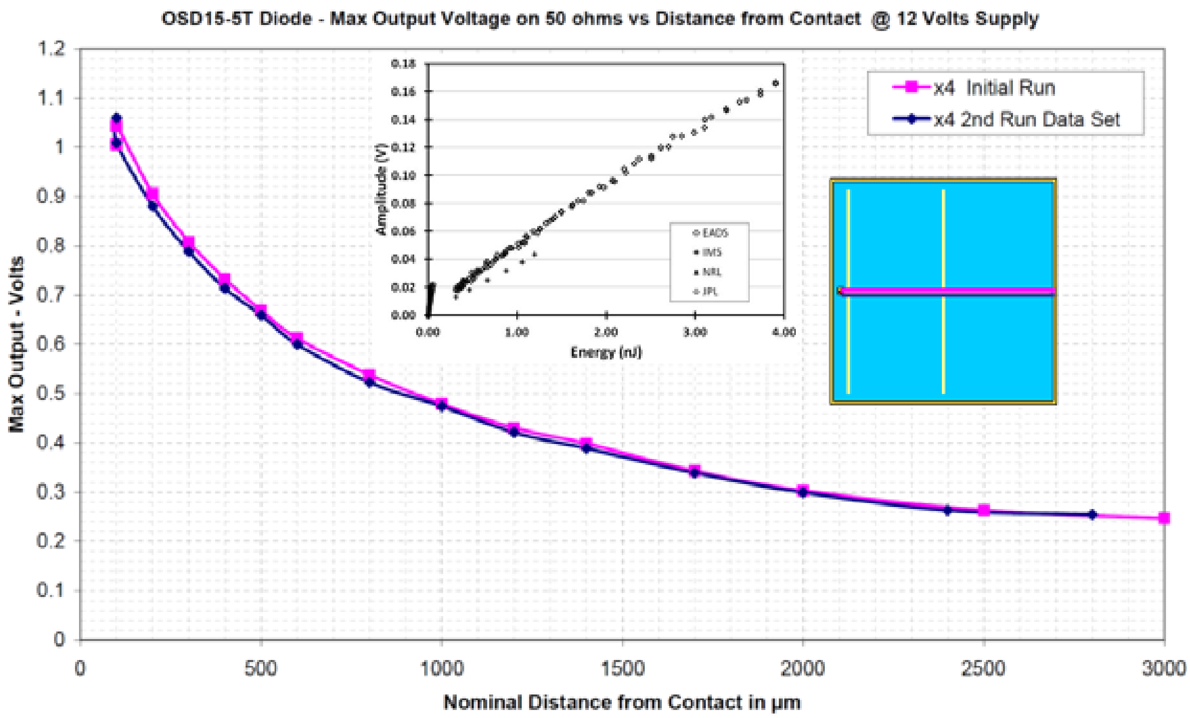


Figure 2.3-5: Maximum voltage response on centre line at 3nJ pulse energy

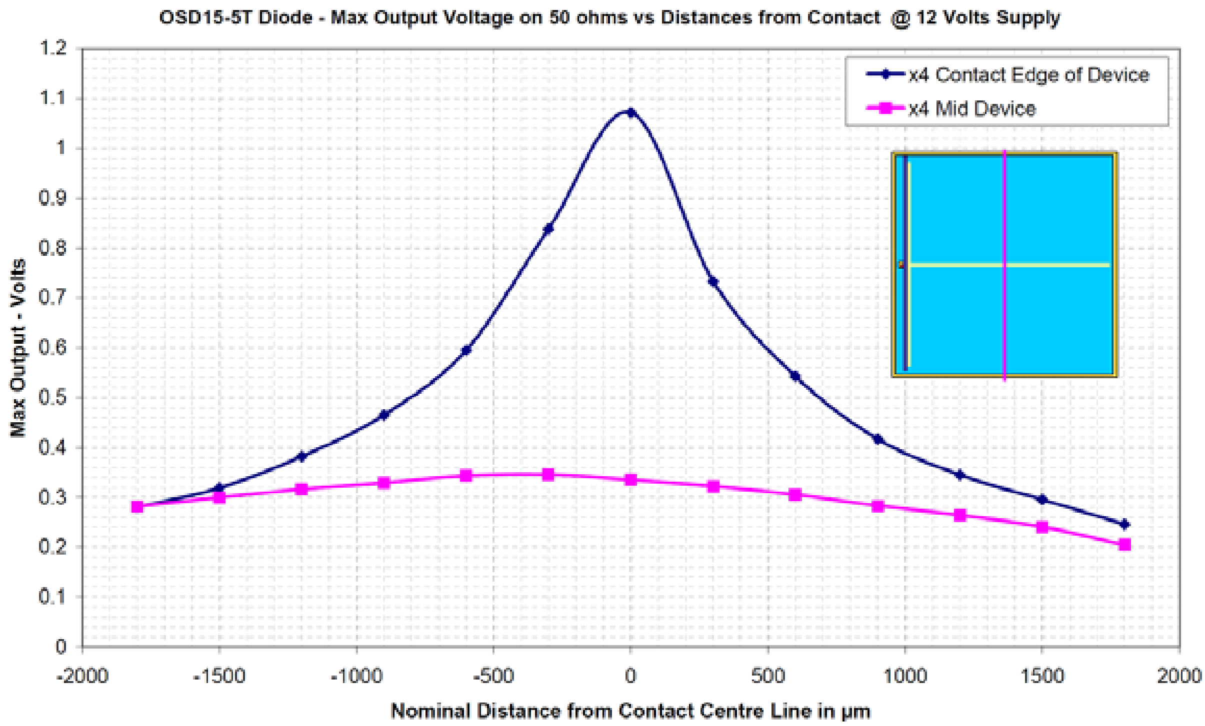


Figure 2.3-6: Maximum voltage responses across the centre line at 3nJ pulse energy

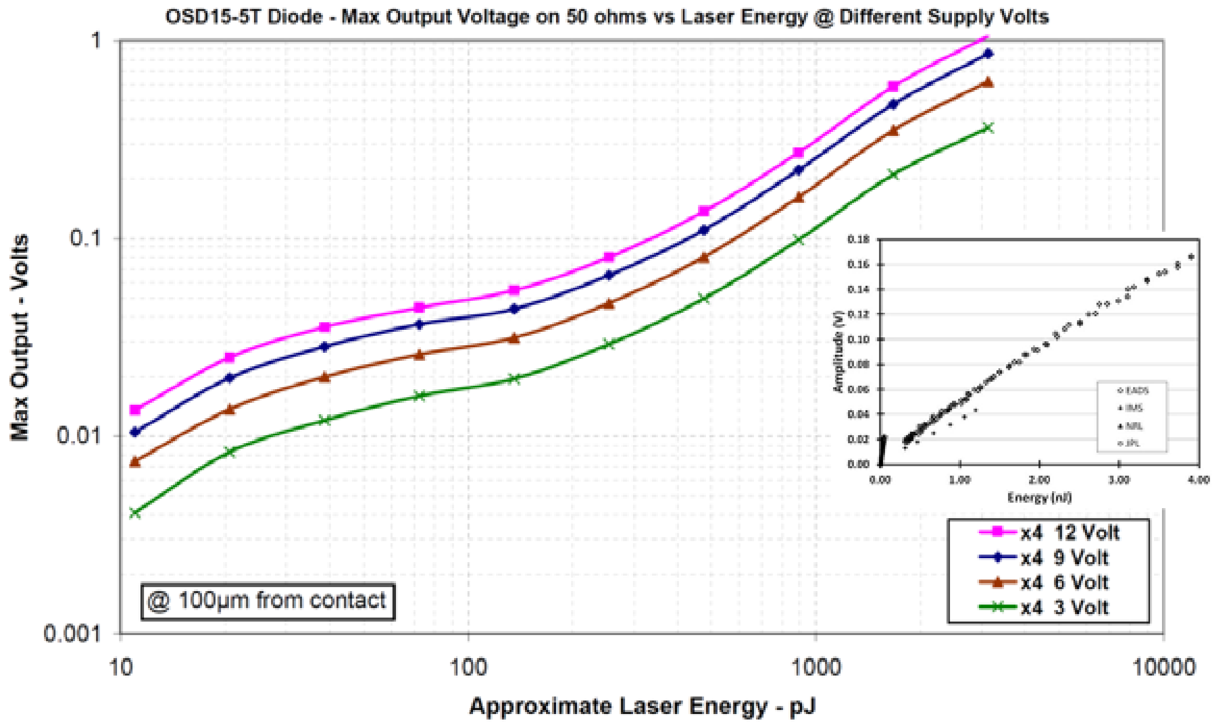


Figure 2.3-7: Maximum Voltage Response on 50 Ohm scope Termination w.r.t. Laser Energy

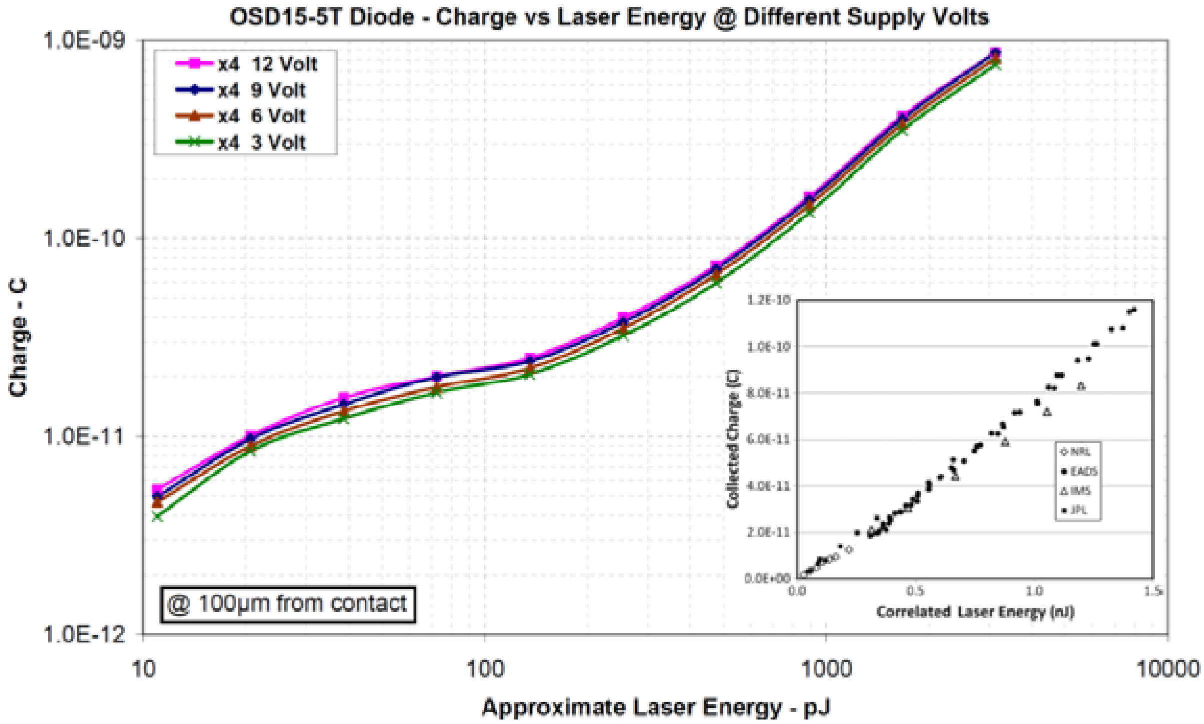


Figure 2.3-8: Integrated Charge Response (50 Ohm scope Termination) w.r.t. Laser Energy

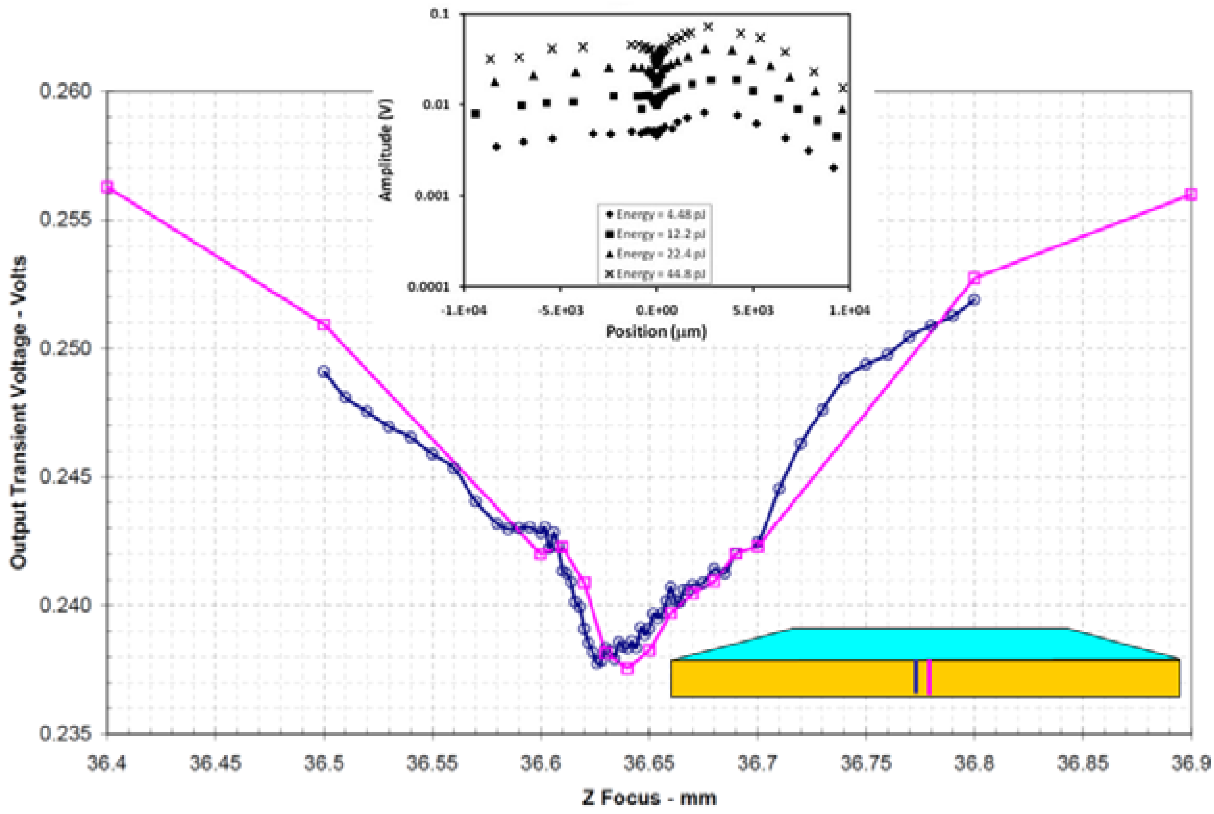


Figure 2.3-9: OSD15-5T sensitivity variation in depth

3 LASER SET TESTING OF THE RHFL4913A VOLTAGE REGULATOR

3.1 Introduction

3.1.1 The MBDA Nd-YAG SEE laser was used to evaluate the single event transient (SET) responses of the STMicroelectronics RHFL4913KPA adjustable voltage regulator. The objective of this testing was to provide SET amplitude verses duration (width) plots plus example worst case output behaviour transients for a number of test conditions. The RHFL4913A was tested for three VIN – VOUT values; two output capacitor values and three load conditions. The device was comprehensively laser scanned at the central values of VIN – VOUT, output capacitance and load condition. The most sensitive areas identified from the initial scan were then rescanned with higher and lower values of various test condition requirements.

3.2 Laser SET Trial

3.2.1 Device Description: The RHFL4913KPA is a radiation hard adjustable positive voltage regulator with inhibit control, in the 16 pin flat package, manufactured by STMicroelectronics of France. The device has maximum ratings for VIN of 12 volts; VOUT of 9 volts; IOUT of 2 amps and power dissipation of 15 watts. The output voltage is defined by the set resistances in accordance with the equation: VOUT = 1.23 (RSET 1 + RSET 2) / RSET 1 where RSET 1 should not exceed 10k ohms. Tantalum input and output capacitances of not less than 1µF are mandatory and it is recommended that these are decoupled using 470 nF polyester capacitors. It was suggested that Schottky diodes be used to prevent negative voltage excursions where inductances were present in the circuit.

3.2.2 The test circuit is given in Figure 3.2-1. The circuit includes Schottky diodes, although there are no inductances in the circuit as a device protection precaution.

3.2.3 The input and output voltages were monitored on oscilloscopes using low capacitance Tektronix P6243 scope probes [1 Mohm; <1pF] into a Tektronix TDS5104B Scope [Max 5GS/s or 200 ps/point and 256 bit voltage resolution]. But note that no transients were actually observed on the inputs. The voltage scales were DC coupled and set to provide the optimum resolution capability for the maximum potential voltage range on the two primary channels with the output channel being backed up at a consistent 0.2 V/div AC coupled setting that gave 8 mV/point resolution, resulting in signals of ±32 mV being detectable over the oscilloscope noise floor.

3.2.4 Similarly the time base of the oscilloscope(s) was set to ensure capture of the full transient durations with the optimum time resolution. The Tektronix TDS5104B Scope was set to record 5000 data points per oscilloscope trace. A signal transient having a minimum of 5 samples was therefore 1ns duration and the longest transient at the maximum sample rate setting gave a maximum transient duration of 1µs. For longer durations the time resolution of the data was reduced in proportion: thus for a 1ms trace the time resolution became 200ns / point. The configuration settings were adjusted throughout the trial for optimal capture of the results.

3.2.5 The test conditions for the trial are shown in Figure 3.2-2, those highlighted in bold being the ones actually employed.

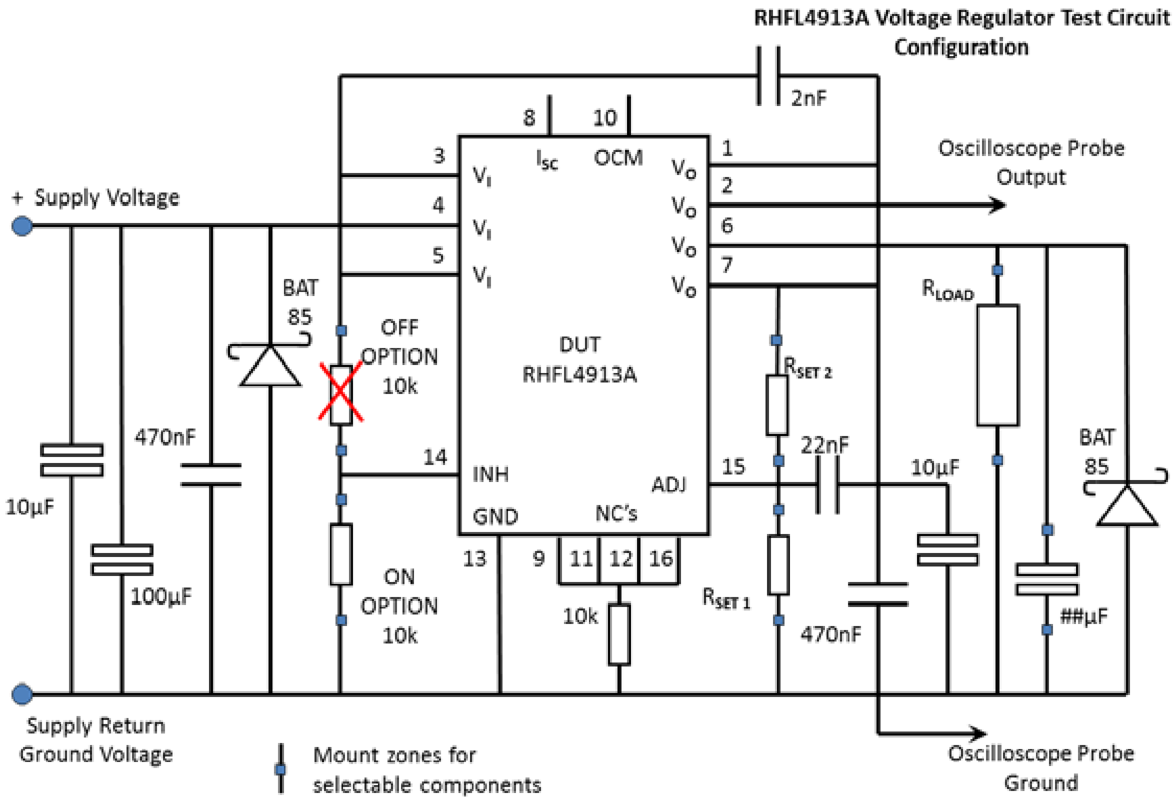


Figure 3.2-1: RHFL4913A Test Circuit (note that the OFF OPTION 10k resistor was not present during laser SET trials)

TEST FUNCTION	VIN	VOUT	VIN to VOUT	Output Load	Output Cap	Set Resistors
BASE LINE Tests 1	6.3V	3.3V	3.0V	300 mA	10.47μF	10k / 16.8k
VIN to VOUT Test 2 Test 3	4.8V 10.3V	3.3V 3.3V	**1.5V** **7.0V**	300 mA 300 mA	10.47μF 10.47μF	10k / 16.8k 10k / 16.8k
Output Cap Test 4	6.3V	3.3V	3.0V	300 mA	**110.47μF**	10k / 16.8k
Set Resistor Test 5	6.3V	3.275V	3.025V	300 mA	10.47μF	**1k / 1.65k**
Load Current Test 6 Test 7	6.3V 6.3V	3.3V 3.3V	3.0V 3.0V	**30 mA** **1.0 A**	10.47μF 10.47μF	10k / 16.8k 10k / 16.8k
Output Voltage Test 8 Test 9 Test 10	4.5V 8.0V 12.0V	**1.5V** **5.0V** **9.0V**	3.0V 3.0V 3.0V	300 mA 300 mA 300 mA	10.47μF 10.47μF 10.47μF	10k / 16.8k 10k / 16.8k 10k / 16.8k

Figure 3.2-2: RHFL4913A Test Conditions (bold were selected)

3.3 Laser SET Results

3.3.1 The device was scanned with spiral pulse arrays right across the die as had been planned for the various conditions shown in Figure 3.2-2. The results are therefore extremely numerous and detailed. The full set of trial files will be supplied to ESA on a DVD. This section is therefore confined to an overview of the responses through the presentation of significant examples.

3.3.2 Firstly, this section reviews an example set of results at the die location indicated by the arrow in Figure 3.3-1, which was one of the most sensitive spots. More generally, the yellow dashed rectangle designates the most sensitive region of the die, although laser pulsing was performed in other areas too. The groups of SET events shown in Figures 3.3-2 to 3.3-11 were obtained from spiral arrays delivered at this location. Please refer to the Figures themselves for details of the test conditions in each case.

3.3.3 The basic results at this location showed SET that incorporated both a high amplitude (1.25V) but short duration (1E-7s) transient (Figure 3.3-2) and also a smaller amplitude (~0.4V) late time transient with a delayed onset, but lasting ~0.1ms (Figure 3.3-3). The late time behaviour (but not the early time behaviour) was significantly mitigated when a 100µF capacitor was fitted between pin 7 and earth (Figures 3.3-4 & 3.3-5). Reducing the set1 & set 2 resistor values also modified the long timescale behaviour but had only a marginal effect upon the prompt response (Figures 3.3-6 & 3.3-7). Higher load current caused oscillations in the long term response to die away slightly more rapidly, but exacerbated its amplitude (Figures 3.3-8 & 3.3-9). Higher V_{in} to V_{out} slightly increased the initial amplitude of the late time response (Figures 3.3-10 & 3.3-11). In all cases the prompt response was relatively unaffected. The conclusion is that the late time response must relate to feedback around the circuit, whereas the prompt response was independent of feedback and therefore relatively unaffected by changes in the test conditions.

3.3.4 The amplitude-duration scatter plots shown in Figures 3.3-12 to 3.3-17 are for the ensemble of laser pulses delivered to the die for scans under various test conditions as detailed in each chart. They include all the pulses for the 19 worst-case spiral arrays, all of which were delivered within the yellow-dashed box in Figure3.3-1. These diagrams show a very complex overall behaviour. Some features are worth noting. The high amplitude short duration responses emerge as a distinct group from the late time (usually) low amplitude responses in every case. The higher load current case can be seen in Figure 3.3-15 to significantly exacerbate the late time responses more generally (i.e. the specific case noted above extends to a wider area of the die). Note also that the low load current case exacerbated the positive-going early and late time transient amplitude.

3.3.5 Laser pulse energies were: 3000pJ for shots 100 to 391 & shots 451 to 628; 500pJ for shots 400 to 418; 70pJ for shots 419 to 437; 12pJ for shots 438 to 450 (where a shot was 122 laser pulses in a spiral configuration delivered off a single trigger.)

