Laser Simulation of Single Event Effects in Pulse Width Modulators and Memories

Final Presentation of ESA/ESTEC Contract No. 16916/02/NL/PA (Phase 2)

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Introduction

- Second phase of an ongoing laser SEE research collaboration with the European Space Agency
  - Utilising MBDA's Single Event Radiation Effects in Electronics Laser (SEREEL)
- Principal research topics
  - Laser Memory Mapping
  - Laser SEE sensitivity profiling using multi-wavelength testing
  - Laser SEE testing of complex devices: Pulse Width Modulators
- In parallel: design and implementation of a second generation laser SEE test facility known as SEREEL2

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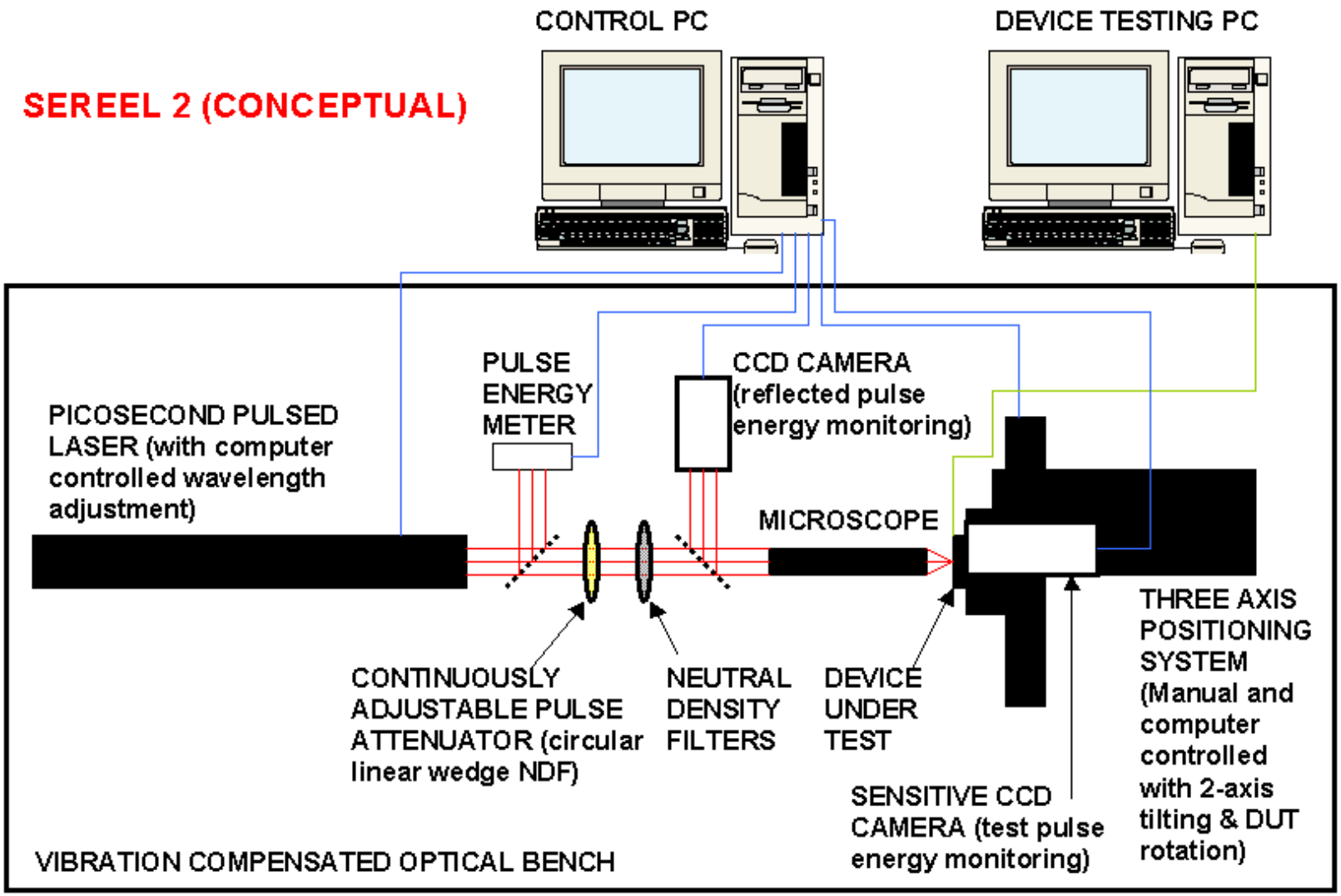
The principles of laser SEE testing



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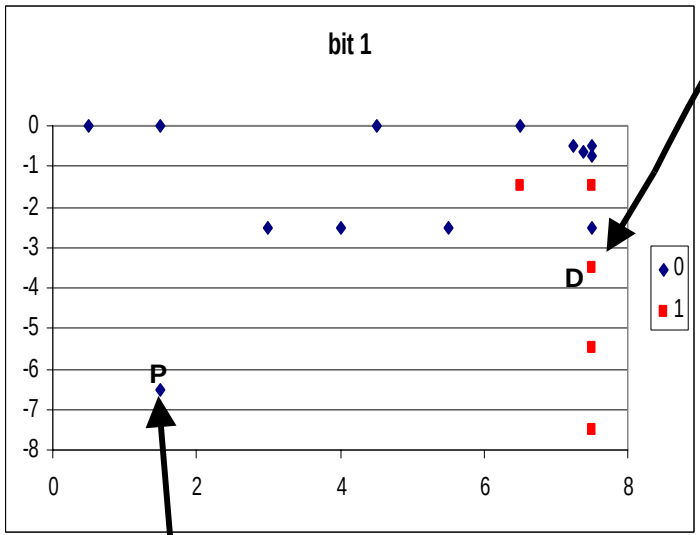
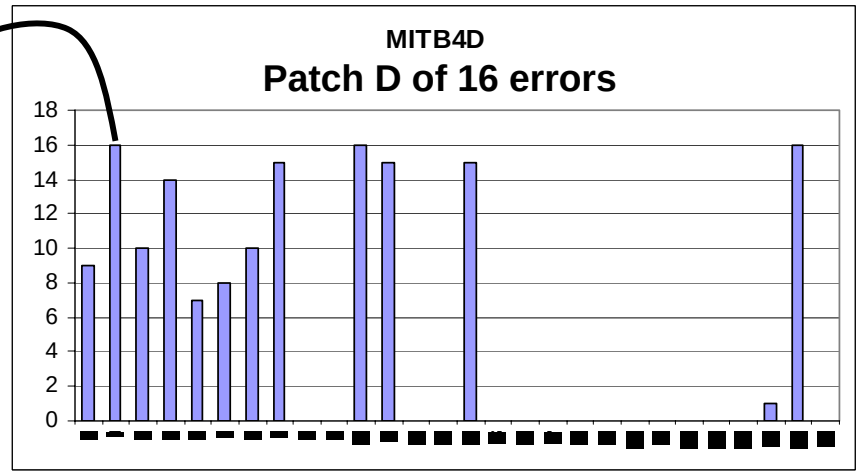
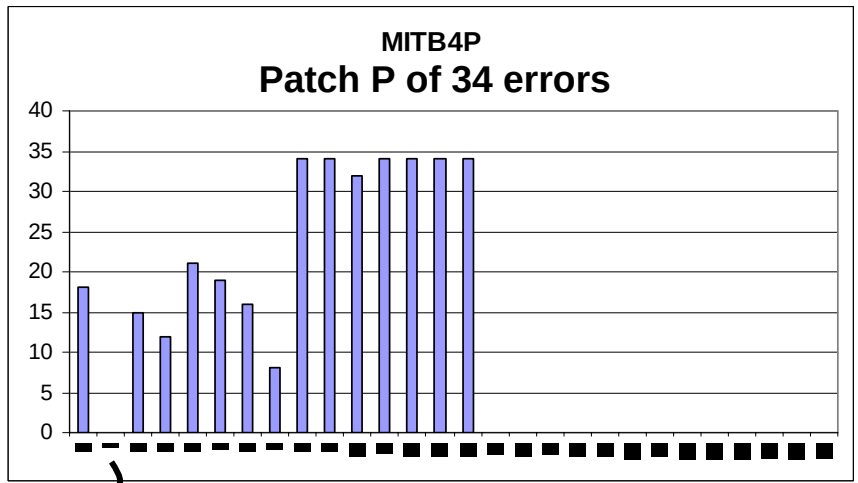
Laser Memory Mapping - Error Patch Approach

