Radiation detection: novel approaches and readout capabilities exploiting latchup topology via bipolar, MOSFET and MESFET transistors

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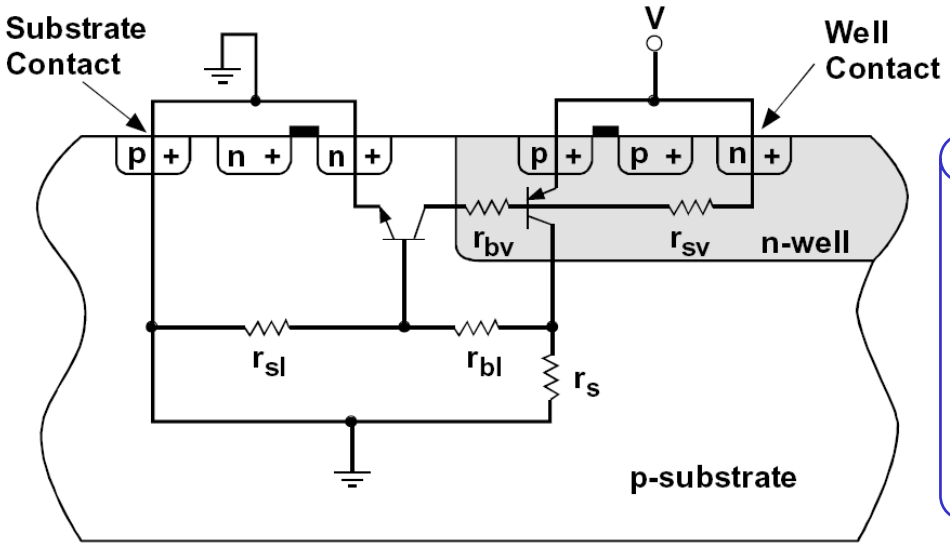
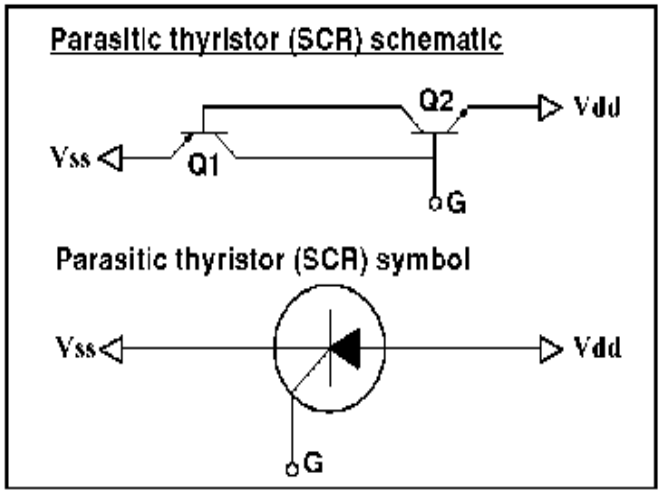
Outline

- Introduction to the Latchup Effect
- First tests via commercial BJTs
- Collaboration: Bologna, RAL(STFC), Poli_Turin
  - Use of MOS transistors
- The CREE 24010 SiC MESFET

What the "Latchup Effect" is

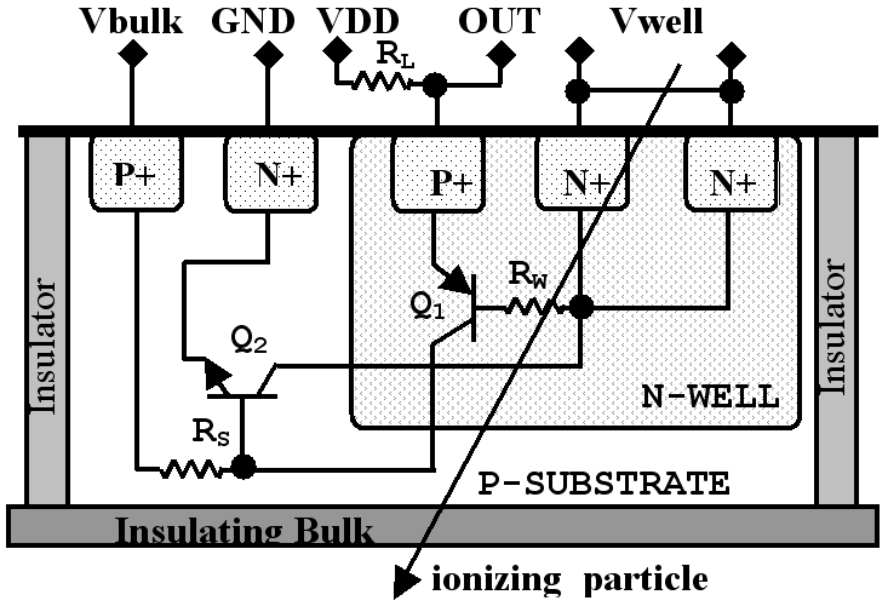


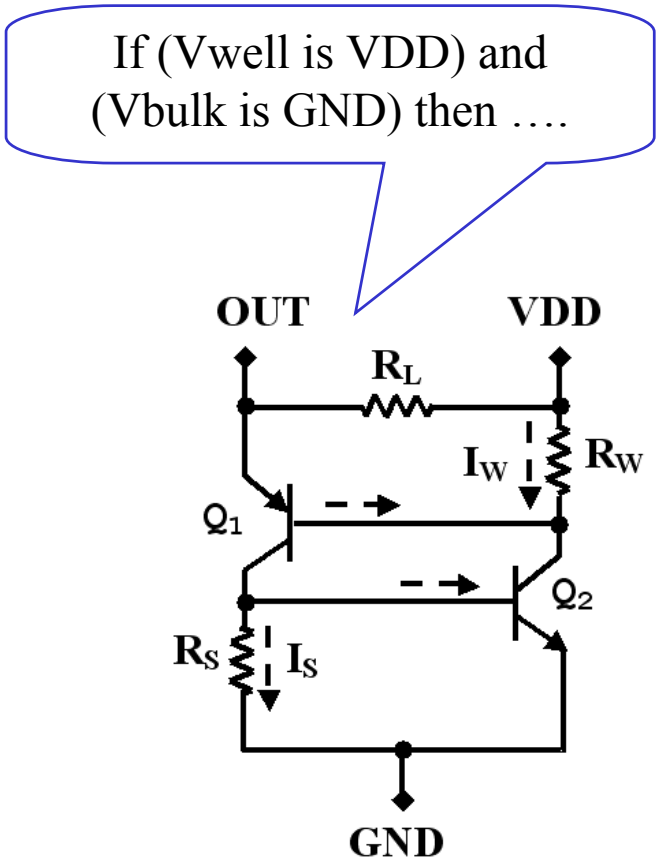
Basically, it is an ingnition af a parasitic thyristor-like structure within a CMOS device and is ignited by induced charges inside the silicon whatever their origin.



