PROJECT

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TITLE

Heavy Ion Effects in PWM's of the types UCC1806 and UC1825A

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SUMMARY

This report presents the results from heavy ion irradiation on PWM's UCC1806 and UC1825A from Texas Instrument. The dice have been manufactured at the Unitrode facility at Merrimac.
No Single Event Latch-up (SEL) or hard errors were observed for UCC1806 and UC1825A up to an LET value of 64.8 MeV/mg/cm^2.
Both device types are very sensitive for soft errors with LET threshold around 20 MeV/mg/cm^2 for UCC1806, 10 MeV/mg/cm^2 for UC1825 and both have cross sections about 1E-3 cm^2.
Depending on test configuration, the soft errors are more or less frequent.
Results from the present tests and recent experiments on the same devices indicate a wide spread in results. No soft error was observed which caused more than two PWM output drop-out. The long inhibit observed in some of the presented pictures for UC1825A in the present report are solely due to extra capacitance in test cables.

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1. ABSTRACT

This report presents the Single Event Effects results from heavy ion tests on two types, UCC1806 and UCC1825A, of Pulse Width Modulator (PWM) controllers from Texas Instrument. Both types have been manufactured in the Unitrode foundry at Merrimac, UCC1806 in BiCMOS and UC1825A in Bipolar technology.

2. INTRODUCTION

Pulse Width Modulator controllers are commonly used in various switching mode power supply systems. PWM's offer special features designed to optimize the controller while minimizing the need for external circuitry. The devices generally have an error amplifier, an oscillator circuit, an output circuit and internal reference voltage. In some controllers such as the ones tested here there are also protection features as current limiting and soft-start.

Depending on the implementation of the different devices the effect of heavy ion can be significant in spaceflight hardware. UCC1806 has recently been heavy ion tested in two different test set-ups [1,2]. The TERMA [1] set-up was a heavy ion test of a real application where no errors could be observed. In a recent attempt to verify the results [2] with different implementation of the PWM, heavy ion errors were clearly detected.

The present investigations performed at the European HIF facility at CYClotron of Louvain la Neuve in Belgium have been guided by the set-ups and the results from the previous tests [1, 2].

2.1 References

[1] SEE Verification Test of Various Designs Using UCC1801/1805/1806 for Rosetta R. Harboe Sorensen and H. Jensen, 4th D/TOS-QCA Final Presentation Day, Jan 2001

[2] Heavy Ion Single Event Effects in UCC1806 PWMs, TOS-EPC/04.116/SL, S. Landstrom and R. Harboe Sorensen, ESA/ESTEC test report, 27 April 2004

3. TEST SAMPLES

3.1 UCC1806

UCC1806 is a low power, dual output, current mode Pulse Width Modulator controller. Three samples were prepared for the tests whereof two were irradiated with heavy ions The tested samples have been manufactured in a BiCMOS process at Unitrode Merrimac.

Part Type	UCC1806
Manufacturer	Texas Instrument (Unitrode/Merrimac)
Date Code	0146
Quality	Mil Temp
Bias Condition	5V
Package	Ceramic 16 DIL
Serialization	#1, #2

Figure 3.1.1 Package, top view

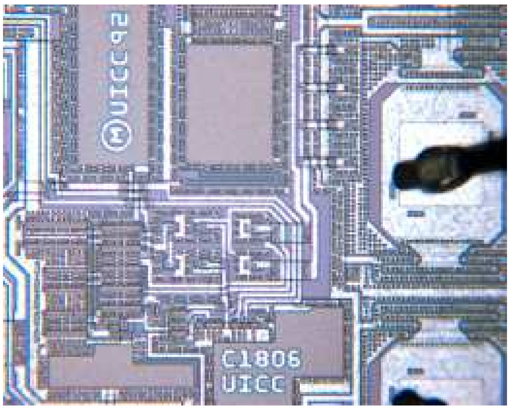

Figure 3.1.2 Chip marking

3.2 UC1825A

UC1825A is a high speed Pulse Width Modulator controller.
Three samples were prepared for the tests whereof two were irradiated with heavy ions The tested samples have been manufactured in bipolar technology at Unitrode Merrimac.

Part Type	UC1825A
Manufacturer	Texas Instrument (Unitrode/Merrimac)
Date Code	0313
Quality	QMLV
Bias Cond.	5V
Package	Ceramic 16 DIL
Serialization	#55, #56

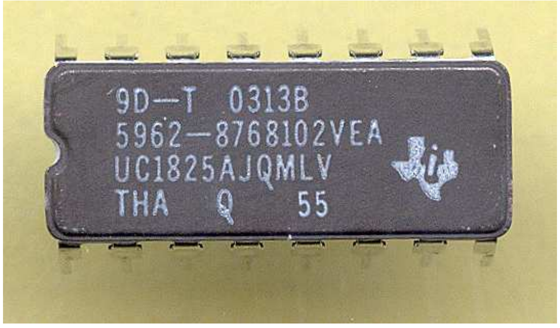

Figure 3.2.1 Picture of the UC1825A

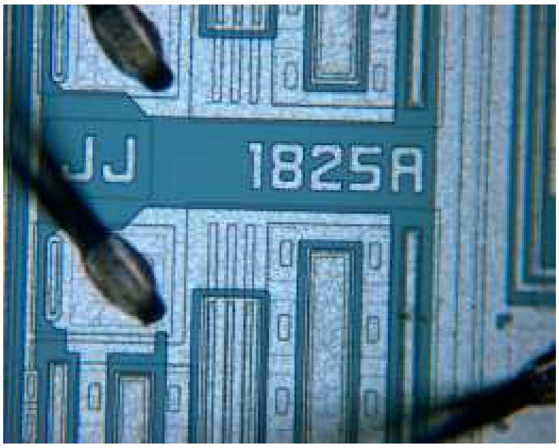

Figure 3.2.3 Chip mark on UC1825A

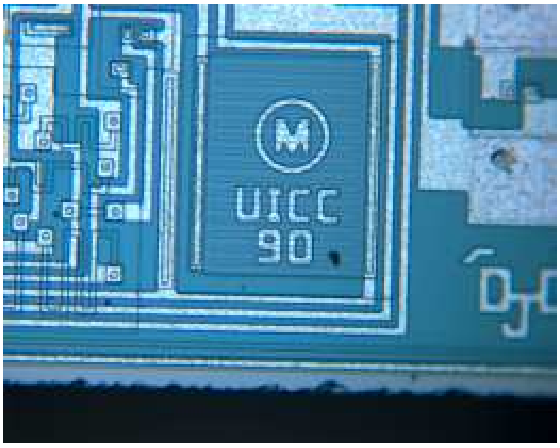

Figure 3.2.4 Chip mark on UC1825A

4. BIAS CONDITION AND TEST SETUPS

4.1 Test Technique

For both PWM types six different parameters have been recorded as a function of heavy ion strike and LET value. Single Event Transients (SET) was measured using two oscilloscopes (Tektronix TDS3054, 500 MHz, 5GS/s) with trig conditions set to the same. The oscilloscope has been triggered for one parameter at the time with all other parameters recorded simultaneous. In each test run all oscilloscope inputs have been recorded. For each trigger set-up, about 30-40 recordings have been saved to the computer.
The test software was developed by use of "Labview software" for the GPIB communication between the computer and the oscilloscopes and to store all results.