Bit 1 values in plotted error patches



Address bit sums in error patches





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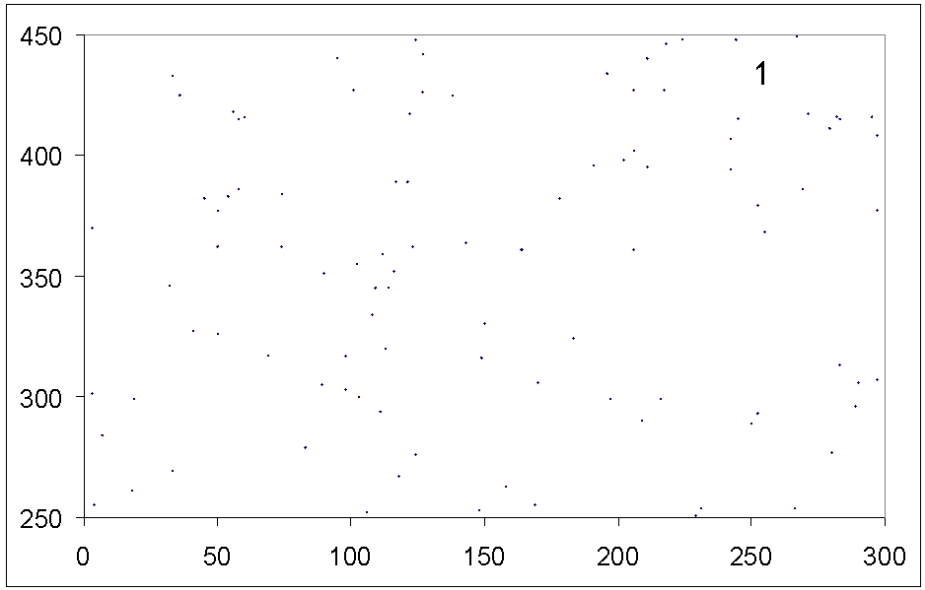
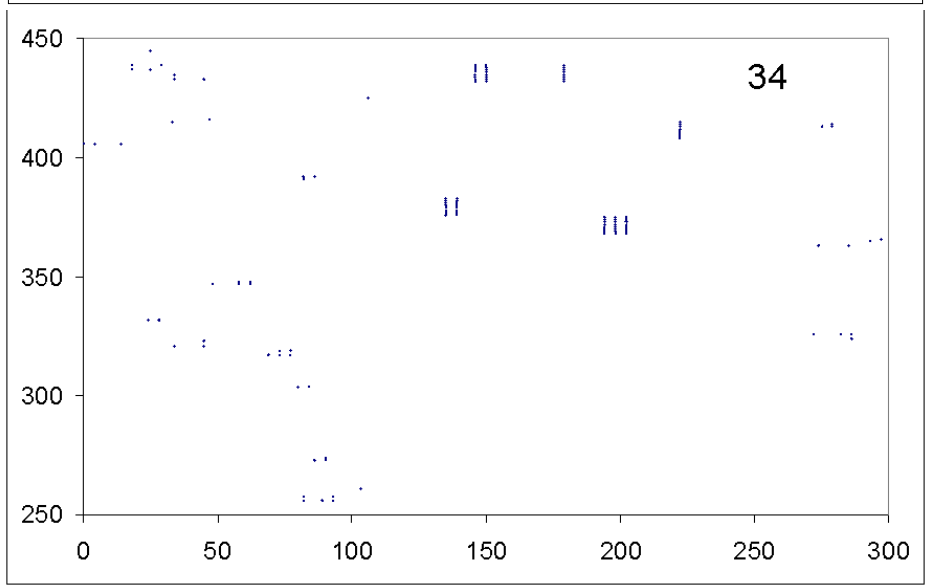
Using laser map to plot ion beam upsets in the Cypress CY7C109

- Using the laser-derived maps to plot previously captured ion beam upsets in a 1Mbit CY7C109 showed previously invisible spatial clustering indicative of MBU's
- The clustering was not present at 1MeV cm^2/mg, but increased with LET and became very marked at 34 MeV cm^2/mg
- The figures show upsets plotted over the same sub-section of the die at 1 and 34 MeV cm^2/mg for the CY7C109





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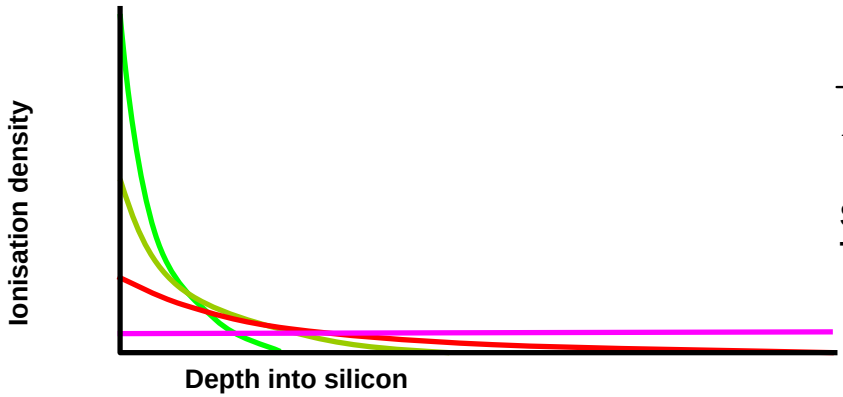
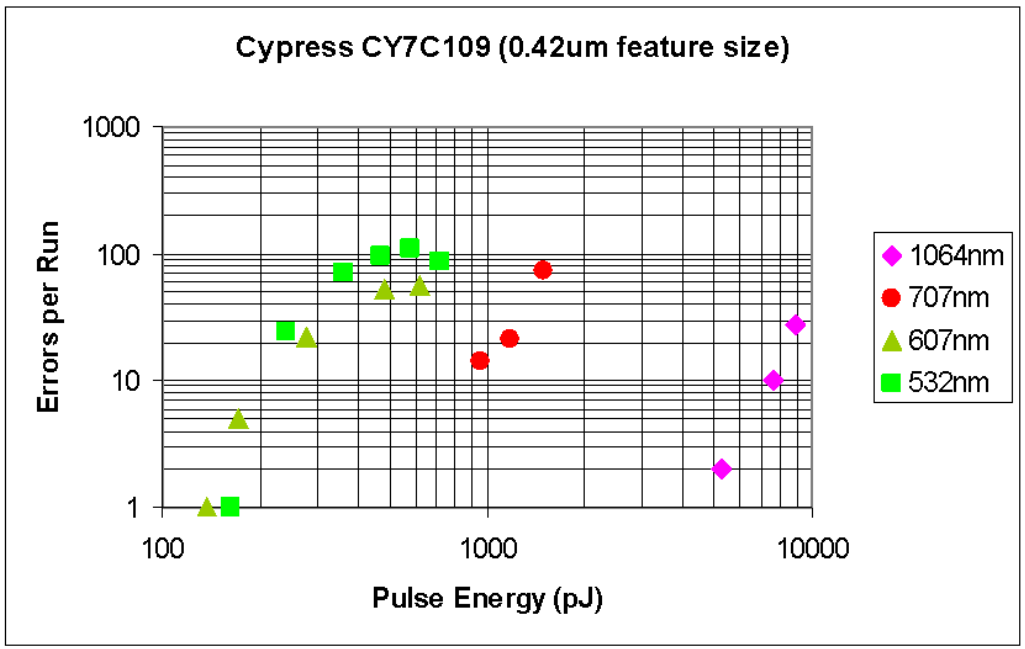
SEE Sensitivity Profiling – Variation with Depth