3.3.6 Summary for the RHFL4913A Voltage Regulator: the device exhibits a short term SET response <0.2µs and also a long term SET response 1µs to 100µs; the latter seems to be attributable to feedback via the ADJUST i/p.

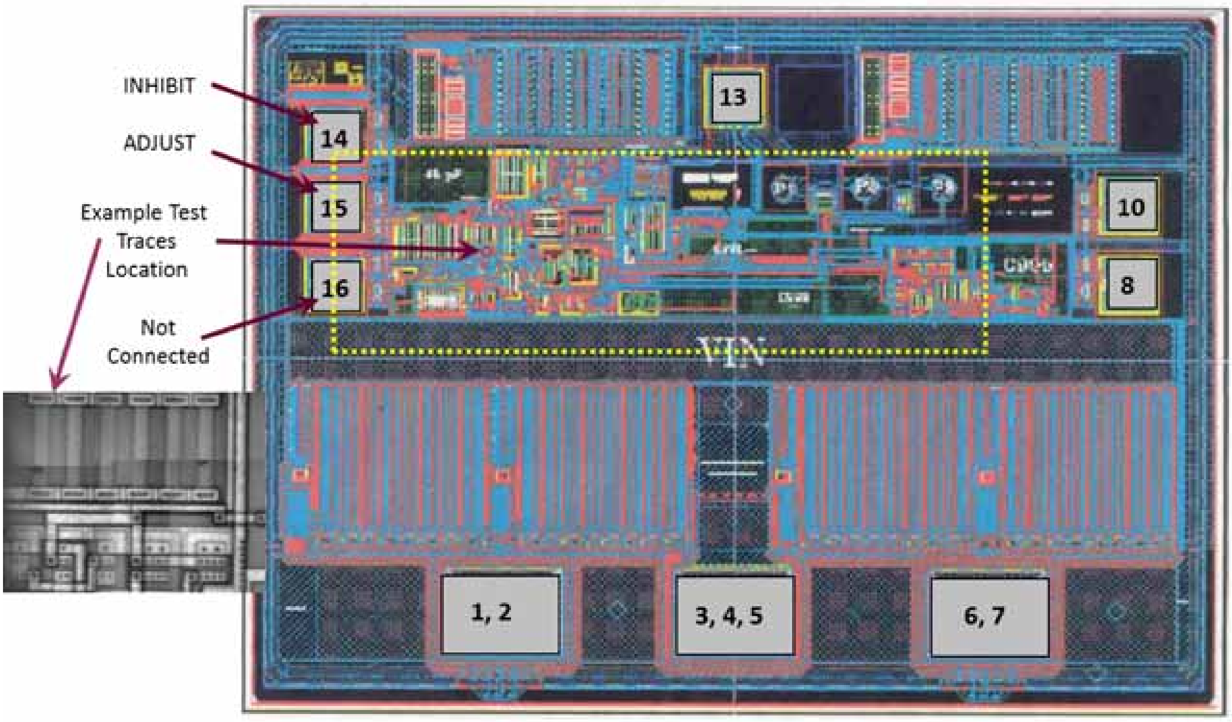


Figure 3.3-1: RHFL4913A IC micrograph indicating Test Trace Laser Pulse Location

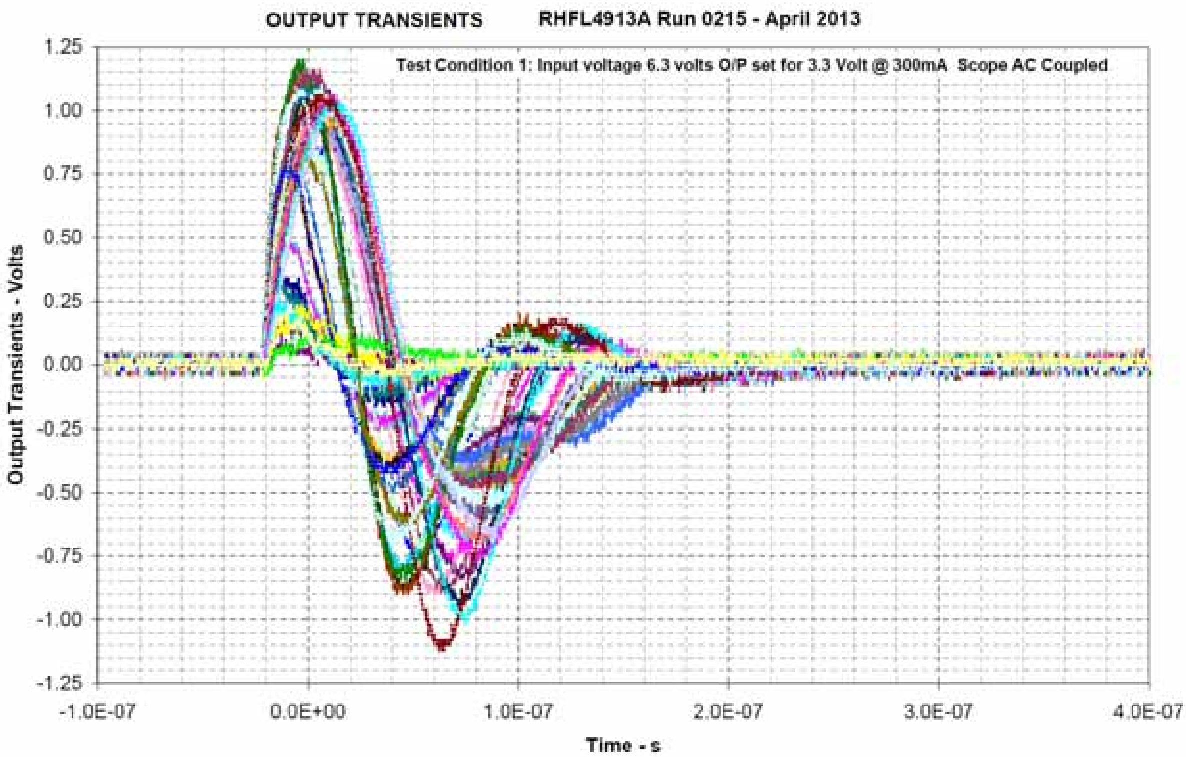


Figure 3.3-2: Output transients – Run 0215 – baseline response – short timebase (37.94mm, 46.957mm)

3.3.7 The

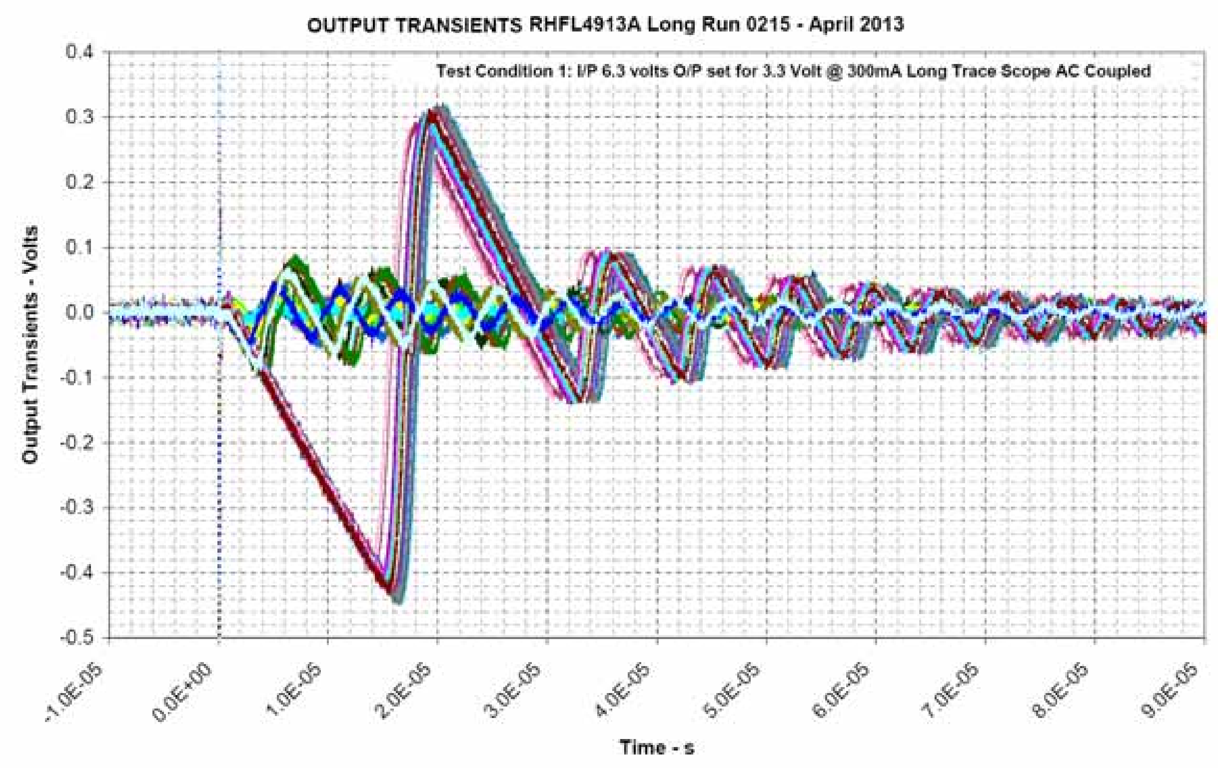


Figure 3.3-3: Output transients – Run 0215 – baseline response – long timebase (37.94mm, 46.957mm)

3.3.8 The

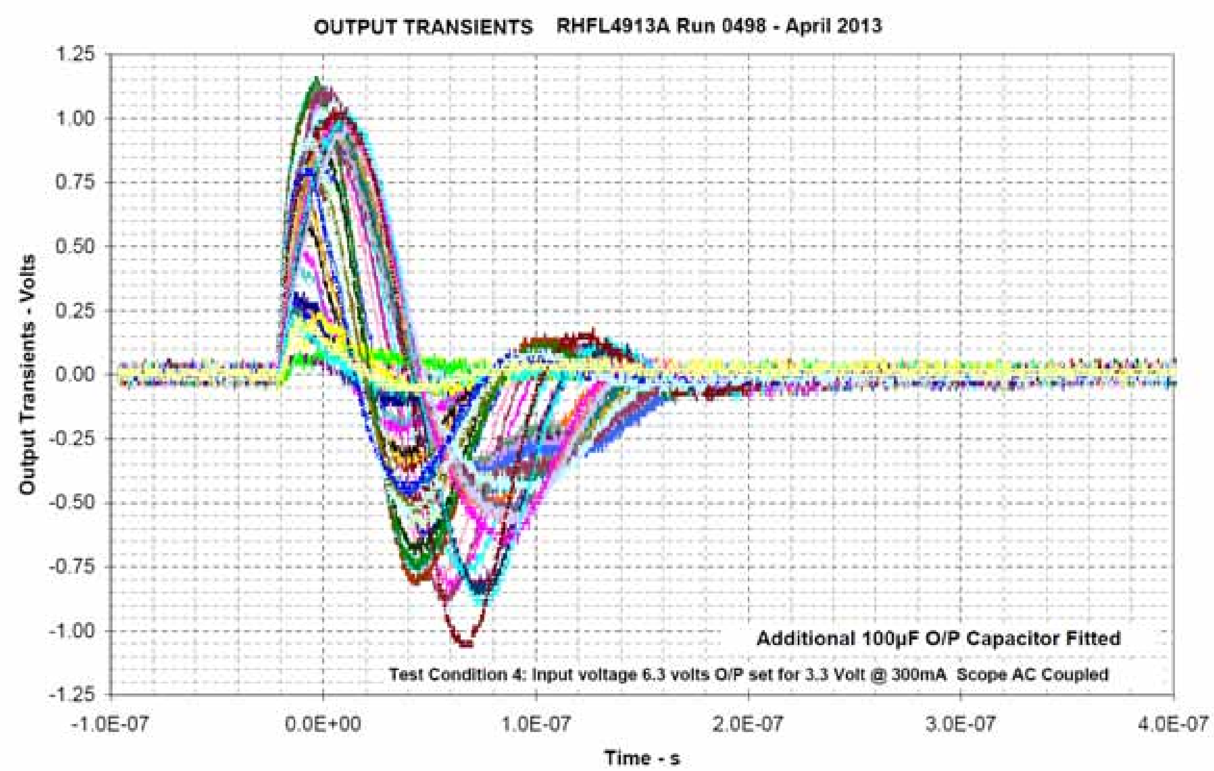


Figure 3.3-4: Output transients – Run 0498 – 100µF capacitor added – short timebase (37.94mm, 46.957mm)

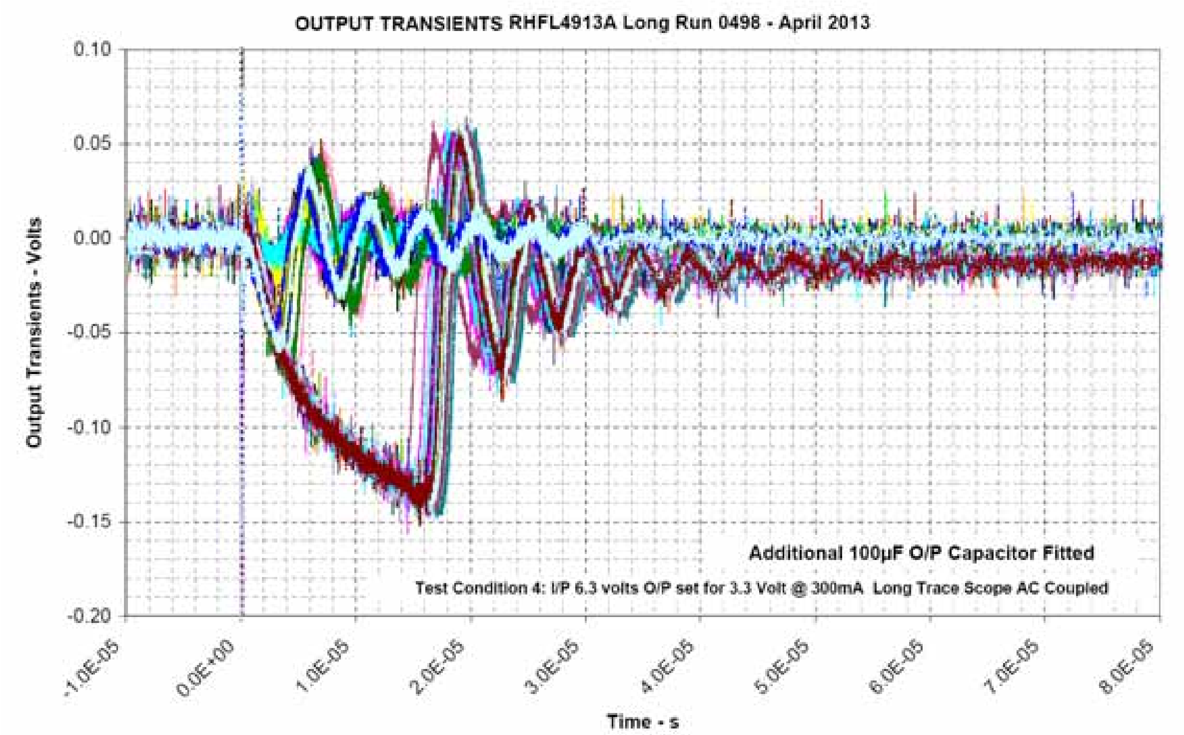


Figure 3.3-5: Output transients – Run 0498 – 100µF capacitor added – long timebase (37.94mm, 46.957mm)

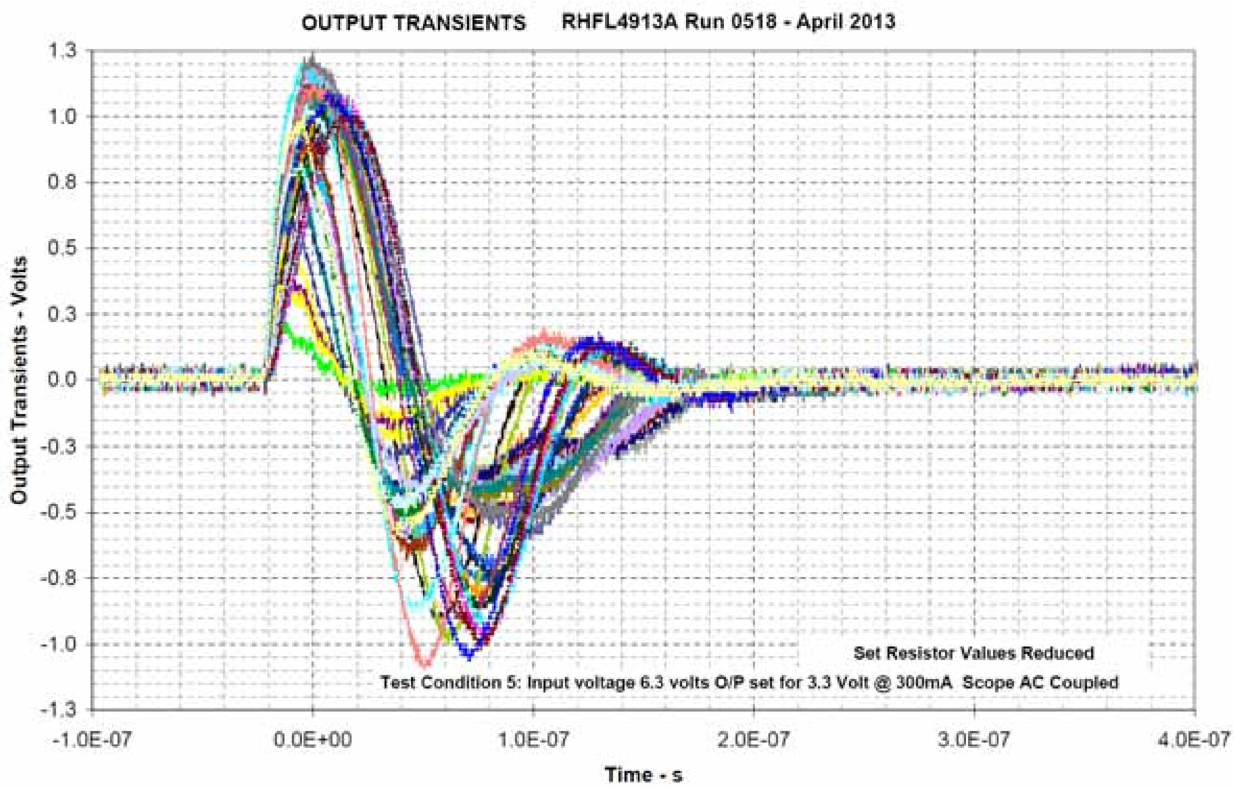


Figure 3.3-6: Output transients – Run 0518 – short timebase - SET RESISTOR VALUES REDUCED (37.94mm, 46.957mm)

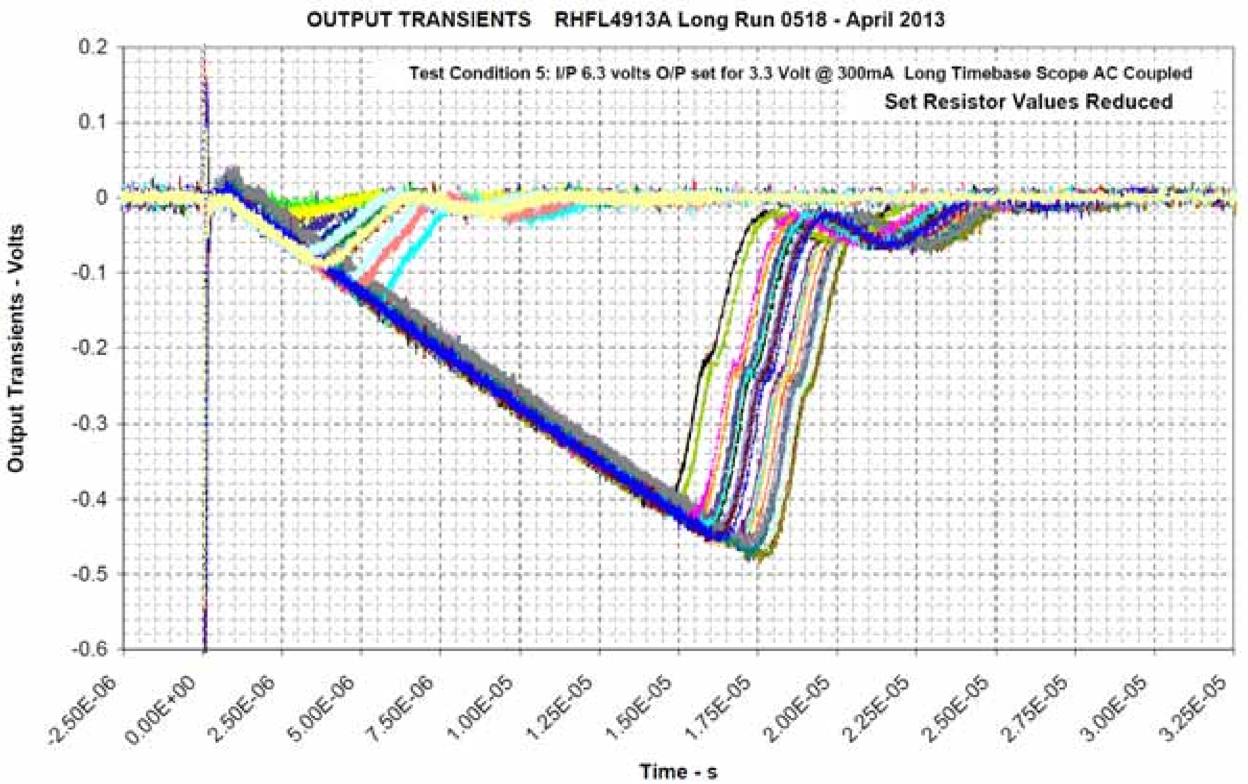
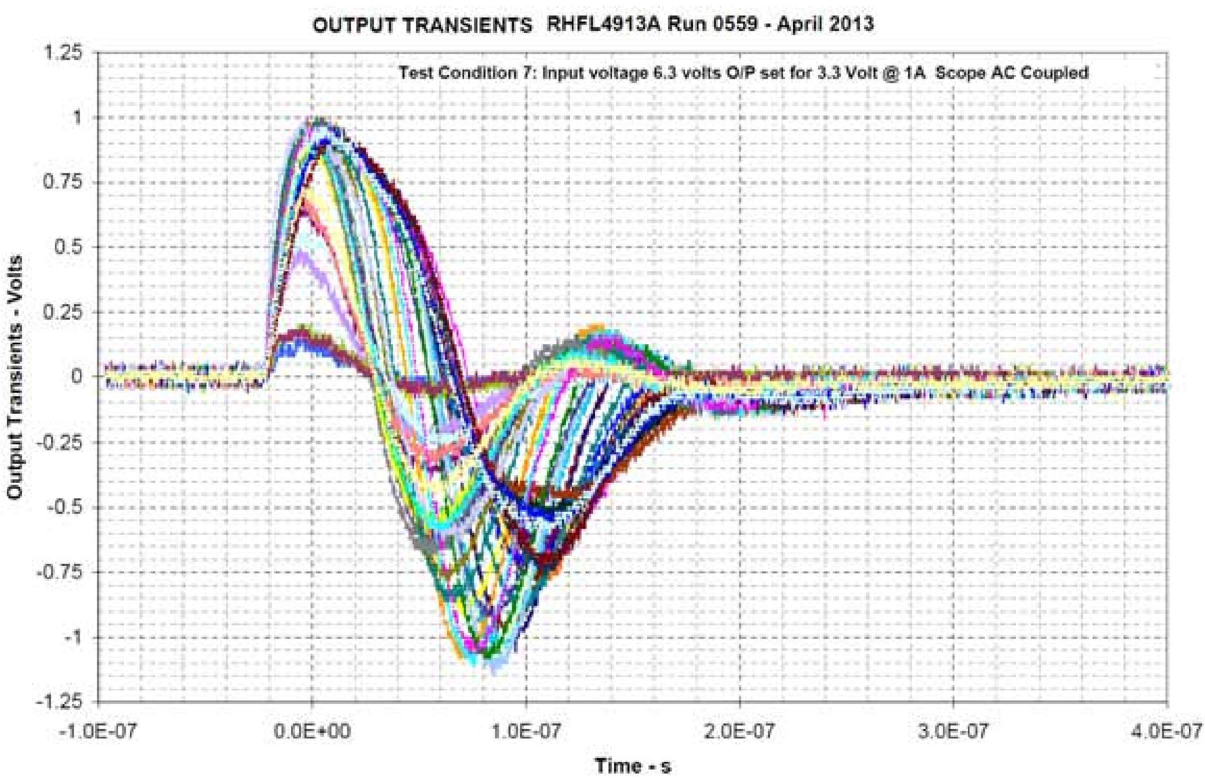


