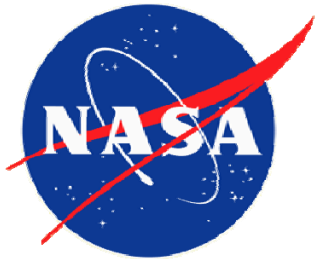


Total Dose Effects on Single Event Transients in Digital CMOS and Linear Bipolar Circuits

S. Buchner, *MEI/NASA-GSFC*
D. McMorrow, *NRL*
M. Sibley, P. Eaton, D. Mavis, *Micro-RDC*
L. Dusseau, N. J-H. Roche, M. Bernard, *Univ. of Montpellier*

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009

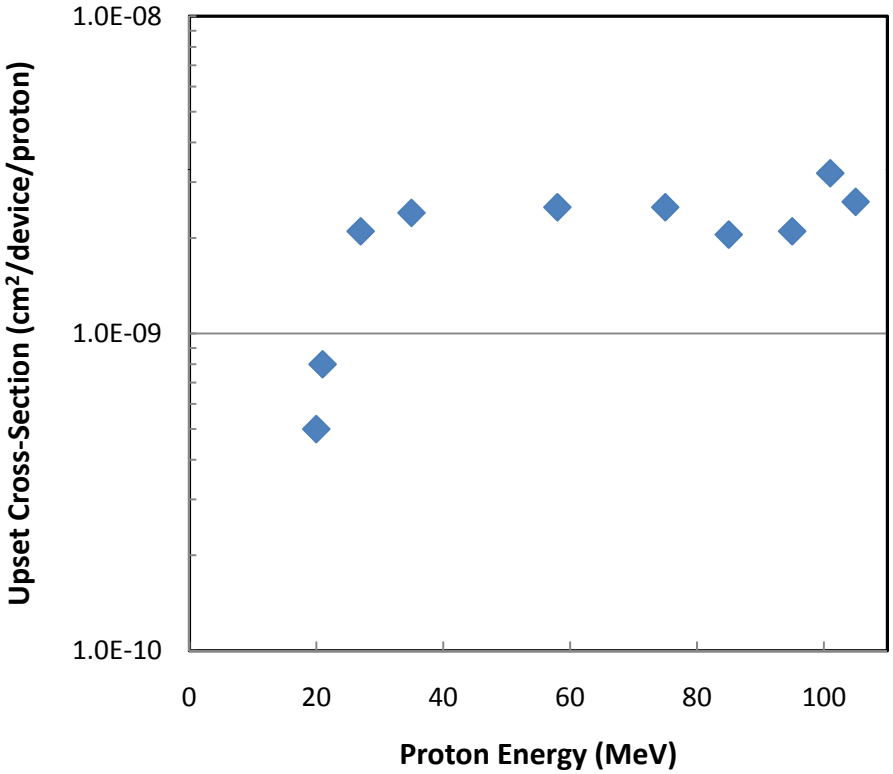
Introduction

- Exposure of ICs to ionizing radiation changes electrical parameters.
- TID effect observed in both CMOS and bipolar circuits:
  - In bipolar circuits, transistors exhibit **gain degradation**
  - In CMOS circuits, transistors exhibit **threshold voltage shifts**
- Changes in electrical parameters can cause changes in SEU/SET rates. Depending on effect, rates may increase or decrease.
- Therefore, measures taken for SEU/SET mitigation might work at the beginning of a mission but not at the end following TID exposure.

Introduction

TID concerns arise during proton testing of circuits with small SEU cross-sections

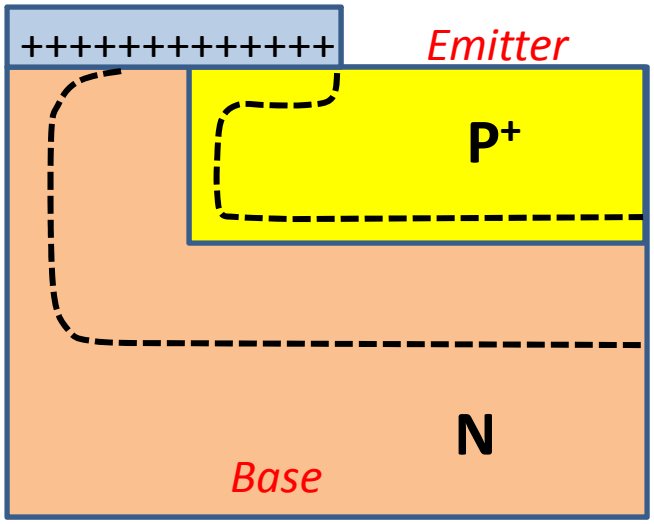
- At 60 MeV, a fluence of $7x10^{11}$ p/cm^2 gives a TID of 100 krad(Si).
- For 10% statistics require 100 upsets or $3x10^{11}$ p/cm^2.
- Assume 50% charge yield in presence of electric field.
- Equivalent TID(e^-) = 20 krad.
- If part has a hardness of 50 krad, can measure 2 points before electrical parameters exceed manufacturer's specifications and part must be changed.
- Schwank et al have investigated proton-induced TID effects in SRAMs (2004)



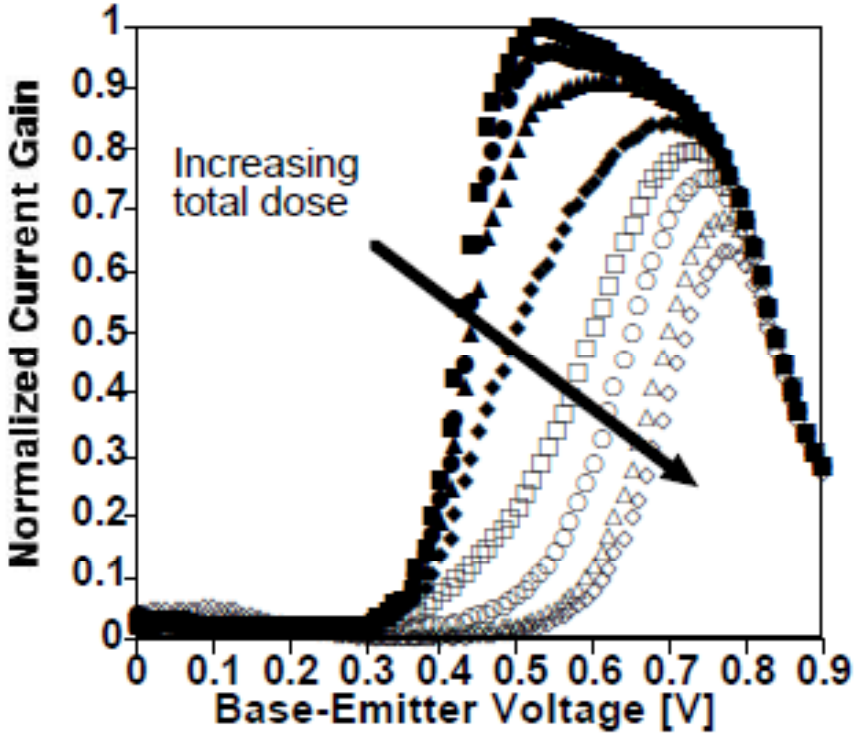
N.J.Buchanan et al. MAPLD 2000

Introduction – Bipolar Transistors

TID causes charge buildup that distorts emitter/base junction field and degrades gain.



Schmidt et al, IEEE TNS 1996

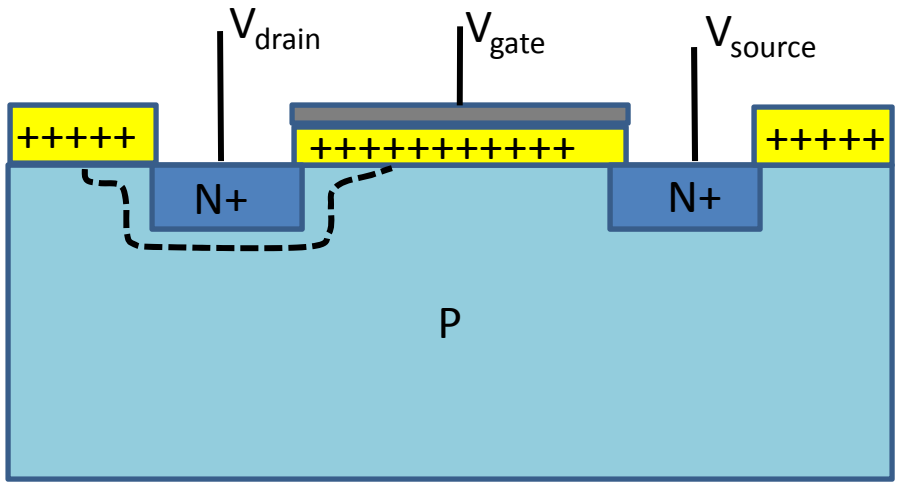


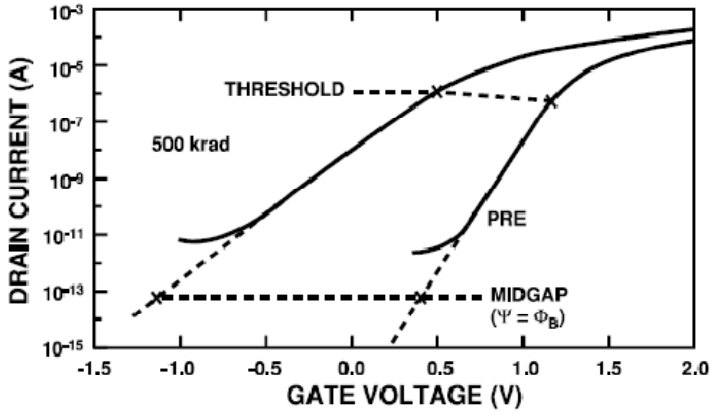
Schrimpf, NSREC 2001 Short Course

Introduction – MOS transistors

TID causes charge buildup that shifts threshold Voltage and increases leakage currents.