$$\frac{Q_{crit}}{E_{abs}(f(\lambda))\,f(\lambda)} = \int_0^{\infty} sens(x)\exp(-f(\lambda)x)dx$$

See "Probing the Charge Collection Sensitivity…" IEEE Trans Nuc Sci, pp.2969-2976, Dec 2002 for details



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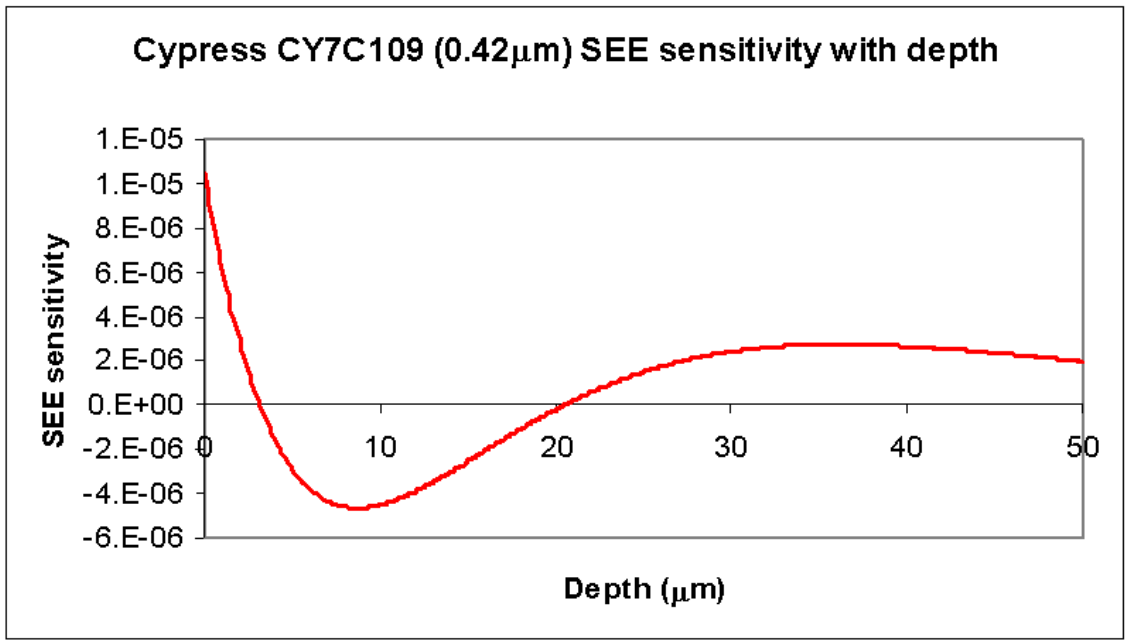
Example of the sensitivity profile derived for the Cypress CY7C109

- The approach often gives a profile that changes sign at different depths
  - The interpretation is that ionisation may cause charge to flow on or off a memory cell node depending on its location relative to the node
- The sensitivity profile seems to range deep into the silicon due to the relatively high sensitivity to infrared
  - This seems to be a laser version of the charge funnelling effect seen with ions



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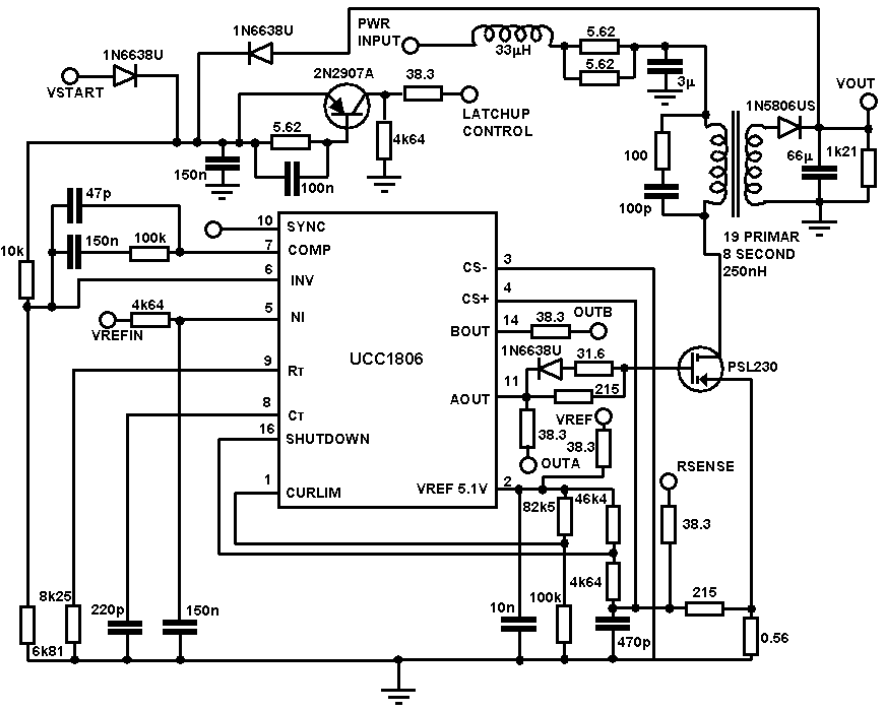
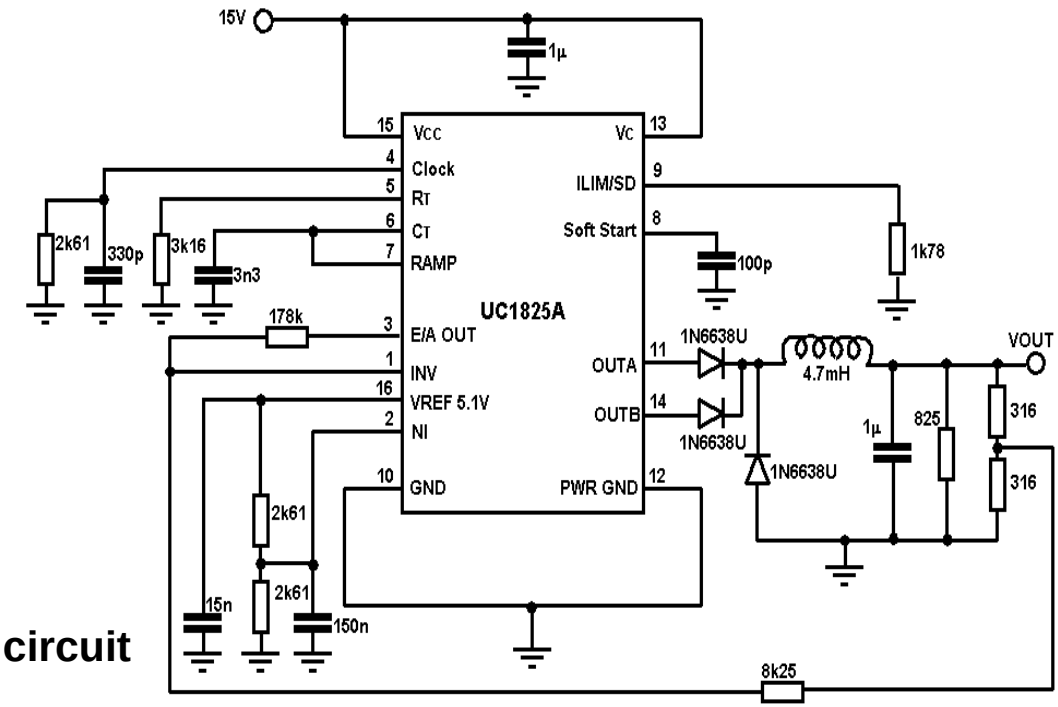
Laser SEE Testing of Pulse Width Modulators – Test Circuits