Traditional CMOS technologies into radiation environments may be susceptible and damaged by latchup

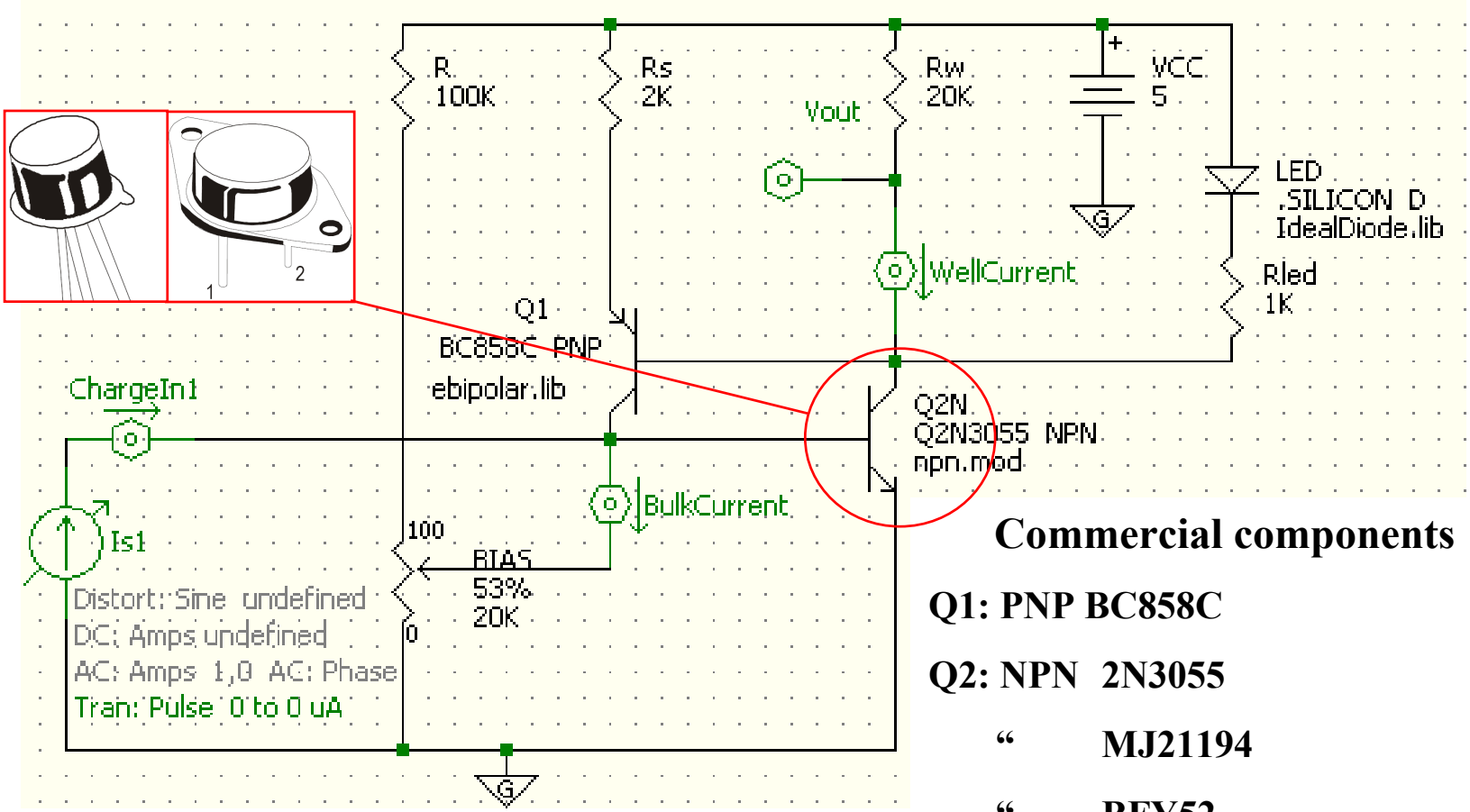
First study since 2005





It is not a reverse-biased diode plus the transistor has an internal current gain

A Prototype



Commercial components

Q1: PNP BC858C

Q2: NPN 2N3055

“ MJ21194

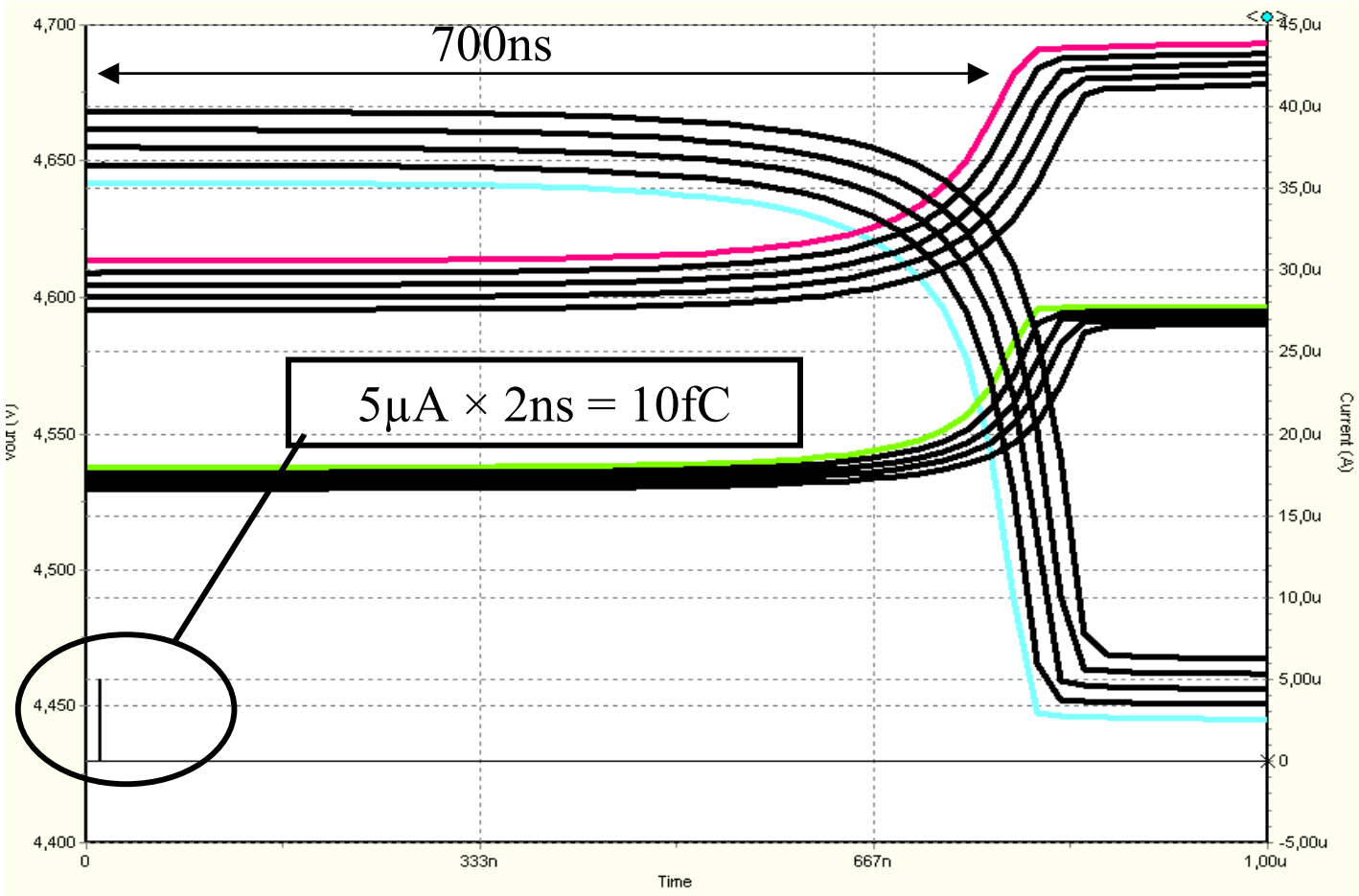
“ BFY52

“ 2N2222A

R_N: multiturn variable resistors

Spice simulation (Q2=BFY52)