N-channel MOSFET





J. Schwank, NSREC Short Course 2002

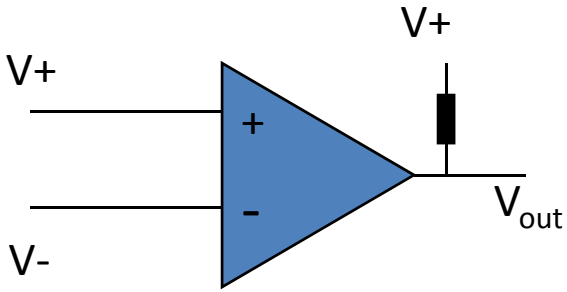
LINEAR BIPOLAR CIRCUIT

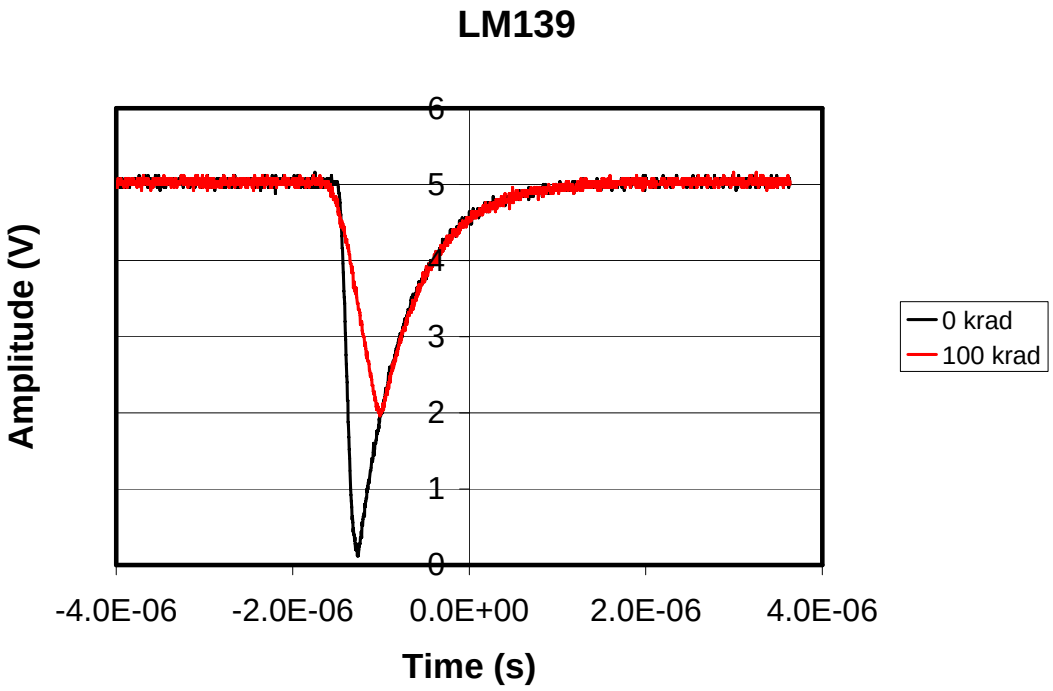
VOLTAGE COMPARATOR – LM139

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009

Voltage Comparator – LM139

- **LM139 -** SETs become smaller with TID





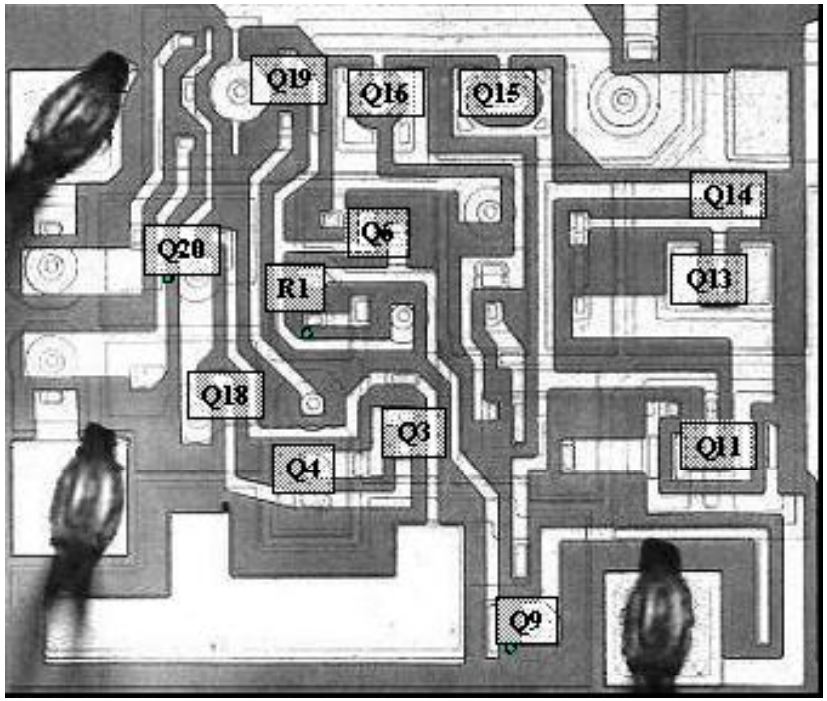
LINEAR BIPOLAR CIRCUIT

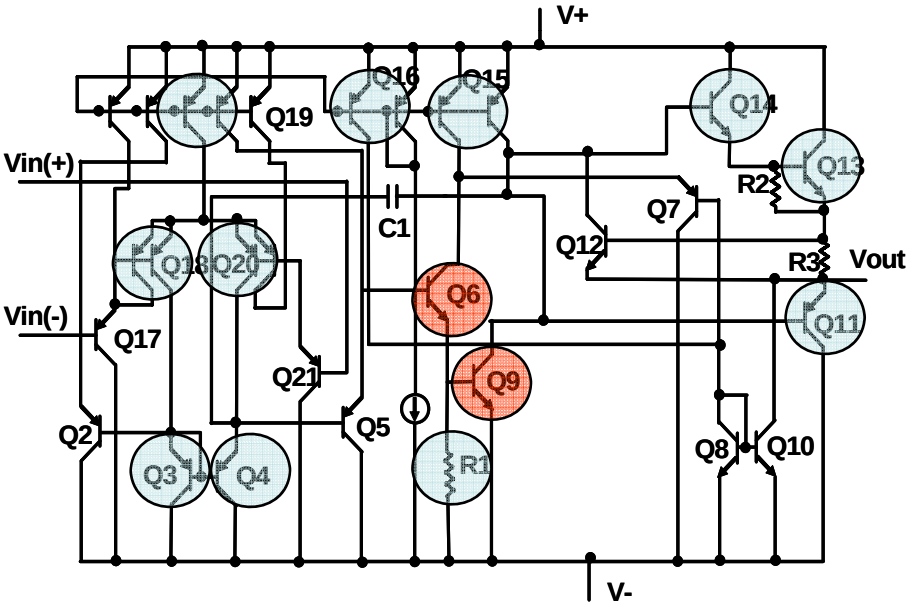
Operational Amplifier – LM124

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009

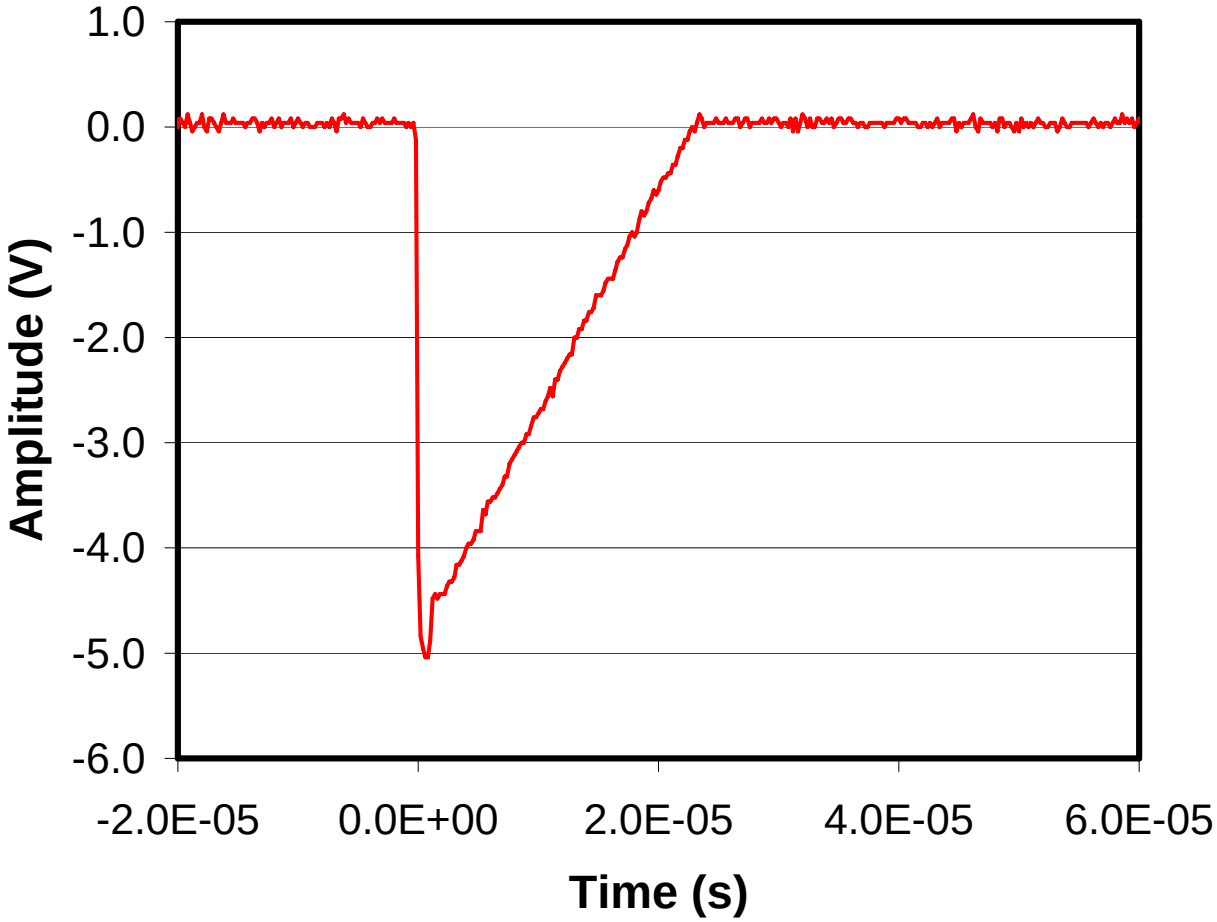
Operational Amplifier – LM124

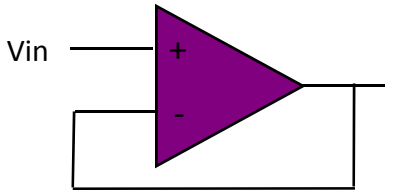
- Used focused pulsed laser to inject charge into Q9 and R.

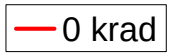




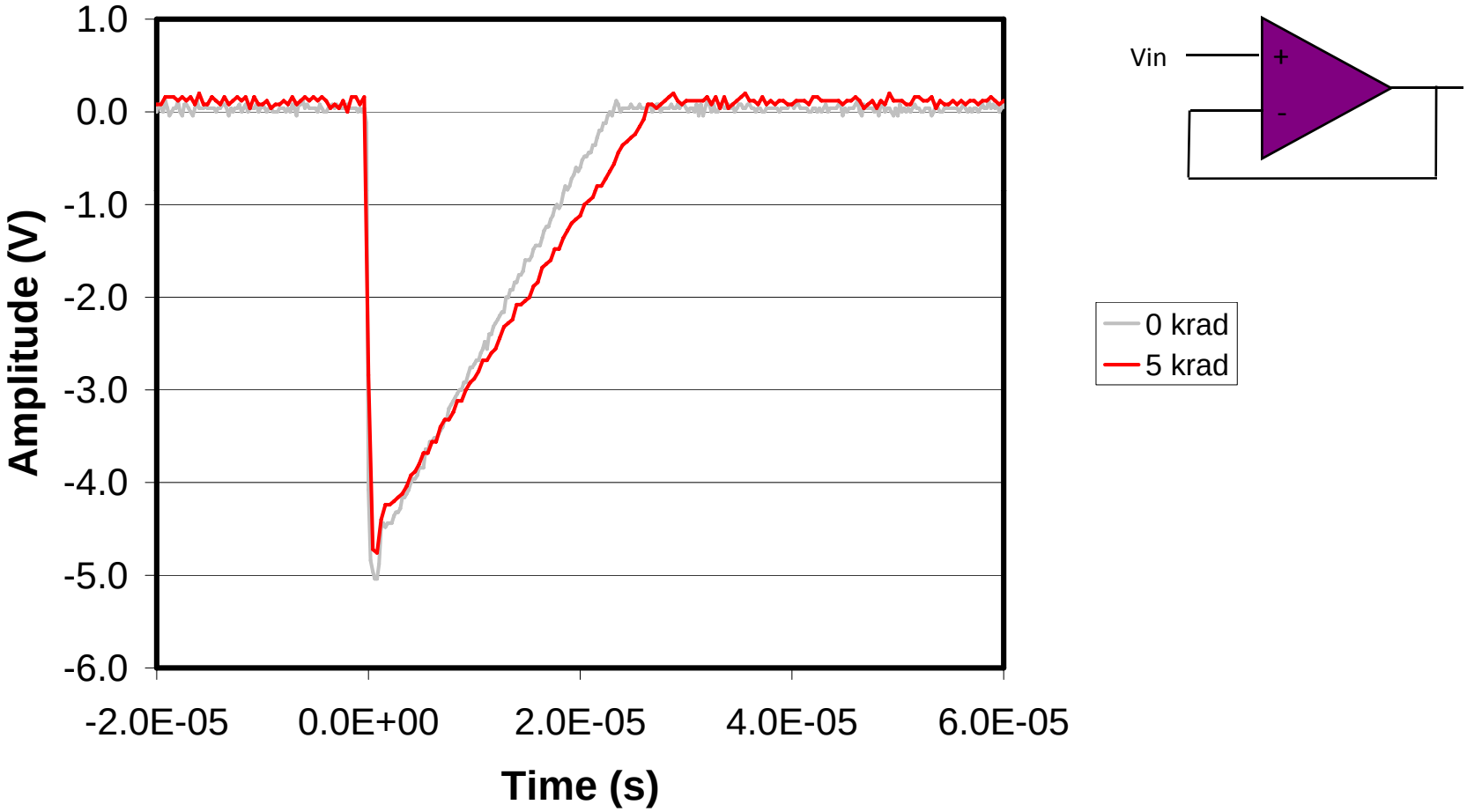
LM124 – Q9 VF


1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Amplitude (V)
-2.0E-05
0.0E+00
2.0E-05
4.0E-05
6.0E-05
Time (s)