UCC1806 PWM test circuit



UC1825A PWM test circuit



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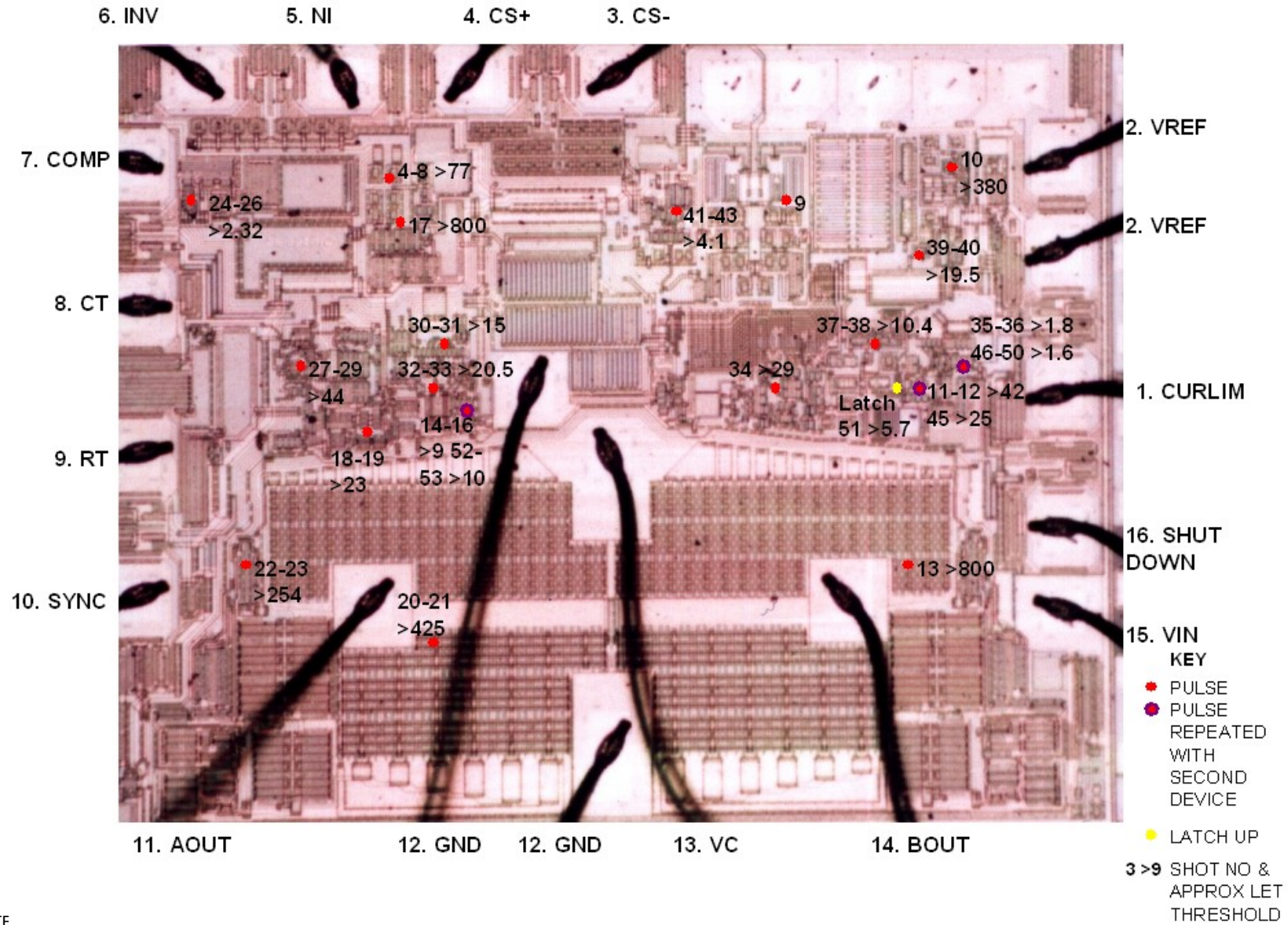
Laser test pulse locations for the UCC1806 (thresholds in MeVcm^2/mg)