Figure 3.3-7: Output transients – Run 0518 – long timebase - SET RESISTOR VALUES REDUCED (37.94mm, 46.957mm)



3.3-8: Output transients – Run 0559 – short timebase - HIGHER LOAD CURRENT (37.94mm, 46.957mm)

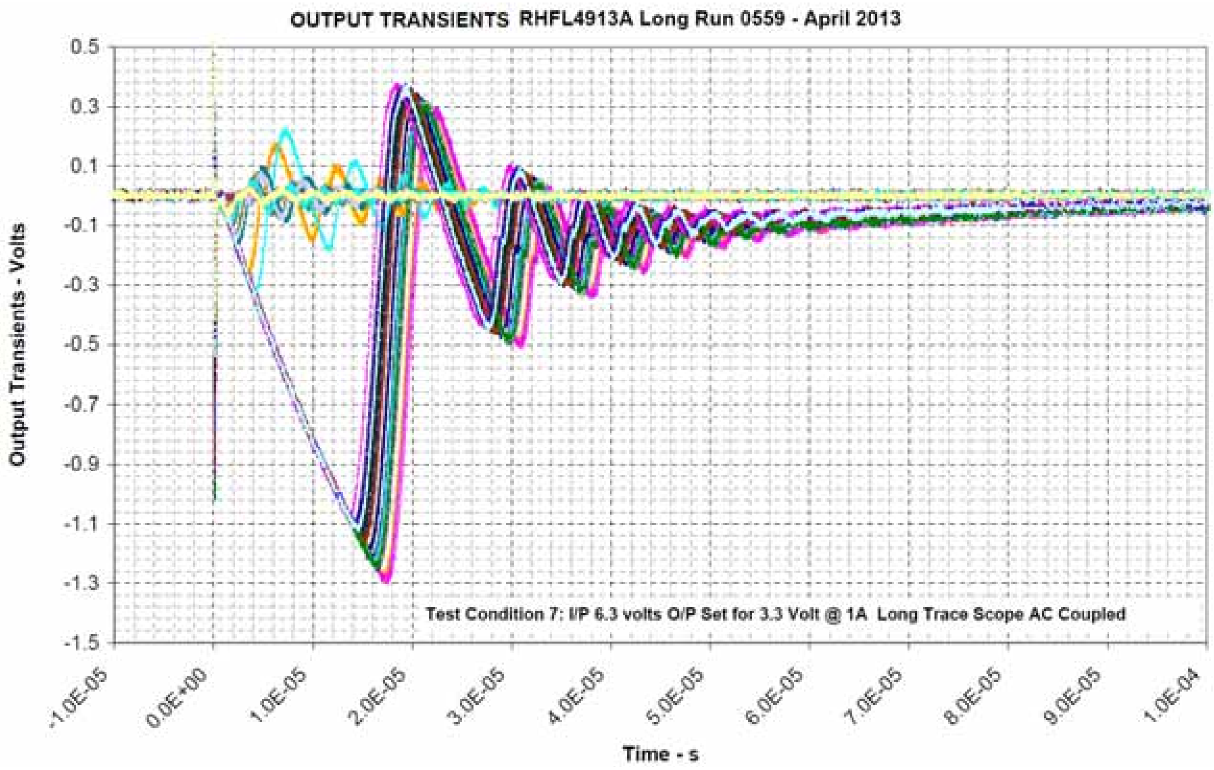


Figure 3.3-9: Output transients – Run 0559 – long timebase - HIGHER LOAD CURRENT (37.94mm, 46.957mm)

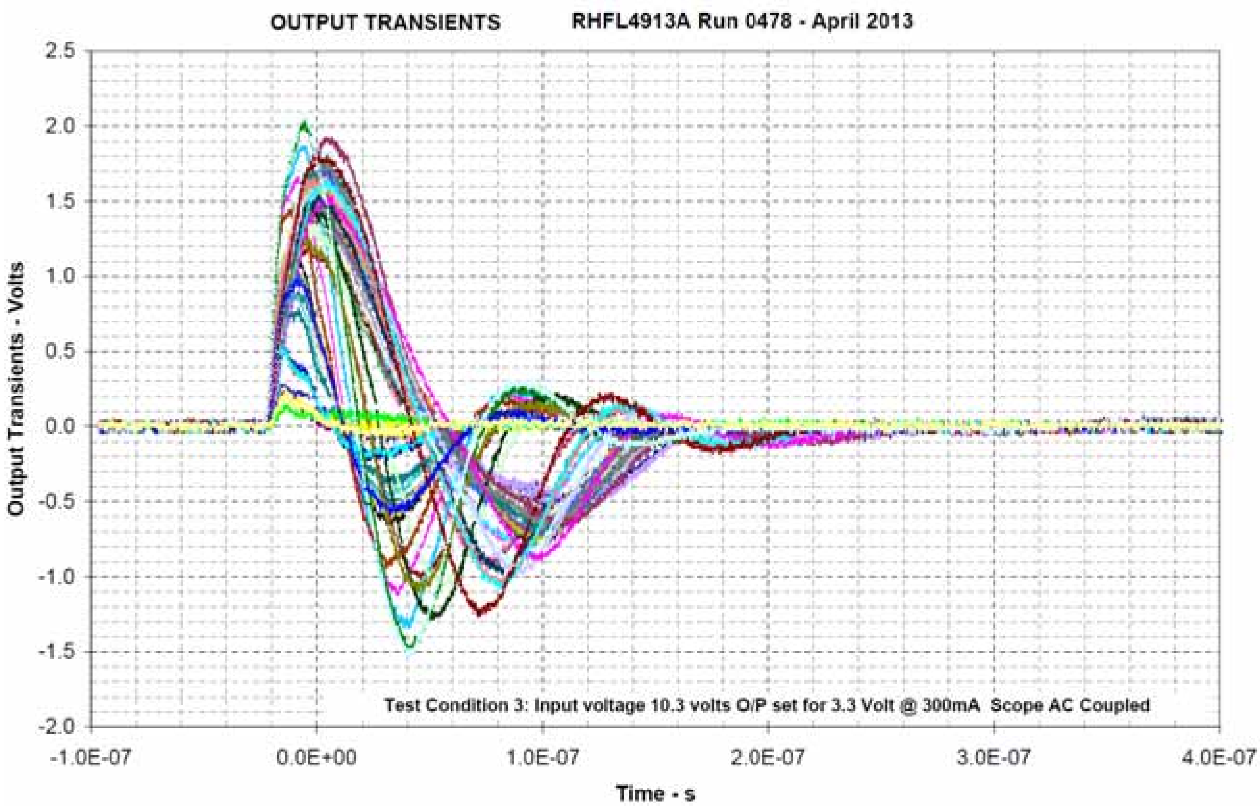


Figure 3.3-10: Output transients – Run 0478 – short timebase -HIGHER Vin to Vout (37.94mm, 46.957mm)

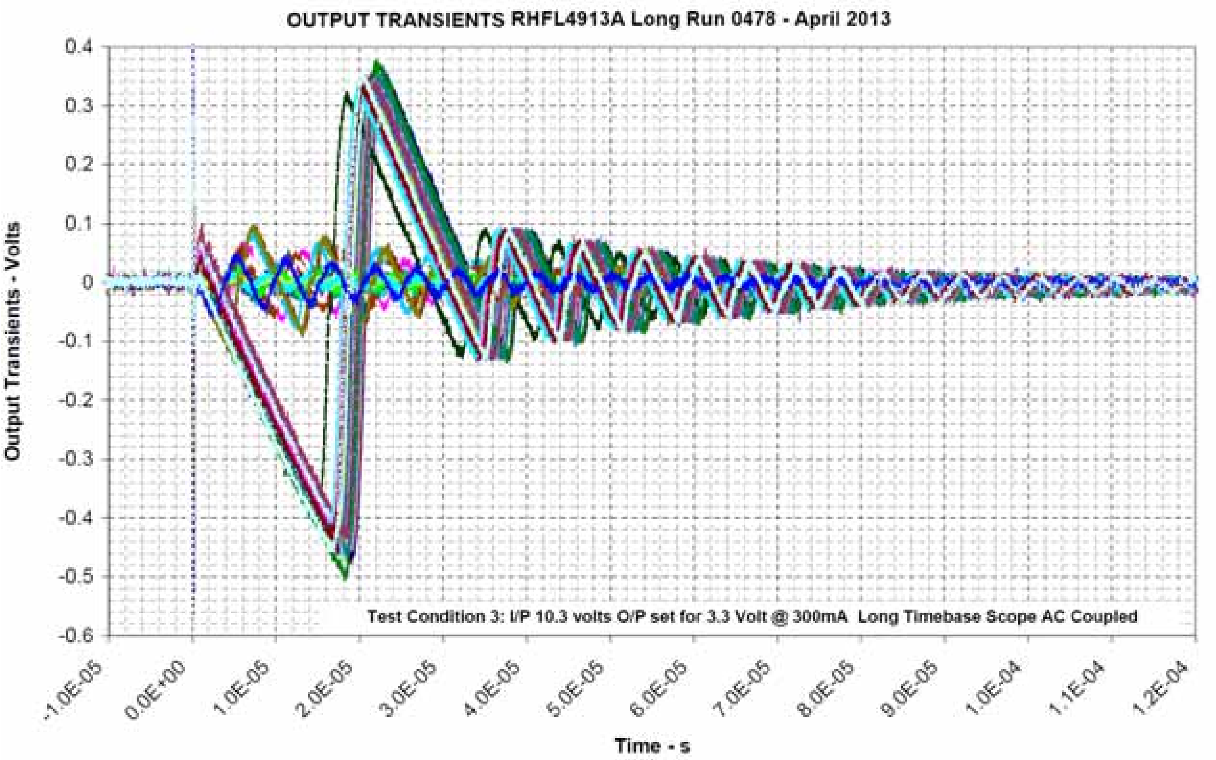


Figure 3.3-11: Output transients – Run 0478 – long timebase -HIGHER Vin to Vout (37.94mm, 46.957mm)

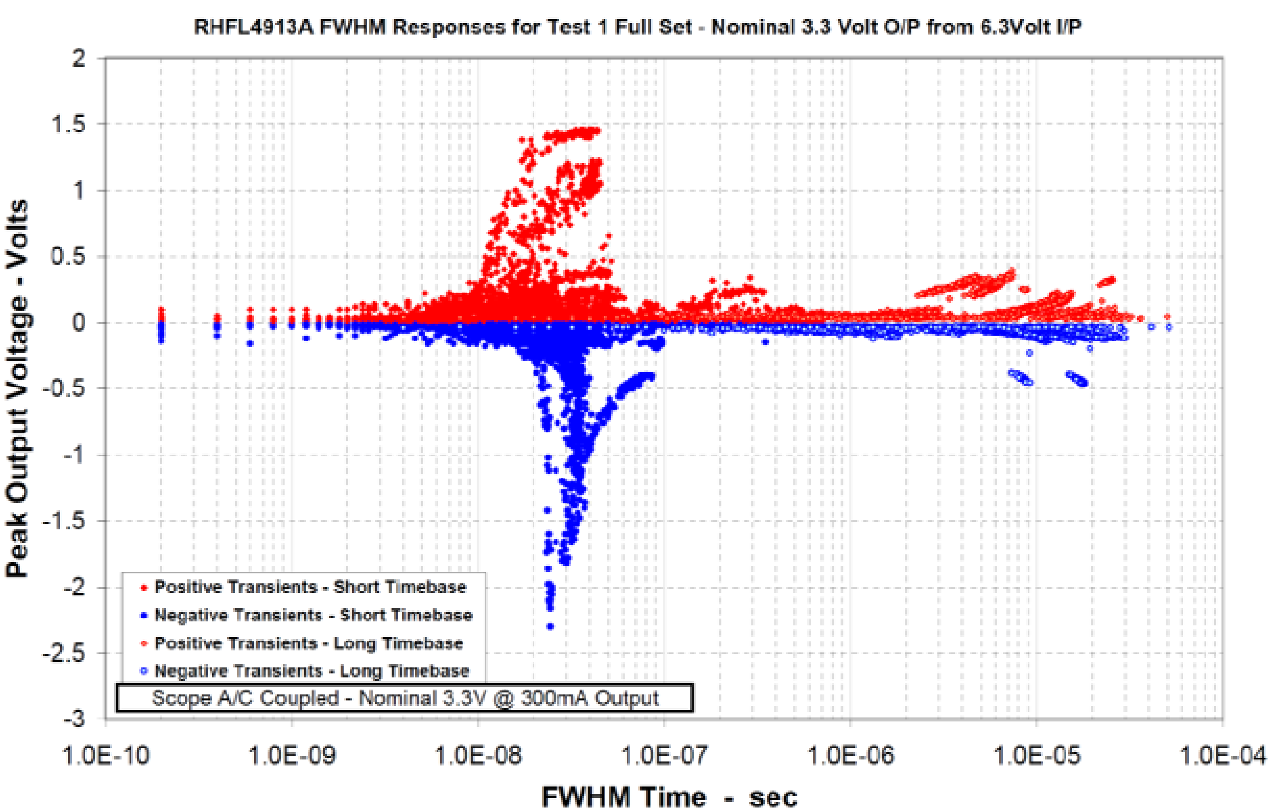


Figure 3.3-12: FWHM responses for test 1 – full set – nominal 3.3V O/P from 6.3V I/P

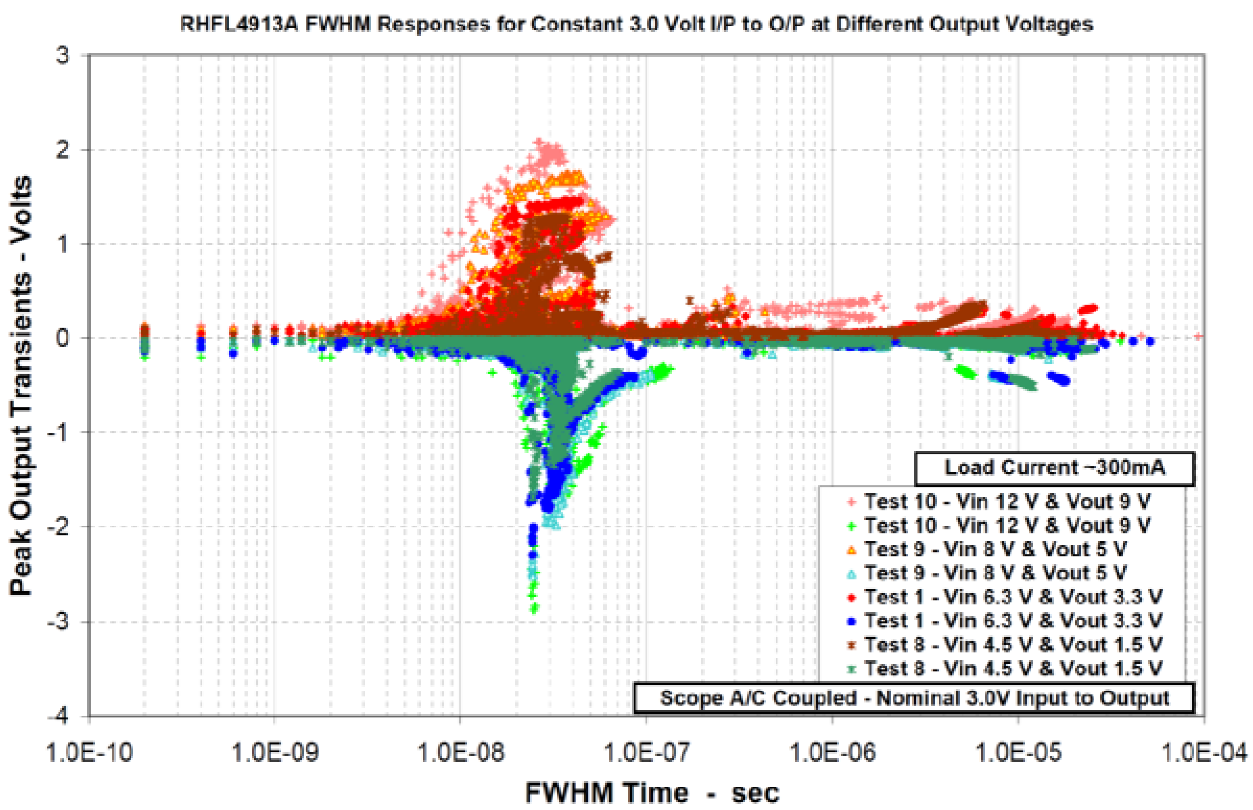


Figure 3.3-13: FWHM responses for constant 3V I/P to O/P at various O/P voltages

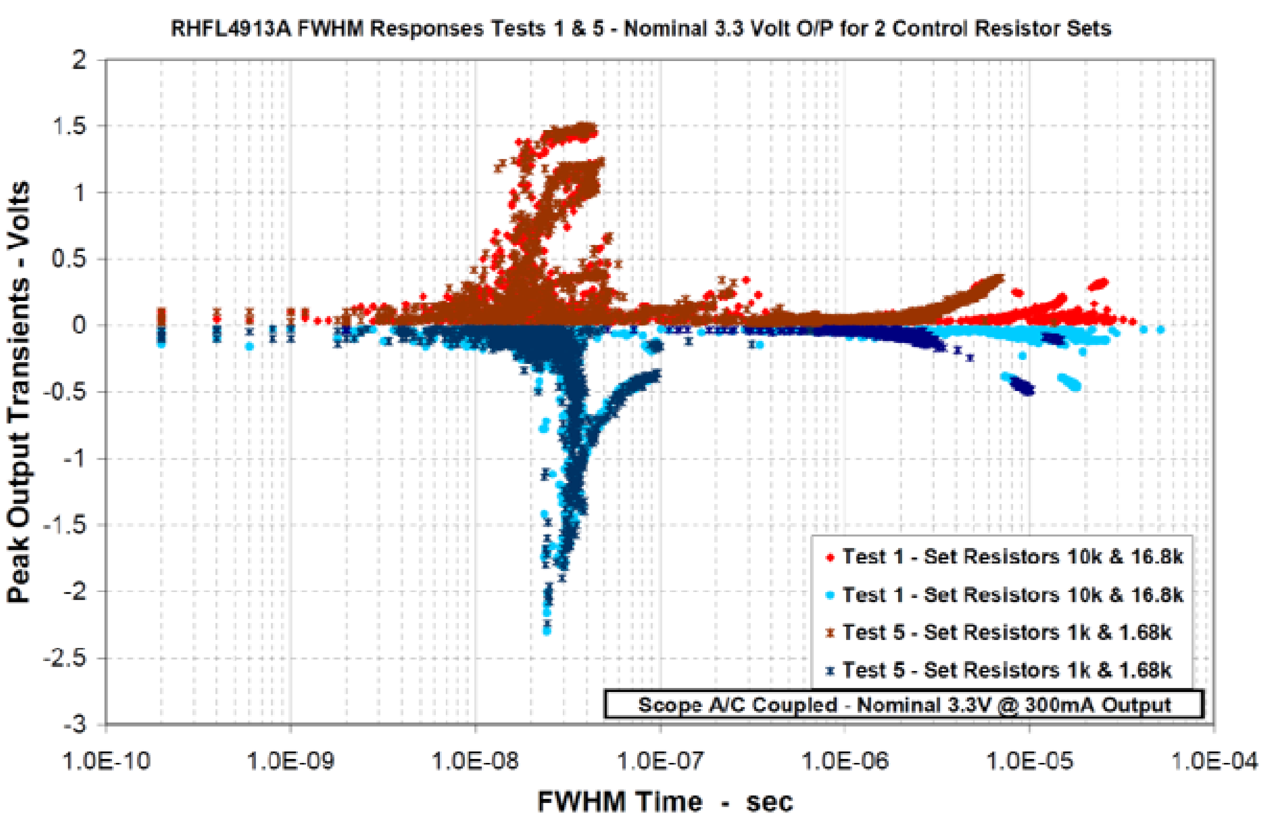


Figure 3.3-14: FWHM response tests 1 & 5 – nominal 3.3V O/P for 2 control resistor sets

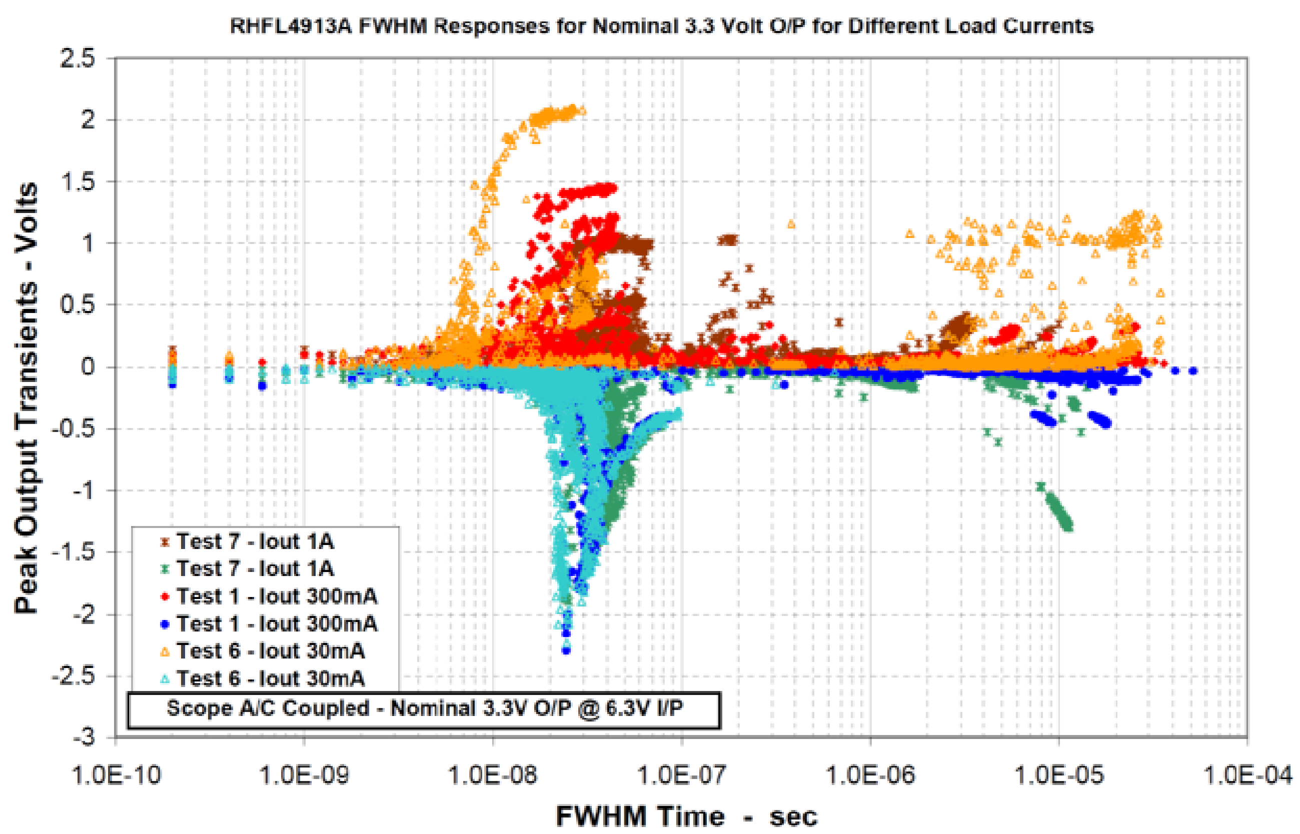


Figure 3.3-15: FWHM responses for nominal 3.3V O/P for different load currents

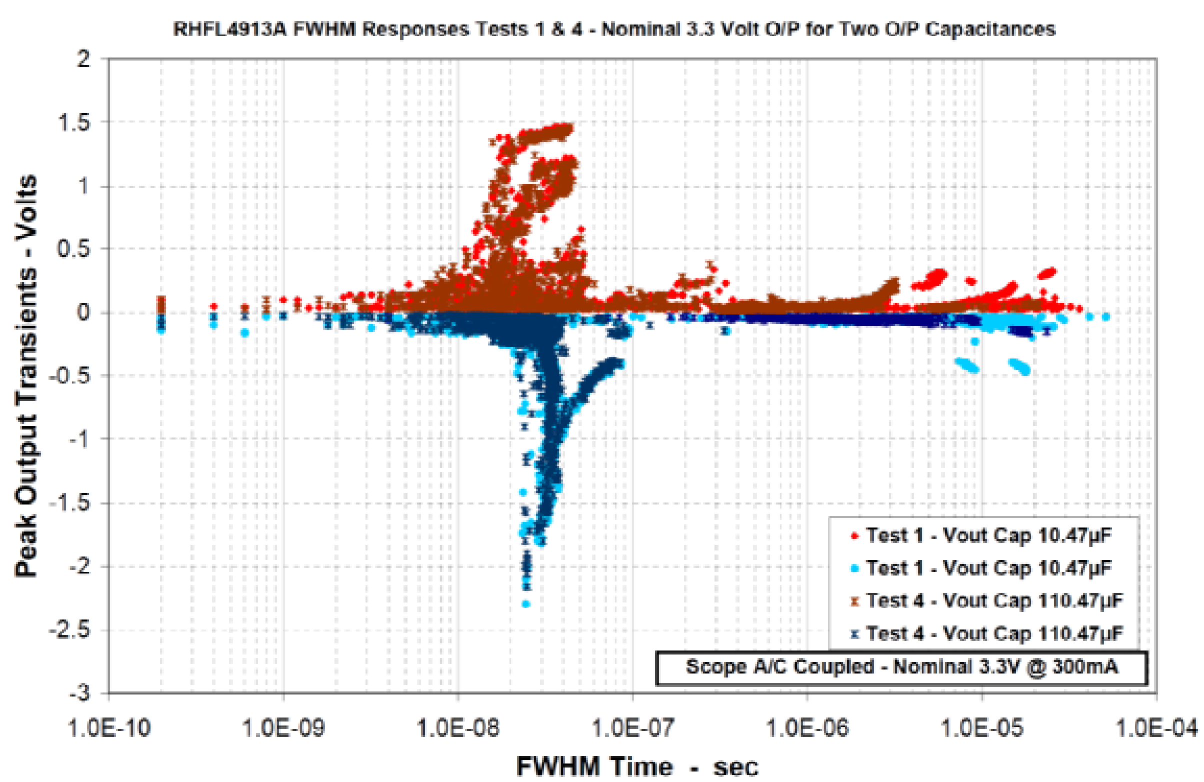


Figure 3.3-16: FWHM response tests 1 & 4 – nominal 3.3V O/P for 2 O/P capacitances