4.2 Test setup for the PWM UCC1806

In this setup the PWM controller was tested in integrated feedback mode with two different capacitors on the reference output voltage, 10nF and 150nF.

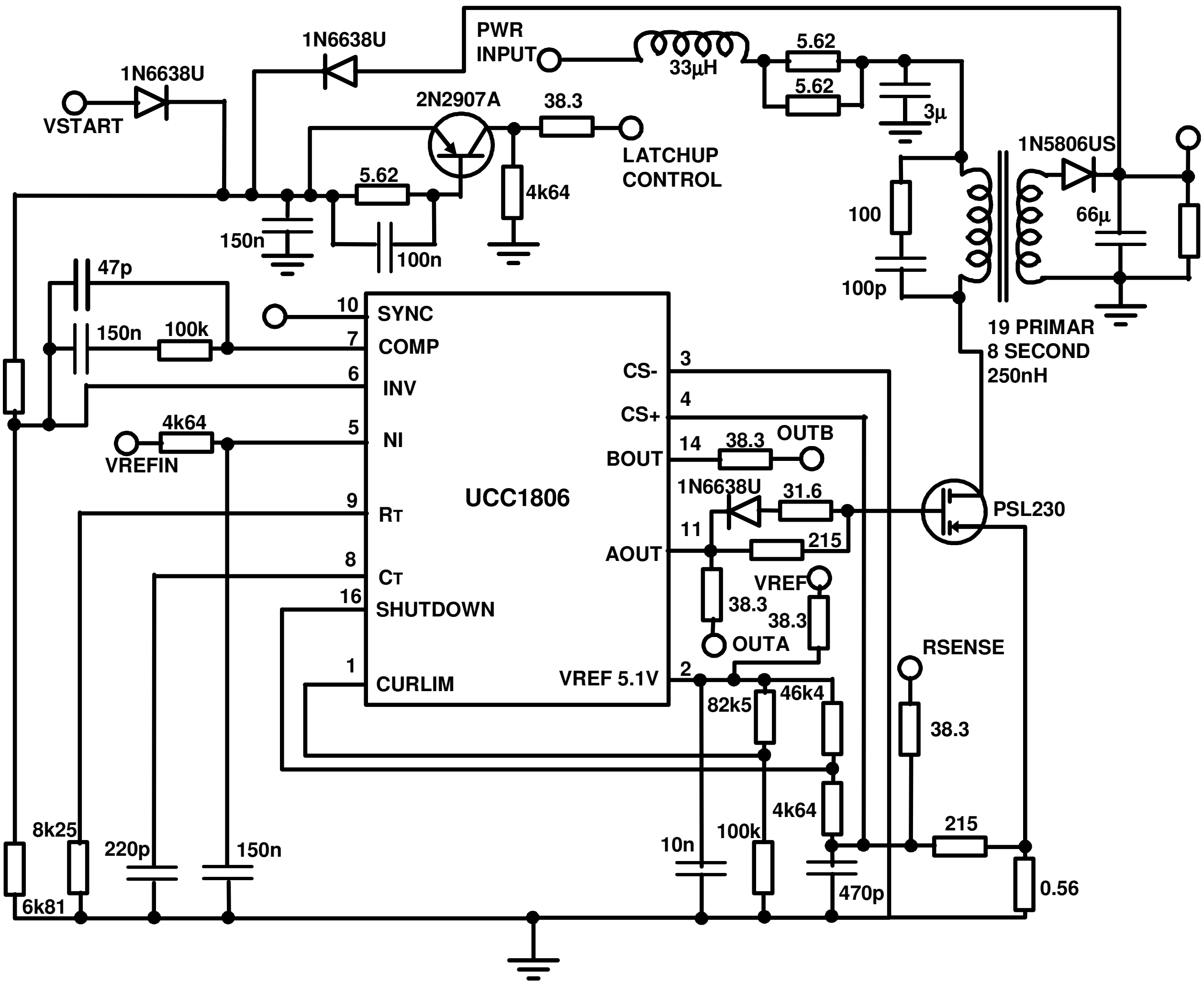

Figure 4.2.1 Test setup diagram for the UCC1806

Recorded signals:

Signal	Circuit Pin	Description	Trig condition
Aout	11	PWM Clock Output	Pulse-width <1µs
Bout	14	PWM Clock Output	no trig
EA	7	Error Amplifier Output	Neg. slope at 1.36V
CL	1	Current Limit input	Neg. slope at 2.80V
Vref	2	Reference Voltage Output	Neg. slope at 0.59V
Rsence		Voltage drop over the source resistor on the external MOSFET.	no trig