Temperature from 30 to 40°C



Well Current	Out Voltage	Bulk Current

Commercial bipolars used
Q2 = 2N2222A BFY52 2N3055

TO-18 metal can

Estimated B-E charge collection area

10÷100 μm^2

TO-39 metal can

Estimated B-E charge collection area

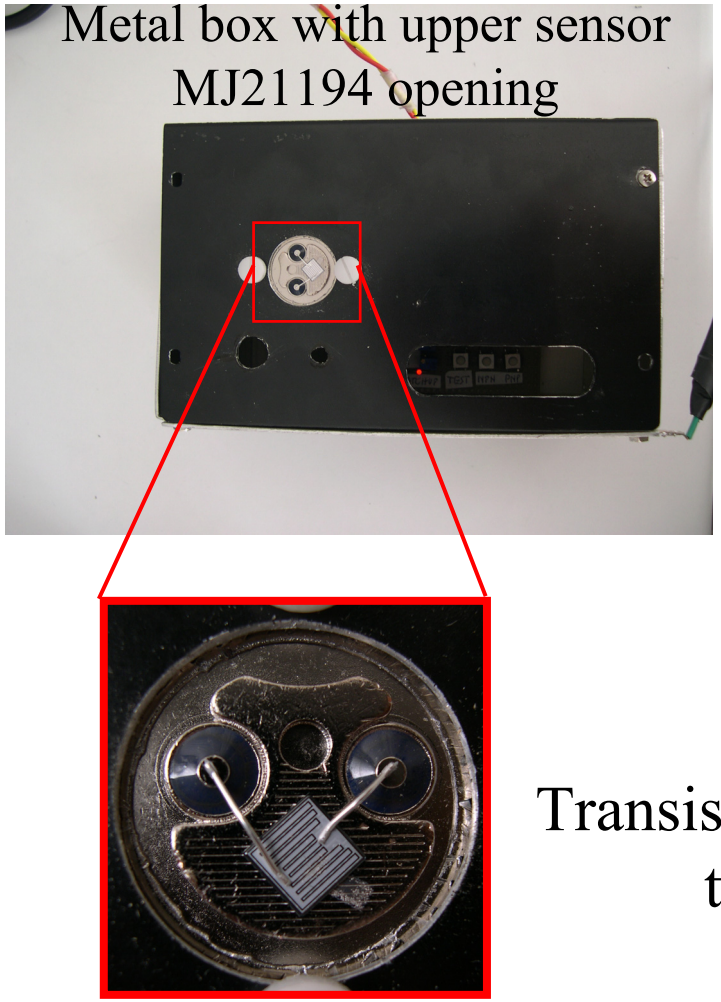
100÷10000 μm^2

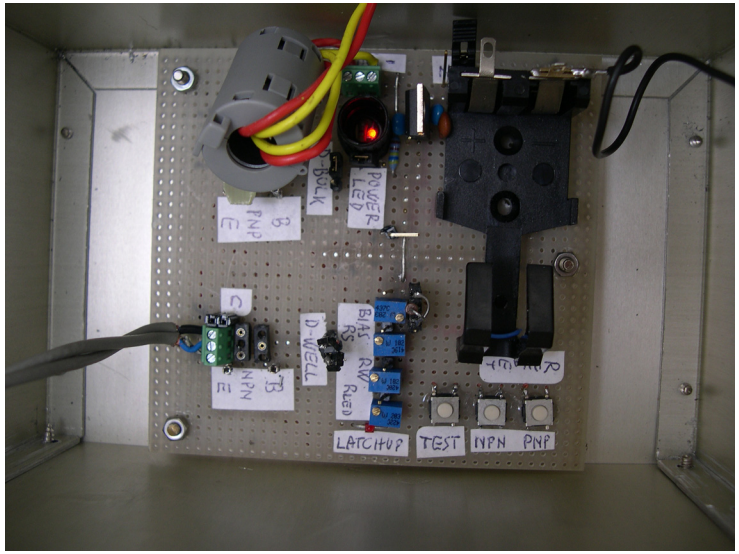
TO-3 metal can

Estimated B-E charge collection area

1 mm^2

Prototype Construction (Q2=MJ21194)