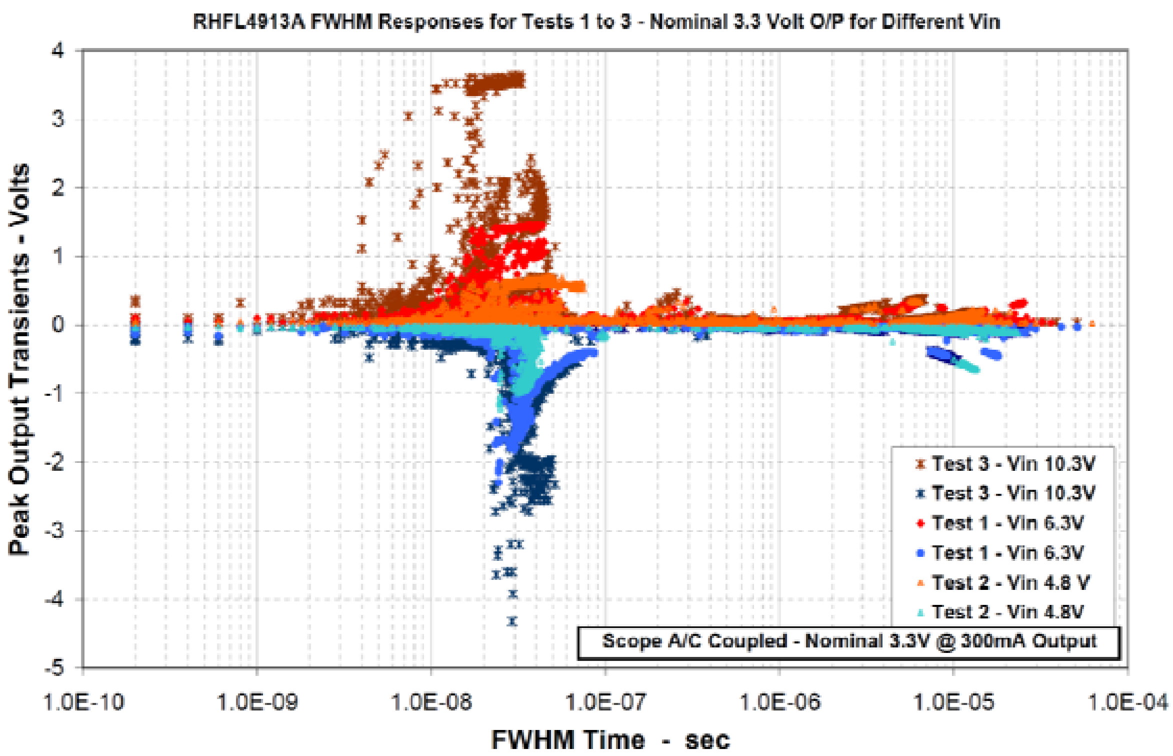


Figure 3.3-17: FWHM response for tests 1 to 3 – nominal 3.3V O/P for different Vin

4 LASER SET TESTING OF A G8340 PHOTODIODE & MAX3268 AMPLIFIER COMBINATION

4.1 Introduction

4.1.1 The MBDA Nd-YAG SEE laser was used to evaluate the single event transient (SET) responses of the Maxim MAX3268 1.25Gb/s Limiting Amplifier and Hamamatsu G8340 156Mb/s InGaAs Pin photodiode with preamplifier. The objective of the work was to provide SET amplitude verses duration (width) plots plus example worst case output behaviour transients for each device and incorporate the combined transient outputs. The MAX3268 was initially tested with the conditions: supply voltage set to 3.3 and 1.3 volts; +11mV input offset and ten spiral arrays of laser pulses were delivered to a range of significant die locations. The MAX3268 device was subsequently comprehensively laser scanned with test conditions: supply voltage set to 3.3 and 1.3 volts; +11mV input offset. The Hamamatsu G8340 was tested at 3.3 volt supply test conditions. The G8340 device consists of a detector diode and preamplifier and therefore will be laser scanned for the diode and spiral laser pulse arrays were delivered to a wide range of significant locations spread across the preamplifier.

4.1.2 The Maxim MAX3268 is a 1.25Gb/s Limiting Amplifier, with differential input and output having a maximum total gain of 55dB. The device also includes a signal RMS power detector with programmable loss of signal indicator. The operating voltage for the device is +3.0 to +5.5 volts. The differential pair output is positive referenced emitter coupled logic that is recommended to be driven into a 50 ohm load the lower end of which has to be biased to 2 volts below the supply voltage (not ground voltage); thus if the device supply is +3 volts the lower end of the load resistors need to be maintained at +1.0 volt. The large gain makes the amplifier susceptible to small DC offsets in the input signal therefore inputs need to be capacitively coupled such that the inputs operate about the mid supply voltage point with the differential signal only requiring to be <4 mV to achieve the maximum output signal (output voltage saturation).

4.1.3 The Hamamatsu G8340 is a 156 Mb/s receiver for 1.3 to 1.5 μm band optical fibre applications consisting of an InGaAs PIN photodiode with preamplifier. Investigations with the supplier indicated that the photodiode and the preamplifier are supplied by different manufacturers then integrated into the one package. Essentially the pre-amplifiers were bought in items and the pre-amplifier manufacturer continually made changes to the part making quality control difficult for Hamamatsu; thus, they have now withdrawn the G8340 part and only supply the photodiode without the preamplifier [G8195]. The G8340 has an operating voltage of 3.3 volts and requires a minimum output load of 500 ohms.

4.2 Trial Configuration

4.2.1 The test circuit is given in Figure 4.2-1. When the Hamamatsu G8340 is fitted the total supply voltage must be limited to 3.3 volts: thus the second power supply is set to 1.3 volts and the R1BIAS and R2BIAS resistors are not fitted. The coupling capacitors C1IN and C2IN are 220 nF. The trial of the MAX3268 was performed at 3.3 volts.

4.2.2 The +3.3 volt supply test on the MAX3268 was initially performed without the G8340 fitted and the R1BIAS and R2BIAS resistors were fitted using 15 kohms, which gave a differential input voltage of ~ 11 mV. Subsequently, the G8340 was inserted for testing and the bias resistors were removed. The tests were configured so as to give both positive and negative differential input voltages.

4.2.3 The MAX 3268 Die is shown in Figure 4.2-1. Its dimensions are 1.55 mm x 1.55 mm with a significant proportion used for the external bonding of the device and the compensation capacitor element occupying approximately one third of the active device area. The primary active area is therefore estimated to be around 1.3 mm x 1.1 mm. The active elements of the device are seen at the lower side of the die map. Given the nominal active zone dimensions a full row across the device will required 14 spirals of 122 pulses in each of 14 rows to cover the active area plus further targeted spiral sets. The full scan of the device therefore resulted in the device being exposed to a total of 196 spirals of laser pulses or 23912 laser pulses.

4.2.4 It was planned to purchase bare die of the MAX 3268 and have them mounted by a sub-contractor. However, after having initially accepted the order, the supplier eventually reported that the manufacturer had ceased supplying small quantities of bare die. Therefore, MBDA was obliged to purchase plastic encapsulated parts. The decapsulation process was difficult, due to the small physical size of the devices, and engendered further delays. However, a small number of satisfactorily decapsulated parts (see example in Figure 4.2-3) were eventually obtained, which have been successfully used for the laser SET trials.

4.2.5 Two samples of the G3840 were kindly provided by ESA plus also a useful analysis reports on these parts [11]. One of the G3840 device samples was decapsulated as shown in Figure 4.2-4 by milling around the base of the can. The can package contains the InGaAs photodiode (centre and Figure 4.2-5) and a pre-amplifier microchip (top and Figure 4.2-6), which were individually laser SET pulsed using spiral arrays. The photodiode is about 400µm x 400µm and the pre-amplifier is about 800µm x 800µm.

4.2.6 Details of the supply configuration during laser SET testing are indicated in the diagram of Figure 4.2-7.

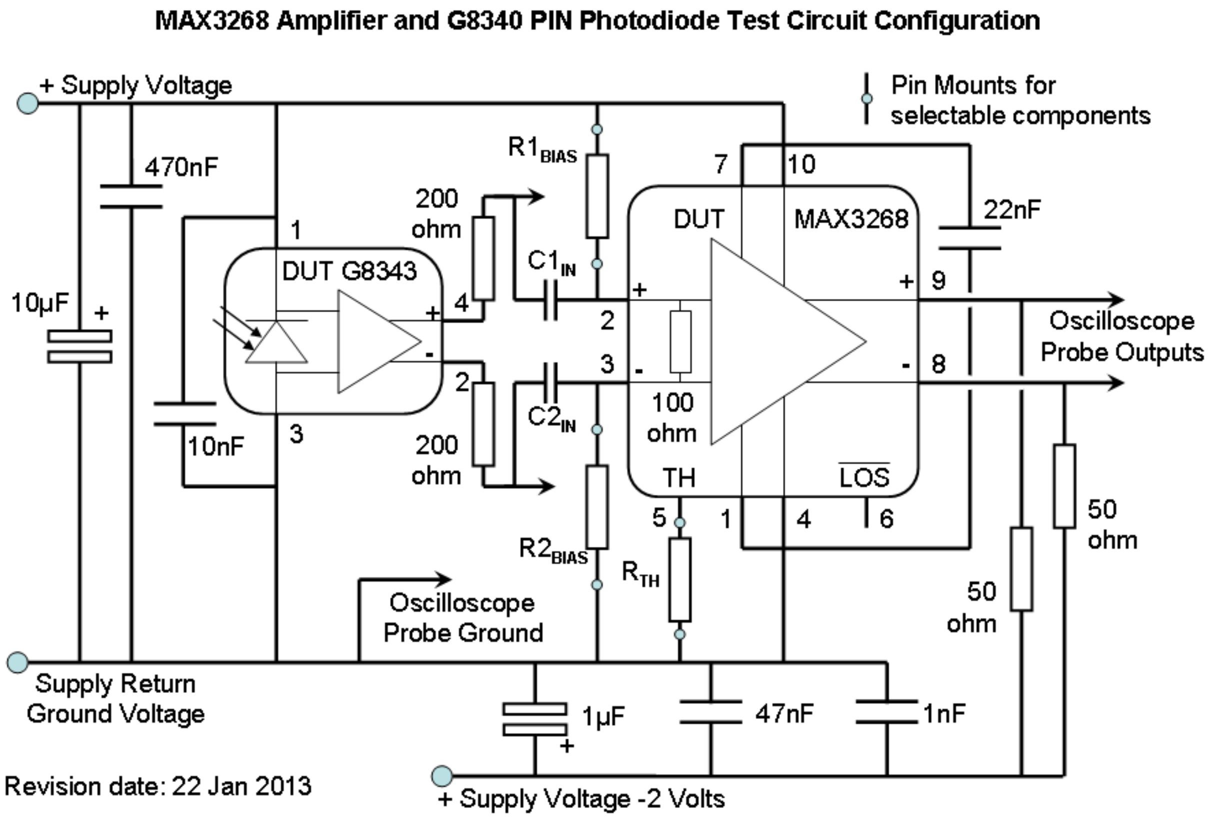


Figure 4.2-1: MAX3268 Amplifier and G8340 PIN Photodiode Test Circuit Configuration