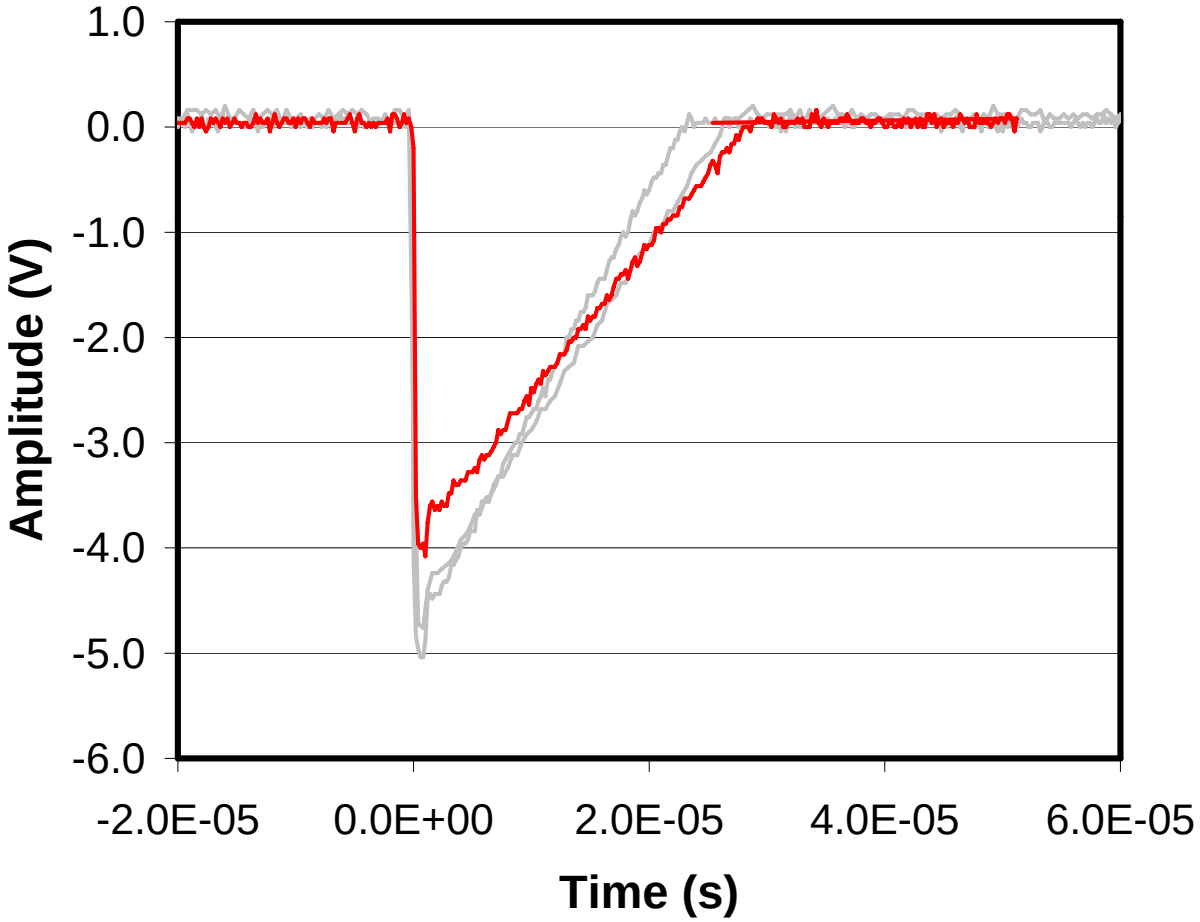

Vin
+
-

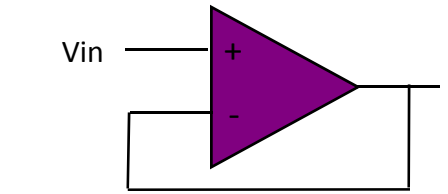

0 krad

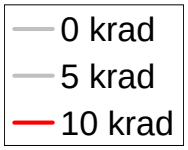
LM124 – Q9 VF


1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Amplitude (V)
-2.0E-05
0.0E+00
2.0E-05
4.0E-05
6.0E-05
Time (s)
Vin
+
-
0 krad
5 krad

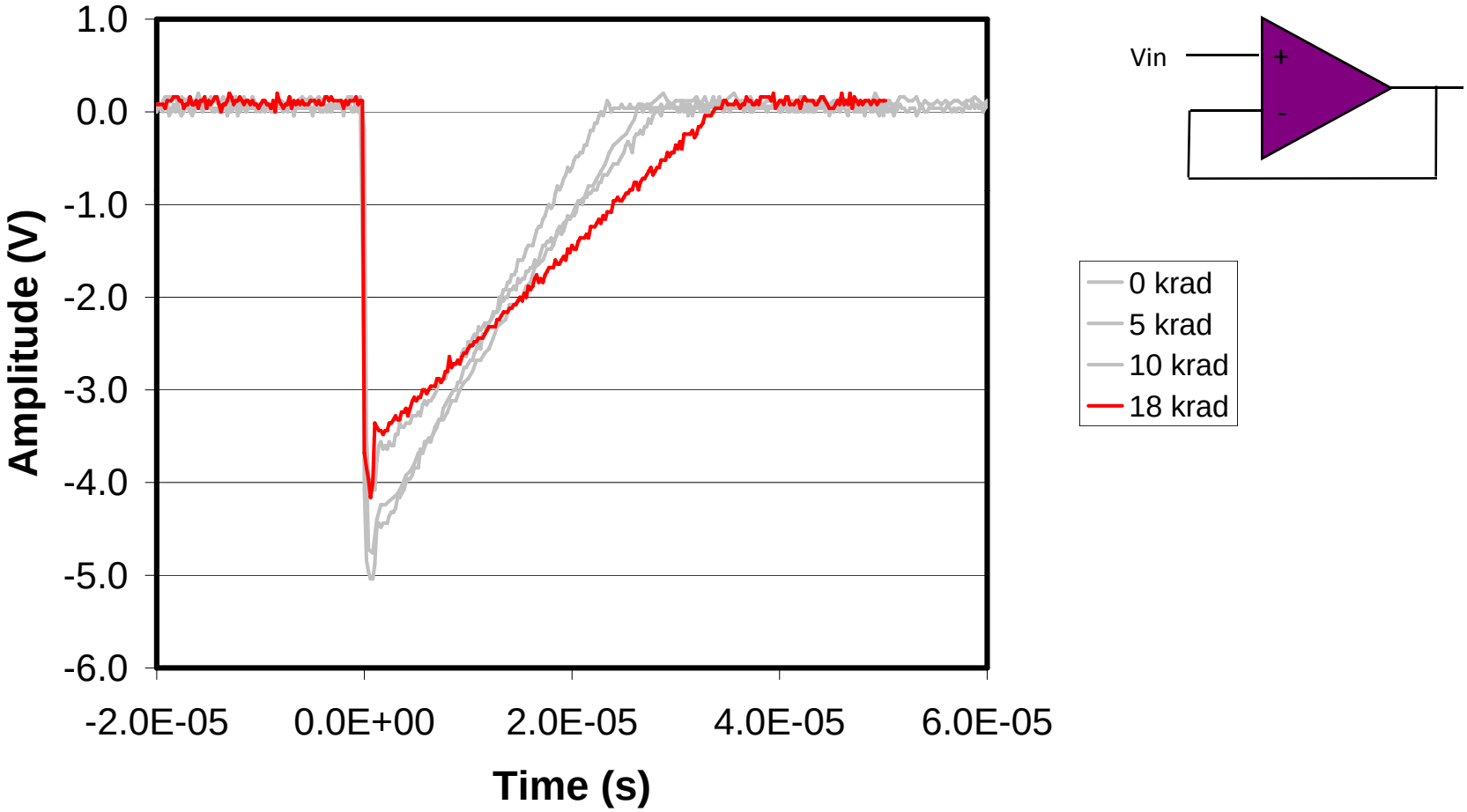
LM124 – Q9 VF


1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Amplitude (V)
-2.0E-05
0.0E+00
2.0E-05
4.0E-05
6.0E-05
Time (s)