4.3 Test setup for the PWM UC1825A

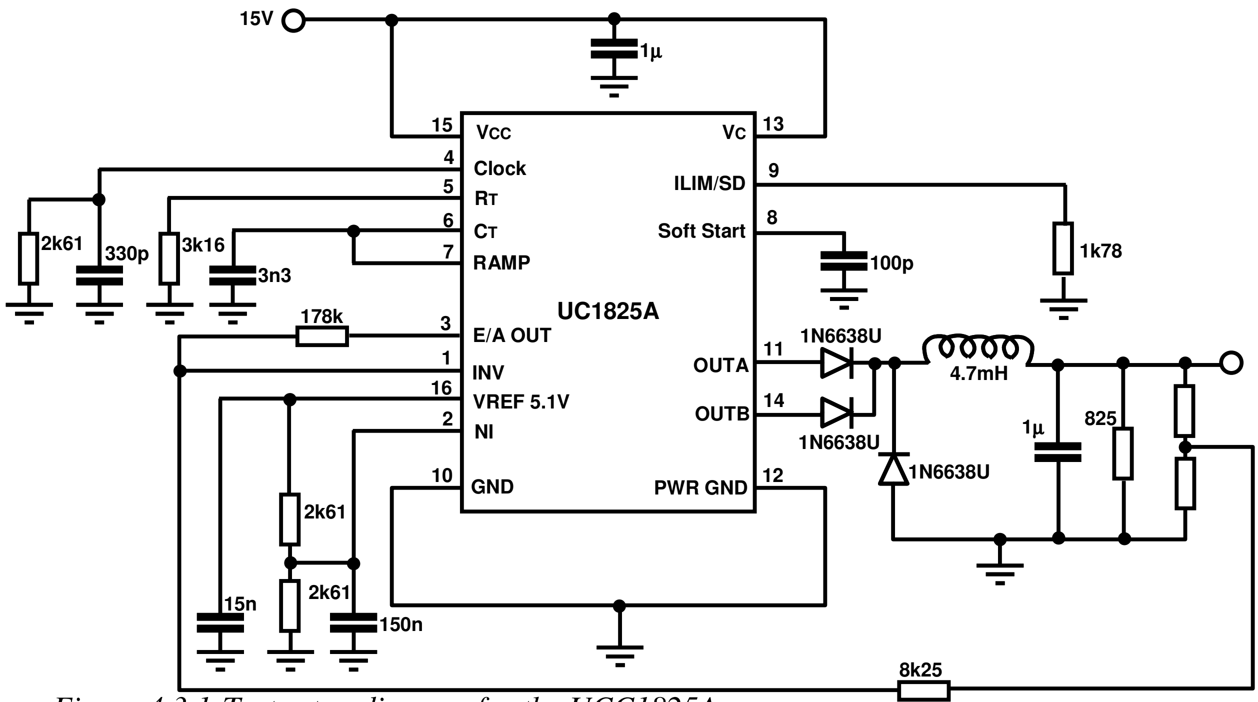

Figure 4.3.1. Test setup diagram for the UCC1825A

Recorded signals:

Signal	Circuit pin	Description	Trig condition
Aout	11	PWM Clock Output	Pulse-width <3µs
Bout	14	PWM Clock Output	no trig
SS	8	Soft Start	Neg. slope at 2.60V
EA	3	Error Amplifier Output	Neg. slope at 2.00V
Vref	16	Reference Voltage Output	Neg. slope at 2.80V
5V out		Rectified Output Voltage	no trig

4.4 Heavy Ion Test Facility

Heavy ion tests were performed at the CYClotron at Louvain la Neuve (CYCLONE) in Belgium. The high energy cocktail (M/Q=3.33) were used in order to ensure sufficient penetration depth in Silicon. The ions used are given in Table 4.1. Test data as ion beam, tilt angle, flux, fluence and SET data for the various test runs are given in Appendix A

TABLE 4.1 HEAVY IONS USED AT LOUVAIN LA NEUVE IN BELGIUM

Element	Energy MeV	Range µm	LET value [MeV/mg/cm^2]
22 Ne7+	235	199	3.3
40 Ar12+	372	119	10.1
78 Kr25+	756	92	32.4

5. RESULTS

5.1 UCC1806

No Single Event Latch-up (SEL) has been observed for this device up to an LET of 65 MeV/mg/cm^2.
SET data and cross sections looks very much the same for the various tested parameters. It seems as any heavy ion induced transient (SET) generate errors on all parameters. In Fig 5.1.1 the cross sections for one missed output pulse on Aout using a reference voltage of 2.5 volts are shown. No significant difference in cross section could be observed for 1,25 and 5 Volts reference voltage. Comparative measurements were performed for LET=32.4 MeV/cm^2/mg. The results are given in Table 5.1.1 below. Cross section curves for the parameters Aout, Error Amplifier (EA) and Current Limiter (CL) are given in Figs 5.1.2 .

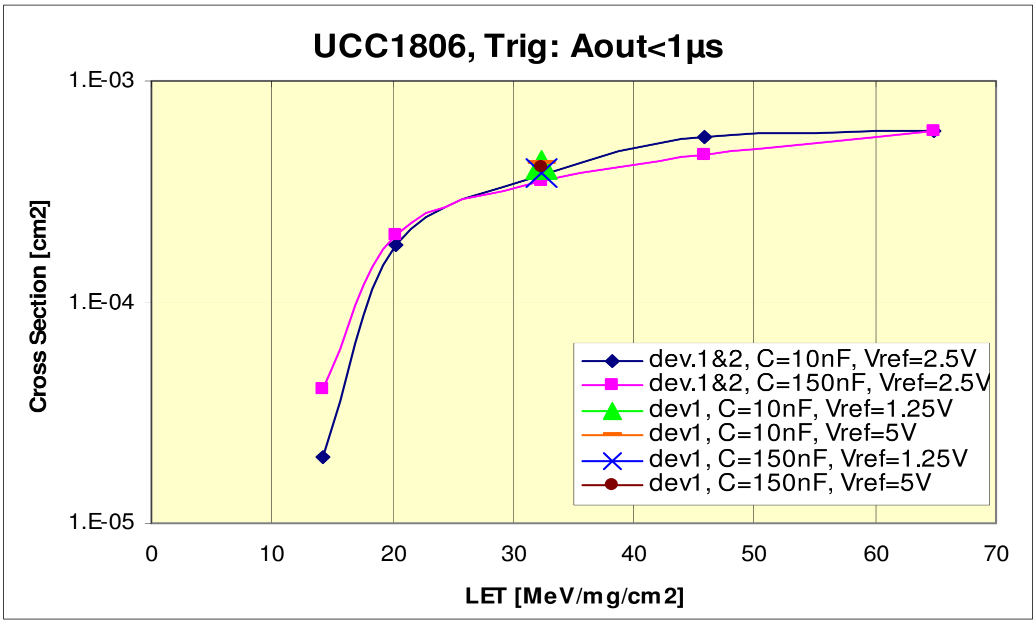

Figure 5.1.1 Cross Section versus LET value for one or more missed pulses on Aout. No difference could be observed for the two different capacitances to reference output voltage

TABLE 5.1.1 CROSS SECTION GIVEN IN CM^2 FOR THREE DIFFERENT REFERENCE VOLTAGES AND TWO DIFFERENT CAPACITORS CONNECTED TO THE REFERENCE VOLTAGE OUT (PIN 2). THE LET WAS 32.4MEV/MG/ CM^2. THE TRIGGERING CONDITION WAS THE SAME AS IN FIGURE 5.1.1

C	Vref=1.25V	Vref=2.50V	Vref=5.00V
10nF	4.20E-04	4.10E-04	4.30E-04
150nF	3.80E-04	3.55E-04	4.10E-04