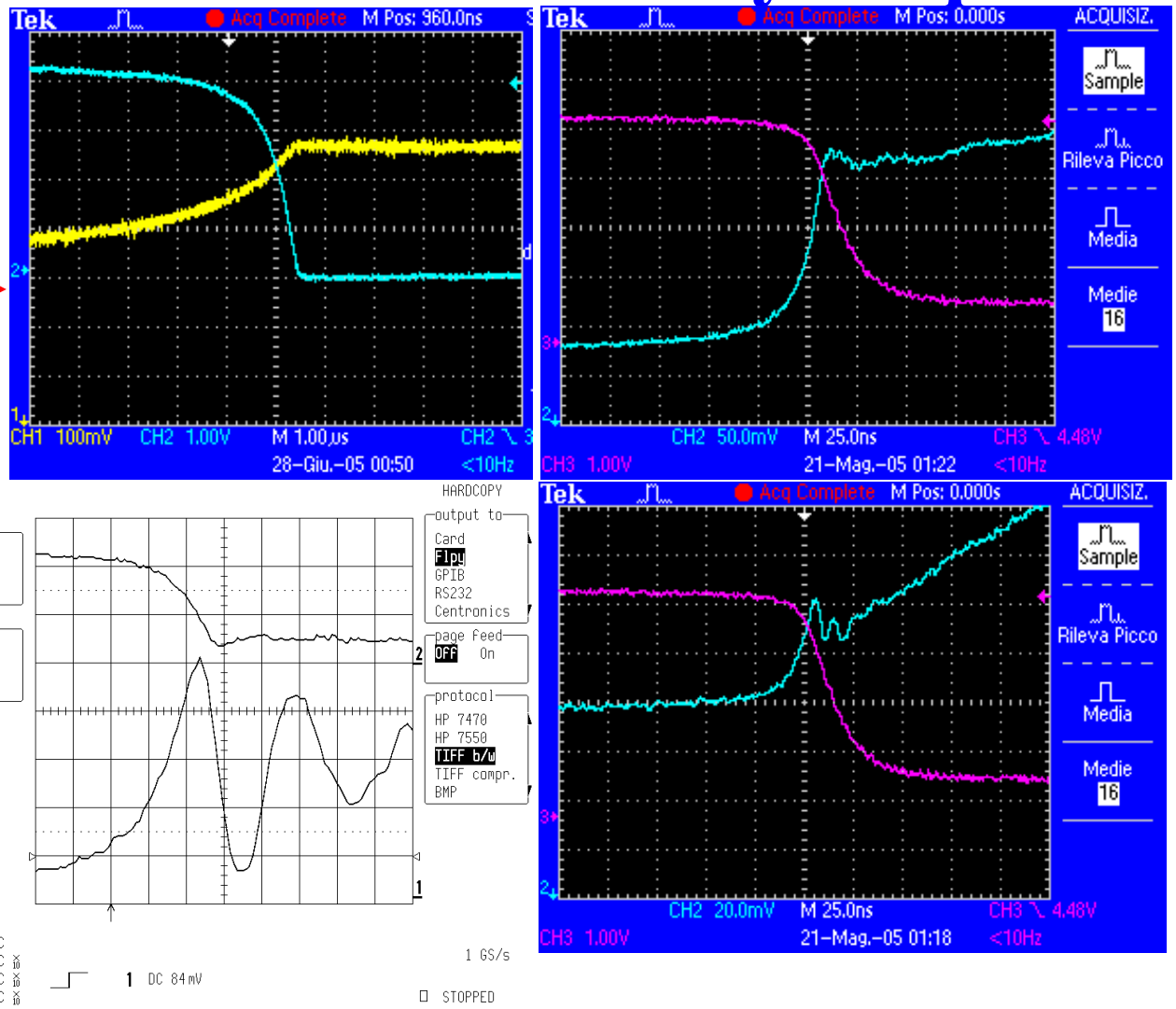
The latchup circuit inside the box

Transistor Base-Emitter bondings of the power bjt MJ21194

Laboratory test
Estimated sensitivity: ≈1pC

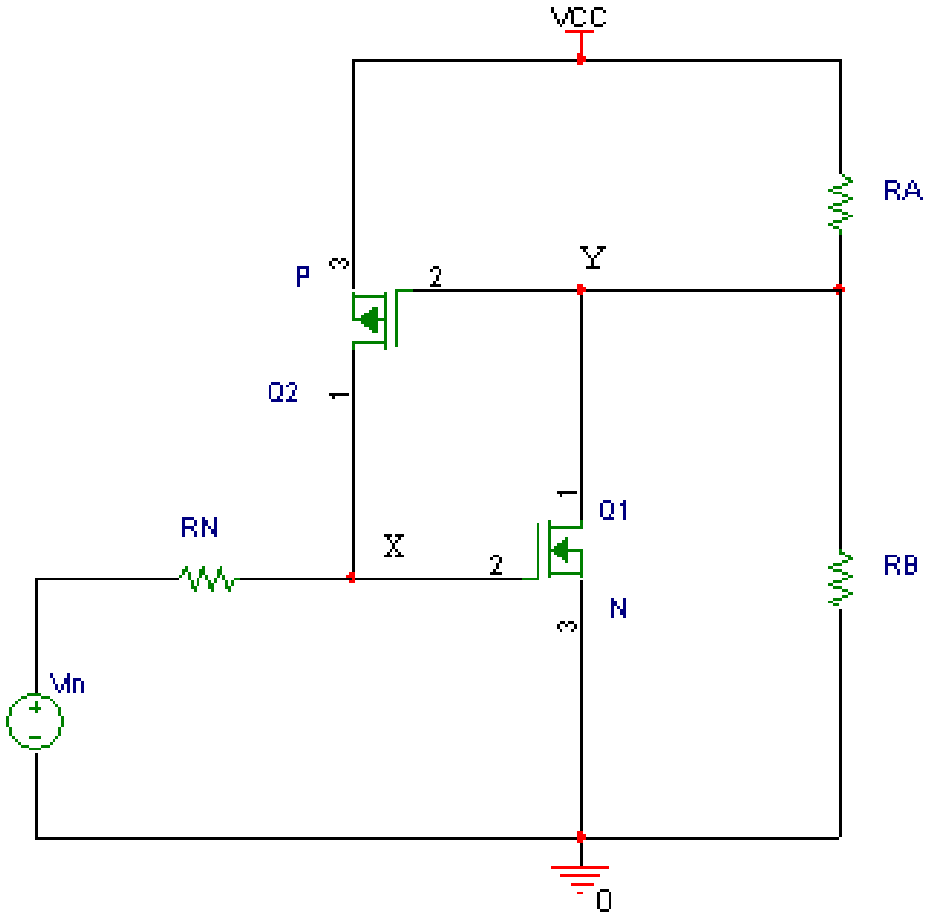
Out signal

Transistor B-E
1pC-estimated
injected charge

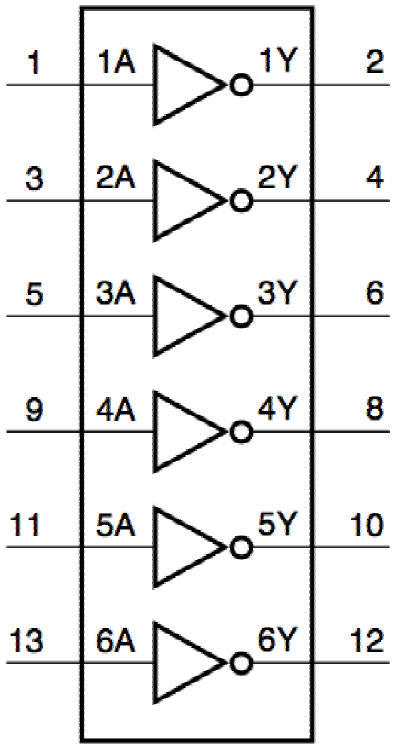


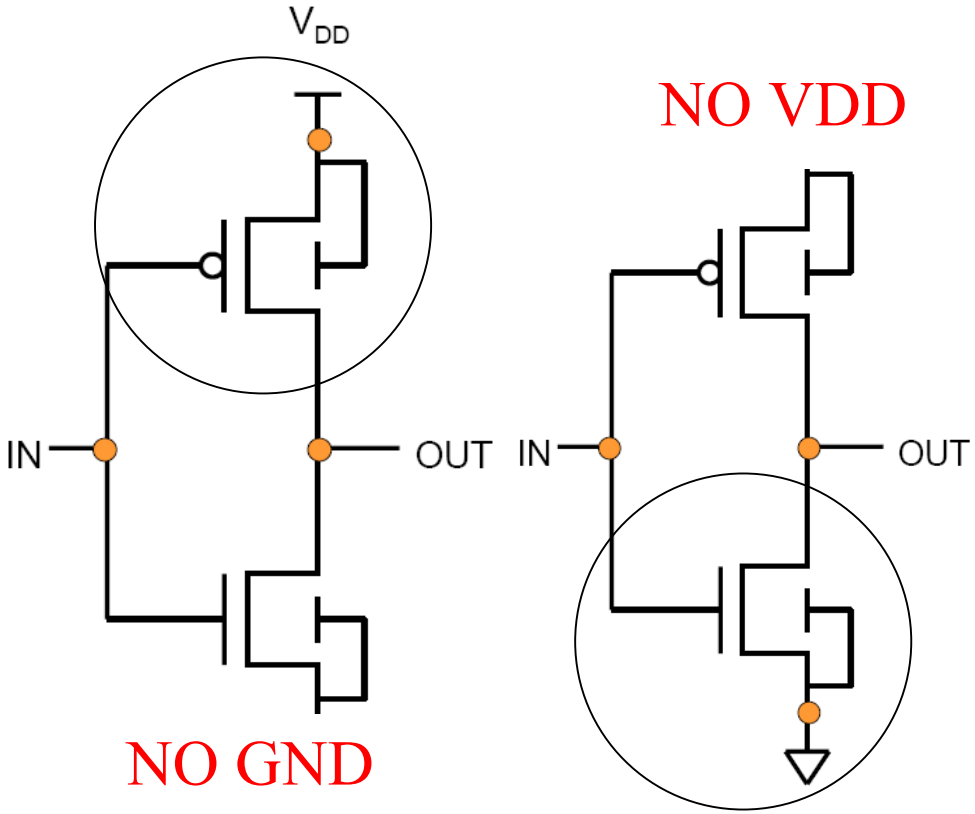
BJT to MOS transistors

All that has been investigated via bipolar transistors (BJT) can be obtained using Metal-Oxide Semiconductor (MOS) transistors