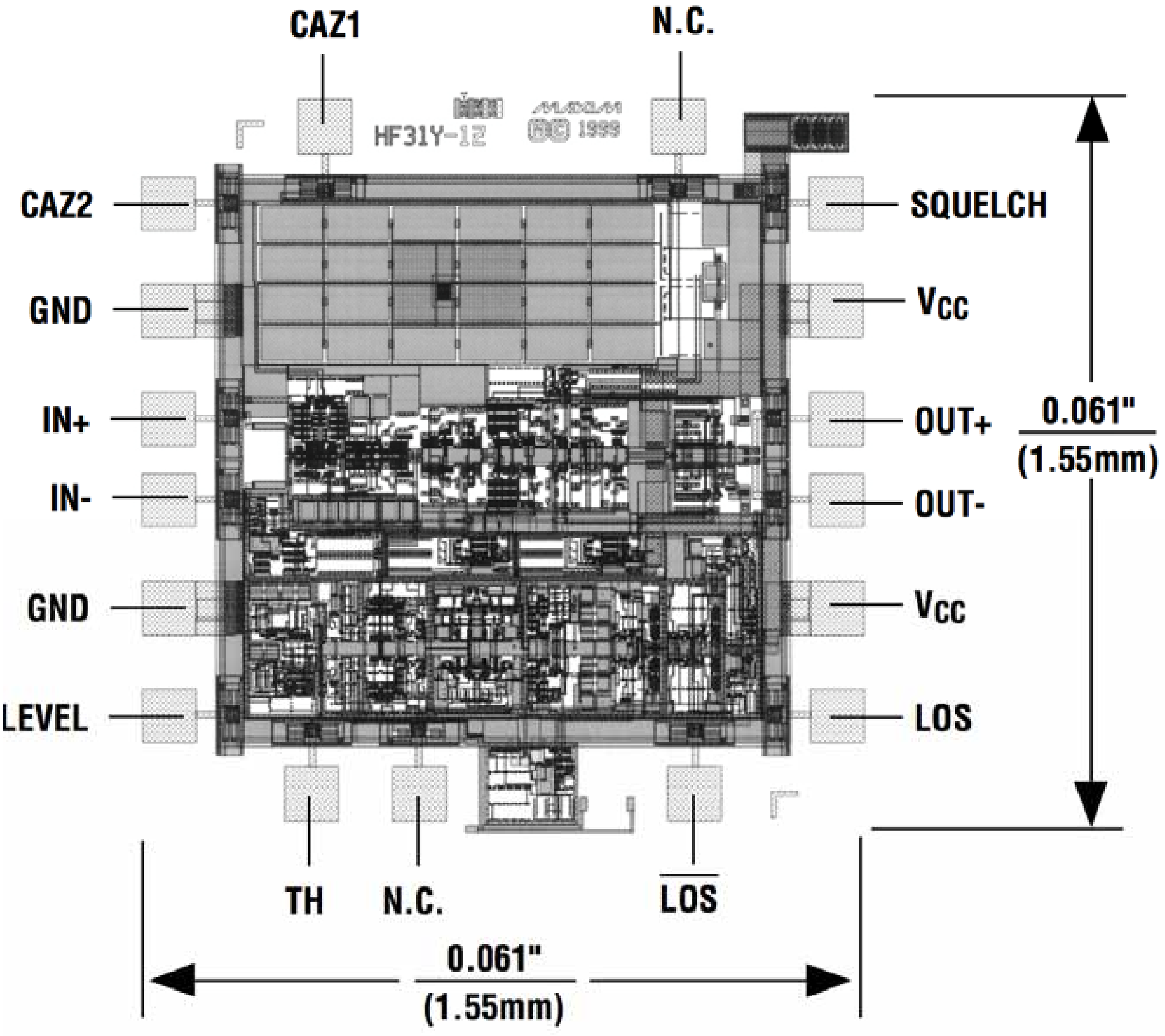


Figure 4.2-2: MAX3268 Amplifier die layout

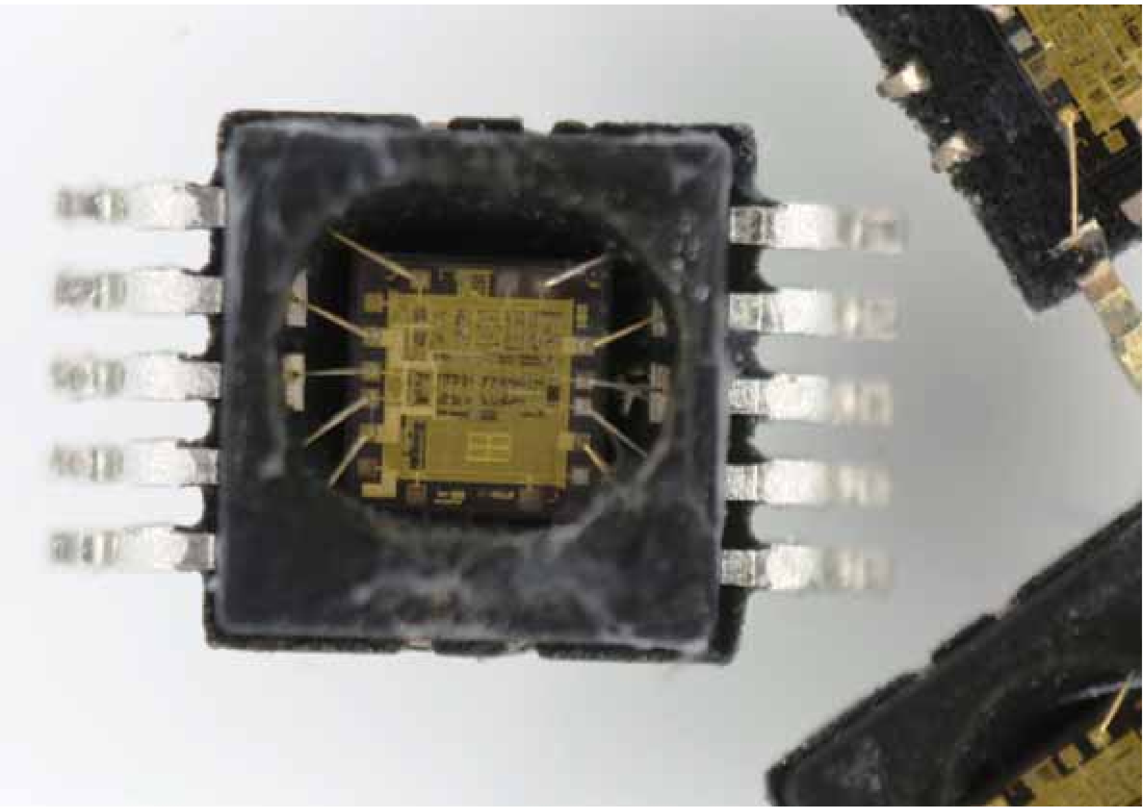


Figure 4.2-3: Plastic decapsulated sample of the Maxim MAX3268 Amplifier

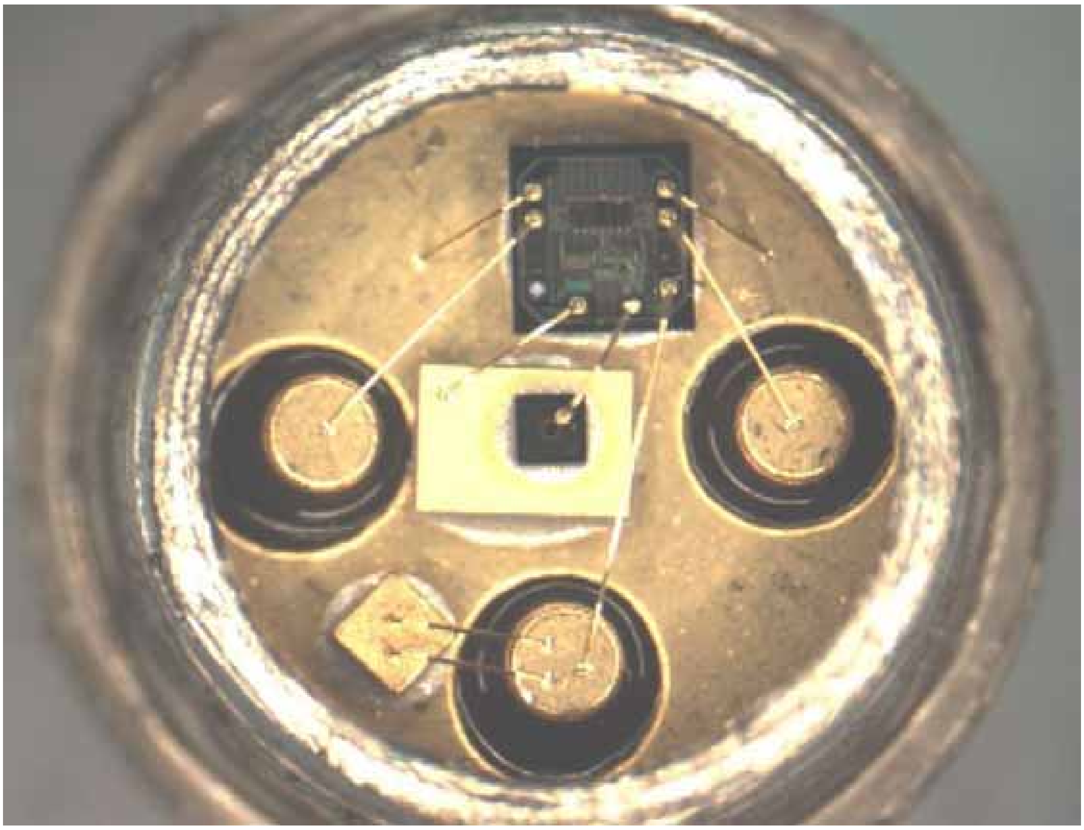


Figure 4.2-4: G8340 Can layout

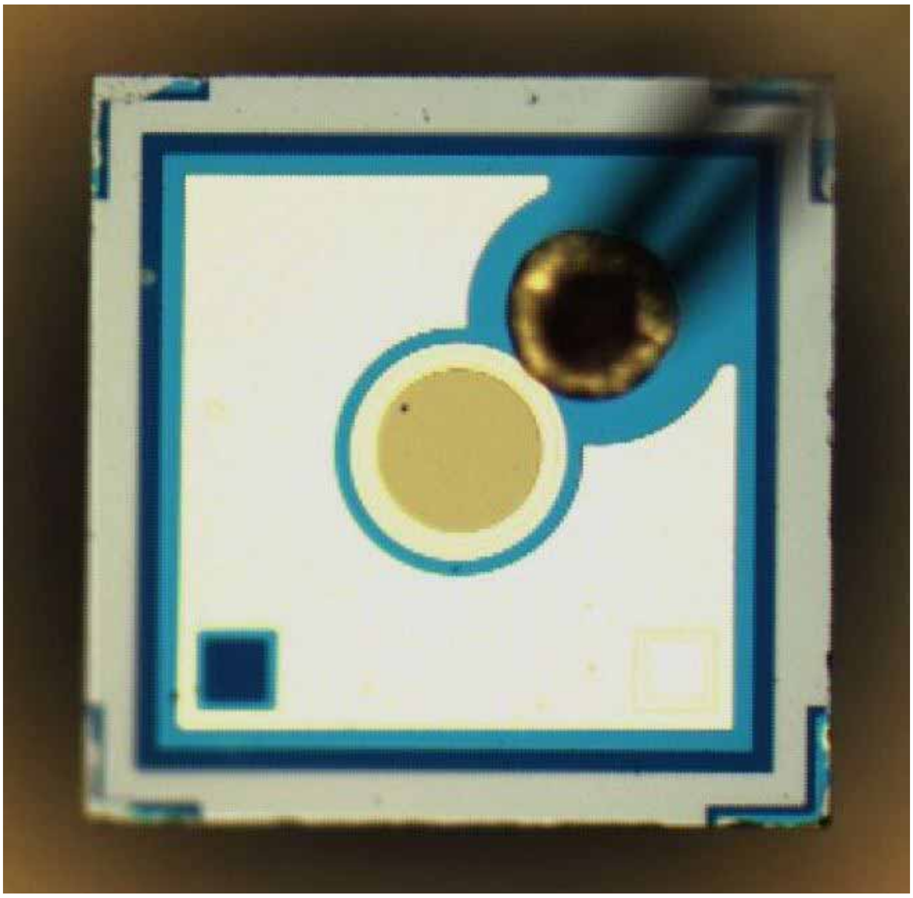


Figure 4.2-5: G8340 Photodiode die

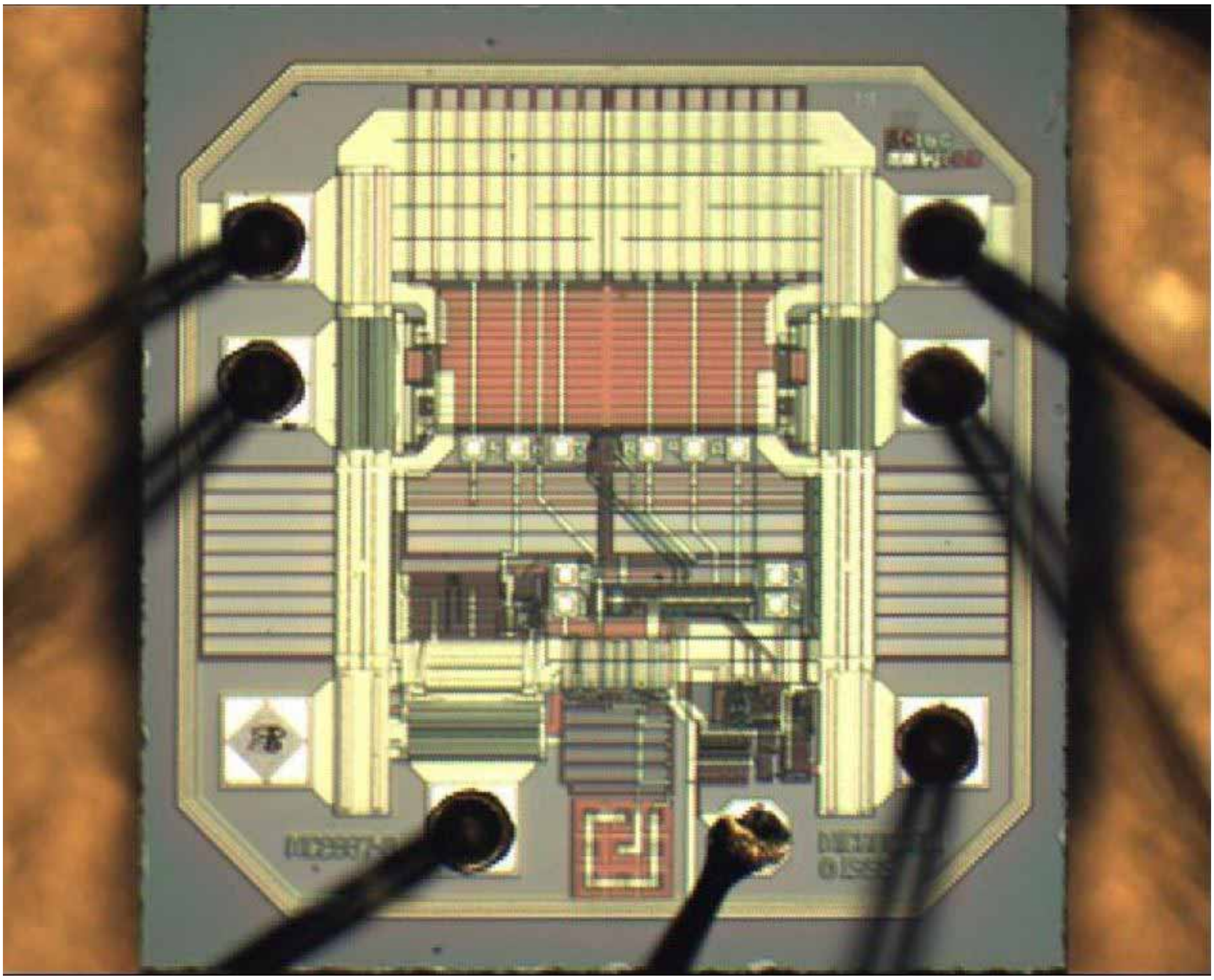


Figure 4.2-6: G8340 Pre-Amplifer die layout

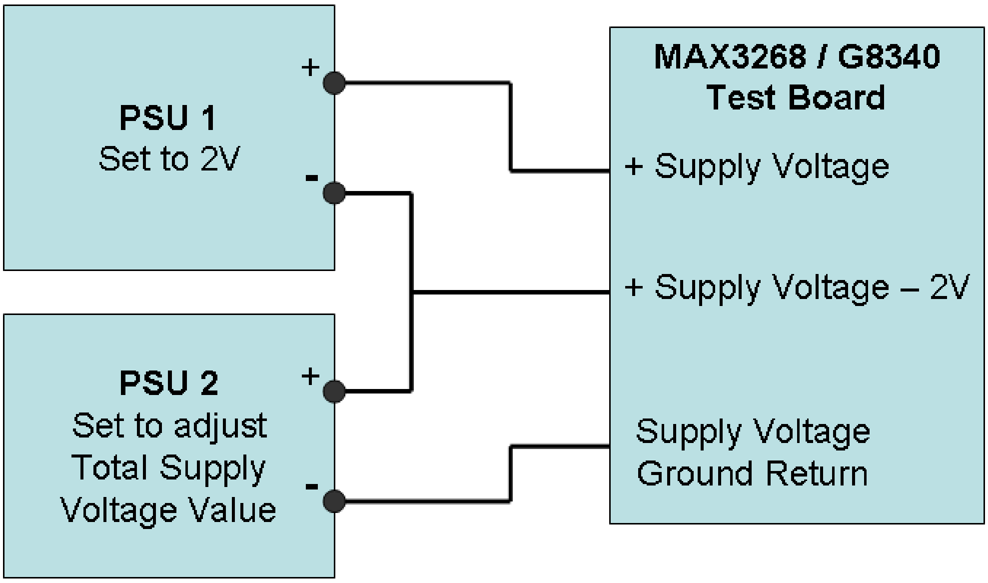


Figure 4.2-7: Supply configuration during laser SET testing

4.3 MAX3268 Amplifier Laser SET Results

4.3.1 The first stage of the trial was the delivery of a range of 19 spiral laser pulse arrays across a scatter of locations as shown in Figure 4.3-1. Test conditions were: supply voltage set to 3.3 and 1.3 volts; +11mV input offset. The G8340 device was not included in the circuit – its outputs were defined by the resistors R1bias and R2bias in Figure 4.2-1, both set to 15kΩ. $R_{threshold}$ was set at 2.7kΩ. Supply current was 57mA. The purpose was to get an initial idea of the range of SET sensitivities exhibited, so as to determine the laser pulse energies that would be most appropriate and productive for the comprehensive laser pulse scan of the die. Laser pulse energies were 35pJ for shot 22; 80pJ for shot 23; 90pJ for shots 5 & 6; 350pJ for shots 7-10, 12, 14, 16, 18 & 20; 960pJ for shots 11, 13, 15, 17, 19 & 21.

4.3.2 Subsequently, a full die scan distribution of spiral arrays enumerated as shown in Figure 4.3-2 was delivered at a laser pulse energy of 60pJ (this equates roughly to an LET of 16MeV cm^2/mg). In Figure 4.3-3 the spiral array locations are colour coded for the approximate sensitivity of the die at each location. The capacitor bank in the upper third of the die shows significant sensitivity. Seemingly, the pulses are instigating partial discharges. Then there are two sub-regions of high SET sensitivity in the detailed logic in the lower portons of the die.

4.3.3 Example SET positive line (pin 9) outputs for the spiral arrays of shots 20 to 23 are shown in Figures 4.3-4 to 4.3-7. These were for a moderately sensitive location near the top edge of the array. The transients developed significantly with increasing pulse energy from a 0.5V amplitude negative-going spike of very narrow width at the bottom of the pulse energy range to a squarish negative pulse of 0.75V magnitude and a step reduction after 0.05µs to 0.4V offset, which last many µs's.

4.3.4 Example SETs groups from selected spiral shots from the comprehensive scan are shown in Figures 4.3-8 to 4.3-14, including a few summary plots of maximum amplitudes (generally negative-going) versus Full Width Half Maximum (FWHM) duration. The low laser pulse energy of ~35pJ was delivered in each of these cases. The amplitude-duration plots show that the events tended to saturate in amplitude at low levels of negative voltage deviation. The amplitude-duration plot of Figure 4.3-14 in particular shows that these SETs exhibited several different plateaus (~1.6V, ~1.5V and ~1.3V). This appears to reflect the plateaus in the Sets themselves (i.e. in the corresponding SET group of Figure 4.3-13.)

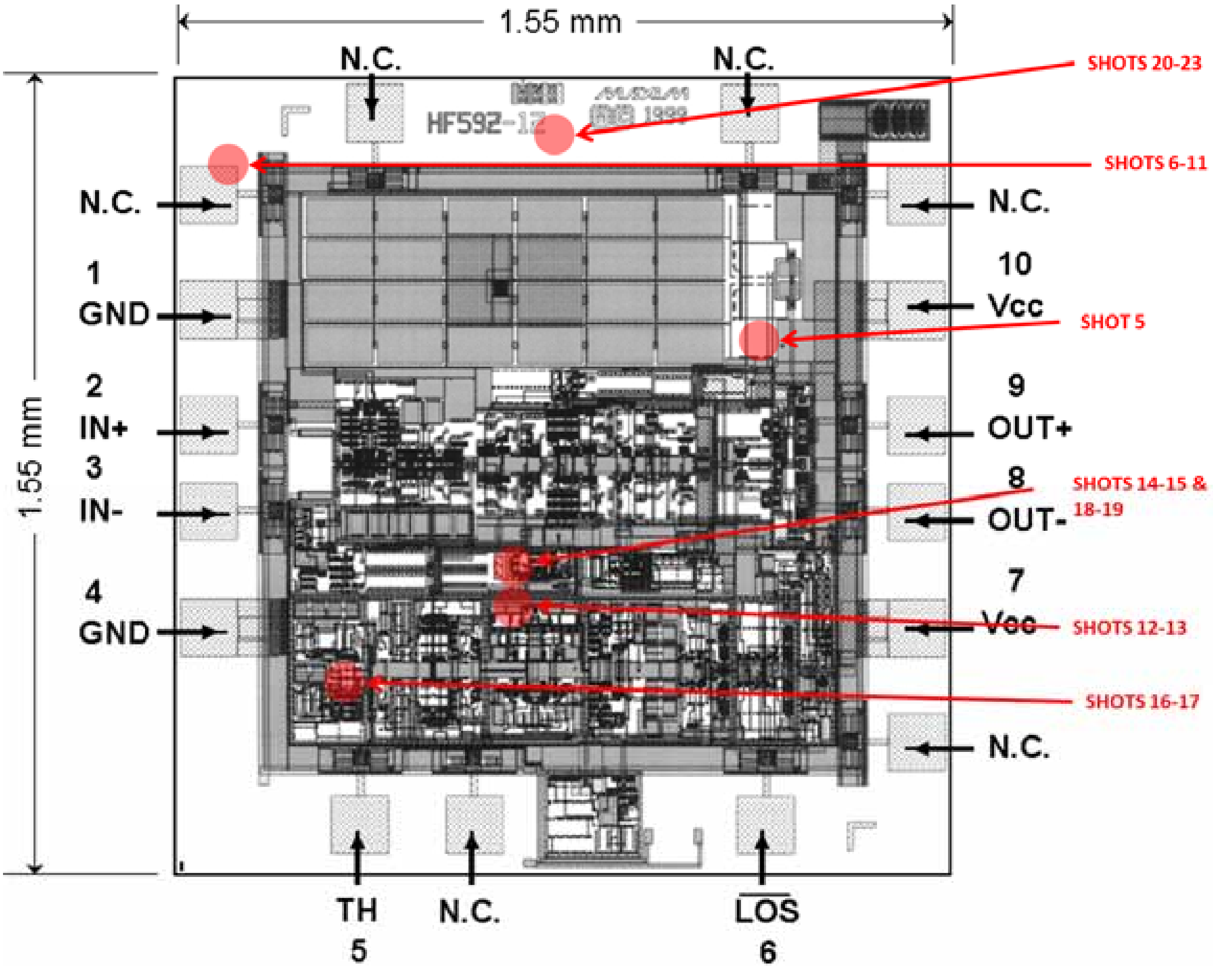


Figure 4.3-1: Initial scatter of MAX3268 spiral laser pulse arrays (enumerated)

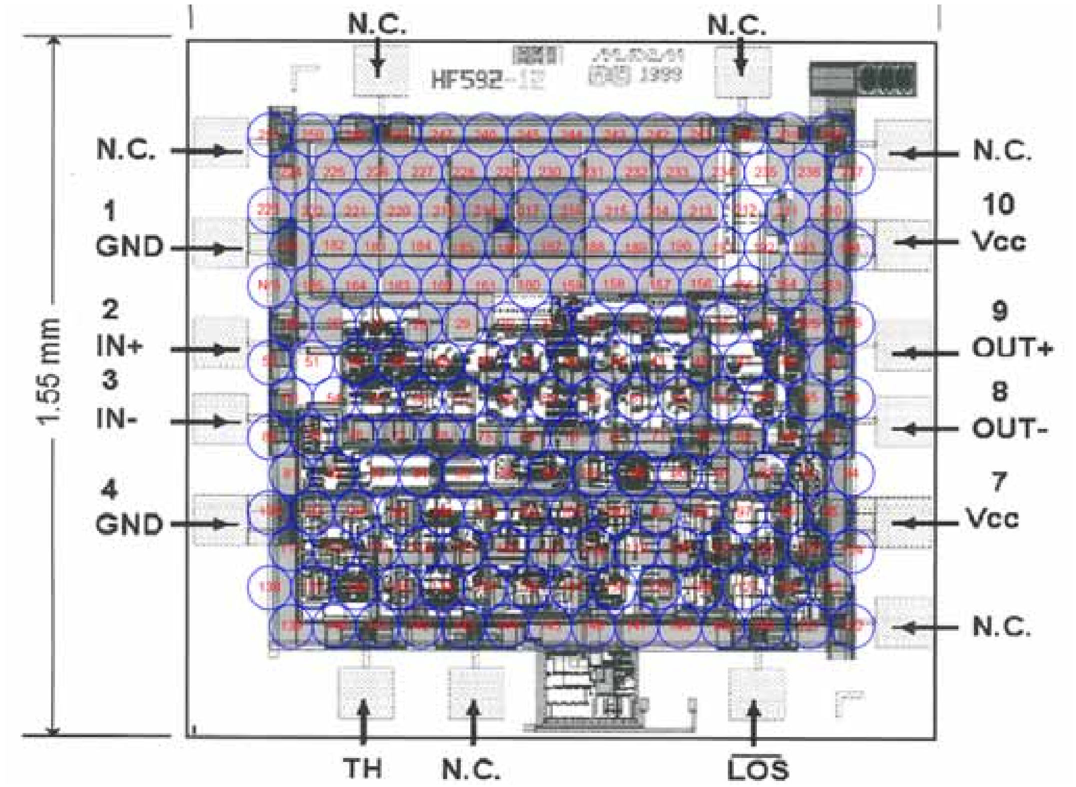


Figure 4.3-2: Full distribution of MAX3268 spiral laser pulse arrays (enumerated)

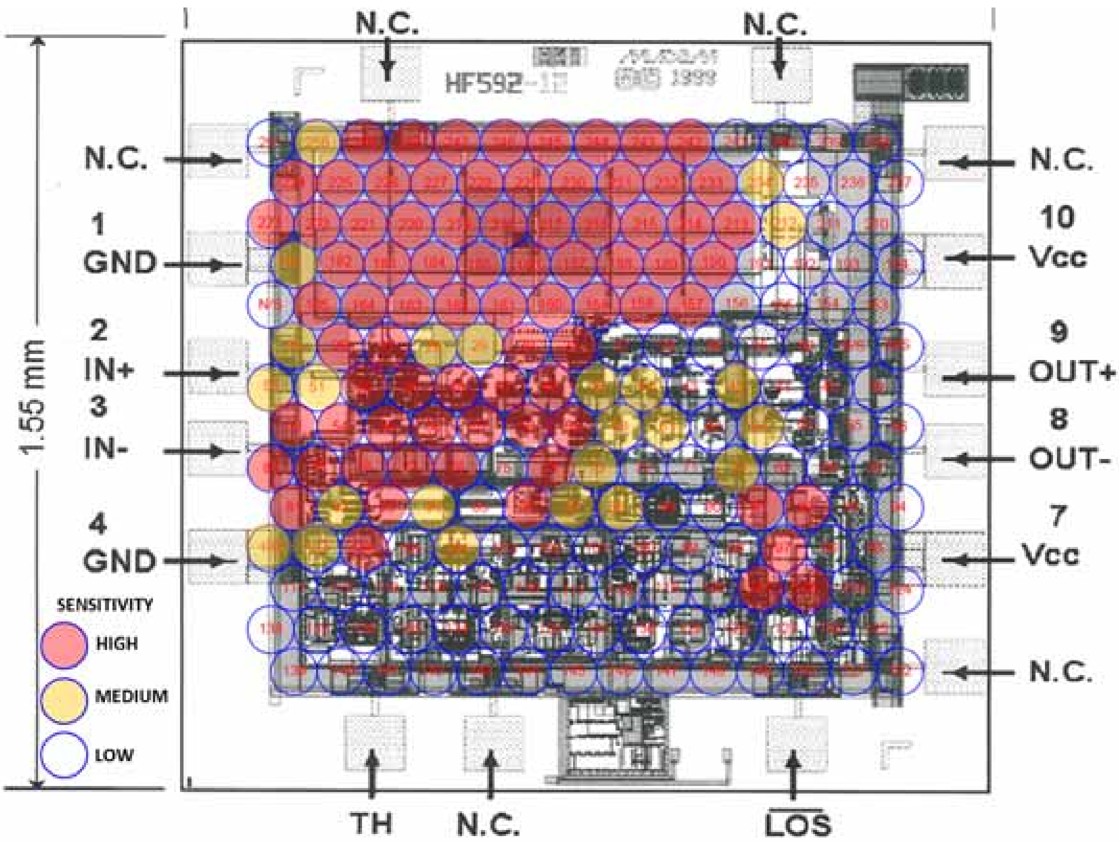


Figure 4.3-3: MAX3268 SET Sensitivities (pink=highest, yellow=medium, none=low)

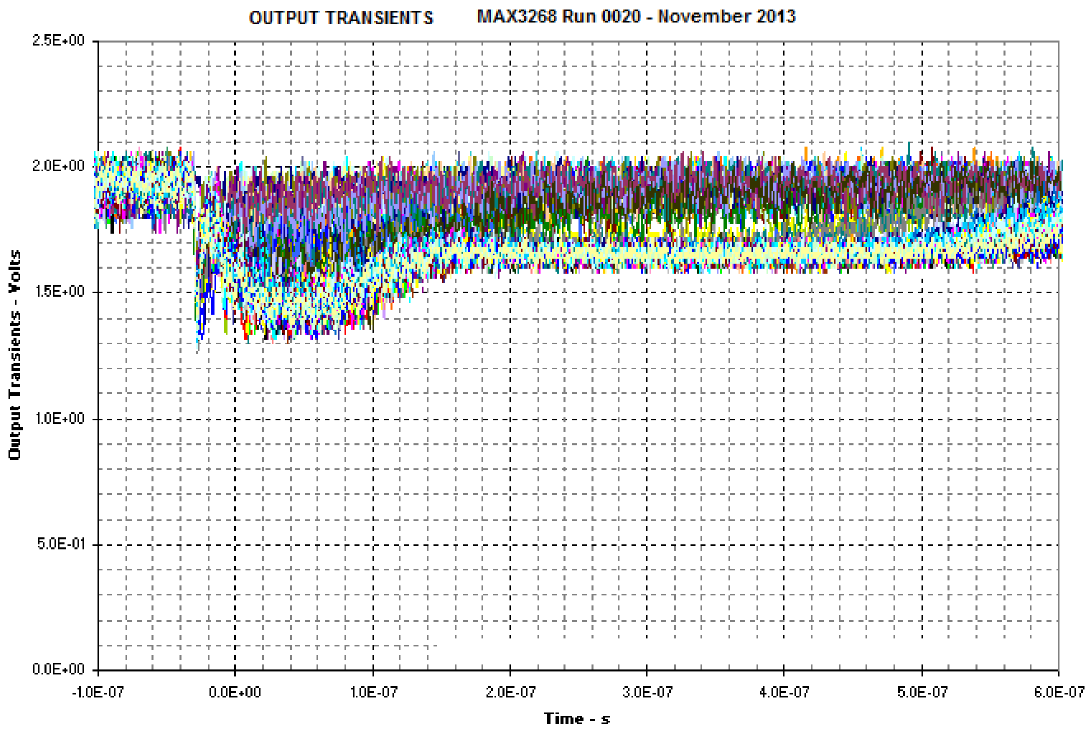


Figure 4.3-4: Shot 20 - Comparative at x4 and 170 attenuator & Laser Pulse Energy ~350pJ

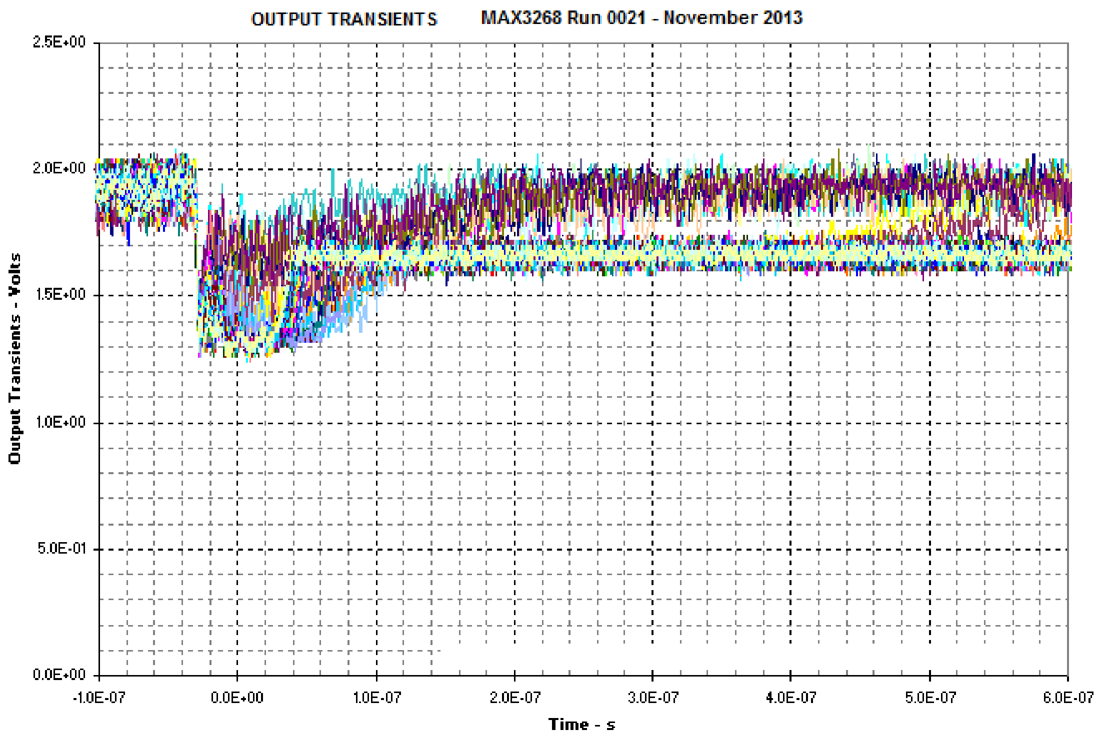


Figure 4.3-5: Shot 21 - Comparative at x4 and 220 attenuator & Laser Pulse Energy ~ 960pJ