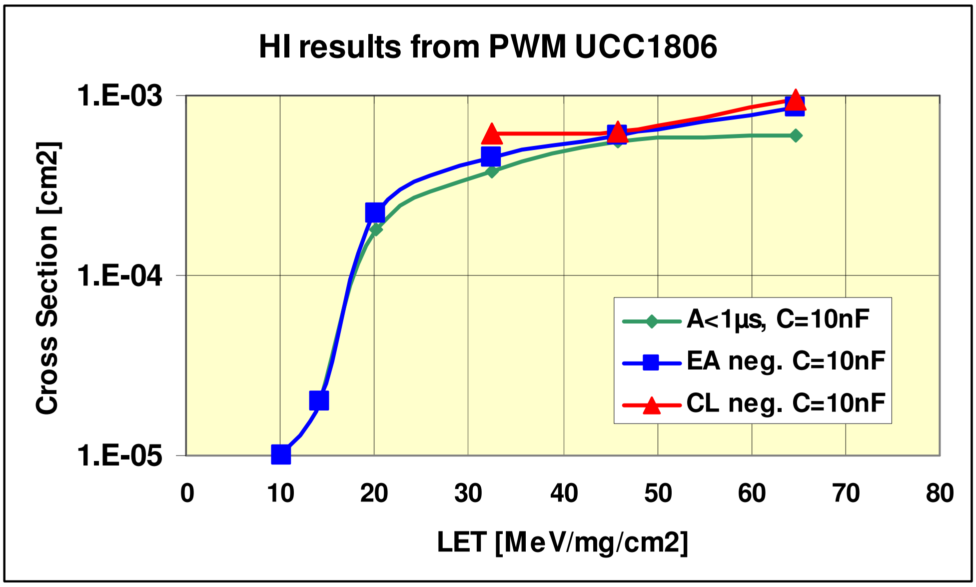

Fig 5.1.2 *Cross Sections as a function of LET values for Aout, Error Amplifier and Current Limiter with 10nF capacitance to reference output voltage. Average data of the two samples.*

S. Landström and R. H. Sörensen [2] have in recent report identified three sensitive areas (functions) on the die, namely; PWM pulse drop-out, latching of PWM clock and control loop transients. In the present investigation cross section of these errors have been measured and given as Aout, Current Limiter (CL) and Error Amplifier (EA), respectively.
The probabilities for critical transients are closely linked to the implementation of the PWM and the design of the DC/DC converter. In ref [2] the cross sections are reported to be about 10 times lower than in the present investigation. These discrepancies can be attributed to the different test set-ups used.

A transient trigged by Aout with all other parameters followed is shown in Fig 5.1.3.
A typical oscilloscope picture when triggering on CL with all other parameters followed is given in Fig 5.1.4. This type of transients are likely due to hit in the reference regulator which will influence the latch controlling the UVLO (Under Voltage Lock Out unit) and the different input voltages to the OP-amplifier comparators.

In the present test it has been observed that a voltage drop on the Vref can lead to a soft start and a change of the pulse period time on the Aout clock (Bout as well). This phenomenon is shown in Fig 5.1.5 where the SET trigger is set on CL. About 10µs before the CL drop, the reference voltage start to decrease and shift the pulse period for next pulse before the CL close down the PWM.

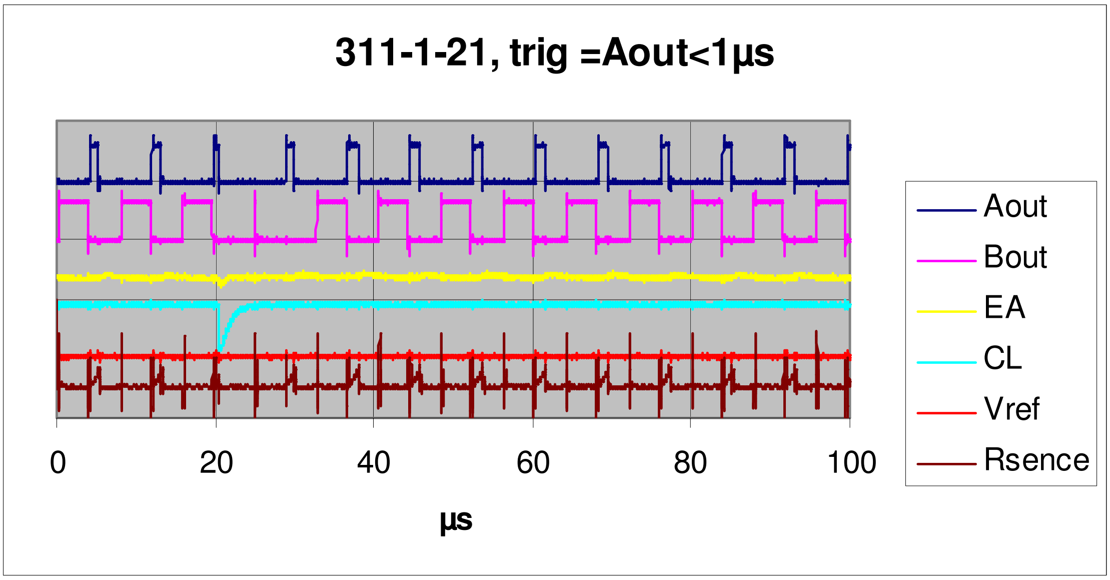

Figure 5.1.3 Oscilloscope picture indicating that one of the latches in the UVLO is hit by an ion. The CL signal show a short response time.

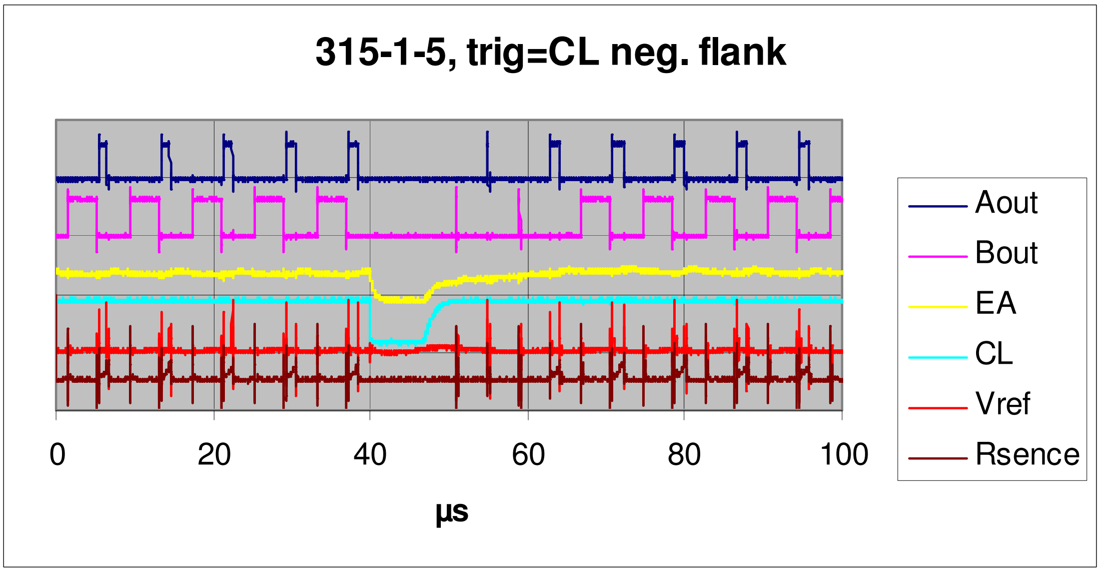

Figure 5.1.4 Typical picture of an error generated in some of the OP-amplifiers controlling the UVLO where almost all signals are affected.