Ref. D/TE

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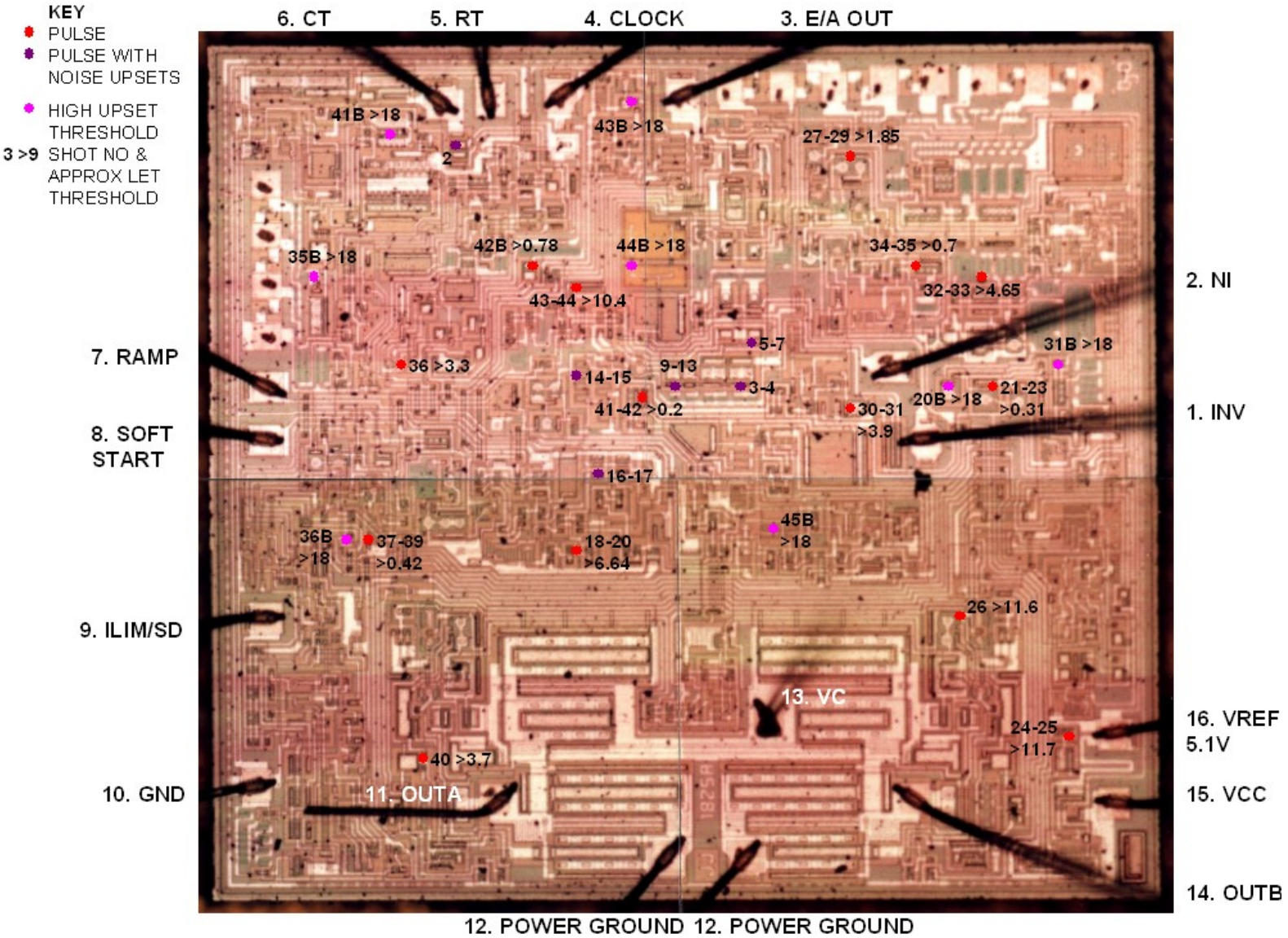
Laser test pulse locations for the UC1825A (thresholds in MeVcm^2/mg)



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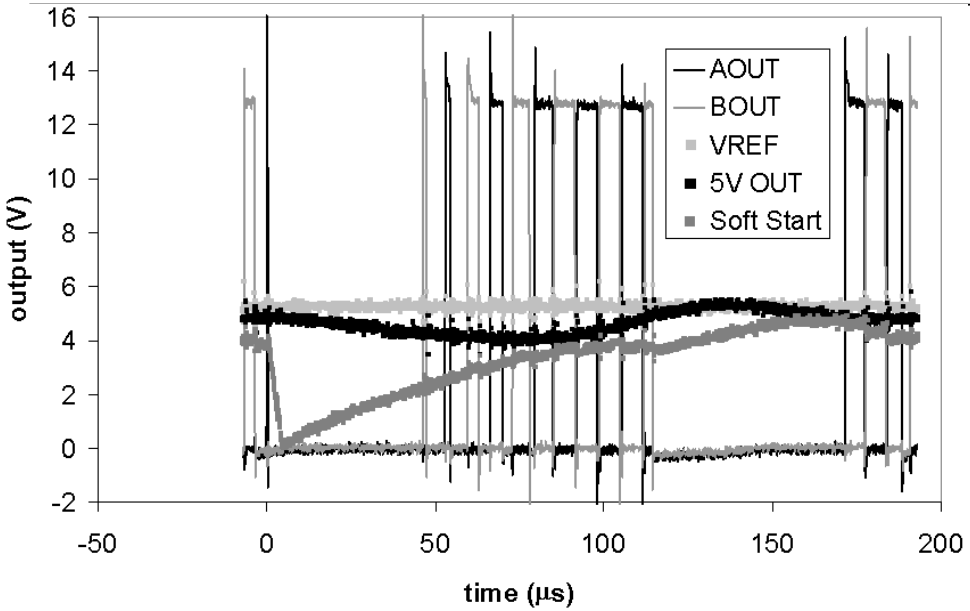
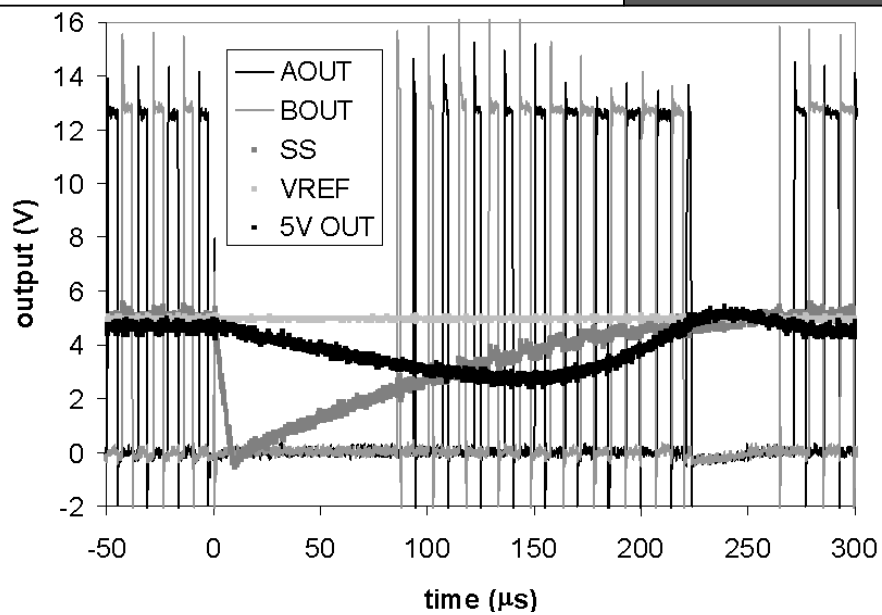
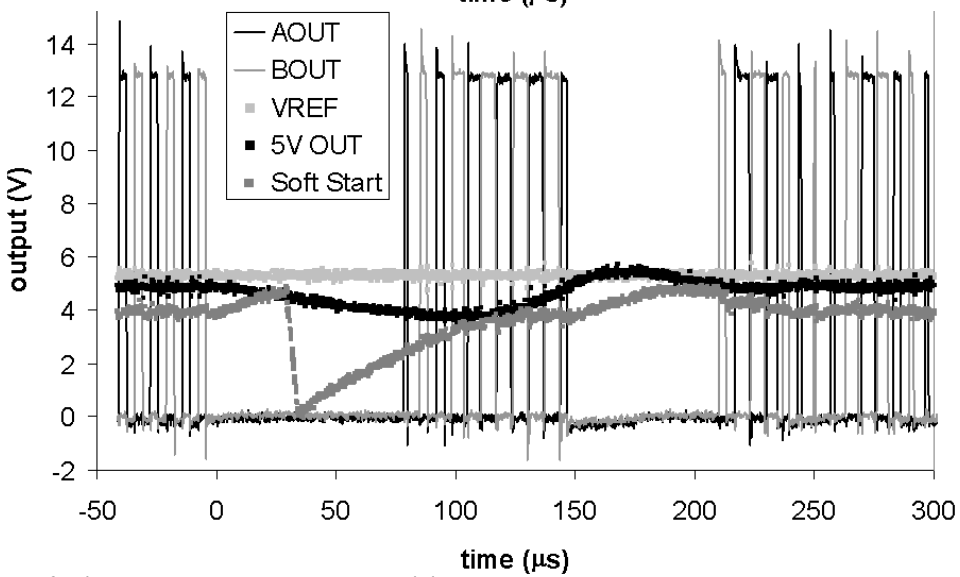
Matching laser and ion SET's in the UC1825A