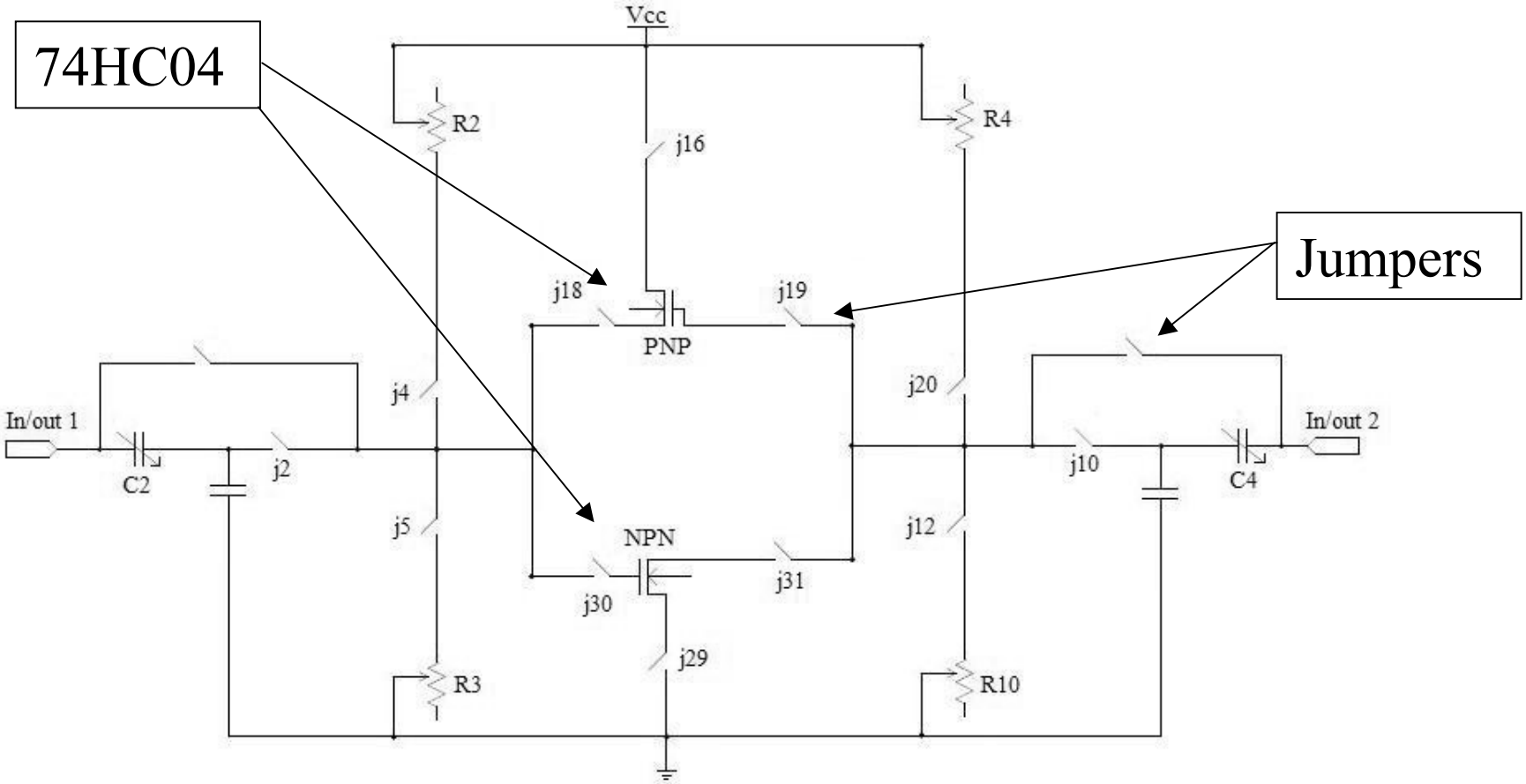
Here is how to use individual commercial MOS transistors (74HC04)



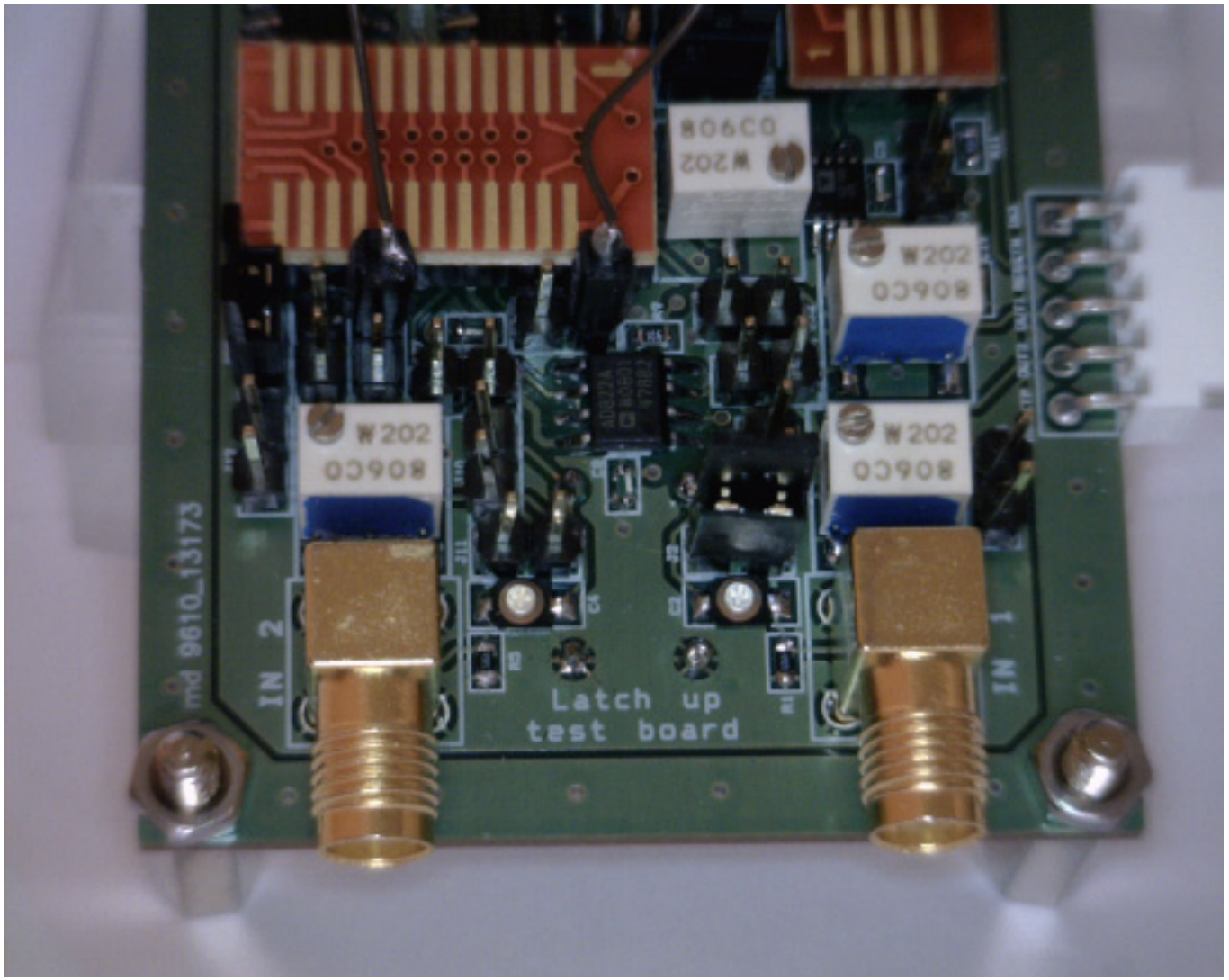


..with some difficulties, honestly

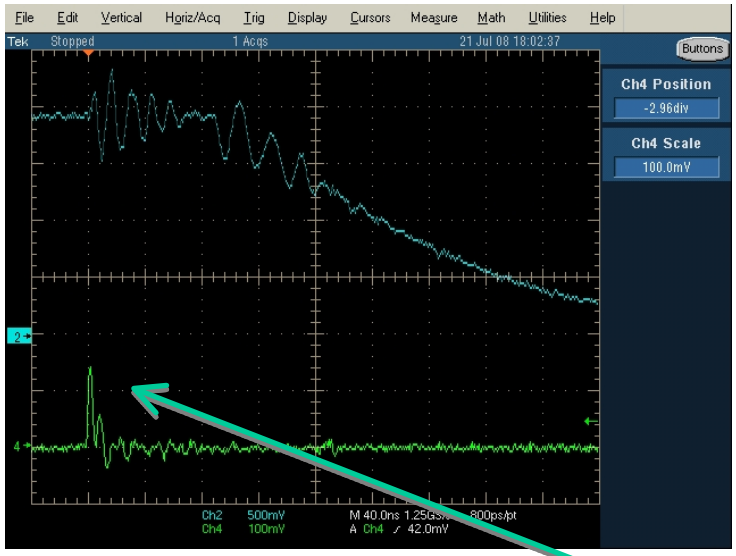
The schematic for many configuration and tuning capabilities