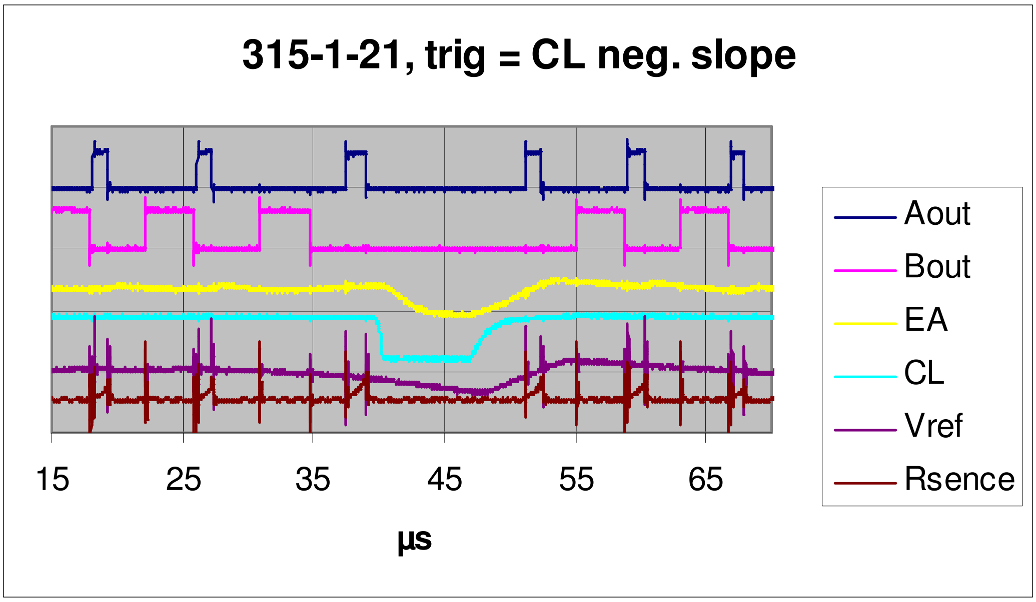

Figure 5.1.5 Oscilloscope picture of measured parameters when negative slope on the CL signal was triggering the oscilloscopes. The Vref starts to decrease at about 10µs before the CL close down the PWM and at the same time shift the Aout pulse period.

5.2 UC1825A

Fig 5.2.1 shows the SET cross section data for the parameters Aout, SoftStart (SS) and Error Amplifier (EA). The Aout and the EA are very similar while the SS is slightly lower in cross section. This indicates that the majority of all SET's involve the SS resulting in missing pulses on the Aout and error in EA. Only a small fraction of all errors observed in the output stage or in the EA do not affect the SoftStart (SS).

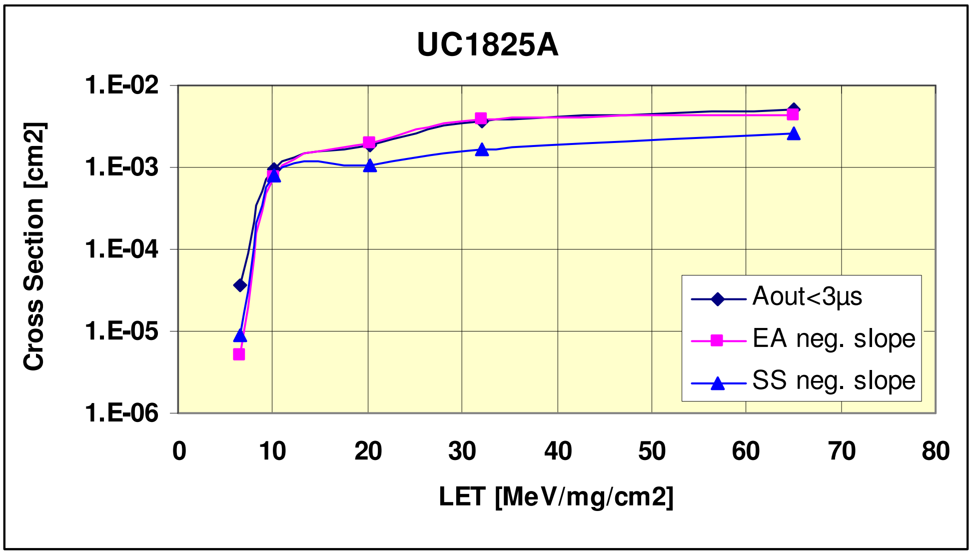

Figure 5.2.1 Cross Sections as a function of LET values for heavy ion induced SET on UC1825A. All data points show the average of the two tested devices. The legend in the right corner indicate the trigger conditions

Figs 5.2.2-5.2.5 show oscilloscope pictures for typical heavy ion events. In each figure, the oscilloscope has been triggered by one specific parameter (given in the fig caption) with all other parameters followed. For each trigger set-up, about 30-40 snap-shots have been recorded. The shown pictures are selected as representative snap-shots of heavy ion strikes.

In this test, the UC1825A was controlling a buck converter in voltage mode by tying the Ct and Ramp pins together. The SHDN/ILIM pin was grounded through a resistor. The buck converter was running in continuous mode and thus shows the characteristic damped resonance when controlled in voltage mode as in this case.

Independent of trigger parameter, a striking similarity in appearance between the pictures is observed. The SET transients seen are what would be expected if the SS-latch is trigged. The SS pin "quickly" discharges the capacitance down to ~0.3V and then returns "slowly" to its normal value of 5V. After the SS pin returns, a ringing is seen on the EA pin. This is caused by the control loop trying to correct the output voltage error caused by the missing pulses. The buck converter resonance is responsible for this behavior, not the SET itself. The actual discharge/charge time and number of missing pulses depend on the capacitance seen on the SS pin, the nominal EA output voltage and of course the switching frequency.