The ion induced SET (above) matches the laser induced SET (top left) located in the error amplifier circuitry, rather than the laser induced SET (bottom left) located in the soft start circuitry

Ion strike probably hit the error amplifier

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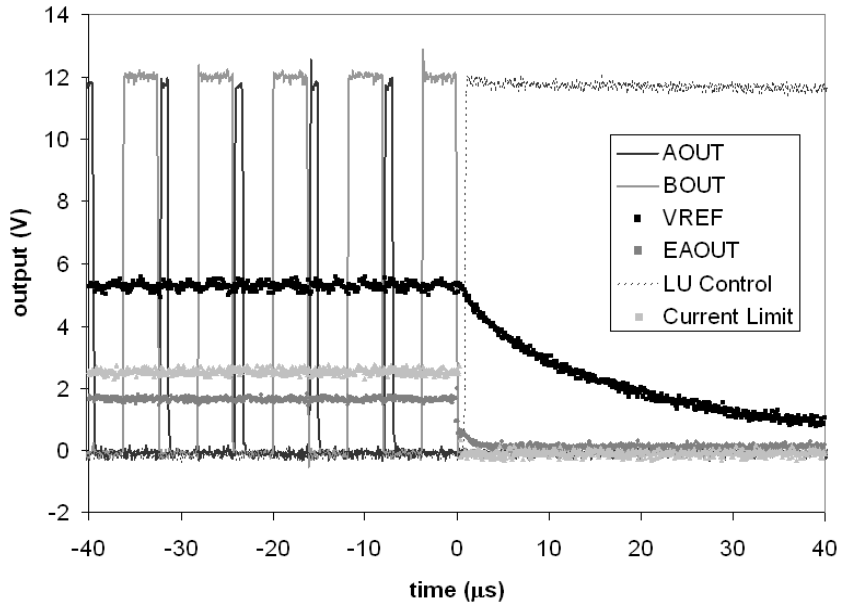
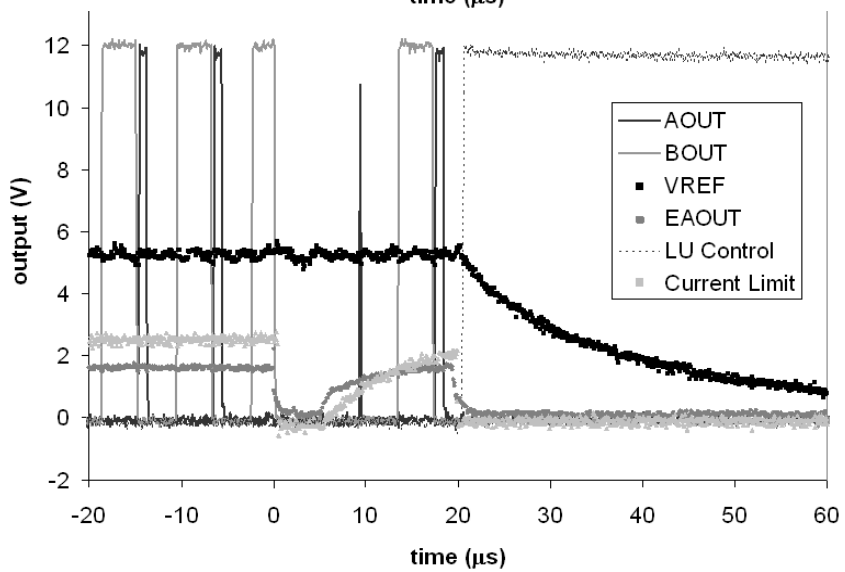
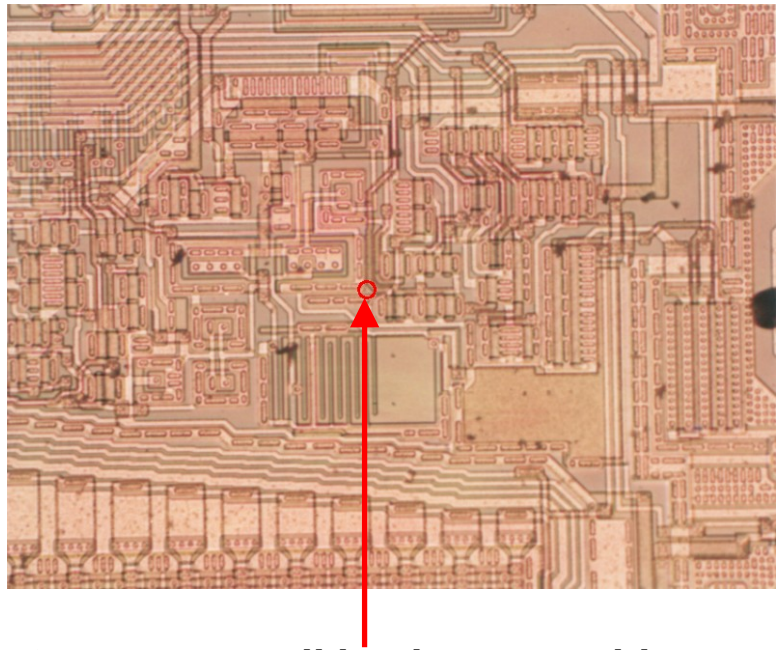
Laser induced latch-up & delayed latch-up in the UCC1806







One very small latch-up sensitive location was found using the SEE laser.

At large laser pulse energies, latch-up was immediate, but, near the threshold laser pulse energy, latch-up was typically delayed to tens of microseconds after upset

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NSREC Paper

- We will be giving a paper on the laser testing of the PWM's at the NSREC Conference in Seattle in July
- **"Laser Simulation of Single Event Effects in Pulse Width Modulators"**
- Paper #PF-6 Thursday 14th July 14:30 – 17:00

Laser Simulation of Single Event Effects in Pulse Width Modulators

A. M. Chugg, Member, IEEE, R. Jones, M. J. Moutrie, R. Hulse, Student, Member, IEEE, S. Mousset and S. Lesage

Abstract— Laser testing aims to identify the sources of PWM SEL sensitivity and reveals new details of PWM SEL behavior, such as enhanced sensitivity during output switching and delayed onset of latch-up near the SEL threshold.

I. Introduction

Recent operational experience has shown that Pulse Width Modulators (PWM's) in spacecraft power subsystems can exhibit unexpectedly severe SEE behaviours. SEE sensitivity in PWM's has also been the subject of recent NSREC papers [1], [2]. The European Space Agency has therefore sponsored a comprehensive investigation to characterise PWM SEE responses and to determine the source and cause of SEE sensitivity in these devices. A peculiar problem has been the difficulty in ambiguously identifying SEE events as a peculiar fluctuation within the PWM circuit. Due to the feedback loops, which are inherent in these devices, SEE disturbances are propagated through various functional circuit blocks, such that it is difficult to discern where they originated. As a means of addressing this issue, two PWM device types have been probed with focussed, picosecond laser pulses using the Single Event Radiation Effects in Electronics Laser (SEREEL) facility at MBDA, Filton. The SEE responses for probing different areas of the microchip dice can be compared and matched with ion beam SEE responses, enabling the SEE susceptibilities to be inferred.