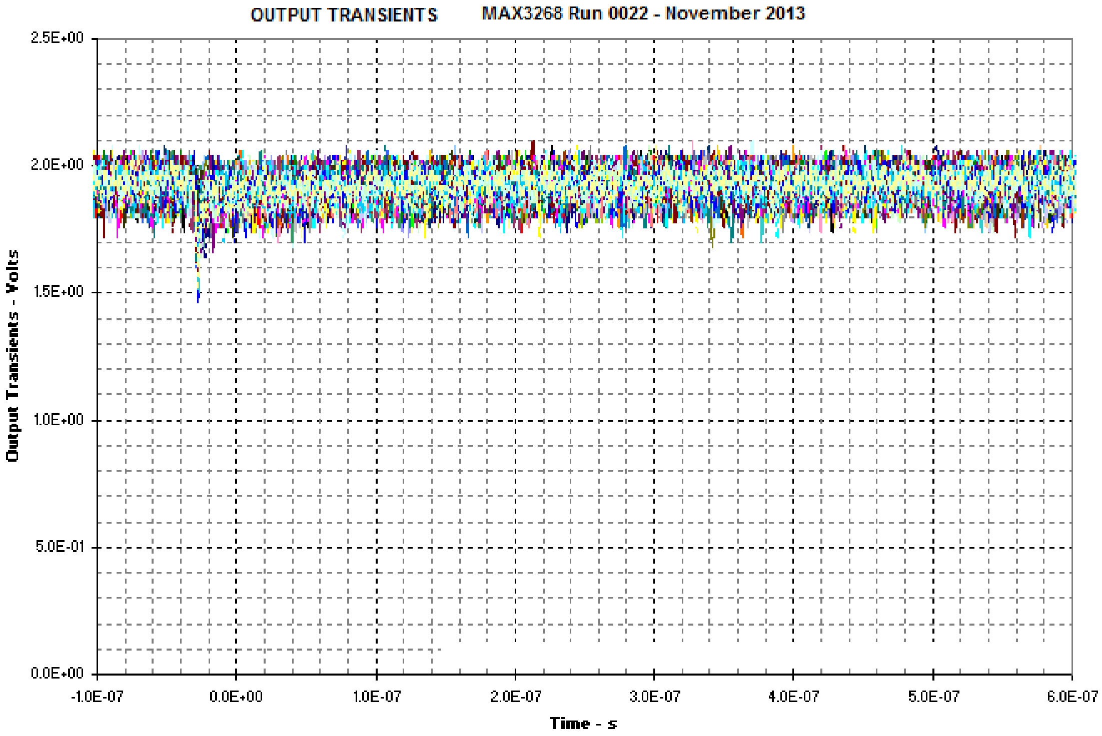


Figure 4.3-6: Shot 22 - Comparative at x4 and 60 attenuator & Laser Pulse Energy ~ 35pJ

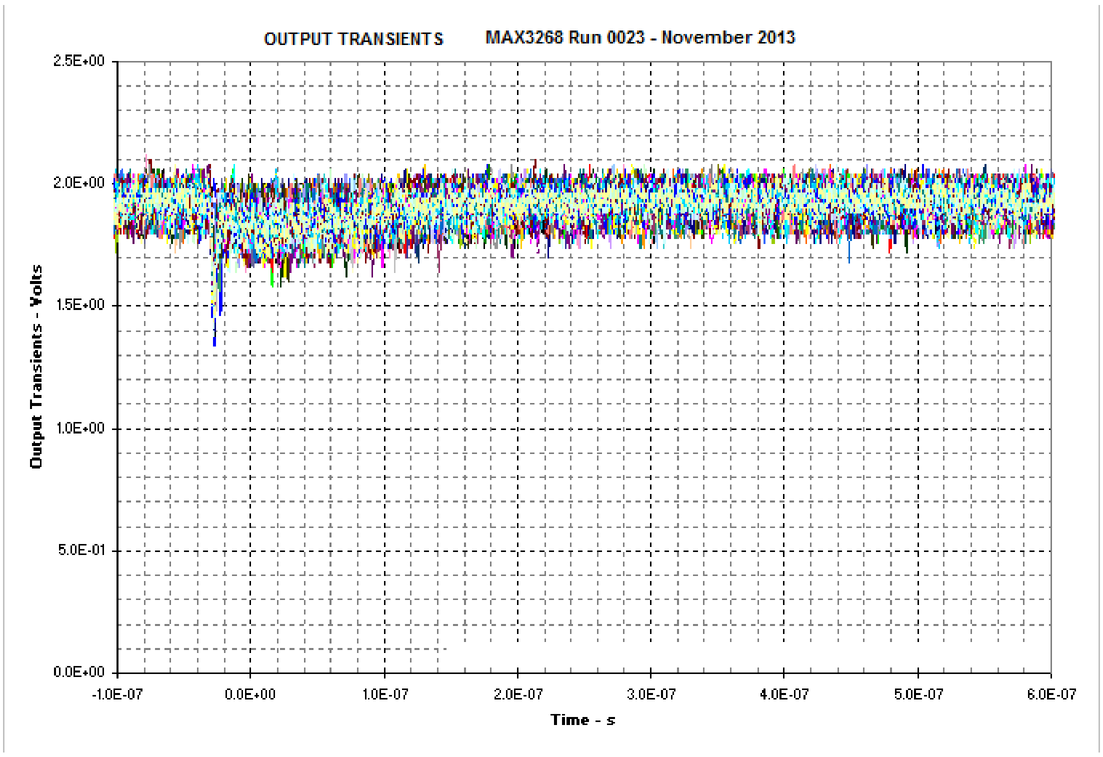


Figure 4.3-7: Shot 23 - Comparative at x4 and 100 attenuator & Laser Pulse Energy ~80pJ

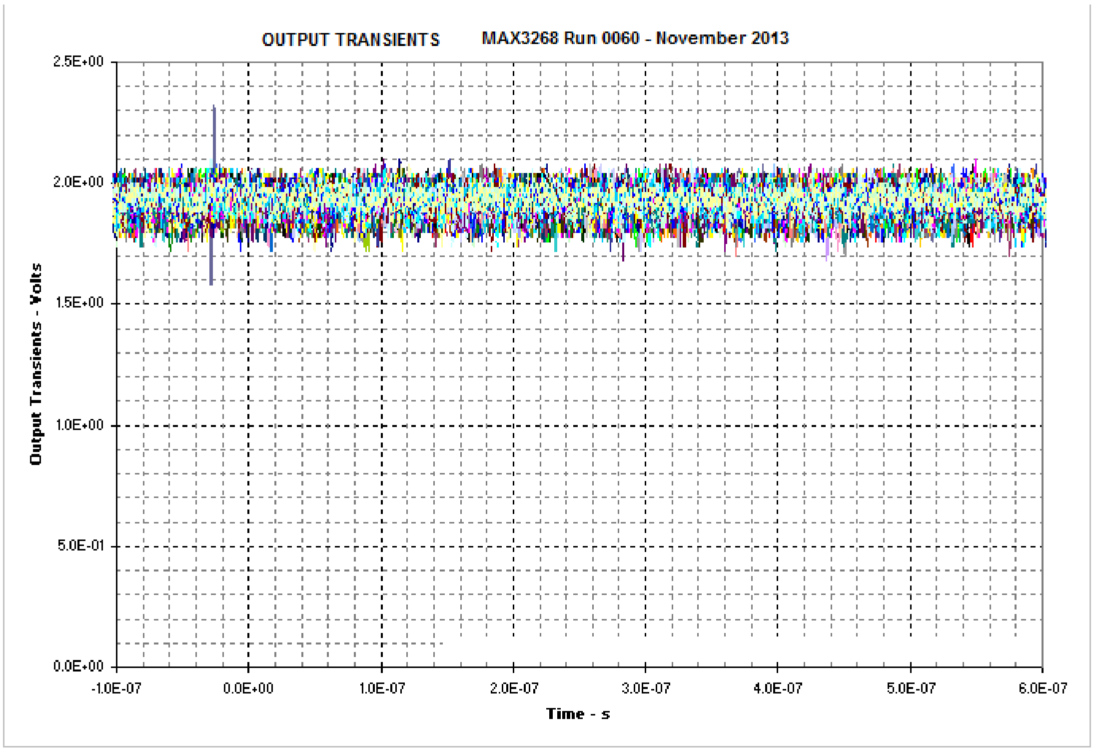


Figure 4.3-8: Shot 60 small output transient & Laser Pulse Energy ~ 35pJ

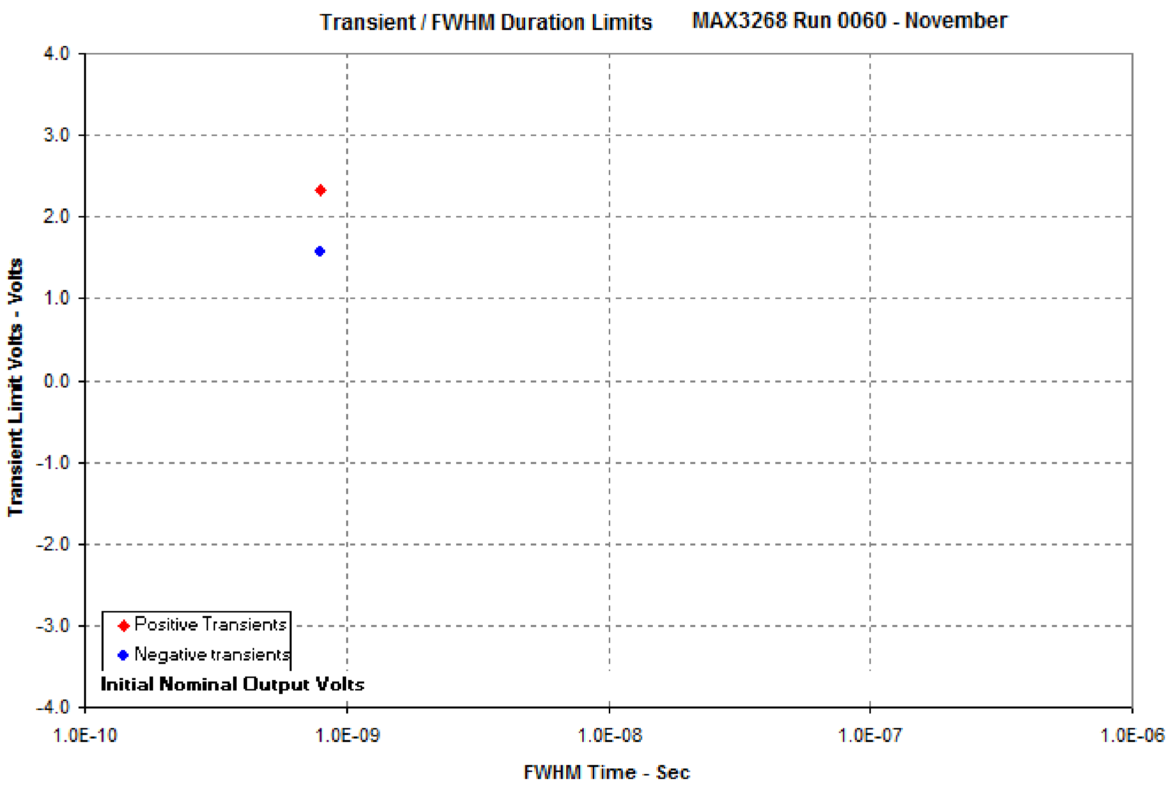


Figure 4.3-9: Shot 60 Transient FWHM duration Limits & Laser Pulse Energy ~ 35pJ

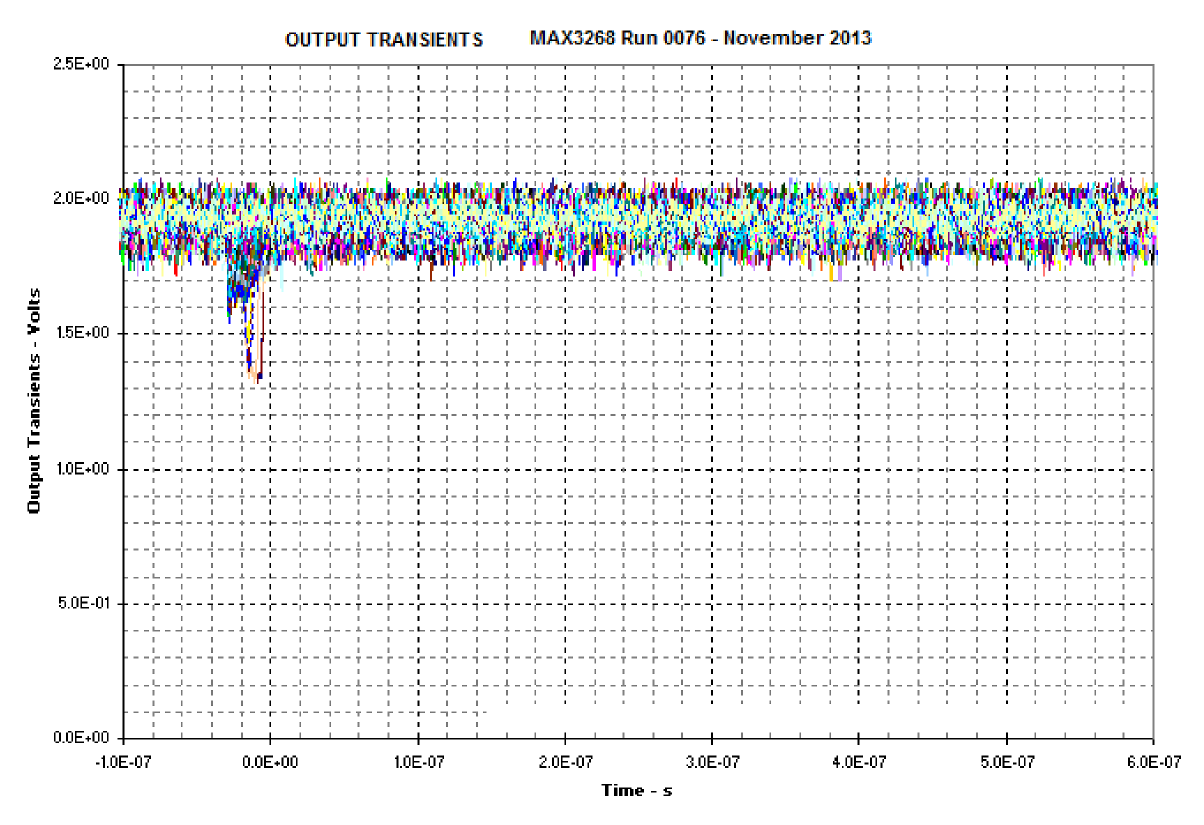


Figure 4.3-10: Shot 76 Output neg transient (35pJ)

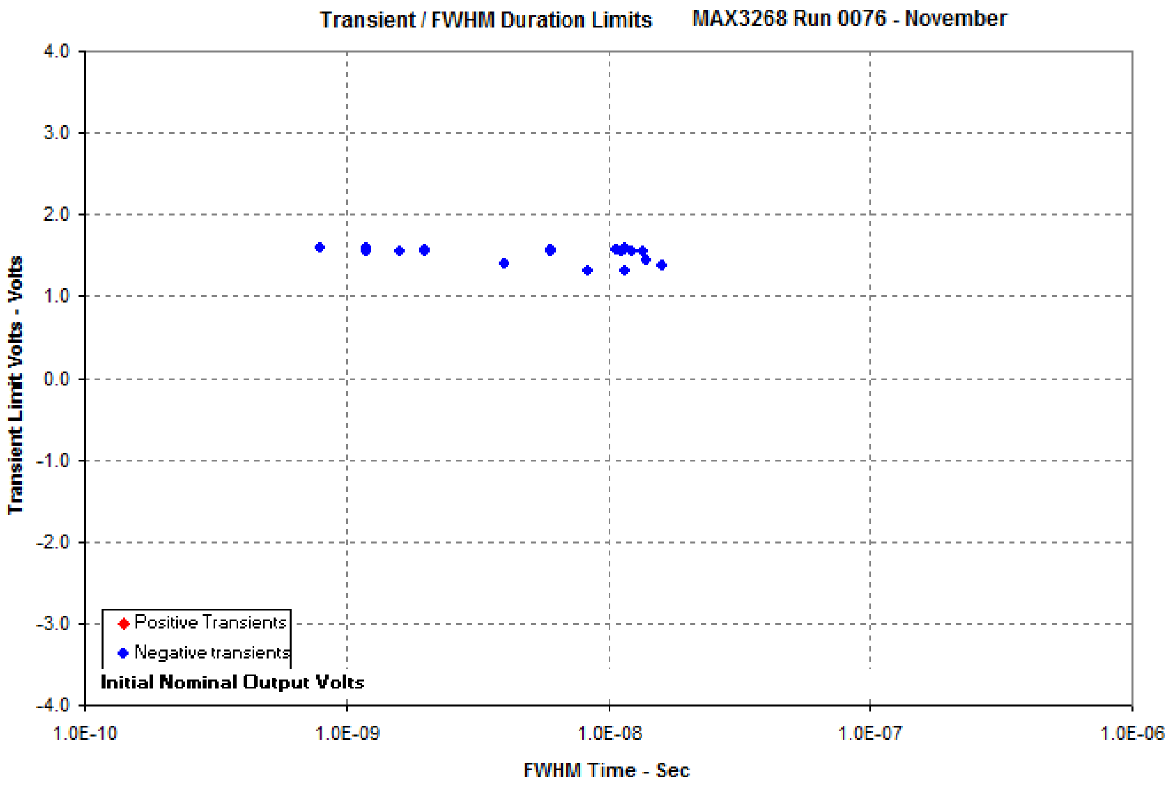


Figure 4.3-11: Shot 76 Transient FWHM duration Limits (35pJ)

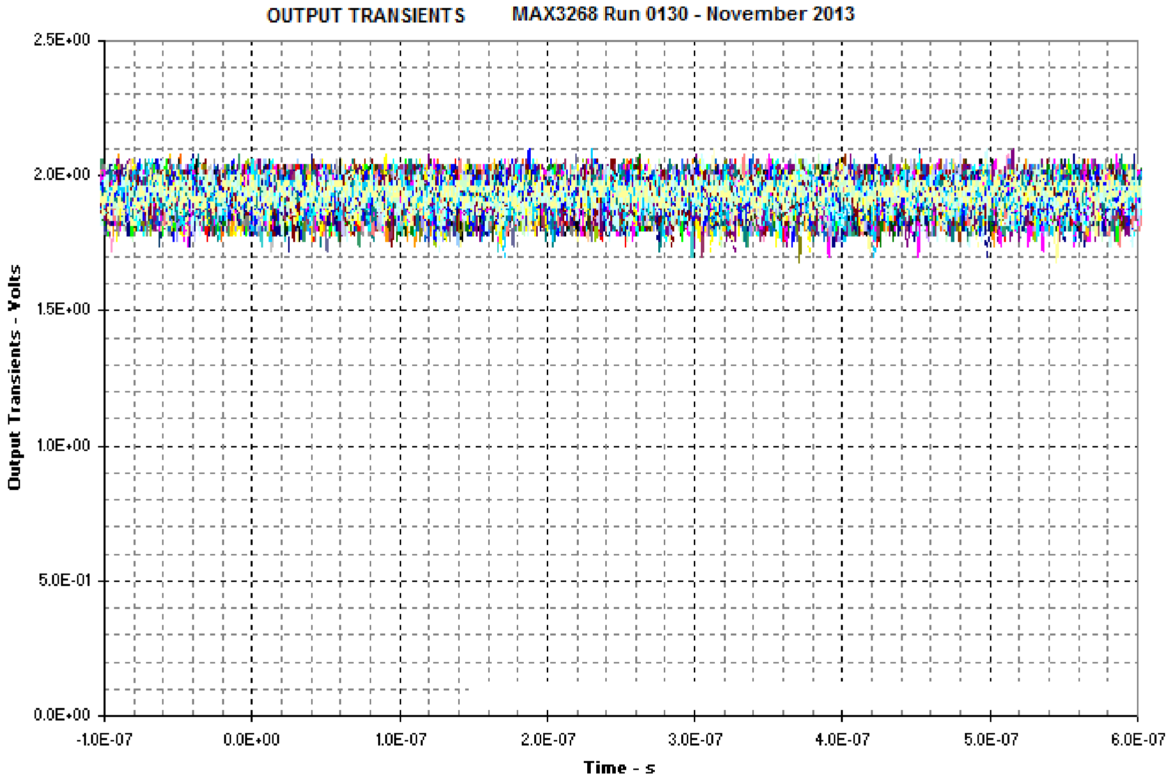


Figure 4.3-12: Shot 130 No visible output transient (35pJ)

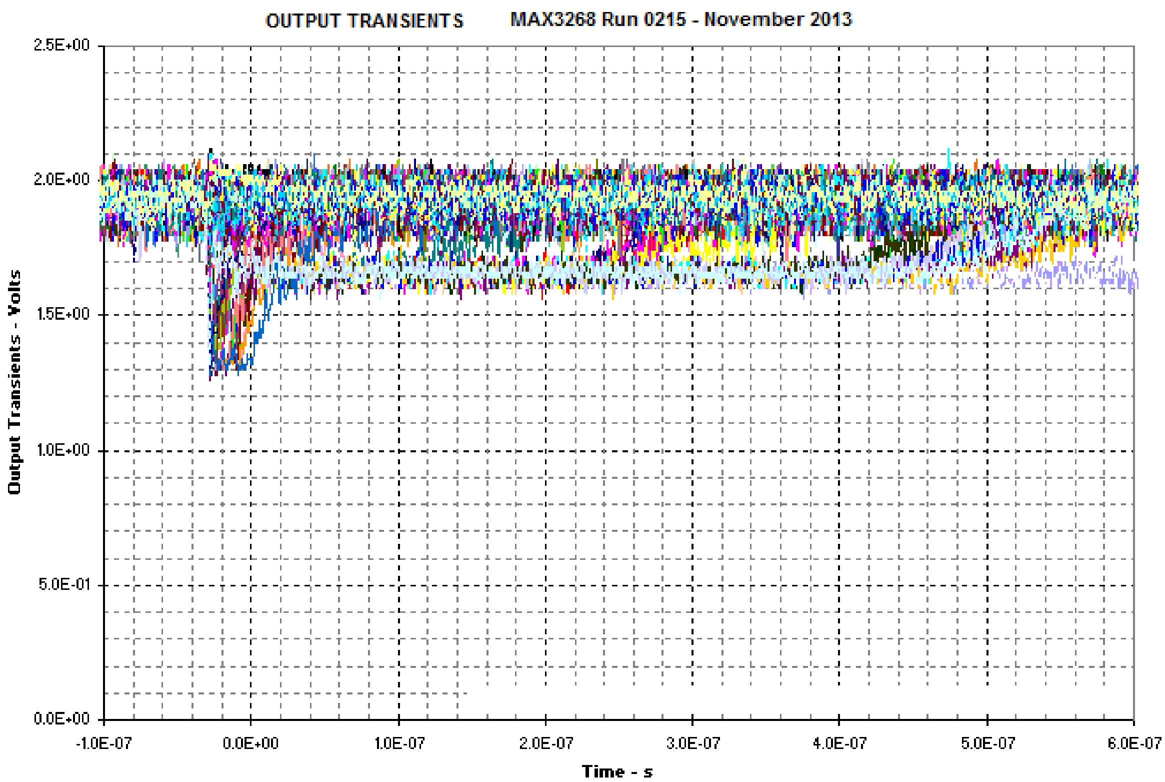


Figure 4.3-13: Shot 215 Output neg transient (35pJ)

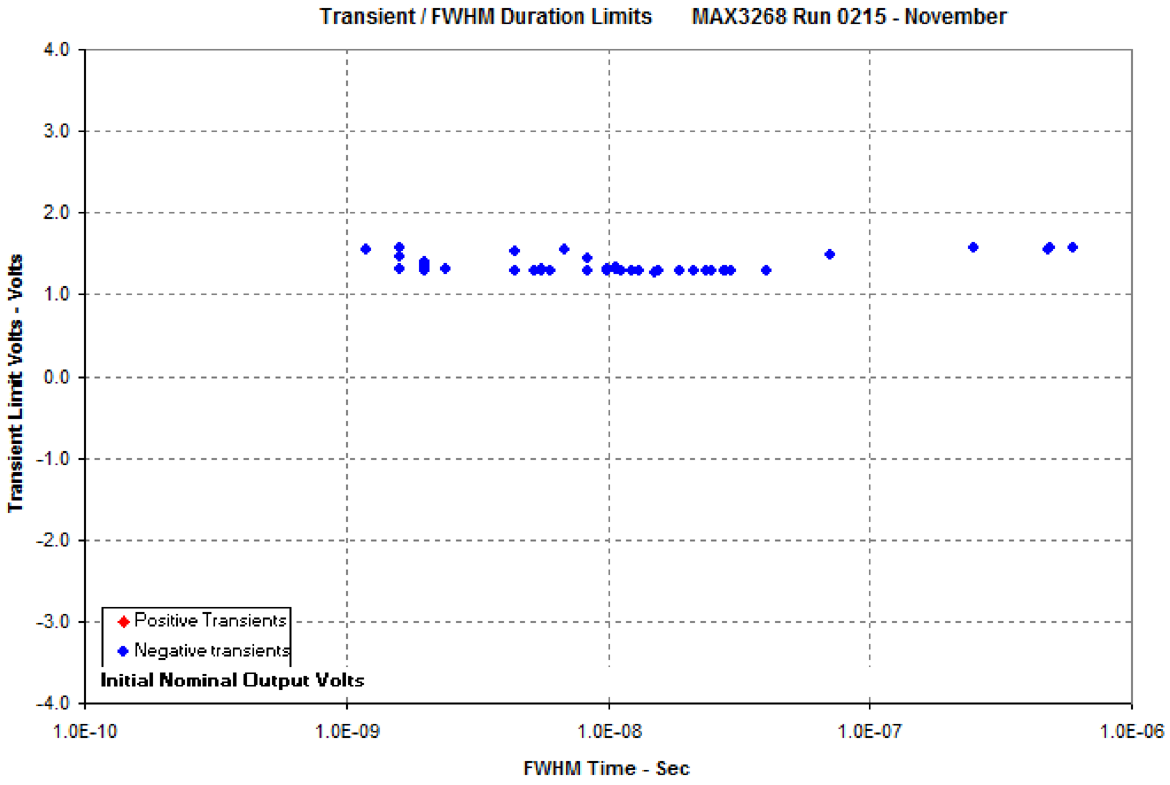


Figure 4.3-14: Shot 215 Transient FWHM duration Limits (35pJ)

4.4 G3840 Photodiode Laser SET Results

4.4.1 The bias resistors were removed and the G8340 device was inserted in the test circuit as shown in Figure 4.2-1. Supply current rose to 70mA.