In the plots below (Figs 5.2.2-5.2.4) it can be seen that many PWM pulses are missing after an SET.
The influence of the test cable has been verified on the PWM type UC1806. In Fig 5.2.5 a SET in CL (Current Limiter) and EA (Error Amplifier) using a test set-up with a capacitance of that in the flat cable (about 200pF) is shown. In Fig 5.2.6, the same test data are shown where the DUT board was equipped with a transistor-driving circuit eliminating the cable capacitance. As can be seen from the figures, the recovery time changed a factor 3.

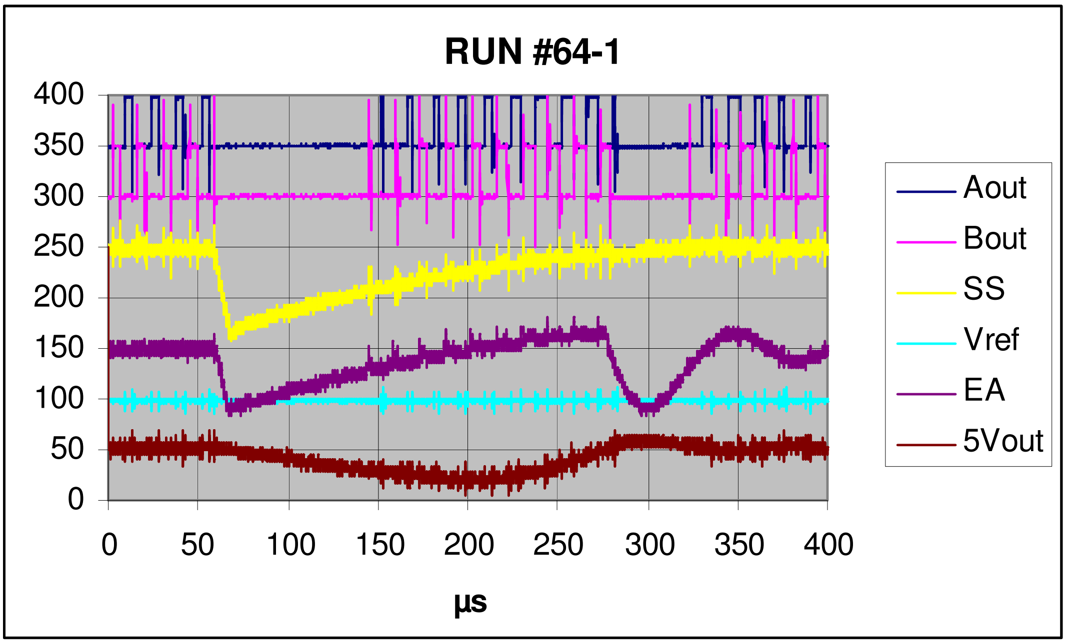

Fig 5.2.2 Oscilloscope picture of various parameters on the UC1825A triggered by the Soft Start. For better visualization, the data for SS, EA and 5Vout have been amplified a factor 4 in the picture. The long recovery times of the signals are due to test cable capacitance (200pF). Elimination of the test cable capacitance will reduce the recovery time with a factor 3.

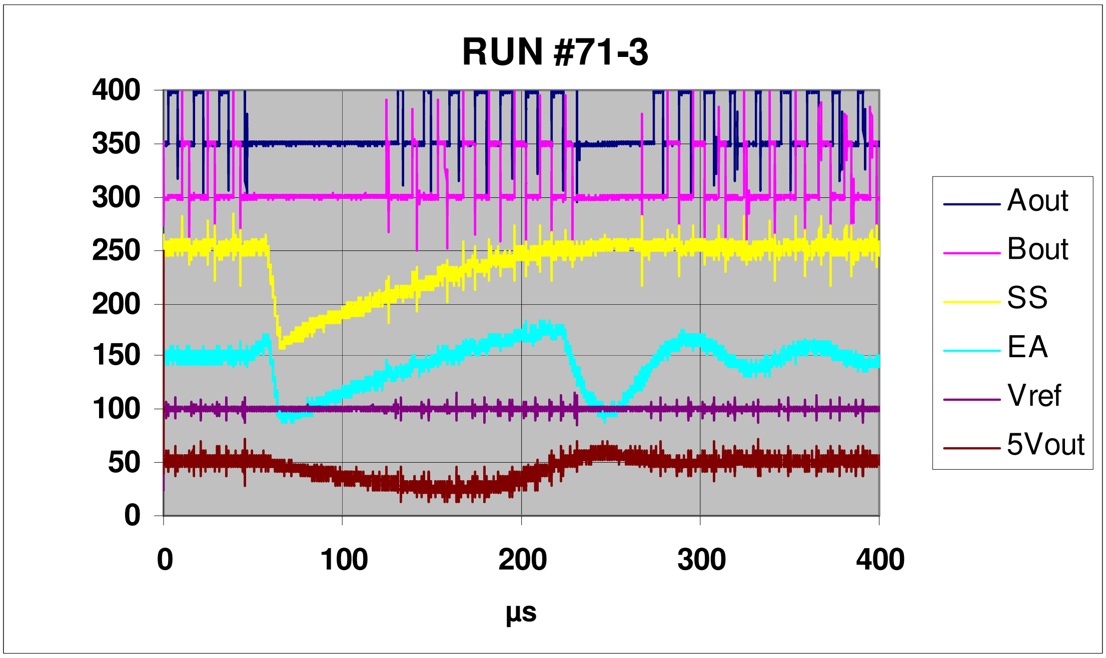

Fig 5.2.3 Oscilloscope picture of various parameters on the UC1825A triggered by the Error Amplifier. For better visualization, the data for SS, EA and 5Vout have been amplified a factor 4 in the picture. The long recovery times of the signals are due to test cable capacitance (200pF). Elimination of the test cable capacitance will reduce the recovery time with a factor 3.