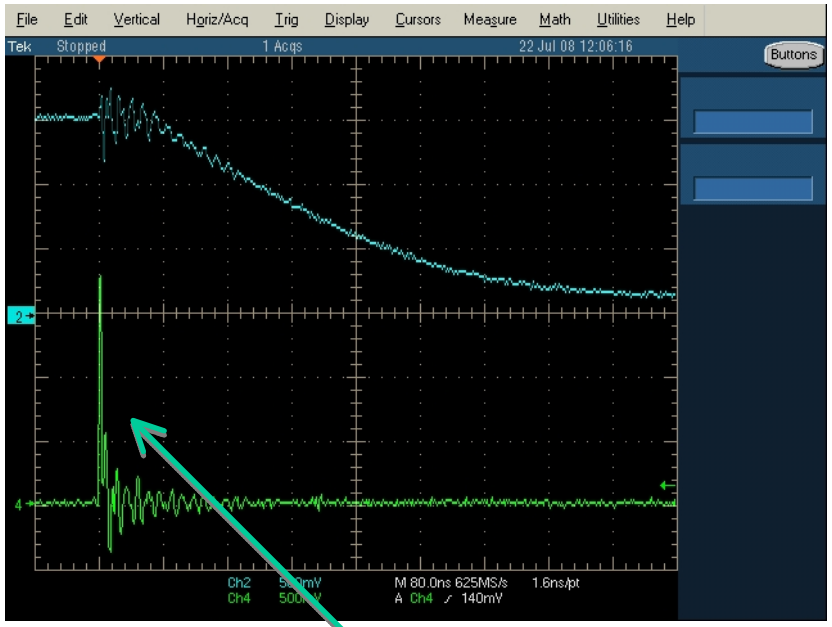


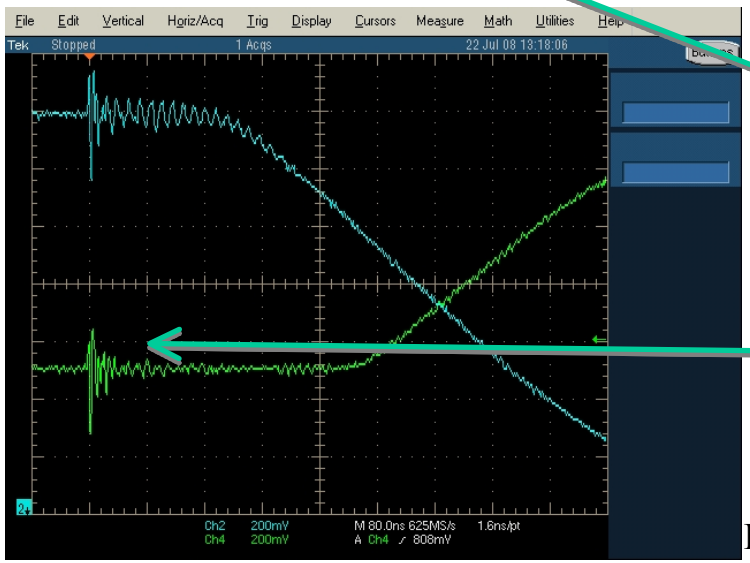
The Test-Board for MOS transistors



Single Latchup ignition







- Blue line is the N-MOS drain (P-MOS gate)

- Green line is the P-MOS drain (N-MOS gate)
  On this line a OverSpike is provided

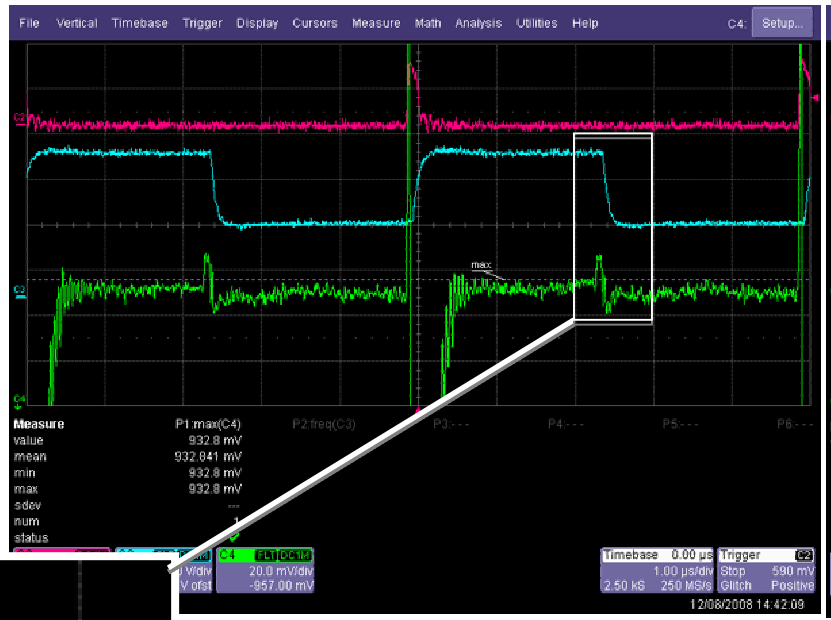
Cyclic Latchup ignition (T=5µs)

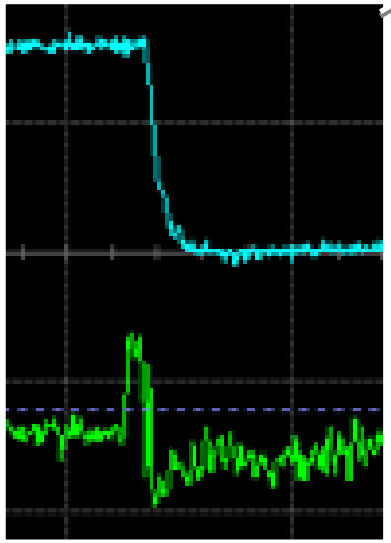
RESET – IGNITION OVERSPIKE - RESET – IGNITION OVERSPIKE

Reset

Output

Ignition OverSpike





- Blue plot is the N-MOS drain (P-MOS gate), "**Output**" (1V/div)
- Green plot is the P-MOS drain (N-MOS gate) with the "**Ignition OverSpike**" (20mV/div)
- Violet plot is a cyclic "**Reset**" with a 5µs period (1µs/div)

No sooner the ignition OverSpike arrives than the circuit latches

Cyclic Latchup ignition (T=5µs)