The laser SEE investigations has also revealed new aspects of the SEE behaviour of PWM's, which are not directly apparent from ion beam data. For example, the laser results have demonstrated that SEE sensitivity of PWM's varies in a way through the output cycle as well as with position on the microchip die. The results indicate that there is enhanced SEE sensitivity when the output voltages are in the process of switching. Furthermore, a single-event latch-up (SEL) was found to have a significantly delayed onset relative to the laser pulse delivery used, when the laser pulse energy was close to the threshold for instigating the SEL.

II. Experimental Details

The MBDA laser SEE testing facility (known as SEREEL) is shown in the configuration used for the present work in Fig. 1. The same facility has previously been used for the results reported in [3] and [4]. The Neodymium-YAG picosecond pulse laser produces wavelengths of 1064nm or (with a frequency doubled) 532nm. Intermediate wavelengths are obtained by passing the green (532nm) pulses through a Raman cell of pressurised gas. Nitrogen was the gas species for this work. It generates wavelengths at 680nm and 707nm in its first and second side Stokes lines respectively. Each Stokes line may be selected and an output energy using a rotating Pellin-Broca prism. The 707nm wavelength in the visible red region of the spectrum was used for this work, since it penetrates the silicon to a depth of the order of 10μm. A microscope is used to focus the laser pulse onto the surface of the delidded microchips to diffraction limited spots. The spot diameter approaches (from above) the limit imposed by diffraction of the pulse out of its own cross-section. For our microscope this limit is slightly larger than the wavelength of the light. The pulse width used throughout the present experiments was 40ps.

Two Unitrode devices were investigated for this work: the UCC1806 low power, dual output, current mode PWM controller and the UC1825A high speed PWM controller. The test circuit (designed by Seth Svensson) for the UC1825A device is shown in Fig. 2. The UC1825A controlled a buck converter in voltage mode by using the CL and Ramp pins together. The TLIM-SD pin was grounded through a resistor. The buck converter ran in continuous mode and thus exhibited the characteristic delayed response when controlled in voltage mode. (The test circuit for the UCC1806 will be included in the final paper.)

Heavy ion data was performed by Seth Svensson at the CYClotron of LOuvain la NEuve (CYCLONE) in Belgium. The high energy ion cocktail (MTV ~ 3.33) was

[1] A. M. Chugg, R. Jones, and M.J. Moutrie are with the Radiation Effects Group, MBDA UK Ltd., FPC267, PO Box 5, Filton, Bristol BS34 7QW, UK, email: andrew.chugg@mbdauk.com.
[2] Stefan Svensson is with the European Space Agency, at ESTEC, Keplerlaan 1, PO Box 299, 2200 AG Noordwijk, ZH, the Netherlands.
[3] Stefanos and S. Lesage were at the Université Catholique de Louvain, Louvain-la-Neuve, Belgium. They are now at Sofics, Gentbrugge, Belgium.

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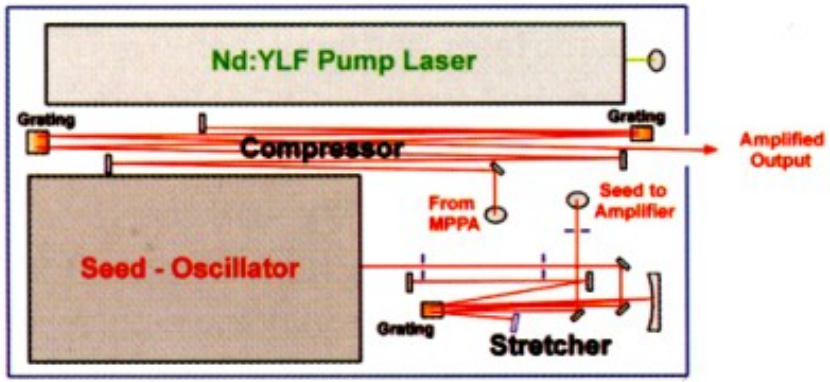
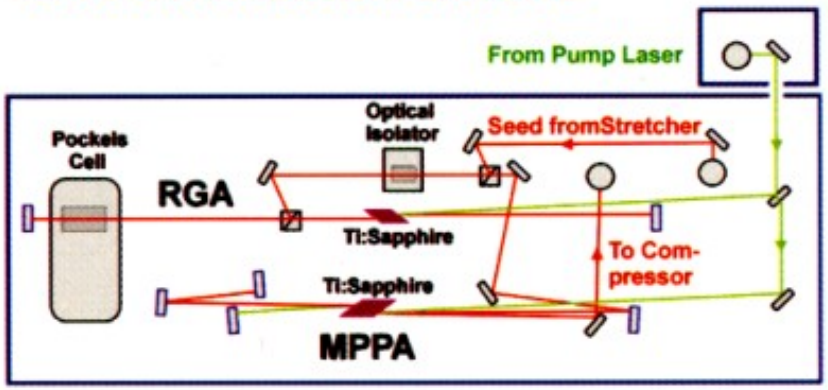
New laser system for the Single Event Radiation Effects in Electronics Laser (SEREEL) facility – SEREEL2