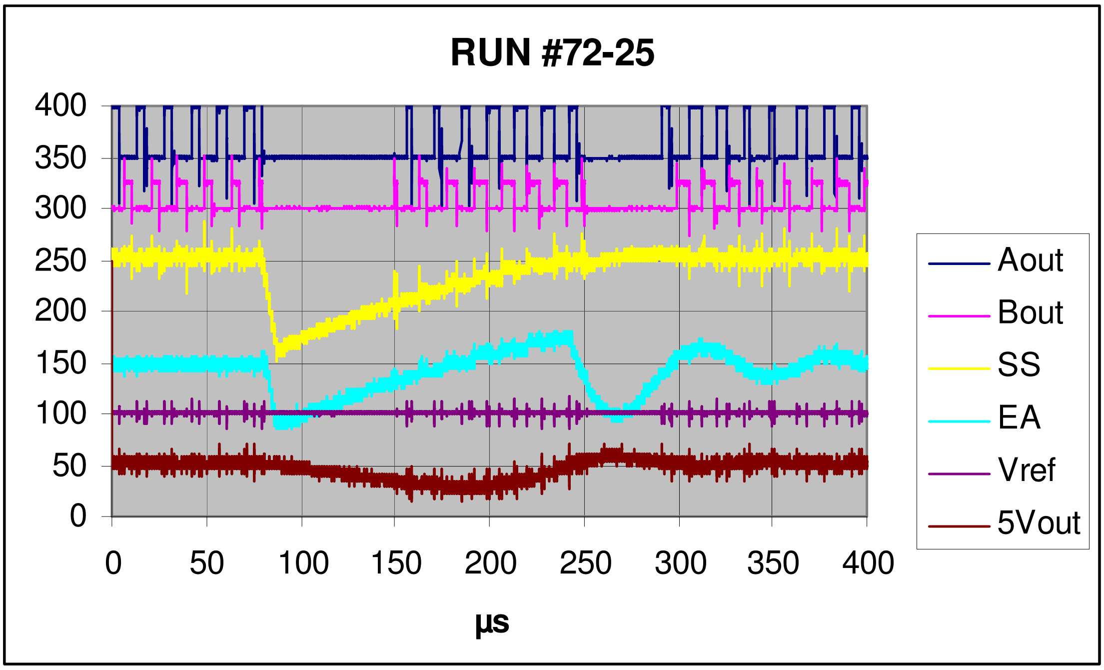

Fig 5.2.4 Oscilloscope picture of various parameters on the UC1825A triggered by the Aout. For better visualization, the data for SS, EA and 5Vout have been amplified a factor 4 in the picture. Bout is reduced a factor of 2. The long recovery times of the signals are due to test cable capacitance (200pF). Elimination of the test cable capacitance will reduce the recovery time with a factor 3.(se figs 5.2.5 and 5.2.6)

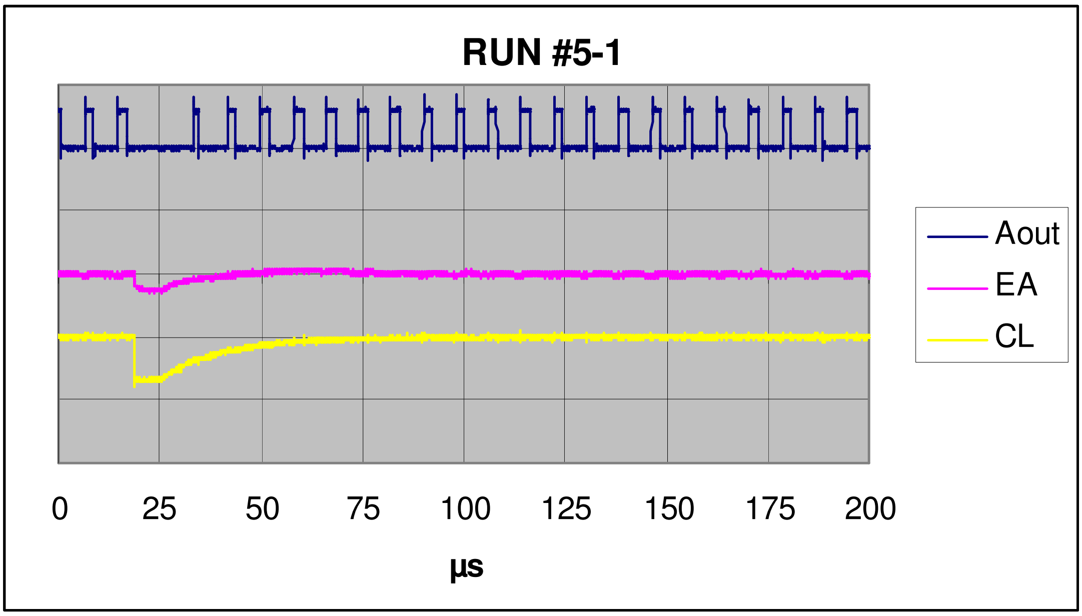

Fig 5.2.5 Oscilloscope pictures of PWM parameters after heavy ion strike using a 3m flat cable (~200pF) to the DUT board giving a Current Limiter pulse of about 30µs.

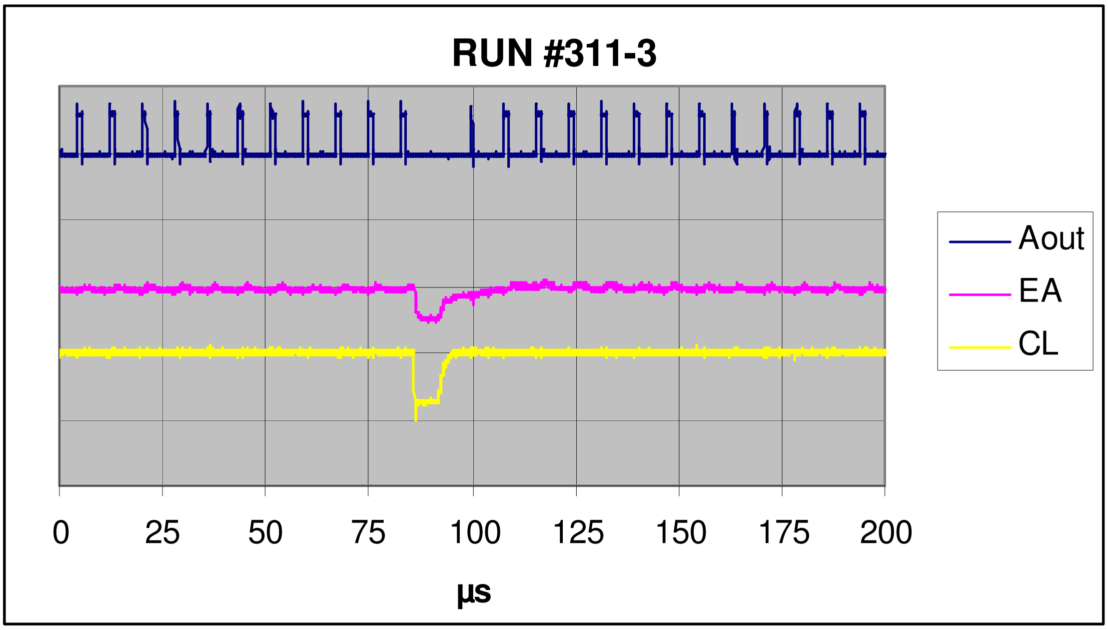

Fig 5.2.6 Oscilloscope pictures of PWM parameters after heavy ion strike using a transistor-driver circuitry on the DUT board eliminating the capacitance in the flat cable. The width of the CL pulse is reduced to about 10µs.