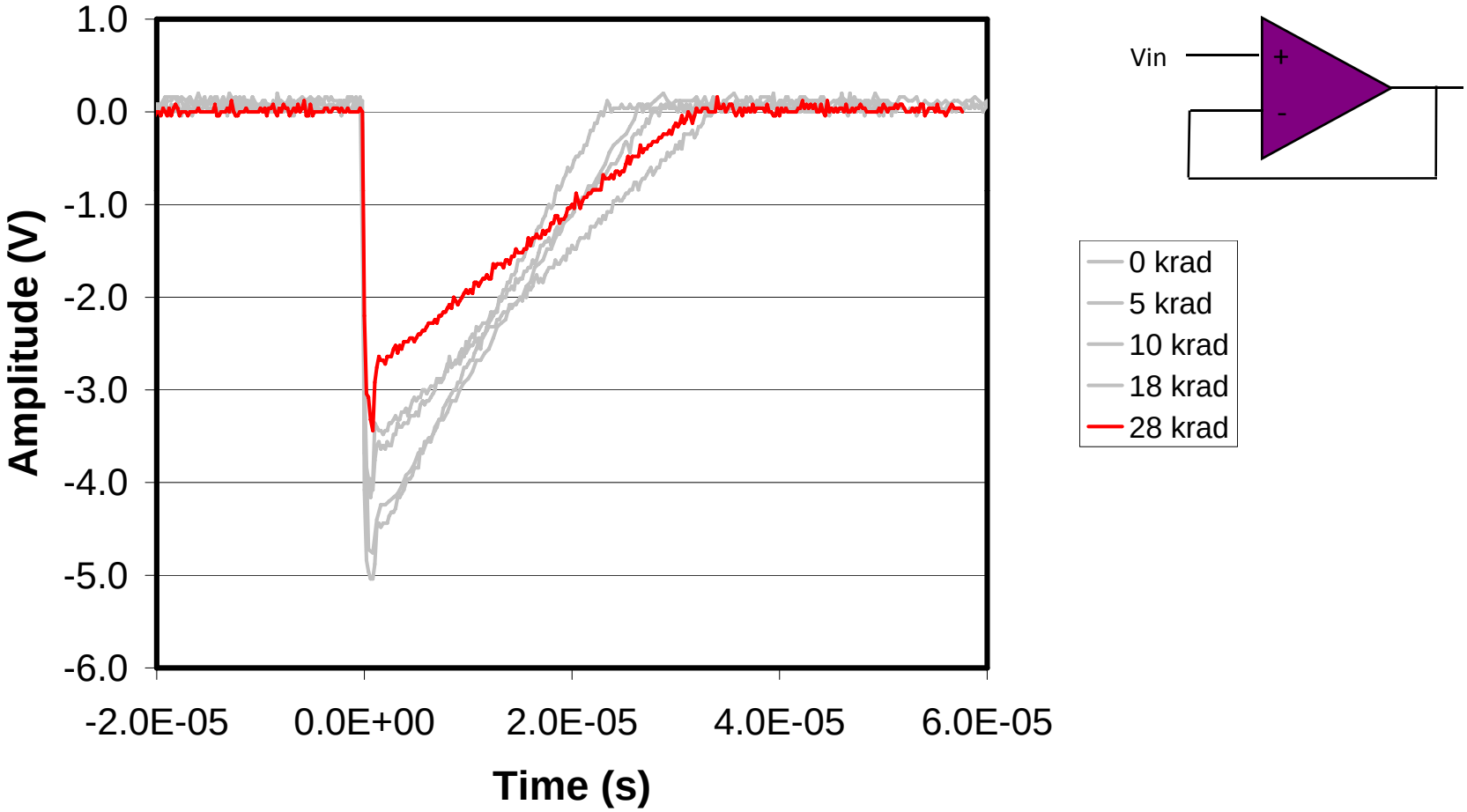

Vin
+
-


0 krad
5 krad
10 krad

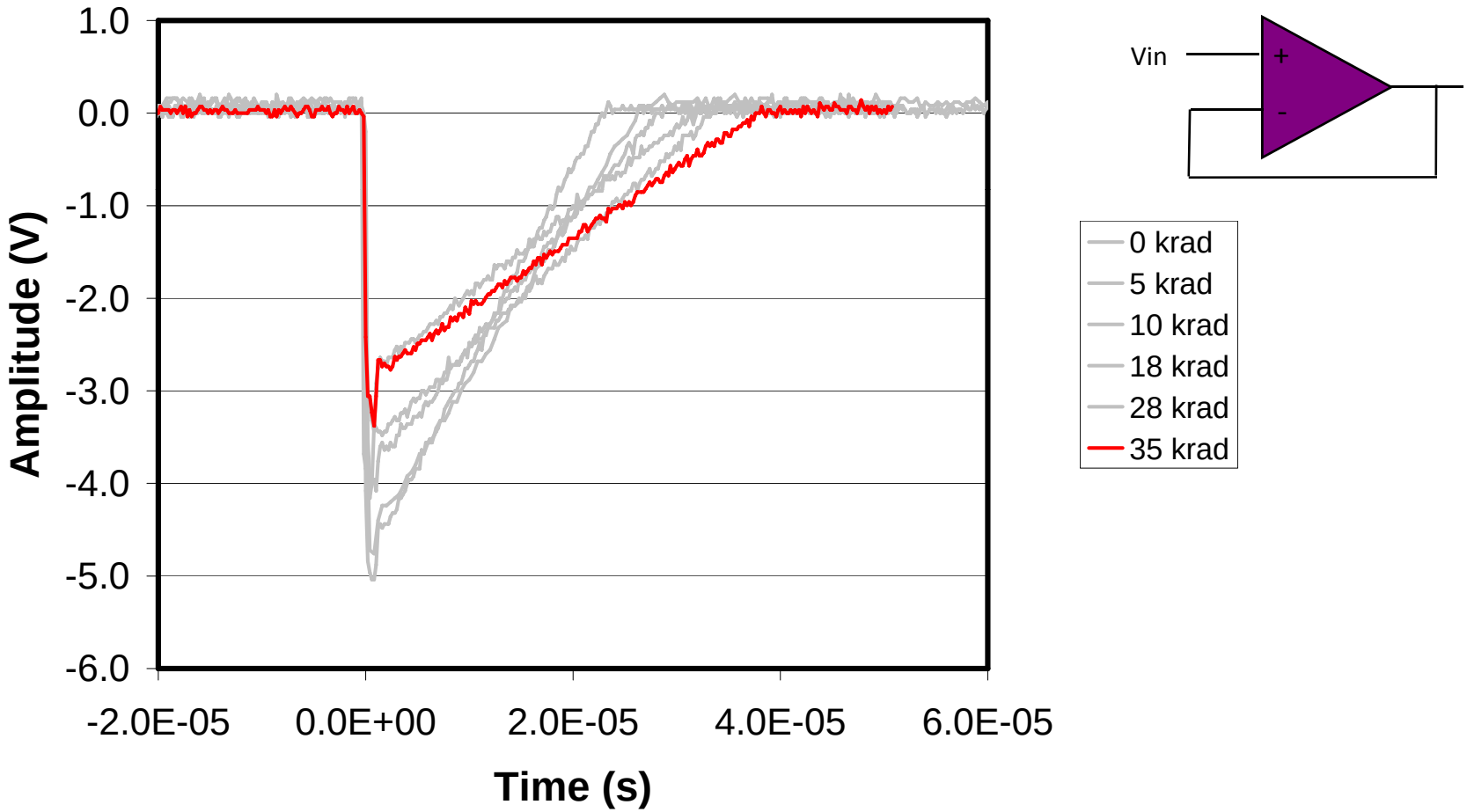
LM124 – Q9 VF


1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Amplitude (V)
-2.0E-05
0.0E+00
2.0E-05
4.0E-05
6.0E-05
Time (s)
Vin
+
-
0 krad
5 krad
10 krad
18 krad

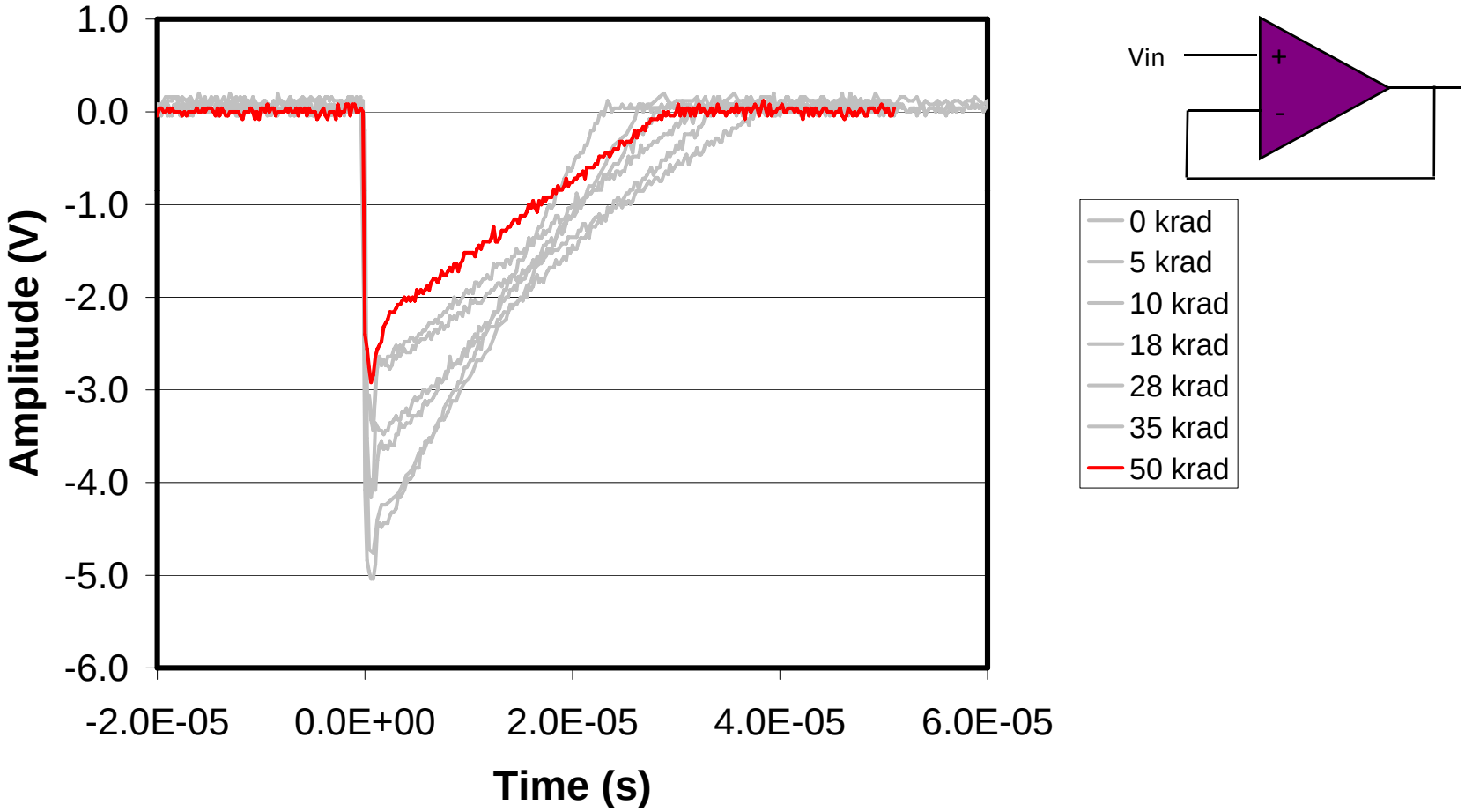
LM124 – Q9 VF


1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Amplitude (V)
-2.0E-05
0.0E+00
2.0E-05
4.0E-05
6.0E-05
Time (s)
Vin
+
-
0 krad
5 krad
10 krad
18 krad
28 krad

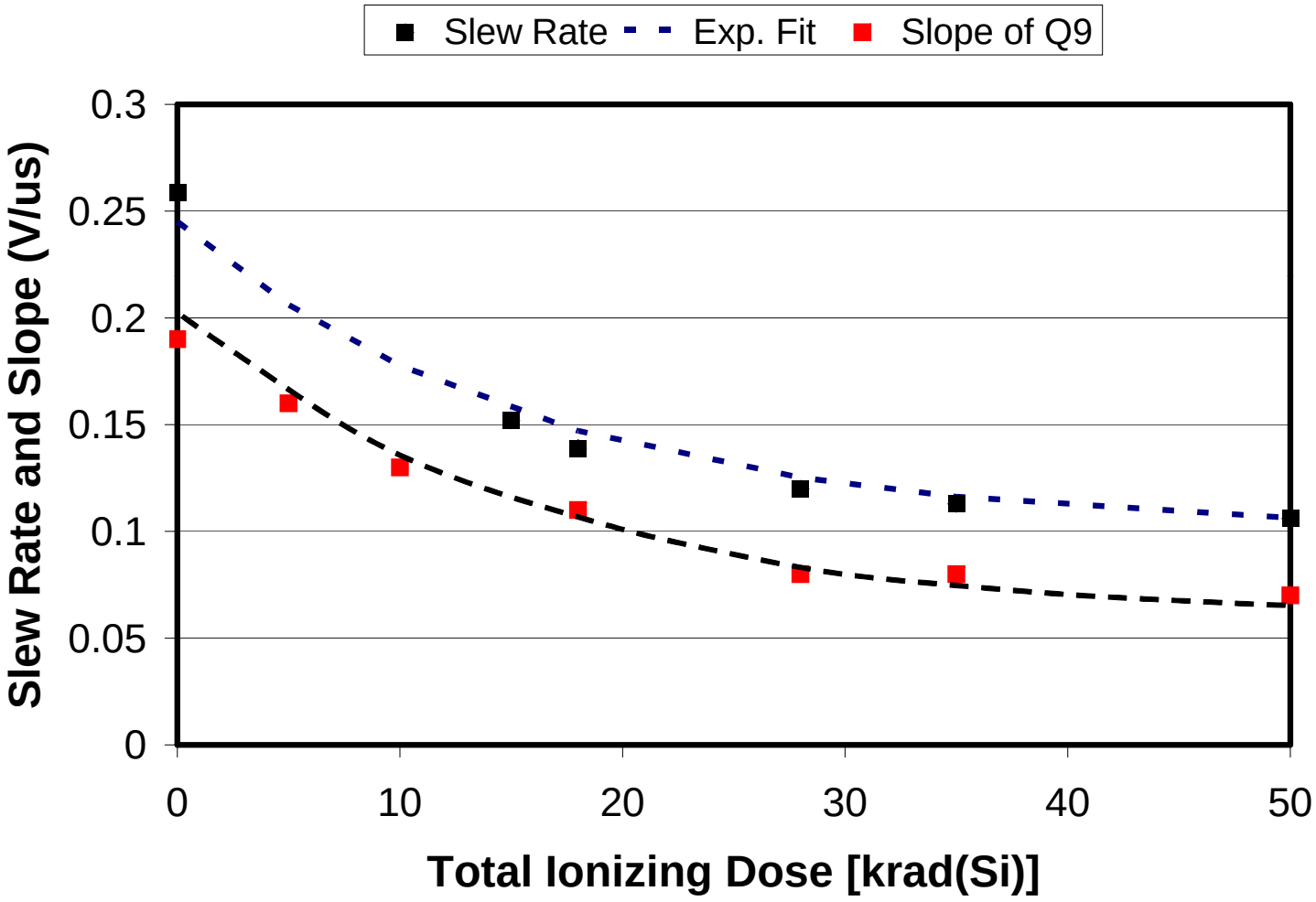
LM124 – Q9 VF


1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Amplitude (V)
-2.0E-05
0.0E+00
2.0E-05
4.0E-05
6.0E-05
Time (s)
Vin
+
-
0 krad
5 krad
10 krad
18 krad
28 krad
35 krad