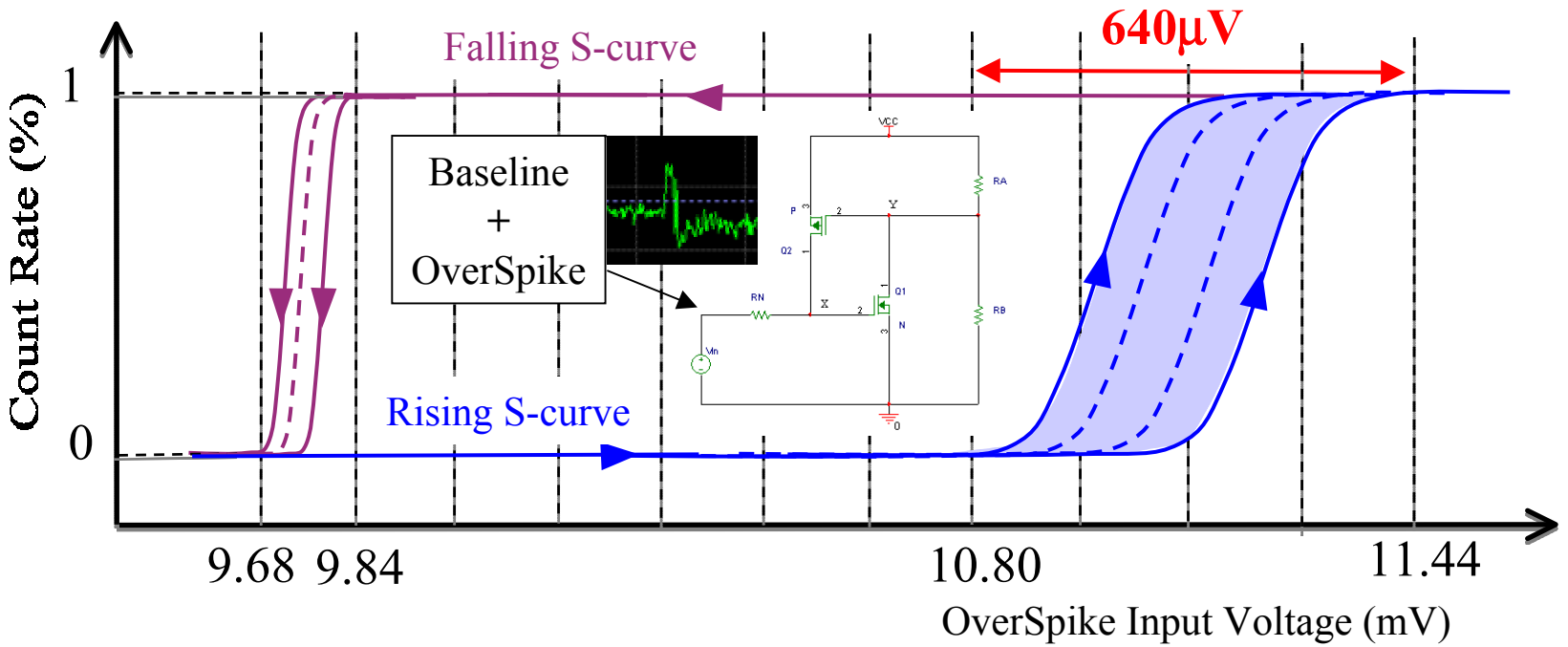
LEFT PICTURE

- The ignition OverSpike is too weak
- Only a few % of the times the circuit latches

RIGHT PICTURE

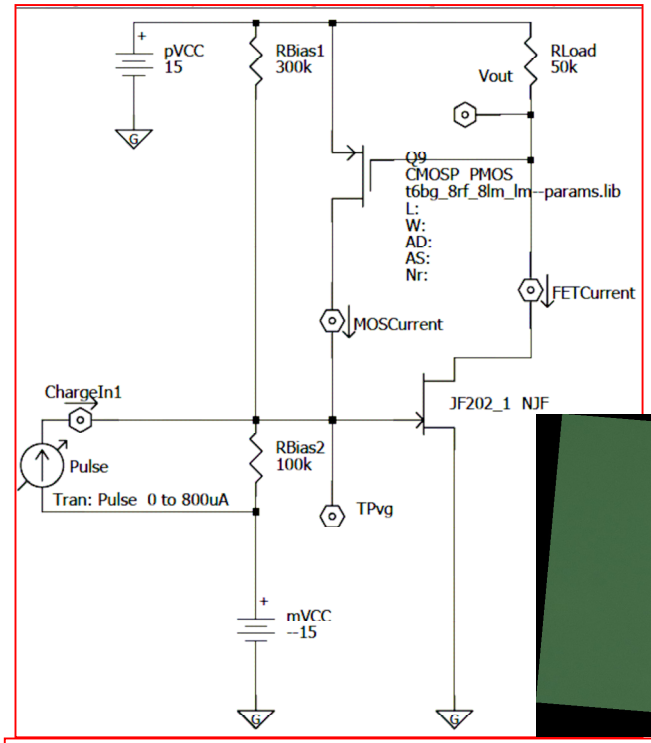
- The ignition OverSpike is high enough
- Most of the times the circuit latches

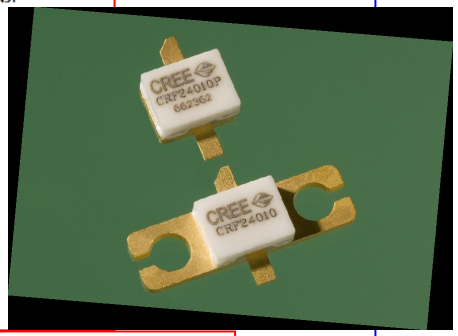
Noise Figure for MOS- Summarized S-curve



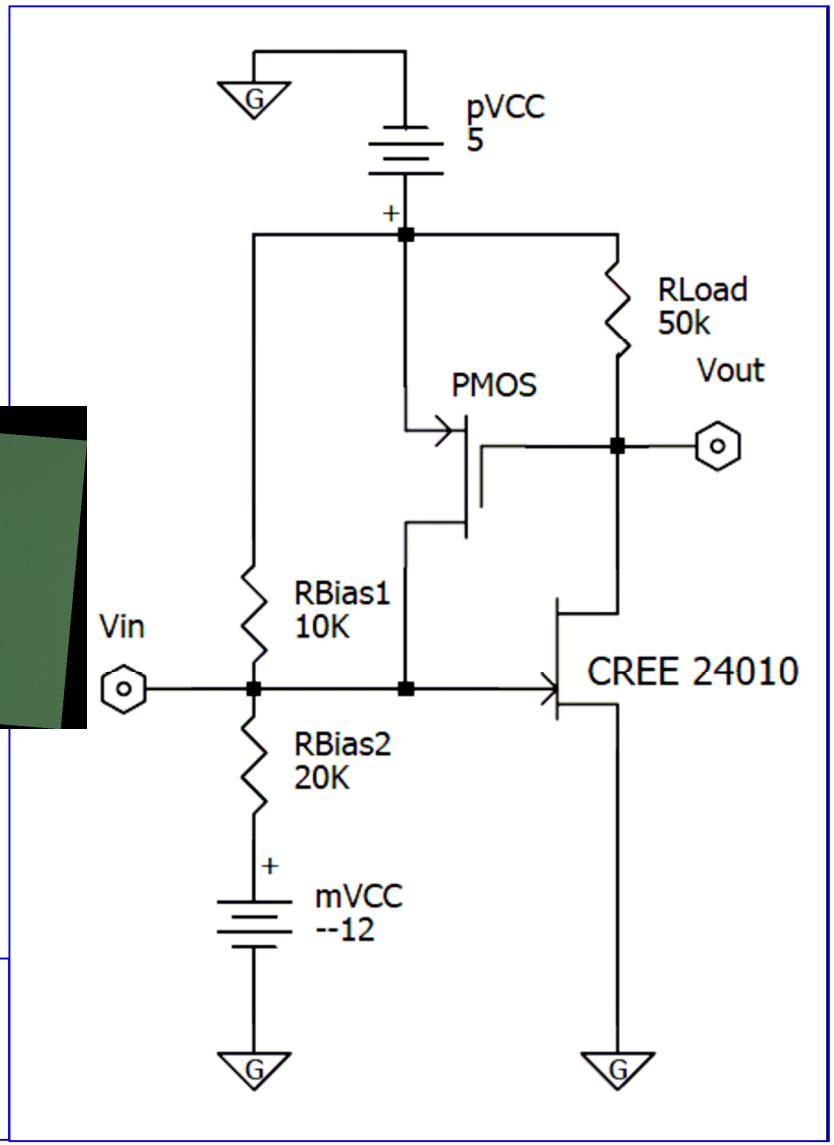
- A biasing gate baseline of about 950mV was used
- Raising curve has an noise figure estimated in ≈ 640µV, **SAY LOWER THAN 1 mV**
- The S-curve has an hysteresis
- The estimated sensitivity, by measuring the input impedence, was confirmed to be ≈ 1pC