4.4.2 The Indium Gallium Arsenide photodiode was SET tested by laying down the two spiral laser pulse arrays designated by the translucent red circles in Figure 4.4-1. Both these arrays were positioned intentionally to cover significant elements of the geometry of the photodiode. The MAX3268 device was incorporated in the circuit for the purpose of these measurements and but the outputs reported were measured at the outputs of the pre-amplifier (C1 and C2 inputs in Figure 4.2-1).

4.4.3 It would be surprising if introducing infrared ionisation energy into the InGaAs device did not produce output signal, because that is the function of this device. InGaAs has a bandgap in the mid-IR and is sensitive at slightly longer wavelengths than silicon photodiodes. The actual signals produced by shot 252 (122 x 35pJ laser pulses) are shown in Figure 4.4-2. It is already discernible in this Figure that several slightly different types of response are present among the 122 SET events traced.

4.4.4 The clearest picture is provided by plotting the recovery time duration for each pulse against its x-y coordinates on the photodiode die. The result for shot 252 is shown in Figure 4.4-3, where the diameter of each plot point indicates the duration of the laser pulse effect. It shows a ring segment corresponding to the intersection of the array with the outer blue ring as giving the maximal duration events. (Note that the device is rotated in the trial configuration relative to the orientation shown in Figure 4.4-1.) The central mustard-coloured circular area of the photodiode also gave events with significant durations. The silver ring segment between the two and the silver area beyond the blue ring gave tiny durations: seemingly, these events are small because the bright silver area is metallisation cover.

4.4.5 A similar plot, also for shot 252, shown in Figure 4.4-4 gives the amplitudes of the events plotted onto their locations on the die. This reveals the same pattern of sensitivity (but less clearly). Again the central circular area and the blue ring consistently give large amplitude events. The vents are only marginally lower amplitude in the vicinity of the silver annulus (most laser pulses would strike near the inner or outer edges of the silver annulus and the laser pulses do not have hard cutoffs with increasing radius from their centres, so enough overlap into the sensitive areas occurs to give large amplitude, though short duration, events.)

4.4.6 The spiral array delivered in shot 253 was located so as to overlap the bond pad area, which is a blue circular patch intersecting the circular sensing area of the photodiode. The group of SET events produced (Figure 4.4-2) is very similar to that for shot 252, except that the duration distribution is a little wider. The variation in event duration with laser pulse location (Figure 4.4-6) shows the same pattern of sensitivity in the circular detector area, but also reveals that the blue pad around the bond wire attachment is responsible for the longer duration events seen in this shot (although the events are tiny or non-existent where the pulses were centred on the bond wire itself – as would be expected.) Again the event amplitudes plot in Figure4.4-7 shows the same pattern less clearly, since only the segment of the outer silver area and the bond wire patch gave small amplitude events.

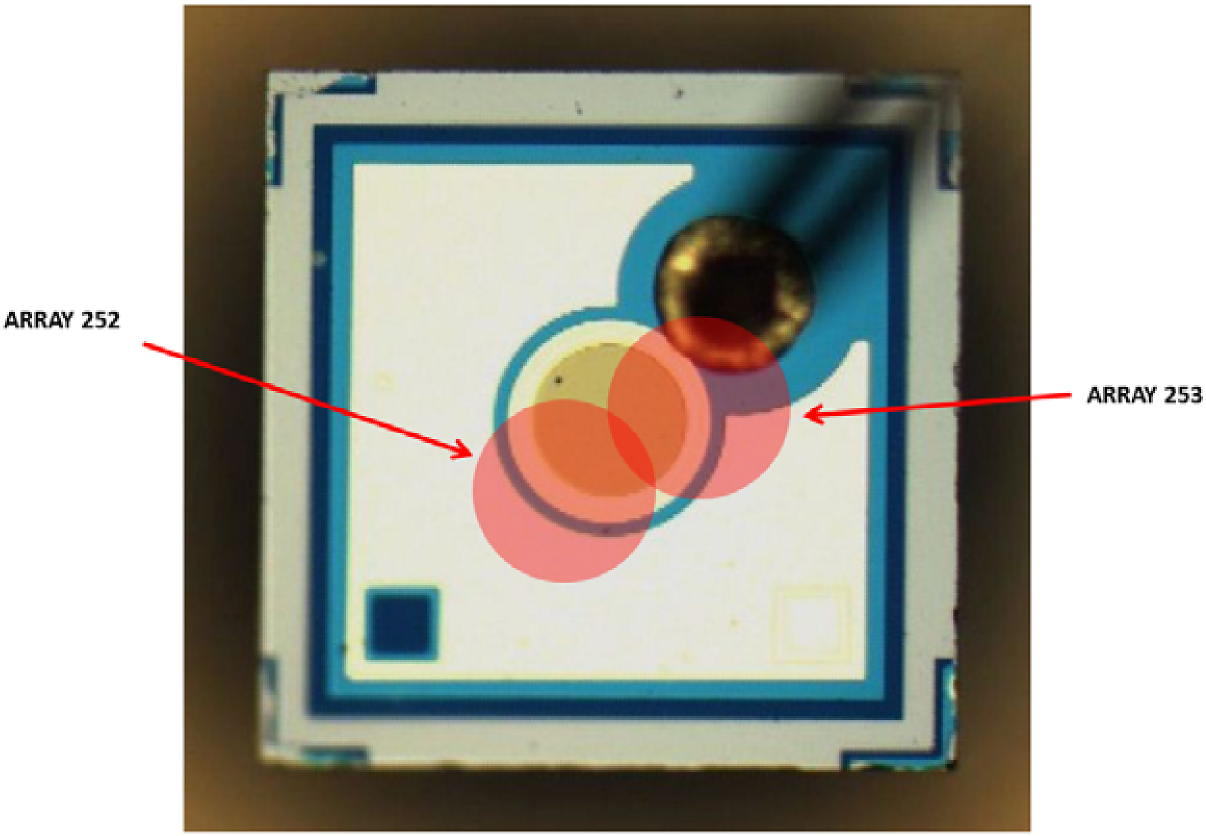


Figure 4.4-1: G8340 photodiode spiral arrays

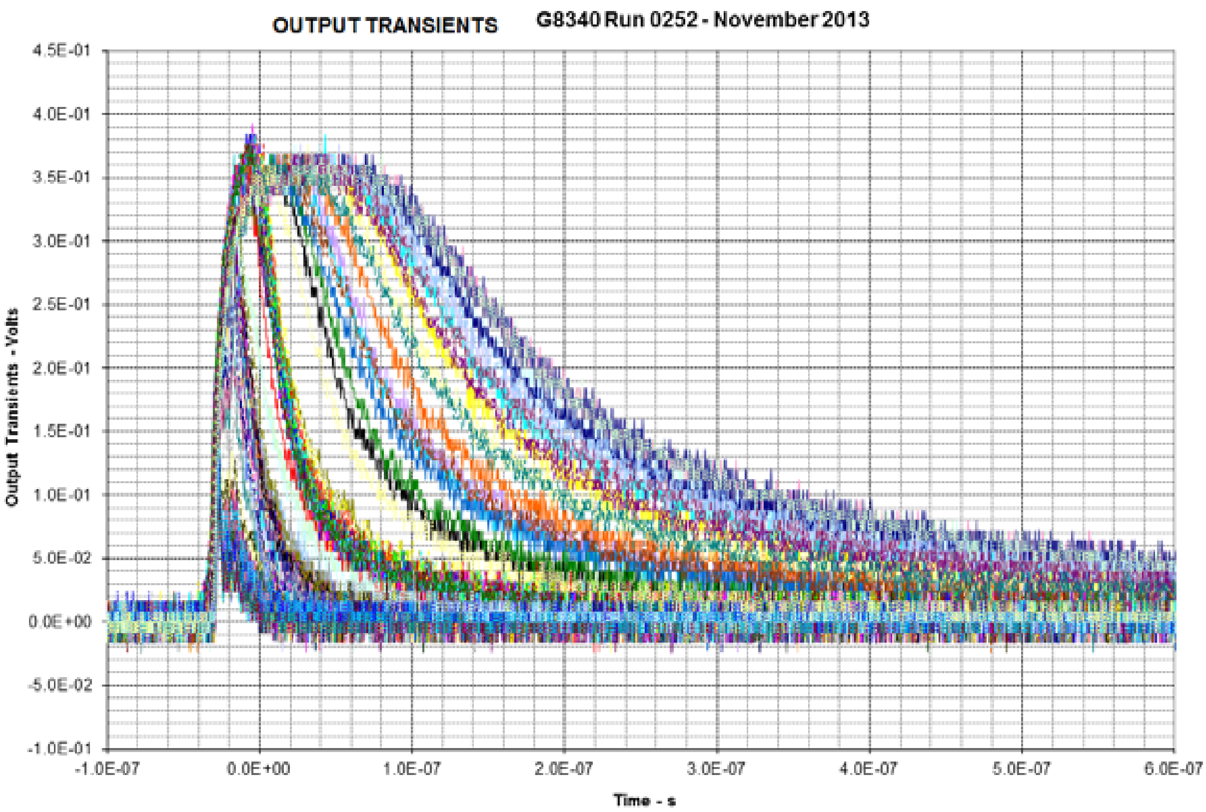


Figure 4.4-2: G8340 diode SETs for shot 252

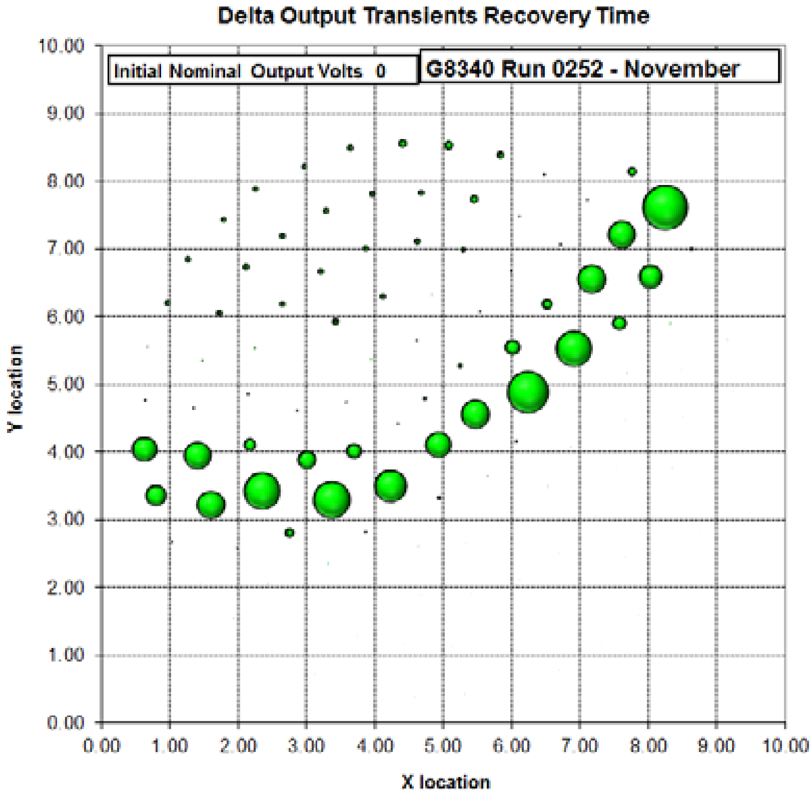


Figure 4.4-3: G8340 photodiode shot 252 output recovery time

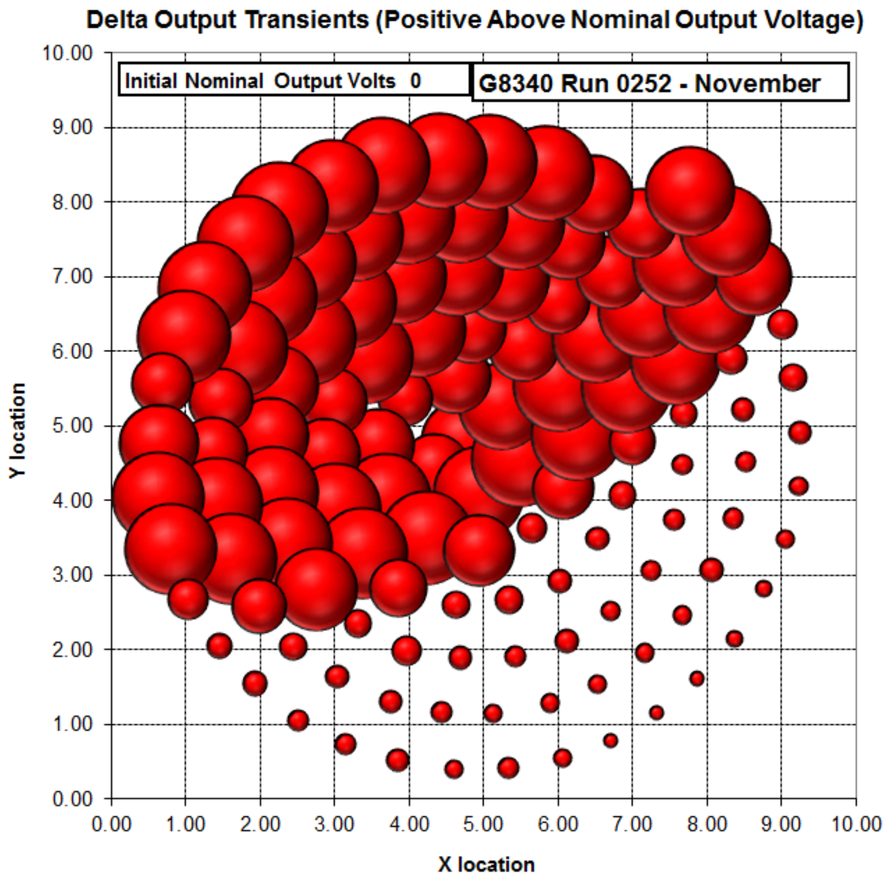


Figure 4.4-4: G8340 shot 252 photodiode max positive SET amplitude

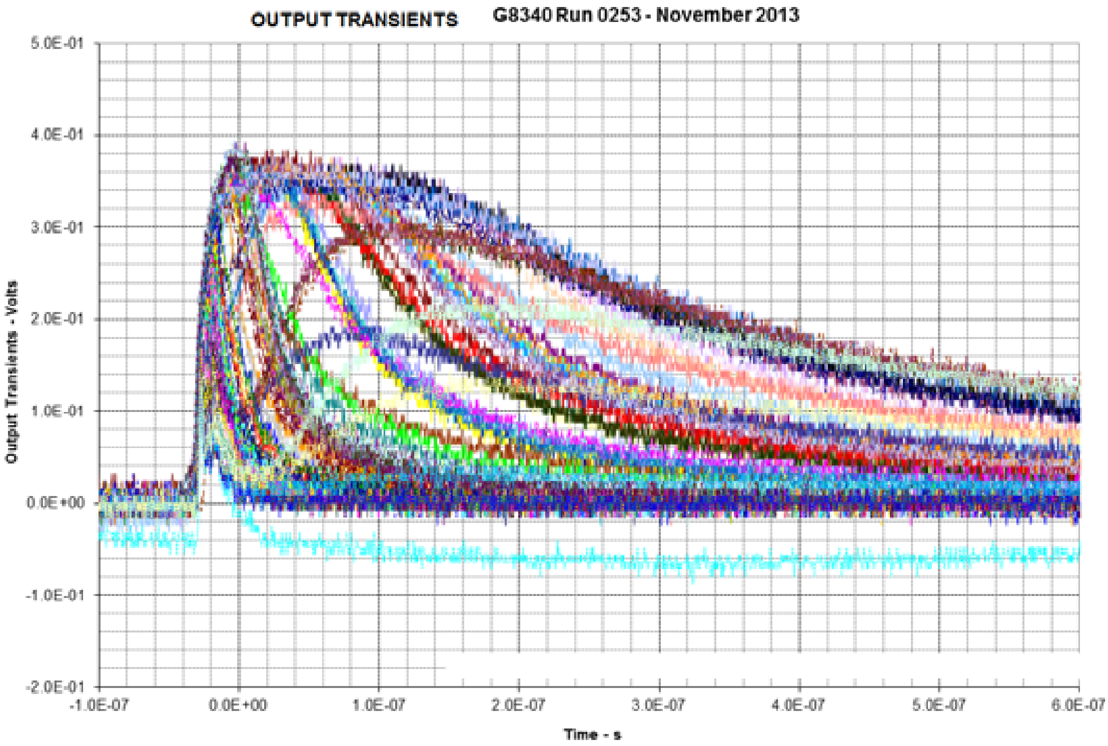


Figure 4.4-5: G8340 diode SETs for shot 253

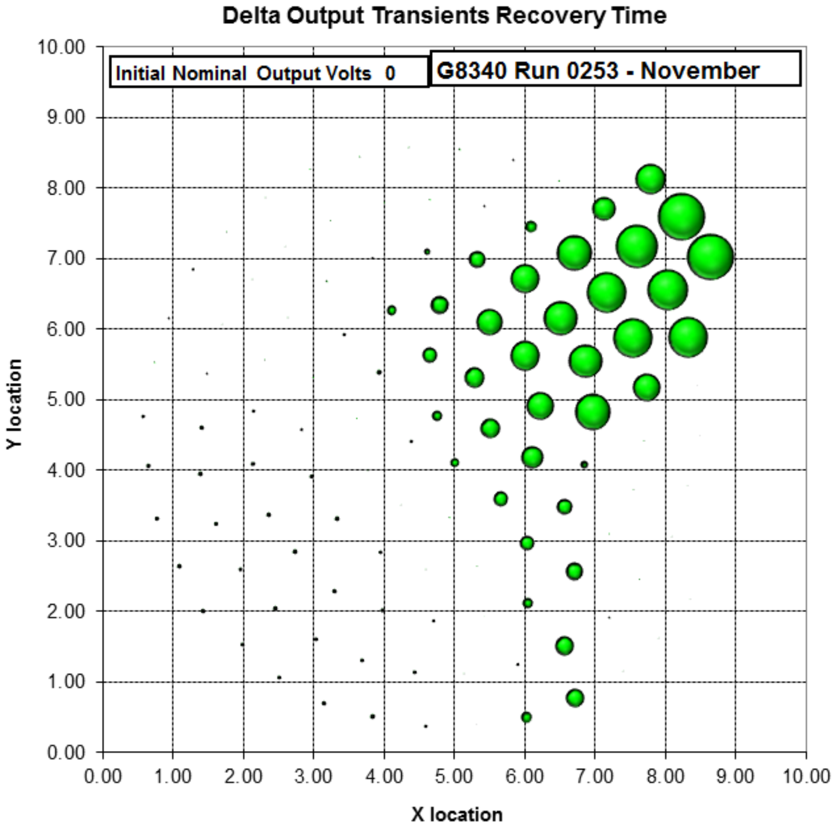


Figure 4.4-6: G8340 photodiode shot 253 SET durations

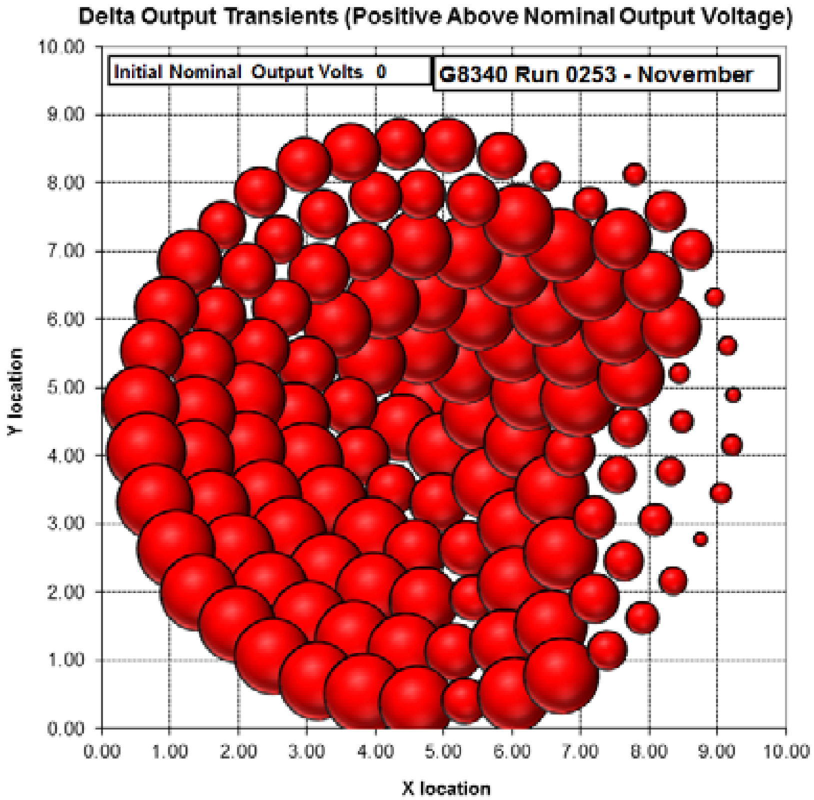


Figure 4.4-7: G8340 shot 253 photodiode max positive SET amplitude

4.5 G3840 Preamplifier Laser SET Results

4.5.1 The trial moved on to investigate the SET responses from the pre-amplifier device within the G8340 can (Figure 4.2-4 and 4.5-1 below). The test conditions were unchanged from those used for the photodiode itself.

4.5.2 Spiral arrays of laser pulses were delivered to a wide range of locations as indicated in Figure 4.5-1 by the transparent coloured circles. The green circles indicate the locations of a number of exploratory shots at a range of laser pulse energies up to around 1000pJ, all of which failed to produce any SETs discernible above the noise threshold. Almost all of the functional areas of this device appear to be insensitive to SETs.

4.5.3 However, small responses were observed for shots 254 and 256 delivered to the area immediately adjoining the input bond pad for the bond wire from the photodiode and also some very small responses for shot 255 delivered a little further up towards the centre of the die. All three of these shots were delivered at 430pJ laser pulse energy.

4.5.4 The SET events for shot 254 are shown in Figure 4.5-2. The maximum amplitude was just 0.06V and the maximum half height duration was less than 2E-8s. The spatial distribution of the SET magnitudes is shown in Figure 4.5-3. Only a small fraction of the area within the overall region covered by the spiral array appears to have been sensitive to SETs. The responses were dominated by about 28 of the 122 laser pulse locations.

4.5.5 The SET events for shot 255 (Figure 4.5-4) were slightly smaller (max amplitude 0.04V). Again there was a scatter of sensitive spots across most of the area of the spiral array (Figure 4.5-5) and again only ~34 of the 122 laser pulses produced an event, perhaps due to metallisation cover.

4.5.6 The SET events for shot 256 reached a magnitude of 0.1V (Figure 4.5-6). A larger proportion of the laser pulse locations gave events (Figures 4.5-7 and 4.5-8), but the top segment of the spiral array region was insensitive. It overlapped a different functional region of the die, which had been covered by one of the green colour-coded spiral arrays (Figure 4.5-1).