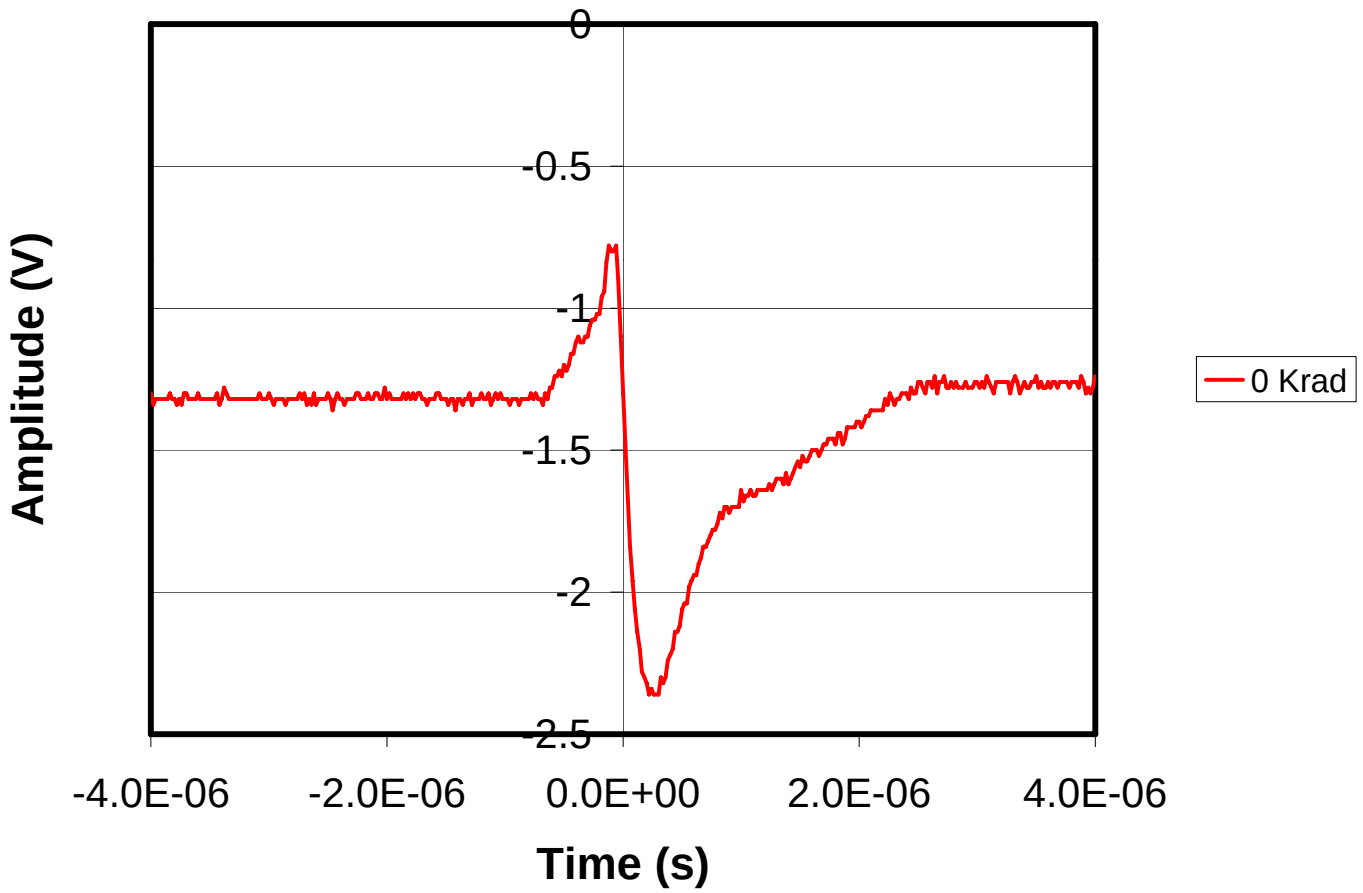
LM124 – Q9 VF


1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Amplitude (V)
-2.0E-05
0.0E+00
2.0E-05
4.0E-05
6.0E-05
Time (s)
Vin
+
-
0 krad
5 krad
10 krad
18 krad
28 krad
35 krad
50 krad

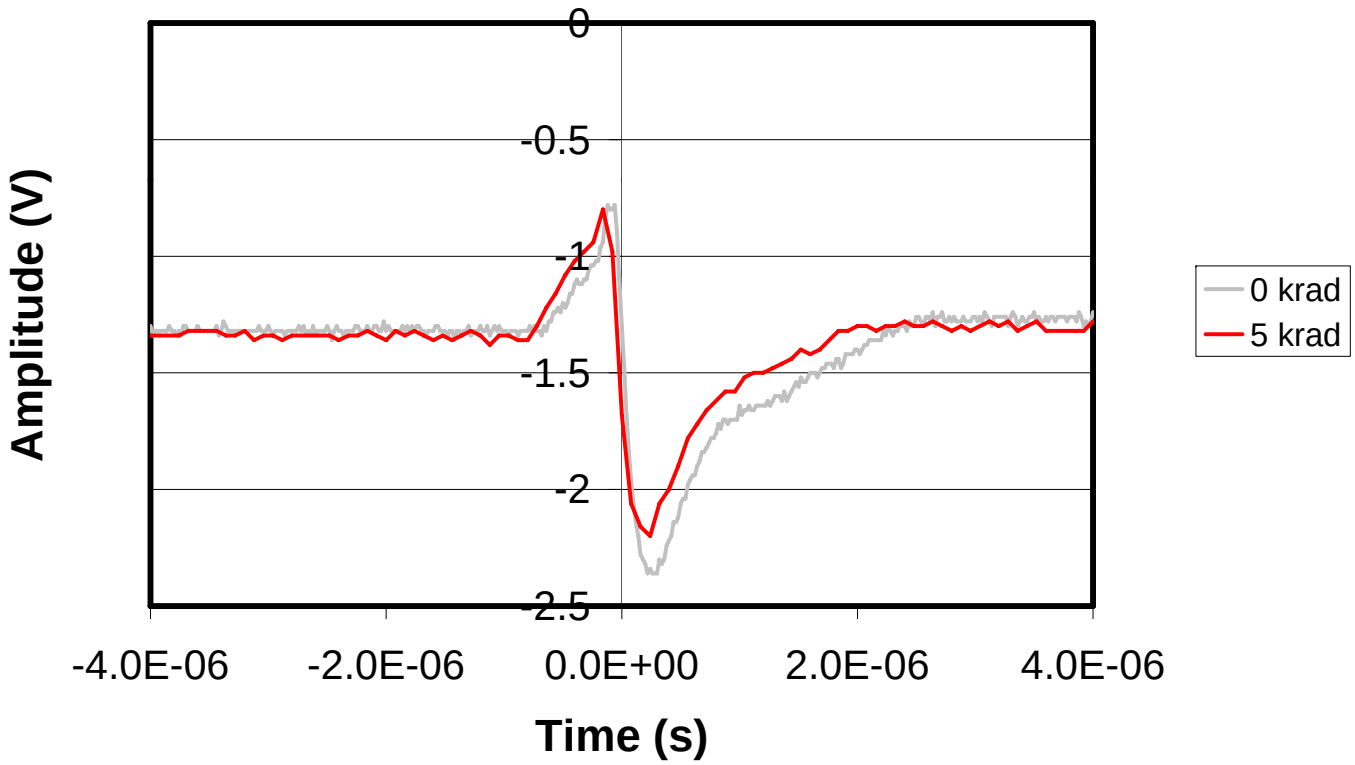
LM124 – Slew Rate



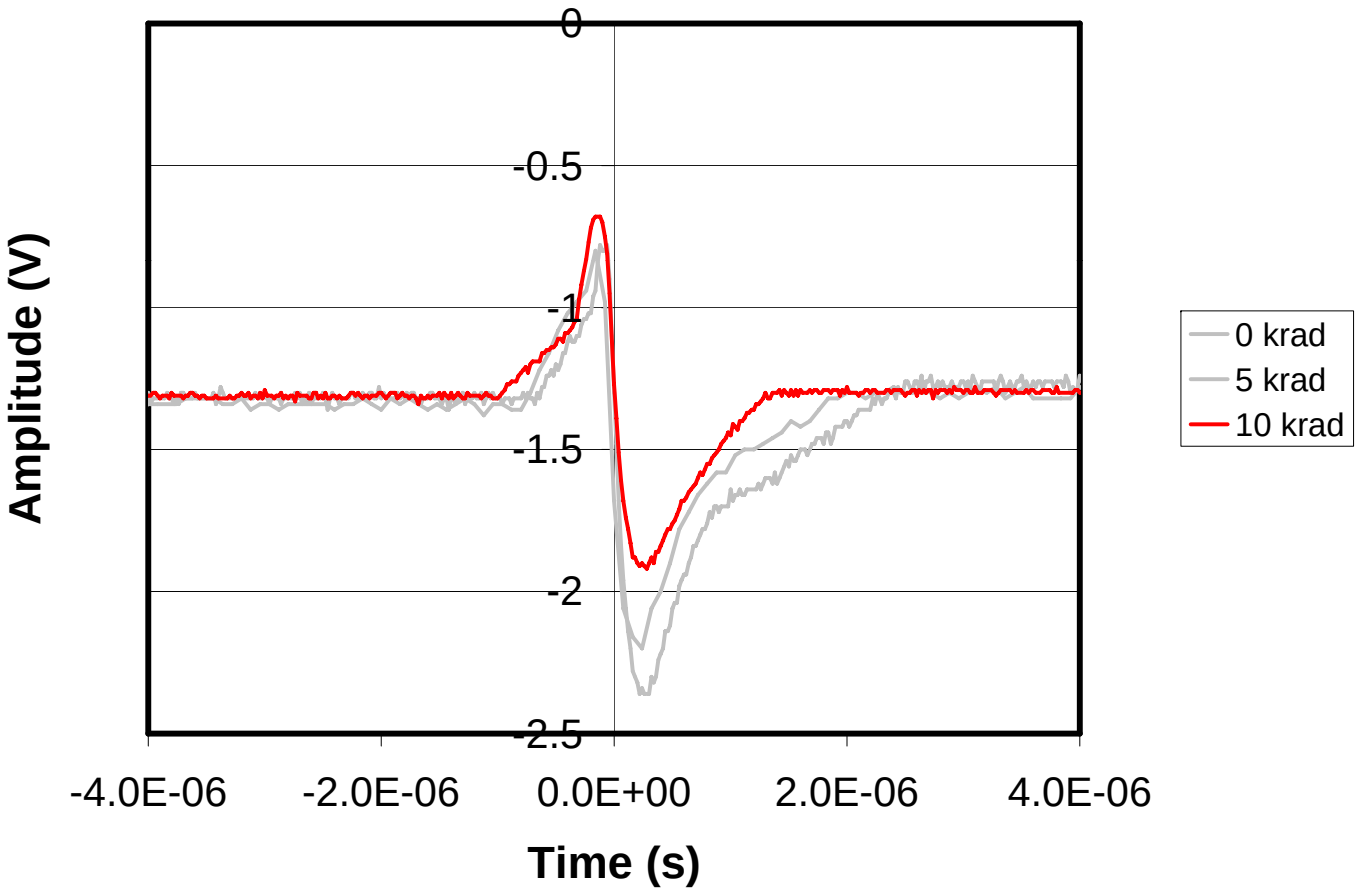
LM124 – R1 (Inverter Mode)