6. CONCLUSION

The PWM's UCC1806 and UC1825A from Texas Instrument have been manufactured at the Unitrode facility at Merrimac.
No Single Event Latch-up (SEL) or hard errors were observed for UCC1806 and UC1825A up to an LET value of 64.8 MeV/mg/cm^2.
Both device types are very sensitive for soft errors with a LET threshold around 20 MeV/mg/cm^2 for the UCC1806, around 10 MeV/mg/cm^2 for the UC1825 and both have cross sections about 1E-3 cm^2.
Depending on the test configuration, the soft errors are more or less frequent. In the recent test [1] of UCC1806, no soft errors were recorded at all. In the present investigation the cross section is measured to be about 10 times higher than earlier reported results.
No soft error was observed which caused more than two PWM output drop-out. The long inhibit observed in some of the presented pictures for UC1825A in the present report are solely due to extra capacitance in test cables.

7. Appendix

Measured raw data:
High penetration, M/Q=3.33 Data, Aug 2004

Ion-tilt	LET	Fluence	device	C [nF]	Reference voltage [V]	SEE Data	Run no
Ar-0	10.1	1E5	2	10	2.50	4	85
Ar-0	10.1	1E5	2	150	2.50	0	84
Ar-45	14.3	1E5	2	10	2.50	2	86
Ar-45	14.3	1E5	2	150	2.50	4	87
Ar-60	20.2	1E5	2	10	2.50	18	89
Ar-60	20.2	1E5	2	150	2.50	20	88
Kr-0	32.4	1E5	1	10	1.25	42	8
Kr-0	32.4	1E5	1	150	1.25	38	13
Kr-0	32.4	1E5	1	10	2.50	42	7
Kr-0	32.4	1E5	2	10	2.50	33	57
Kr-0	32.4	1E5	1	150	2.50	31	12
Kr-0	32.4	1E5	2	150	2.50	40	58
Kr-0	32.4	1E5	1	10	5.00	43	10
Kr-0	32.4	1E5	1	150	5.00	41	11
Kr-45	45.8	1E5	1	10	2.50	65	45
Kr-45	45.8	1E5	2	10	2.50	40	68
Kr-45	45.8	1E5	1	150	2.50	46	46
Kr-45	45.8	1E5	2	150	2.50	47	67
Kr-60	64.8	1E5	1	10	2.50	63	52
Kr-60	64.8	1E5	2	10	2.50	67	65
Kr-60	64.8	1E5	1	150	2.50	62	51
Kr-60	64.8	1E5	2	150	2.50	57	66

PWM UCC1806, trig=Aout<1µs

Ion-tilt	LET	Fluence	device	C [nF]	Reference voltage[V]	SEE Data	Run no
Ar-0	10.1	1E5	2	10	2.50	1	82
Ar-0	10.1	1E5	2	150	2.50	0	83
Ar-45	14.3	1E5	2	10	2.50	2	81
Ar-45	14.3	1E5	2	150	2.50	8	80
Ar-60	20.2	1E5	2	10	2.50	22	78
Ar-60	20.2	1E5	2	150	2.50	37	79
Kr-0	32.4	1E5	1	10	1.25	60	25
Kr-0	32.4	1E5	1	150	1.25	40	30
Kr-0	32.4	1E5	1	10	2.50	52	26
Kr-0	32.4	1E5	2	10	2.50	38	72
Kr-0	32.4	1E5	1	150	2.50	46	29
Kr-0	32.4	1E5	2	150	2.50	46	71
Kr-0	32.4	1E5	1	10	5.00	49	27
Kr-0	32.4	1E5	1	150	5.00	50	28
Kr-45	45.8	1E5	1	10	2.50	56	56
Kr-45	45.8	1E5	2	10	2.50	63	73

Kr-45	45.8	1E5	1	150	2.50	63	55
Kr-45	45.8	1E5	2	150	2.50	68	74
Kr-60	64.8	1E5	1	10	2.50	86	53
Kr-60	64.8	1E5	2	10	2.50	85	76
Kr-60	64.8	1E5	1	150	2.50	77	54
Kr-60	64.8	1E5	2	150	2.50	81	75

PWM UCC1806, trig=EA neg. slope

Ion-tilt	LET	Fluence	device	C[nF]	Reference voltage [V]	SEE Data	Run no
Kr-0	32.4	1E5	1	10	1.25	66	25
Kr-0	32.4	1E5	1	150	1.25	50	30
Kr-0	32.4	1E5	1	10	2.50	61	26
Kr-0	32.4	1E5	1	150	2.50	56	29
Kr-0	32.4	1E5	1	10	5.00	56	27
Kr-0	32.4	1E5	1	150	5.00	62	28
Kr-45	45.8	1E5	1	10	2.50	63	56
Kr-45	45.8	1E5	1	150	2.50	70	55
Kr-60	64.8	1E5	1	10	2.50	96	53
Kr-60	64.8	1E5	1	150	2.50	91	54

PWM UCC1806, trig=CL neg. slope

High penetration, M/Q=3.33Data Nov. 2004, Ref voltage=2.5V

Ion-tilt	LET	Fluence	device	SEE Data	Run no
Ne-60	6.6	4E5	55	17	97
Ne-60	6.6	4E5	56	12	95
Ar-0	10.1	1E5	55	95	77
Ar-0	10.1	1E5	56	94	79
Ar-60	20.2	1E5	55	183	73
Ar-60	20.2	1E5	56	190	80
Kr-0	32.4	5E4	55	186	107
Kr-0	32.4	5E4	56	175	109
Kr-60	64.8	3E4	55	150	108

UC1825, Trig=Aout<3µs

Ion-tilt	LET	Fluence	device	SEE Data	Run no
Ne-60	6.6	4E5	55	2	99
Ne-60	6.6	2E5	56	1	91
Ar-0	10.1	1E5	55	77	69
Ar-0	10.1	1E5	56	76	88
Ar-60	20.2	1E5	55	187	70
Ar-60	20.2	1E5	56	197	87
Kr-0	32.4	5E4	55	197	101
Kr-0	32.4	4E4	56	157	110
Kr-60	64.8	2.38E4	55	125	102

UC1825, Trig on EA-out on neg. slope

Ion-tilt	LET	Fluence	device	SEE Data	Run no
Ne-60	6.6	4E5	55	3	98
Ne-60	6.6	5E5	56	5	93
Ar-0	10.1	1E5	55	79	62
Ar-0	10.1	1E5	56	85	83
Ar-60	20.2	1E5	55	119	63
Ar-60	20.2	1E5	56	95	82
Kr-0	32.4	5E4	55	76	104
Kr-0	32.4	5E4	56	88	111
Kr-60	64.8	5E4	55	132	103

UC1825, Trig on SS on neg. slope