4.5.7 The laser pulse energy was increased to 1000pJ at the shot 256 location. This appeared to result in the failure of the device. This was tested by putting a final pulse array back onto the photodiode. The output signals from the circuit were greatly depressed relative to what had been seen previously from the photodiode.

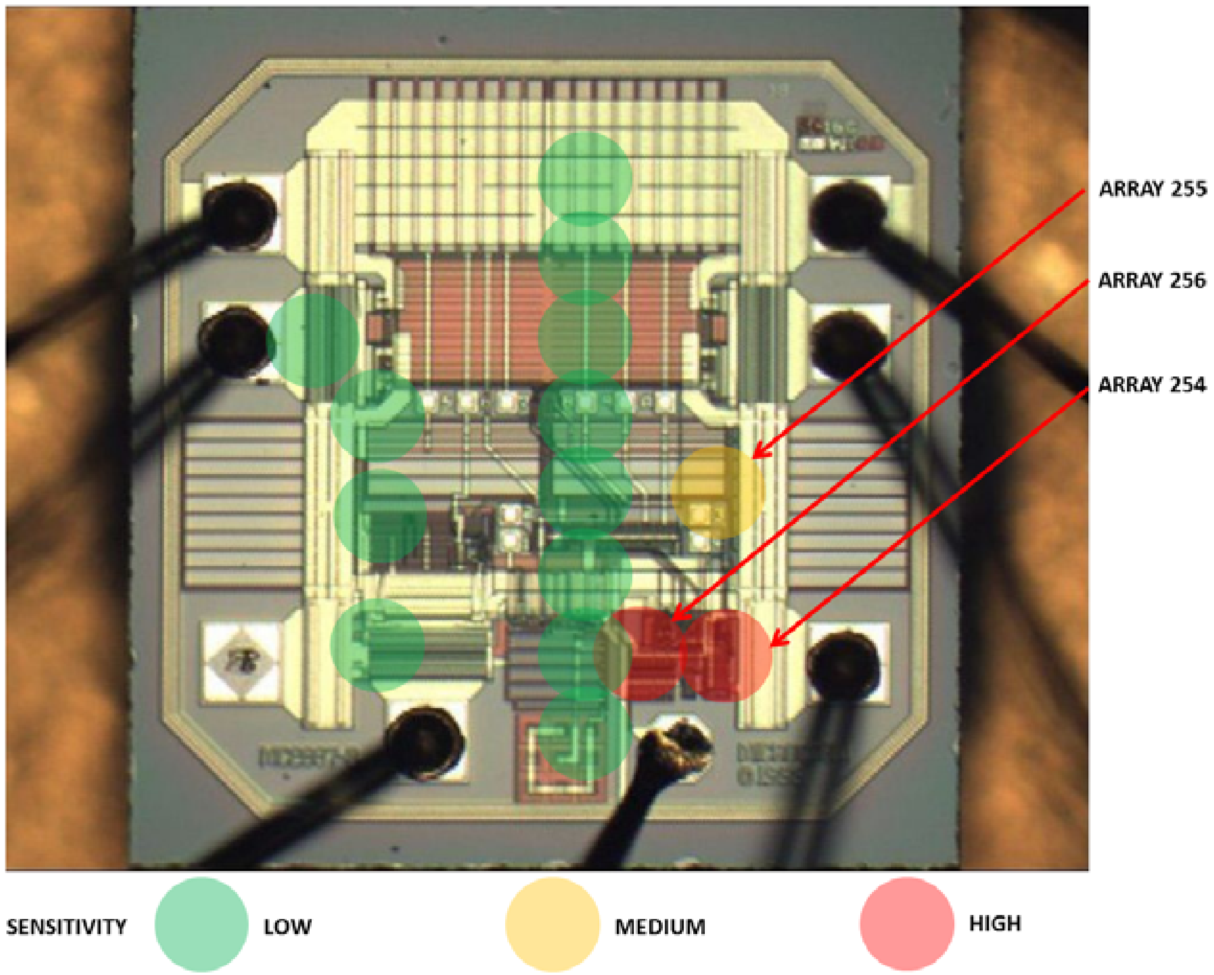


Figure 4.5-1: G8340 preamp spiral arrays

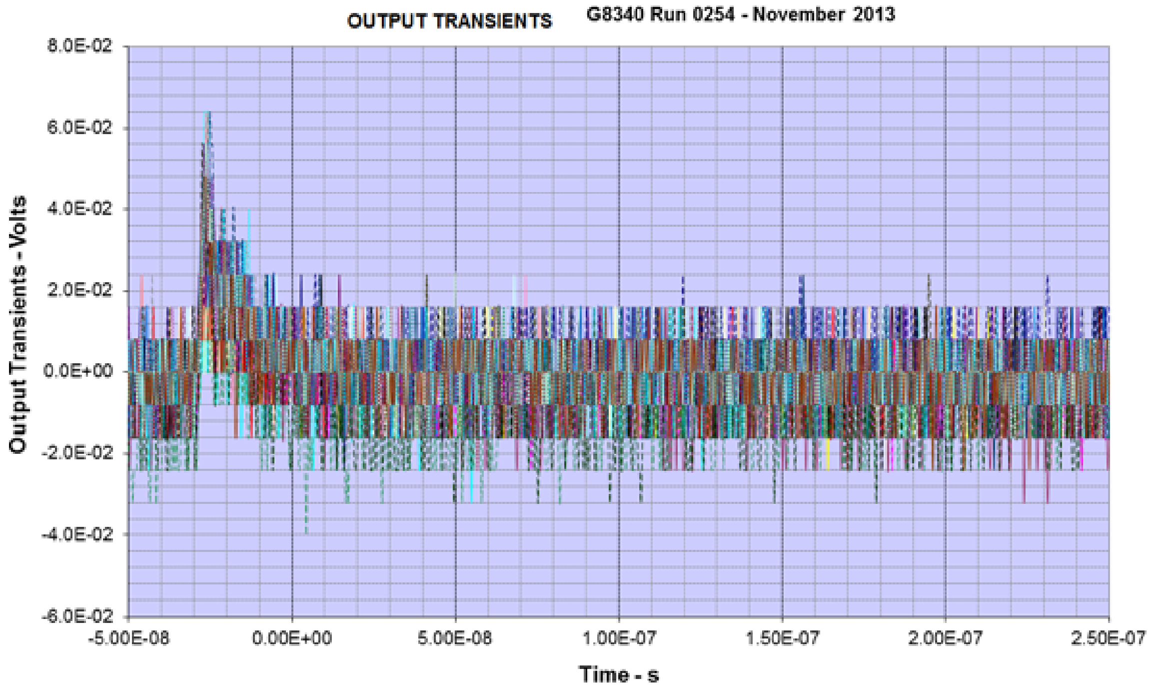


Figure 4.5-2: G8340 preamp input shot 254

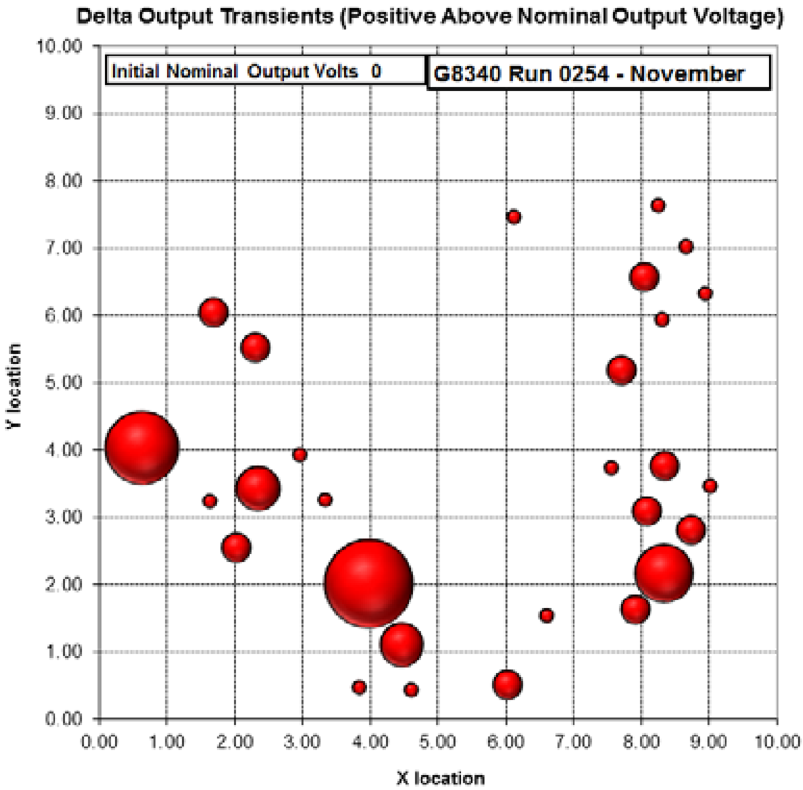


Figure 4.5-3: G8340 preamp shot 254 max pos SETs

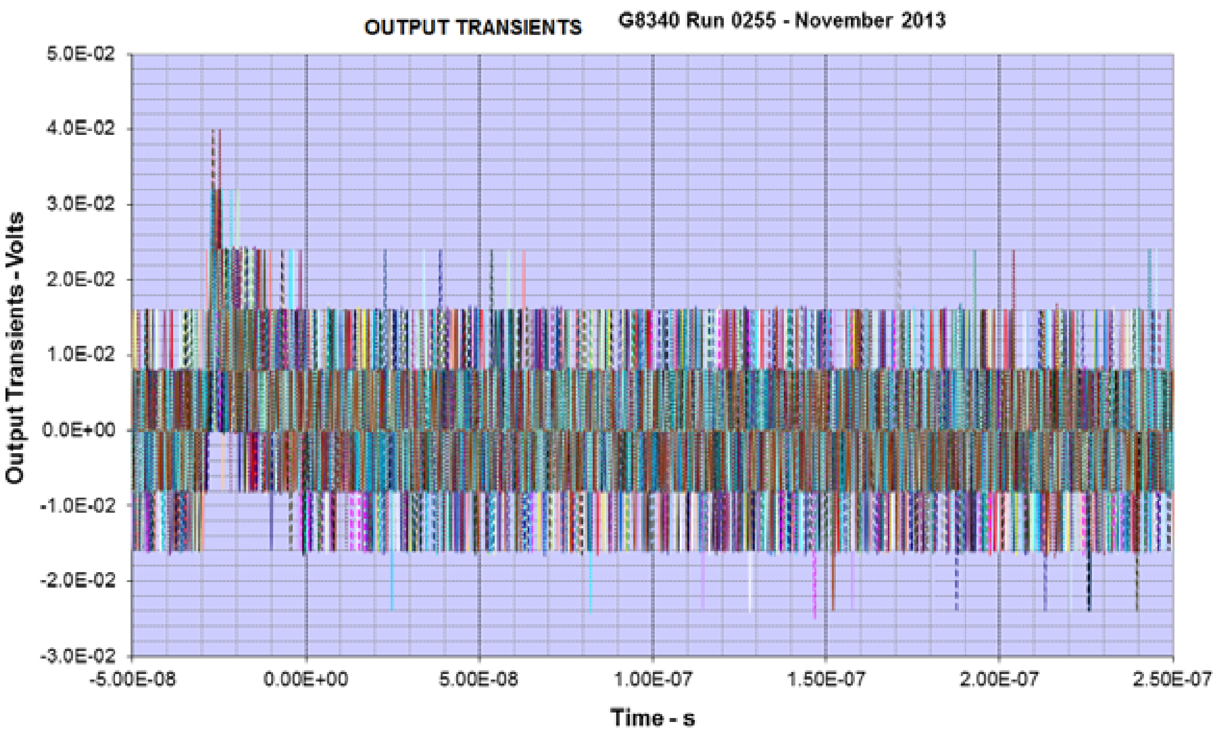


Figure 4.5-4: G8340 preamp shot 255

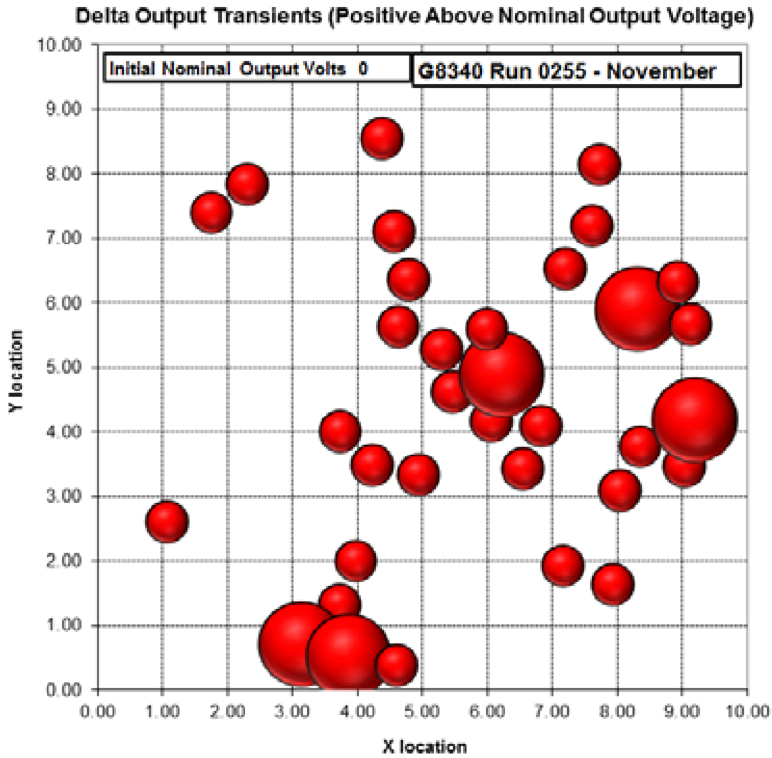


Figure 4.5-5: G8340 preamp shot 255 max pos SETs

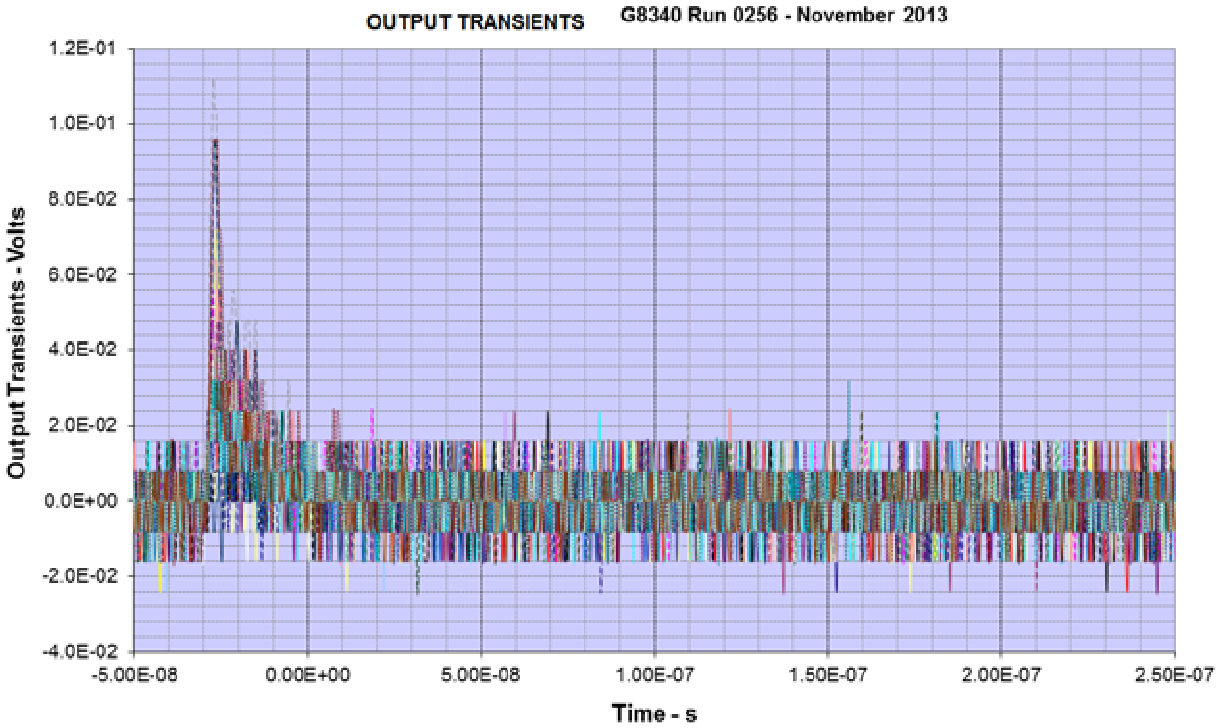


Figure 4.5-6: G8340 preamp input shot 256

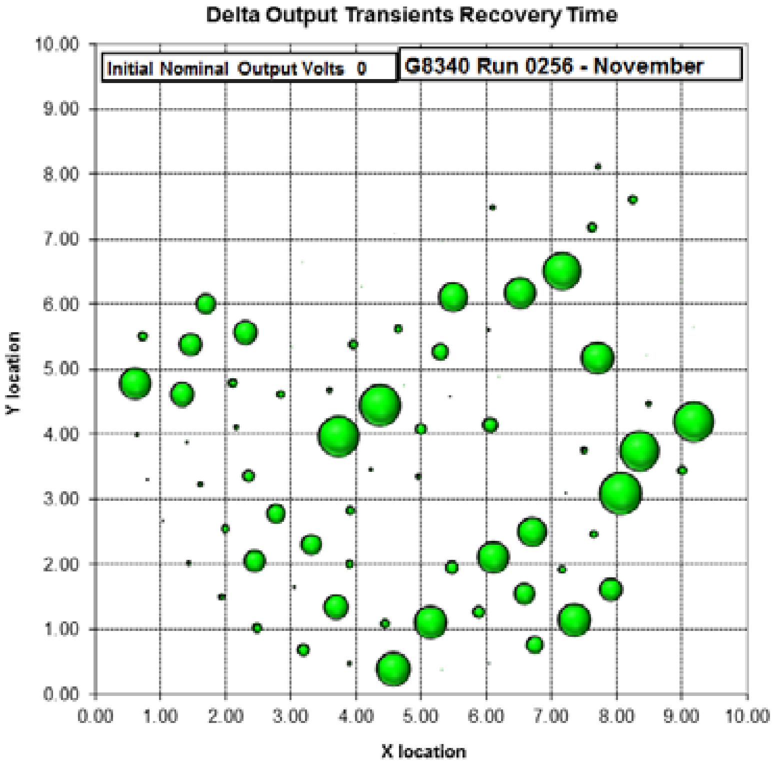


Figure 4.5-7: G8340 preamp shot 256 max duration SETs

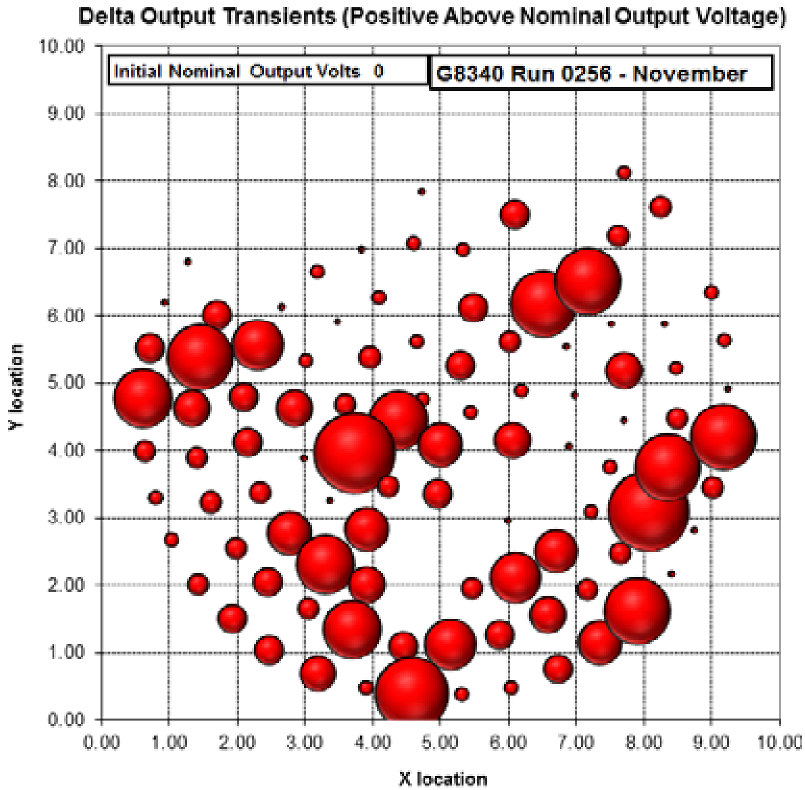


Figure 4.5-8: G8340 preamp shot 256 max pos SETs

5 CONCLUSIONS

5.1 Summary of Achievements

5.1.1 Laser SET trials under COO2 of ESA ESTEC Contract C22333/09/NL/Sfe (Laser SET Testing of Analog Integrated Circuits) have been completed successfully. The particular key SET behaviours of each device type may be summarised as follows.

5.1.2 The OSD15-5T Photodiode: the SETs are highly location dependent; MBDA see faster pulses/responses than previous laser SET investigations in other companies [10], but we obtain the same integrated charge generation as seen at other laser facilities.

5.1.3 The RHFL4913A Voltage Regulator: the device exhibits a short term SET response <0.2μs and also a long term SET response 1μs to 100μs; the latter seems to be attributable to feedback via the ADJUST i/p.

5.1.4 The MAX3268 exhibited significant SET events across several large regions of its die. The SETs tended to saturate in amplitude at less than a volt of deviation from the nominal output, but the SET grew progressively in duration with both the relative sensitivity of the targeted location and with the laser pulse energy.

5.1.5 The G8340 photodiode exhibited significant SET sensitivity across the central circular detector region and especially within the ring of die free of metallisation that surrounds the central circular detector area and also in the bare semiconductor in the area leading rom the circular detector region to the bond wire pad.

5.1.6 The G8340 photodiode pre-amplifier generally exhibited low or negligible SET sensitivity. Only areas of the die close to the input bond wire from the InGaAs photodiode exhibited a significant response and then only generated low amplitude short durations SETs at very high laser pulse energy.

5.2 Future Work

5.2.1 These results continue to demonstrate that profound insights into the underlying causes of radiation particle induced Single Event Effects are readily obtainable through the application of the MBDA SEREEL laser SEE test facility. The ability of the facility to achieve accurately positioned large area coverage of IC dies under computer control is key to the comprehensiveness of the results. The facility remains available to meet future ESA and ESA sub-contractor needs as they arise in the future.

APPENDIX A REFERENCES

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[3] "Improved Fine-Scale Laser Mapping of Component SEE Sensitivity", Andrew M. Chugg, Jonathan Ward, James McIntosh, Nathan Flynn, Peter H. Duncan, Thomas S. Barber and Christian Poivey, Paper F-3 Presented at RADECS 2011.

[4] "Comparison of Single Event Transients Generated at Four Pulsed-Laser Test Facilities - NRL, IMS, EADS, JPL", S. Buchner, N. Roche, J. Warner, D. McMorrow, F. Miller, S. Morand, V. Pouget, C. Larue, V. Ferlet-Cavrois, F. El Mamooni, H. Kettunen, P. Adell, G. Allen and D. Aveline, RADECS 2011 Proceedings.

[5] Interim Report on Laser SET Testing of Analog Integrated Circuits, COO1 of ESA ESTEC Contract C22333/09/NL/Sfe, DR 39664, Andrew Chugg & Peter Duncan, Feb 2012.

[6] "Comparison of Single-Event Transients Induced in an Operational Amplifier (LM124) by pulsed Laser Light and a Broad Beam of Heavy Ions"; Stephen Buchner, Dale McMorrow, Christian Poivey, James Howard Jr, Younes Boulghassoul, Lloyd Massengill, Ron Pease and Mark Savage. IEEE Transactions on Nuclear Science Vol 51, No 5, Pages 2776 to 2781, October 2004.

[7] MAX3268 / G8340 – ESA Laser SET Trial Plan, Issue 1 : Revision 0 : 23 Jan 2013

[8] RHFL4913A – ESA Laser SET Trial Plan, Issue 2 : Revision 0 : 27 Mar 2013

[9] OSD15-5T – ESA Laser SET Trial Plan, Issue 1 : Revision 0 : 21 Jan 2013

[10] Comparison of Single Event Transients Generated at Four Pulsed-Laser Test Facilities - NRL, IMS, EADS, JPL, RADECS 2011 Proceedings.

[11] ANALYSIS REPORT NUMBER CA 0516: Photodiode Device Number G8340-22 by Hamamatsu for Project SMOS, ESA Components Division, Laboratory Support Group

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