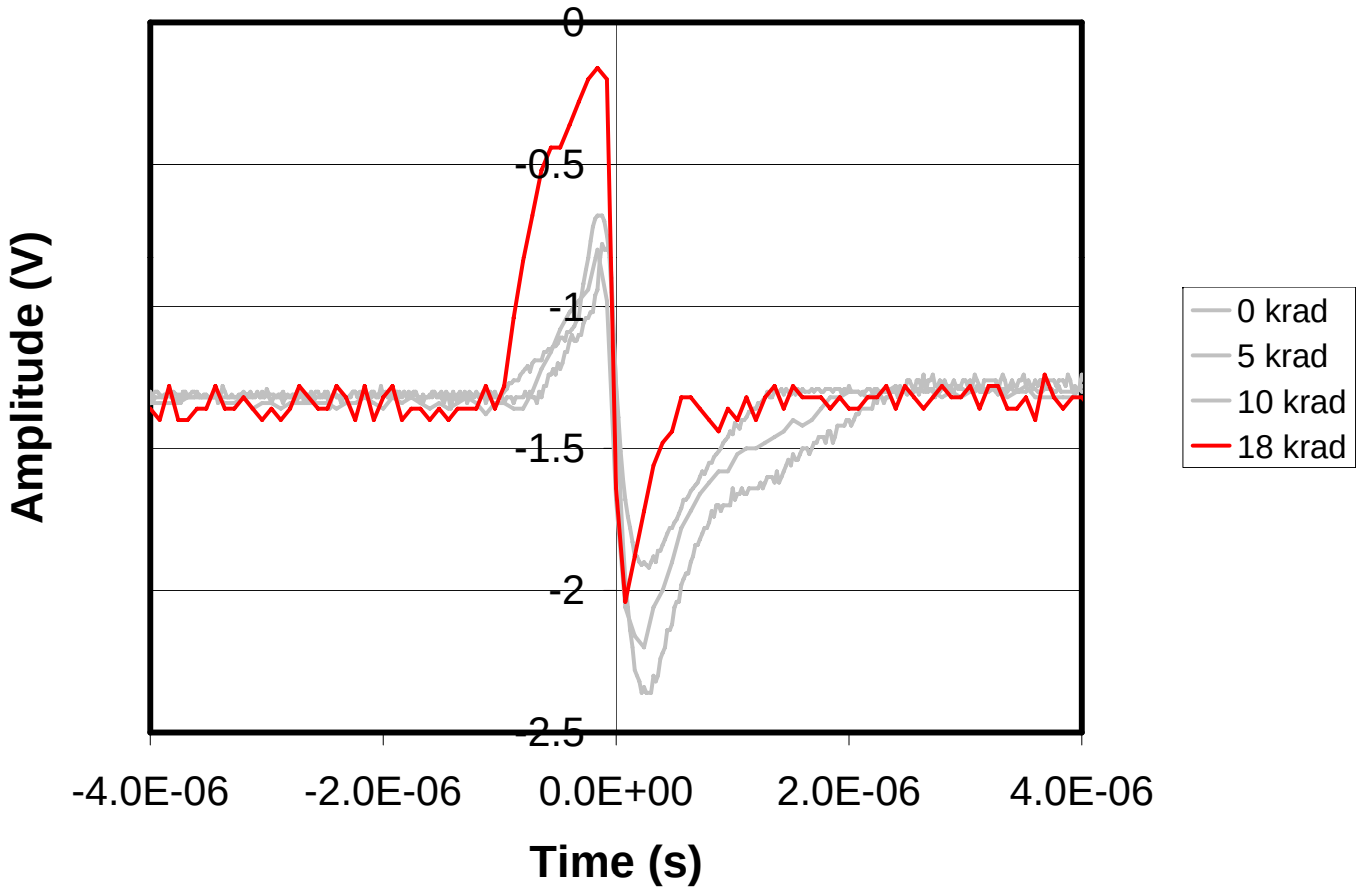
LM124 – R1 (Inverter Mode)



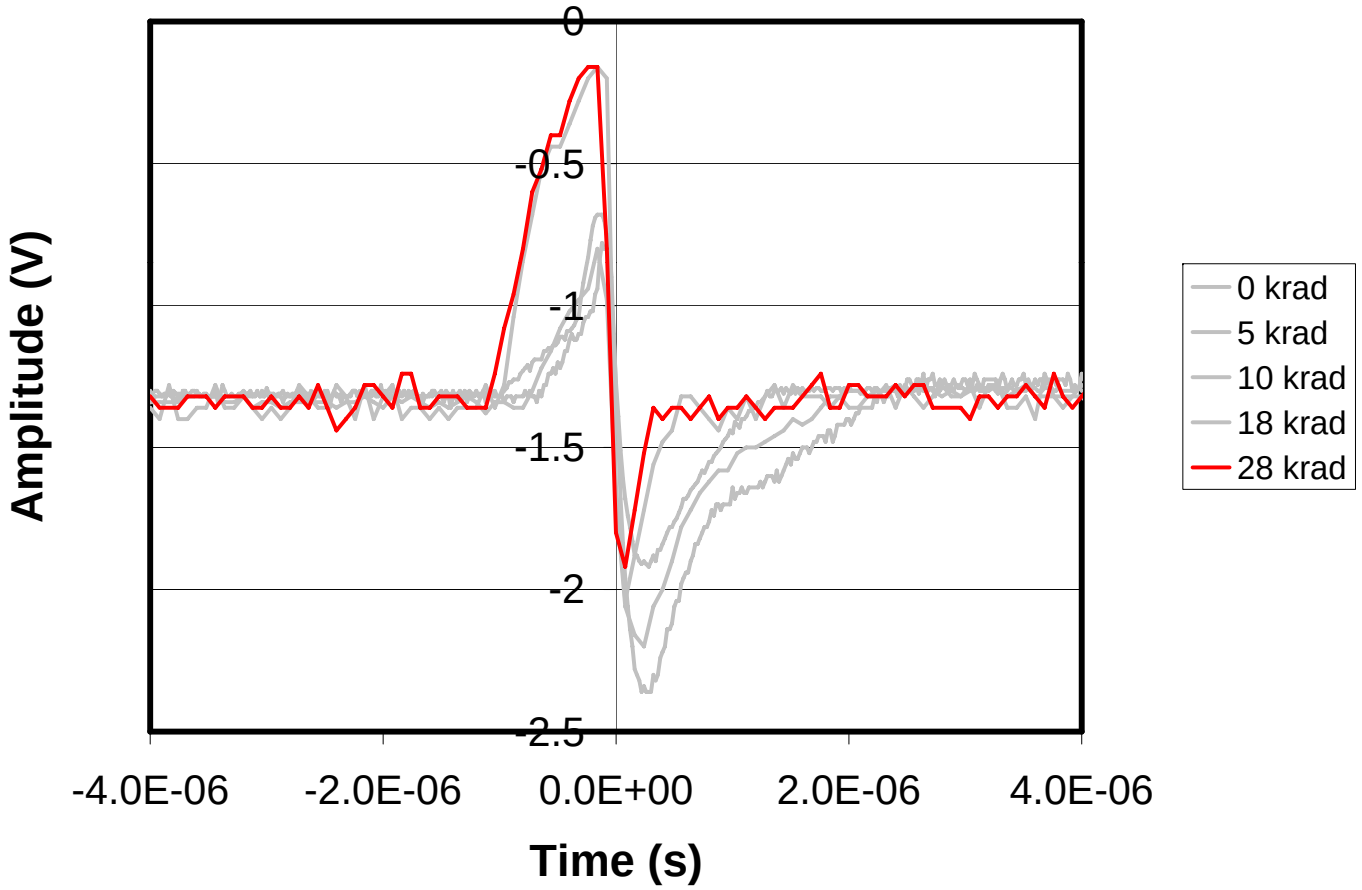
LM124 – R1 (Inverter Mode)



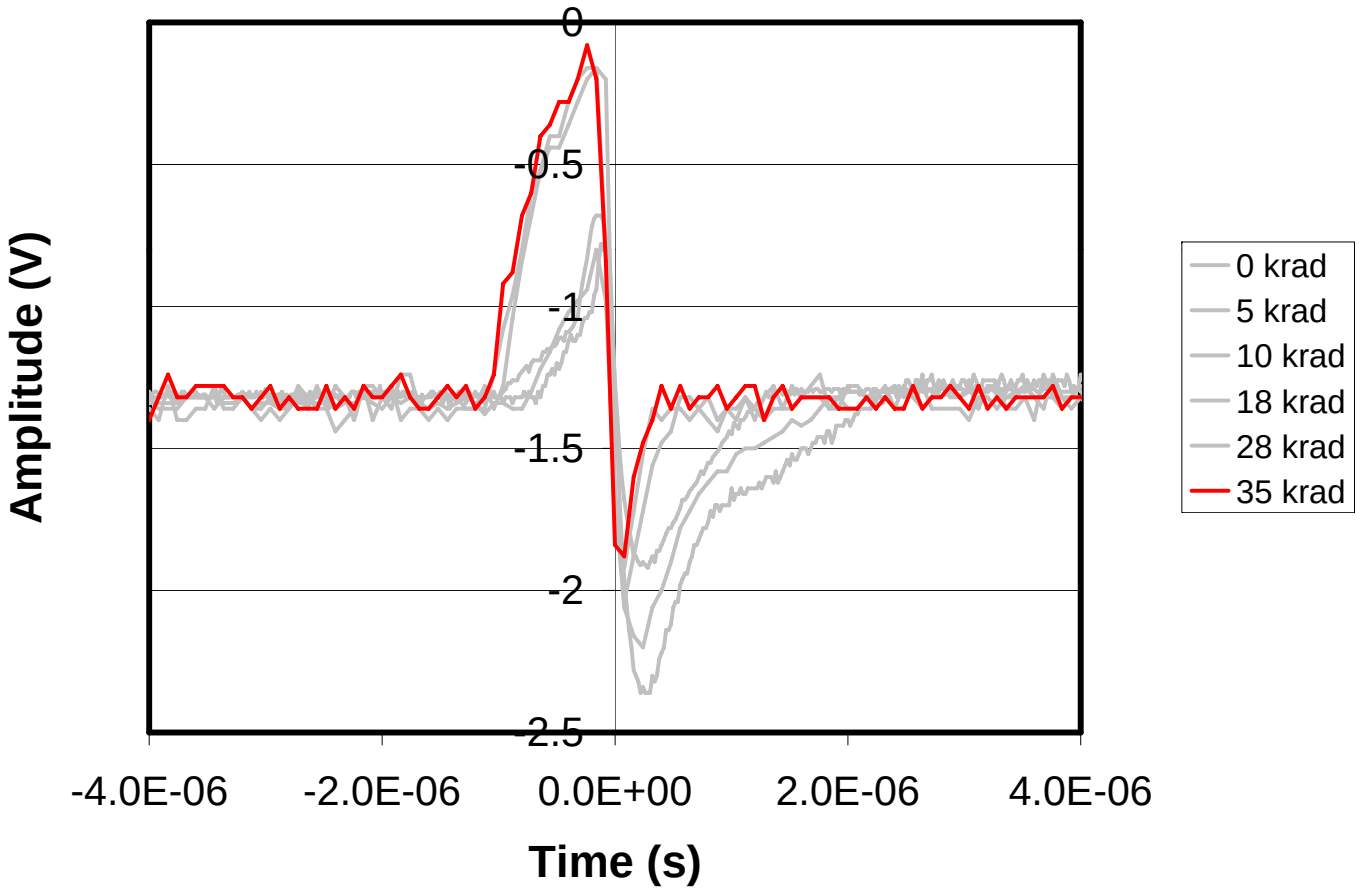
LM124 – R1 (Inverter Mode)