The CREE 24010 SiC MESFET via latchup topology





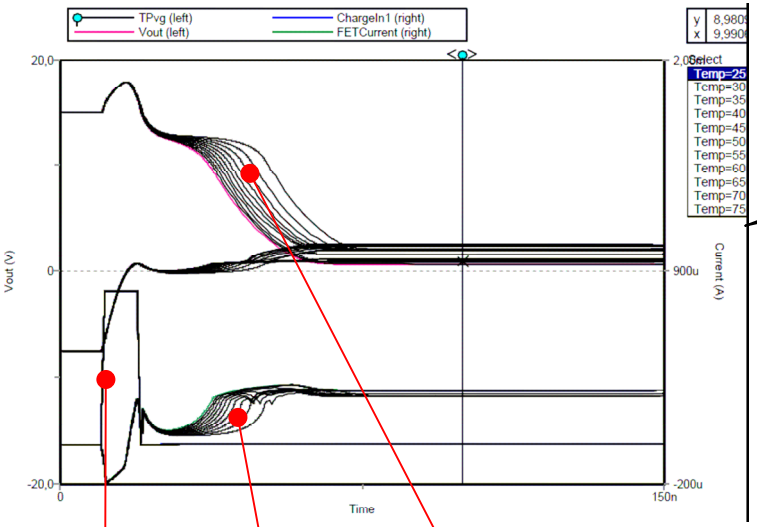
Spice-simulated via JFET model



Actual circuit via MESFET CREE 24010

Mounted on test-board

The CREE 24010 SiC MESFET via latchup topology



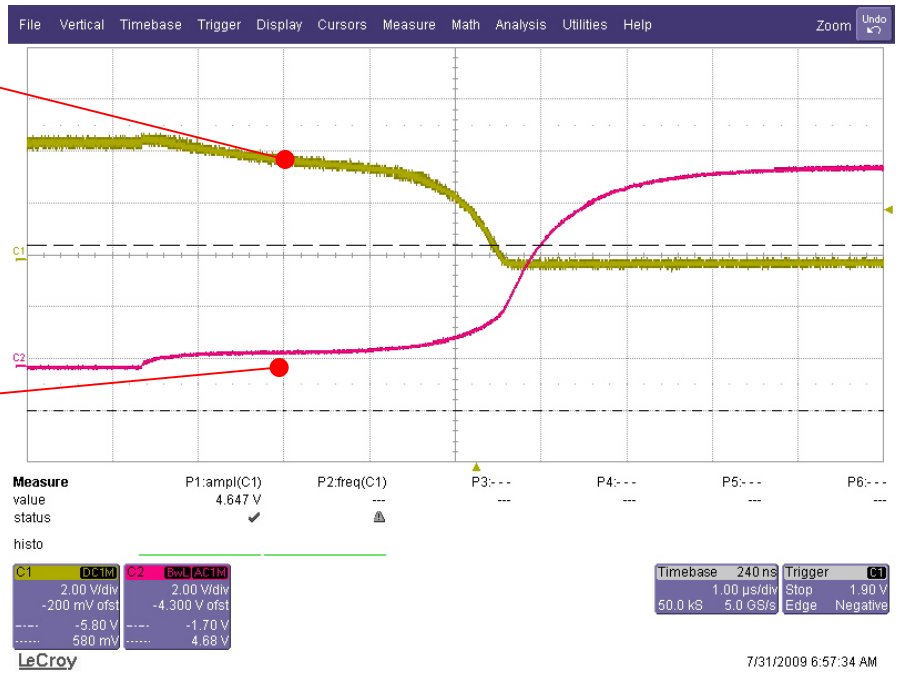
Spice Simulations

Oscilloscope plots

Output on MESFET's drain

MESFET's gate

Input Spike



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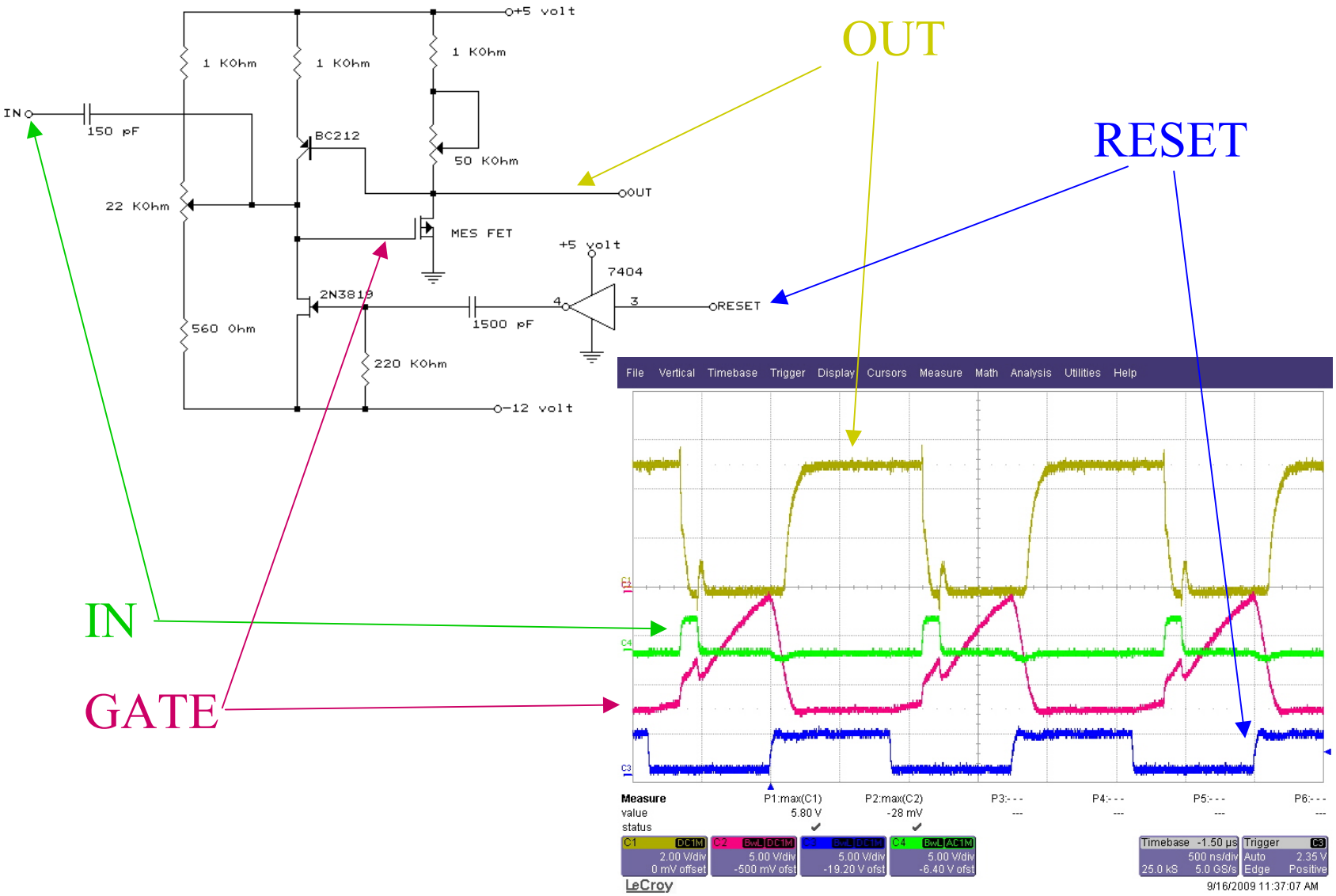

CONCLUSION

Using commercial state-of-the-art MOS transistors we have obtained:

- **an Error Figure of about 640μV,**
- **a sensitivity of the order of 1pC, confirmed like for BJTs,**
- **a readout speed of the order of 1μs.**

Using commercial SiC MESFET transistors we have confirmed the topology and the latchup ignition obtained with BJTs and MOSs

Latchup Mechanism can be exploited in future applications for :

- **particle detection in high-energy physics,**
- **radiation monitoring,**
- **high-temperature, rad-hard applications for SiC**

Advantages: SIMPLE and LOW POWER

An integrated version is required since 2005 ……to go ahead