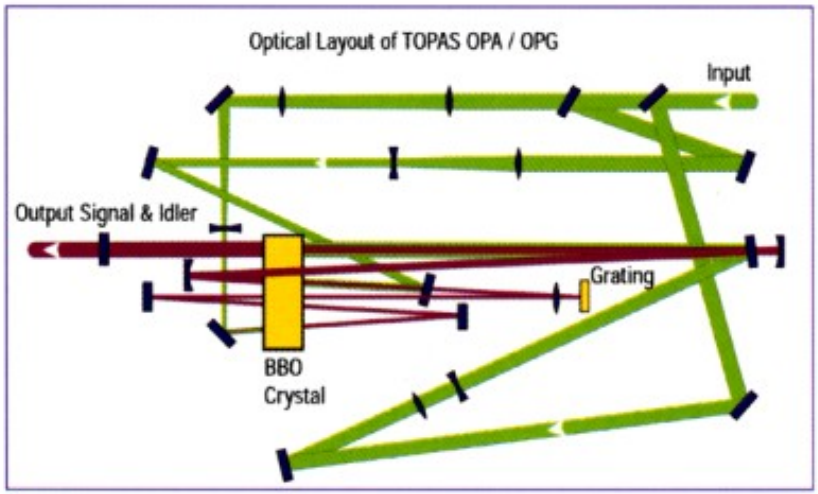
INTEGRA LAYOUT LOWER LEVEL



INTEGRA LAYOUT UPPER LEVEL



TOPAS OPTICAL LAYOUT



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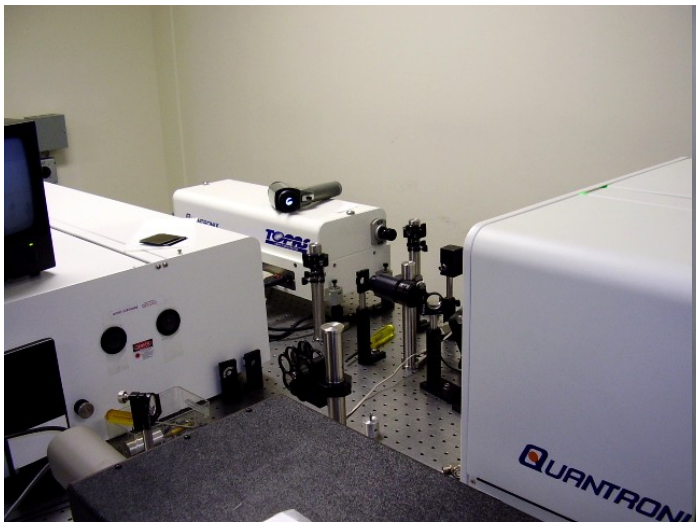
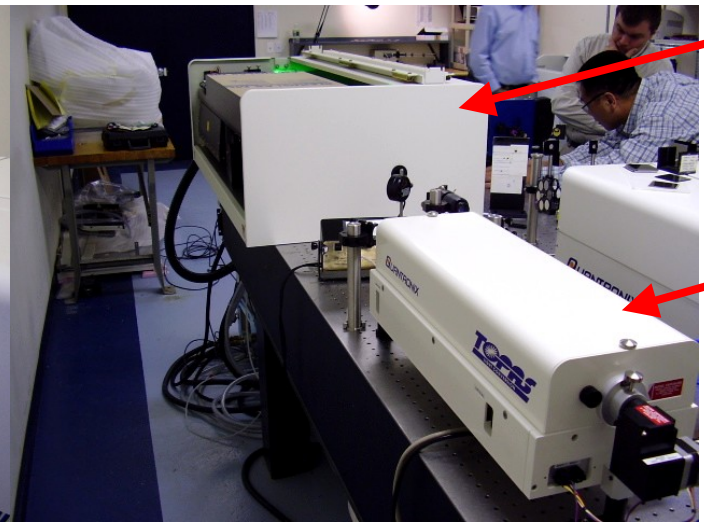
SEREEL2 Laser Commissioning at Quantronix in New York in April 2005



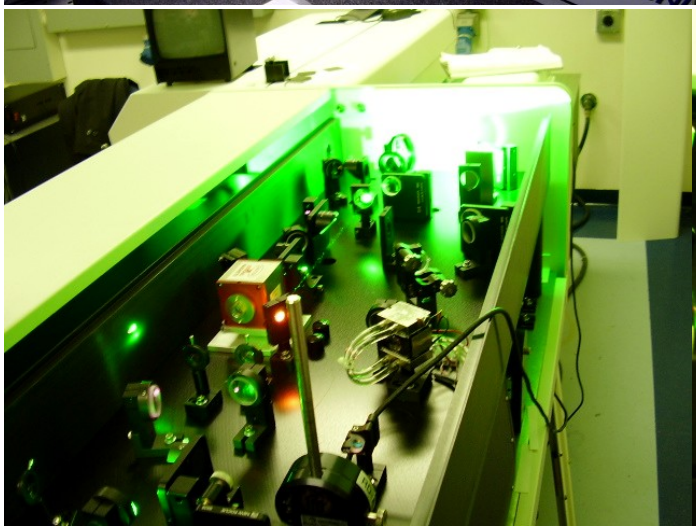


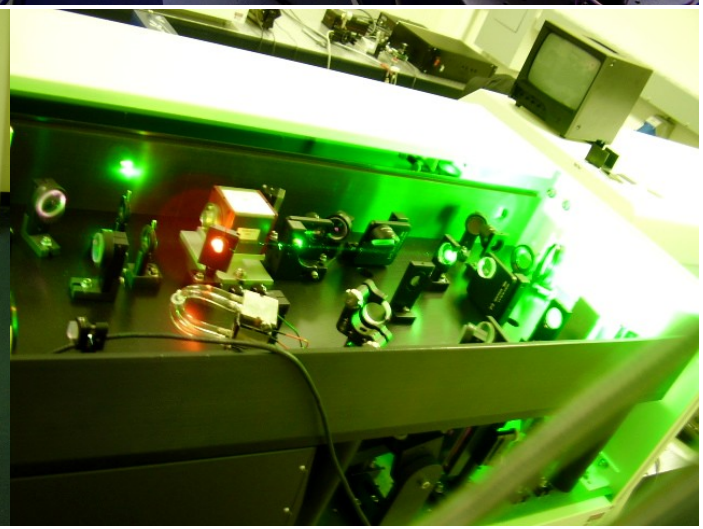
INTEGRA

Pump and seed laser

TOPAS

Optical Parametric Amplifier





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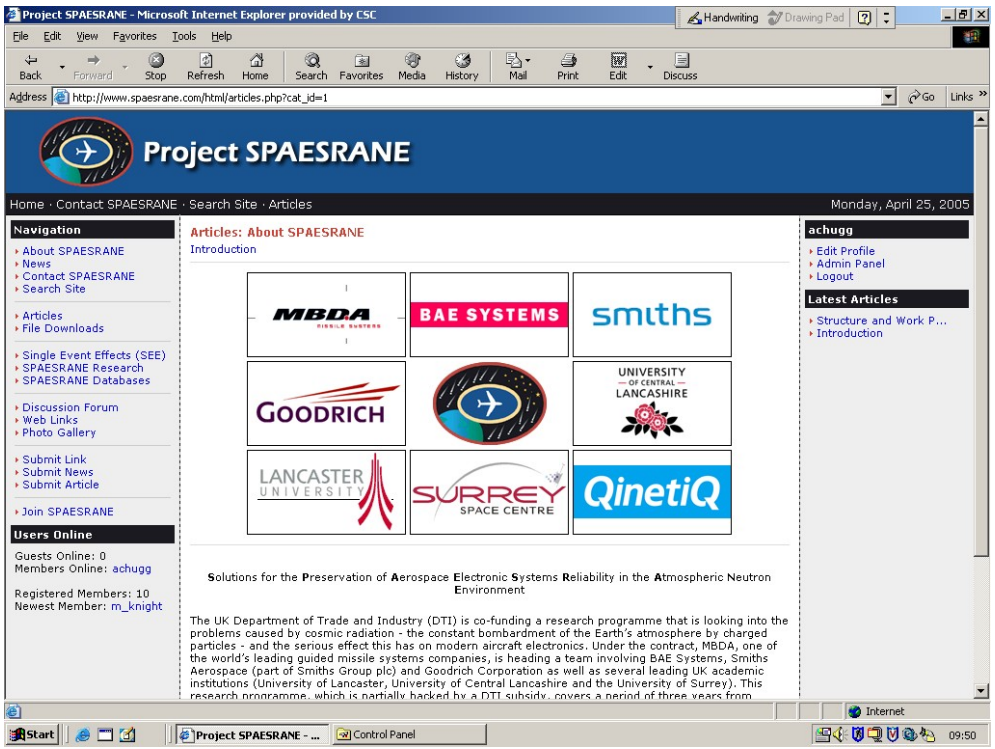
SPAESRANE Website

- More details of SEREEL and updates on the imminent commissioning of SEREEL2 may be found on the SPAESRANE website
  - http://www.spaesrane.com/
- SPAESRANE is the UK research consortium for Solutions for the Preservation of Aerospace Electronic Systems Reliability in the Atmospheric Neutron Environment



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Conclusions

- New techniques for laser mapping of memories developed
  - Rich menagerie of MBU's seen at high LET on mapping old ion beam data
- Laser depth profiling of SEE sensitivity demonstrated
  - Ionisation at different depths causes different direction of charge flow relative to nodes
  - Longer wavelengths (infrared) penetrate the silicon to produce funnelling of charge from the substrate
- Laser SEE testing of PWM's
  - Can infer locations of ion upsets on the dies through correlations with laser induced SEE
  - Laser testing showed delayed onset of SEL near the threshold
- Second generation laser SEE facility (SEREEL2) to be installed at MBDA in June

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