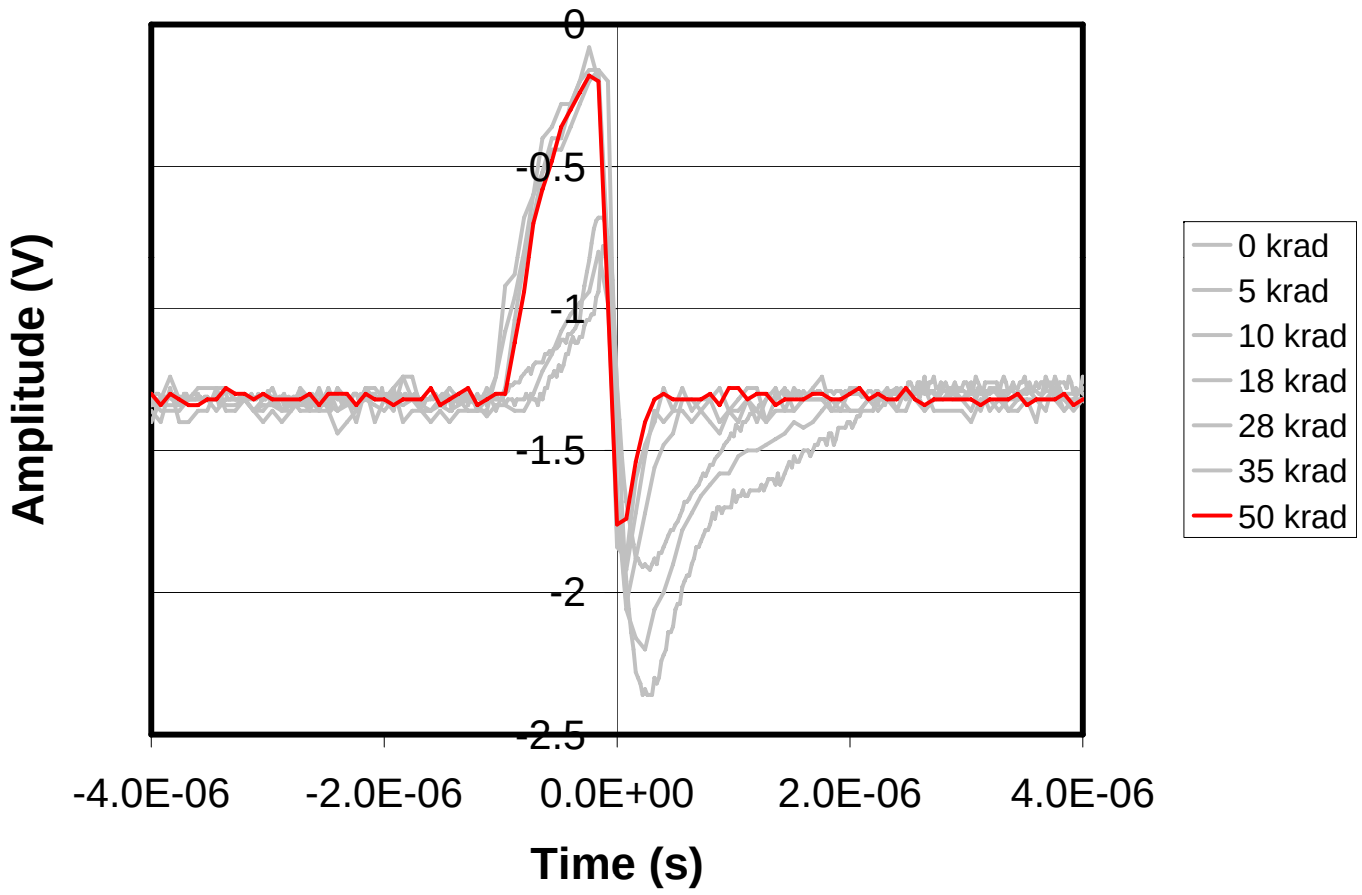
LM124 – R1 (Inverter Mode)



LM124 – R1 (Inverter Mode)



LM124 – R1 (Inverter Mode)



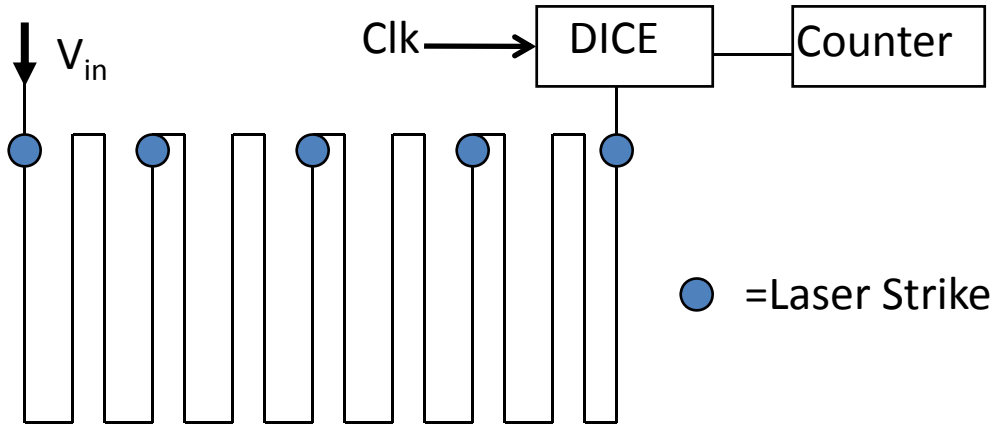
DIGITAL CMOS CIRCUIT

Test Circuit from Micro-RDC

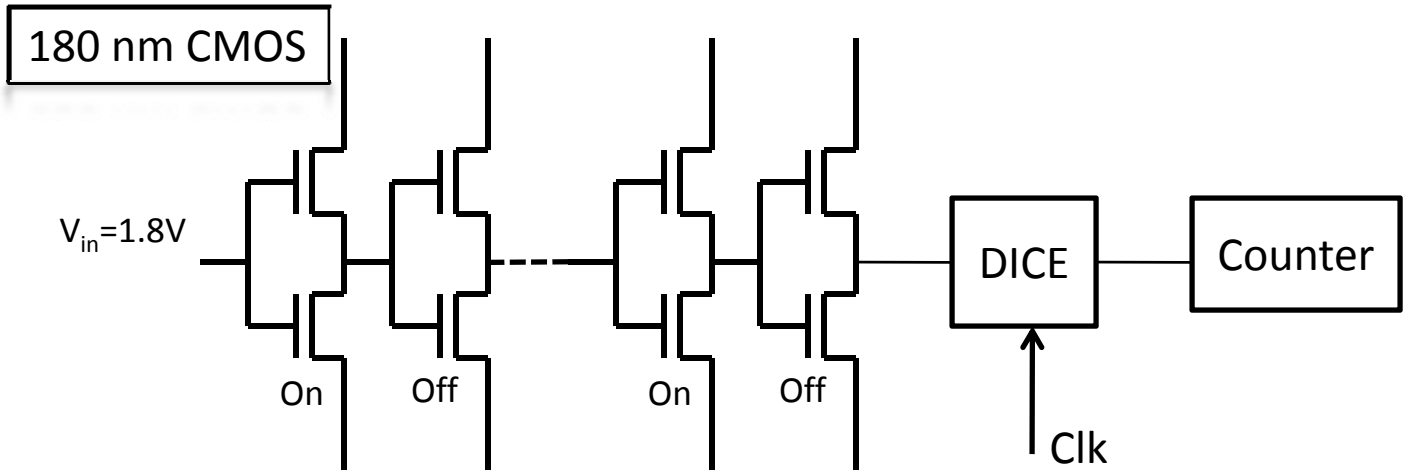
Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009

Digital Test Circuit

- Use pulsed laser to measure transient width



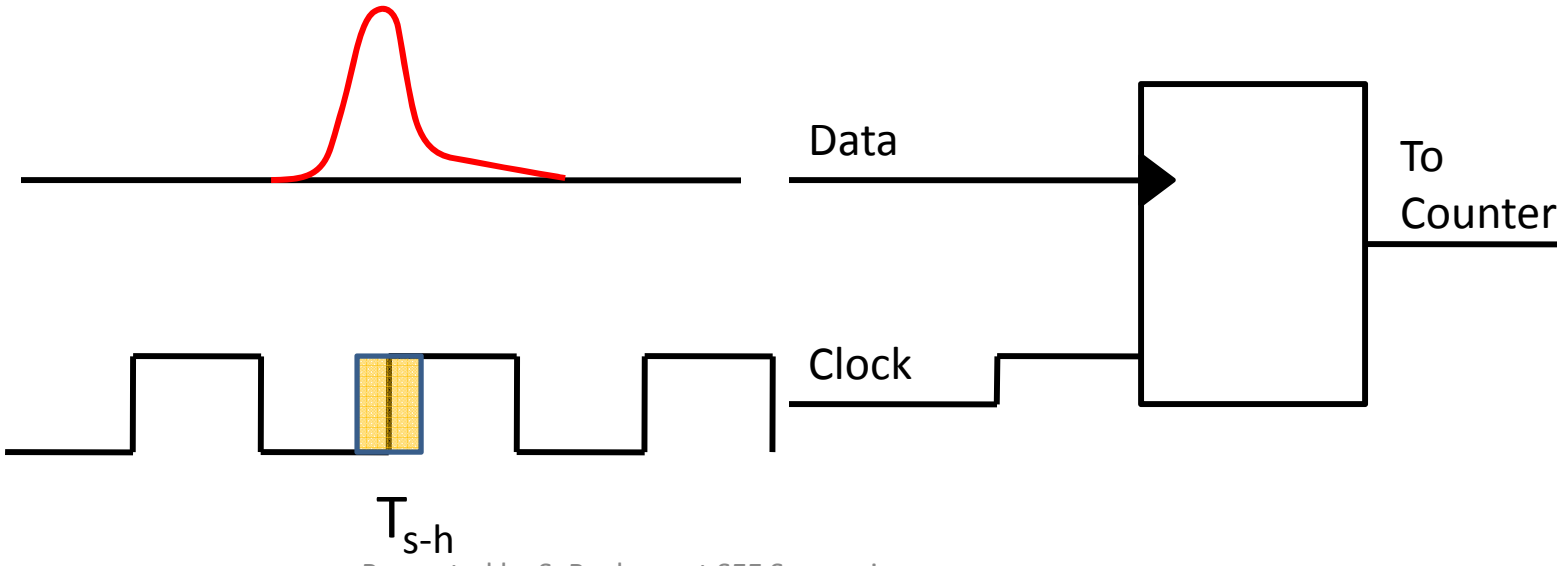
4,000 Inverters



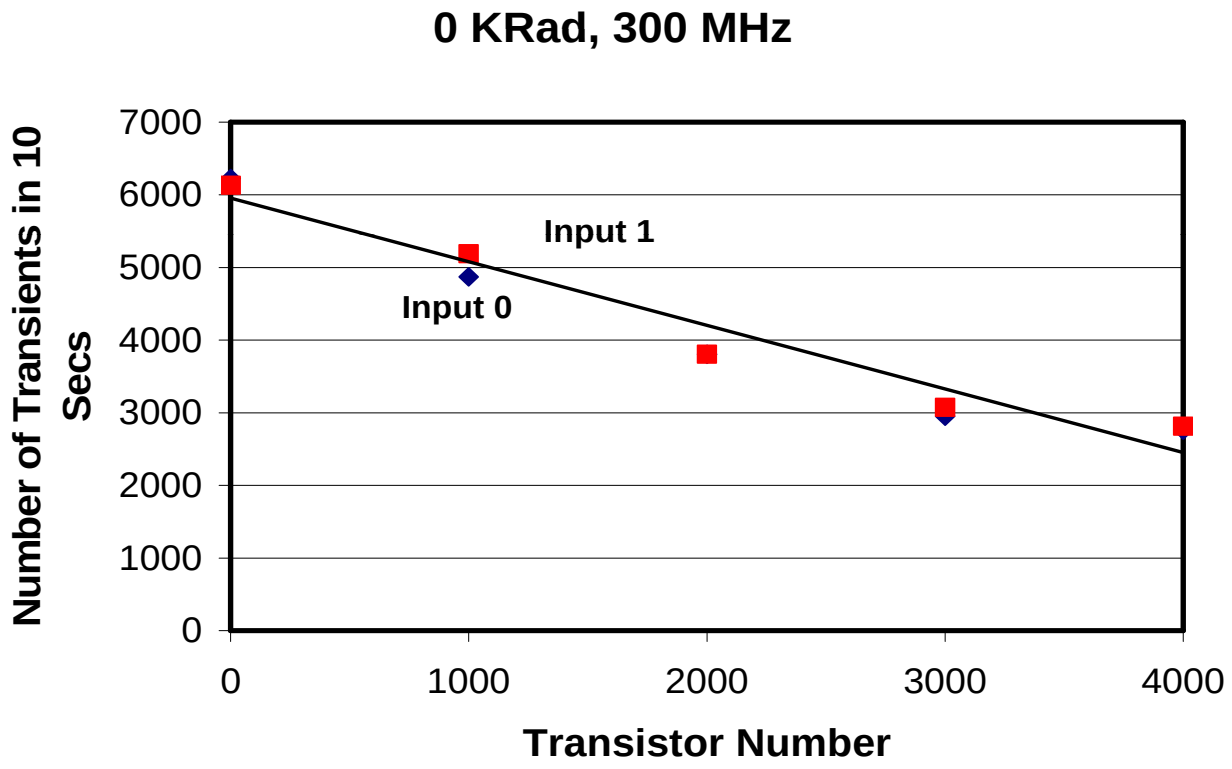
Digital Test Circuit

$$R = (\tau_{pw} - T_{s\text{-}h}) \bullet f_{clk} \bullet f_{laser}$$

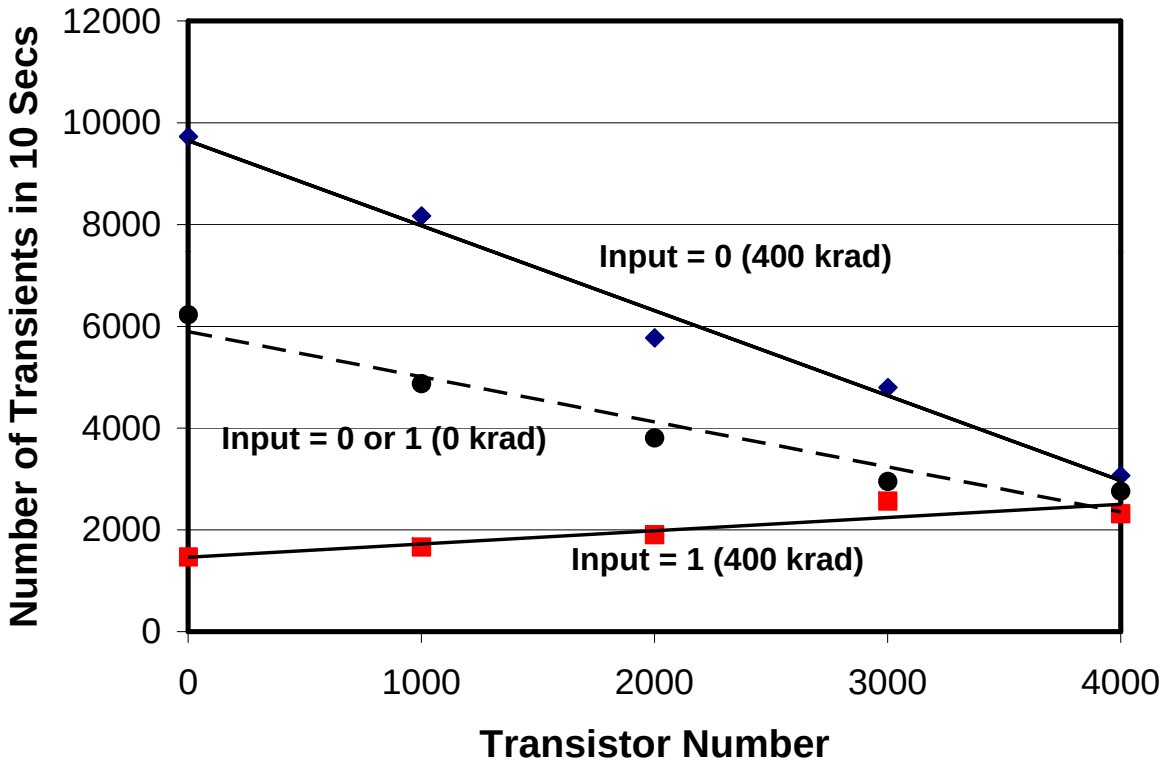
$$\text{Pulse-width} = \tau_{pw} = T_{s\text{-}h} + \frac{R}{f_{clk} \bullet f_{laser}}$$



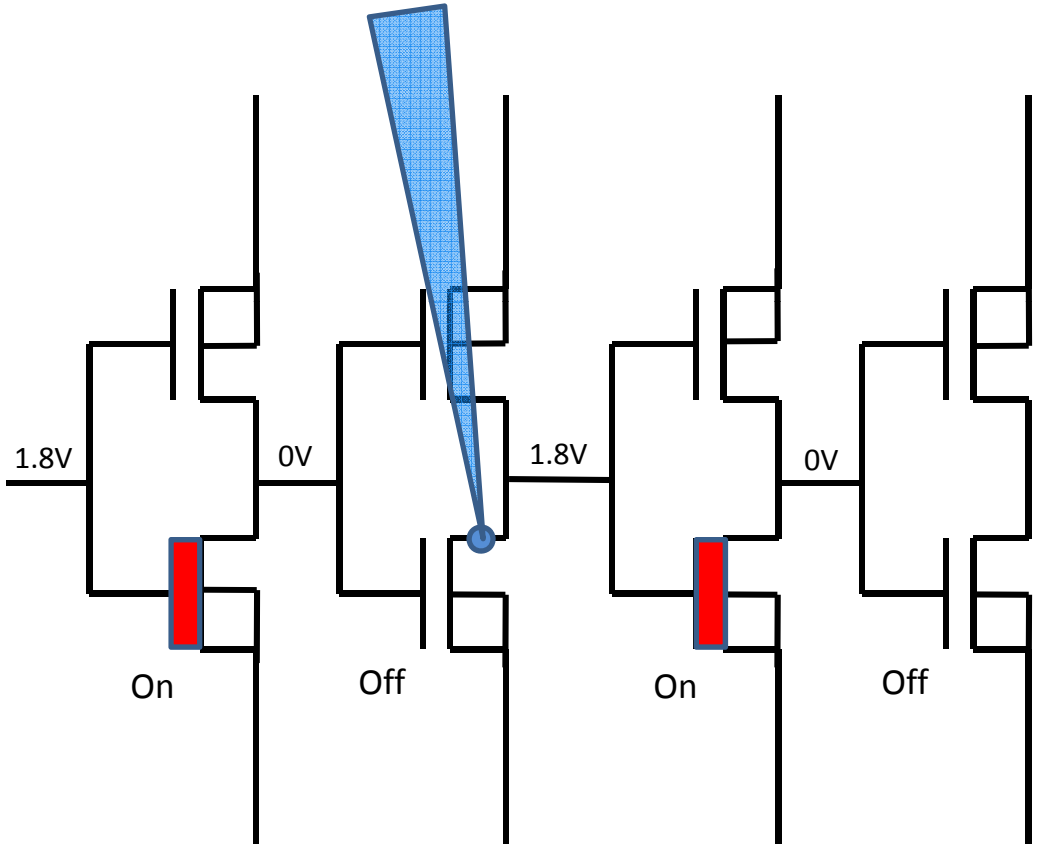
Test Results



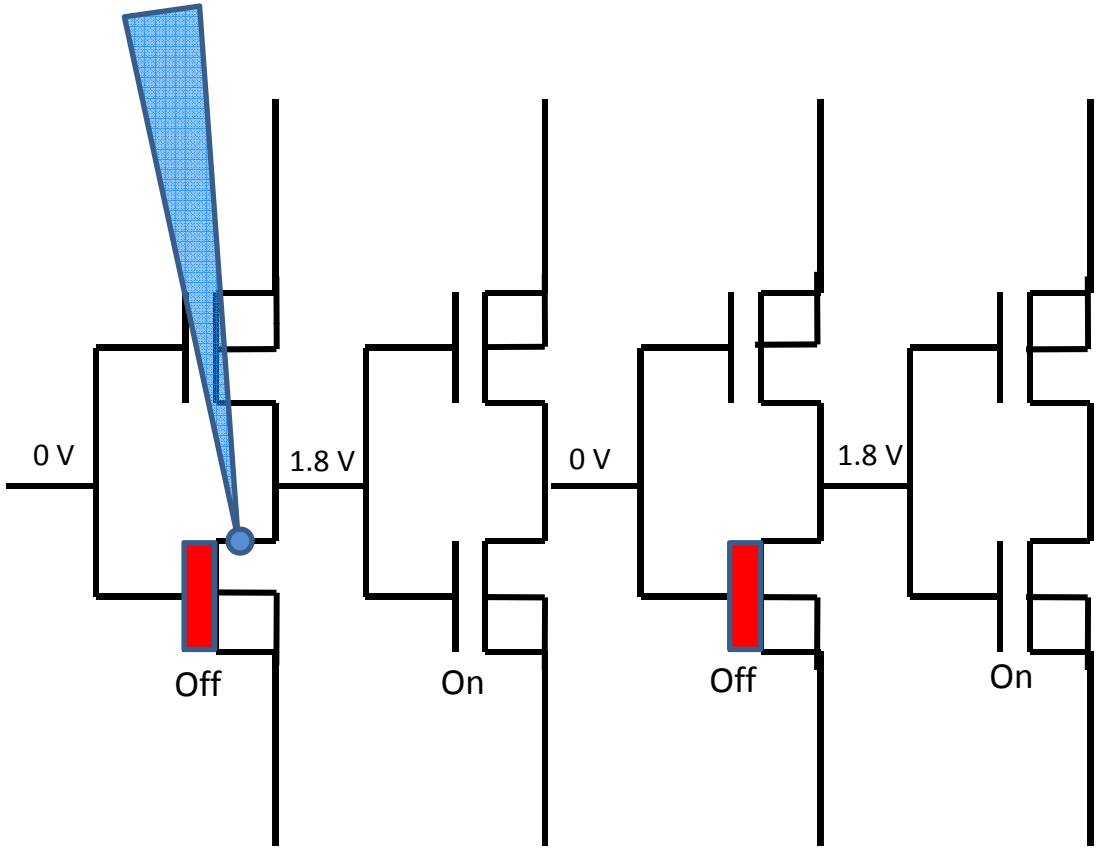
Test Results



Explanation



Explanation



Summary

- Exposure of ICs to ionizing radiation alters their electrical parameters and therefore their SET shapes and sensitivities.
- The effect occurs in both CMOS and bipolar circuits.
- Depending on effect, rates may increase or decrease.
- Effect of TID on SET rates should be considered if SETs cannot be tolerated.
- This work is being extended to other ICs such as a phase locked loop and memories.