

COTS BJT's use cases for smallsats and Safe Operation Areas to avoid radiation effects



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1. Introduction and context
2. TID tests COTS BJTs and SoA
3. Use case: Over voltage protection
4. Use case: Power switch – Proportional Base Drive
5. Single Event Effects tests and analysis and SoA
6. Conclusions

Smallsats:

- **Low cost:** They are generally cheaper building and launching compared to traditional large satellites
- **Rapid Development:** The development cycle is shorter, allowing for quicker deployment.
- **Low scale developers:** SMEs, start-ups and research institutes
- **No capability to procure large quantity of COTS and perform Lot-to-Lot screening** on components
- **Important role in demonstrating new technologies**
- **Innovation:** They offer a platform for testing new technologies and conducting experiments in space.
- **Risk missions:** They offer the opportunity to be pathfinders of larger mission where the risks are not acceptable for spacecrafts equipped more critical technologies.

1970

1980

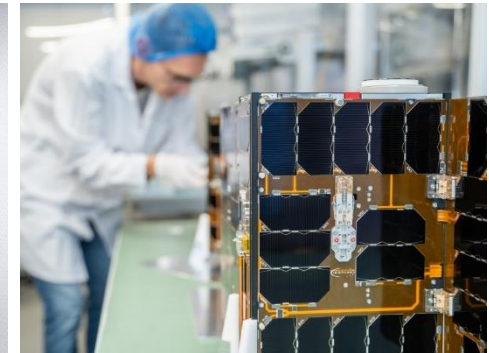
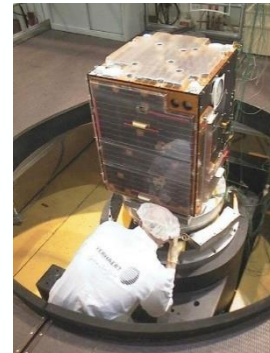
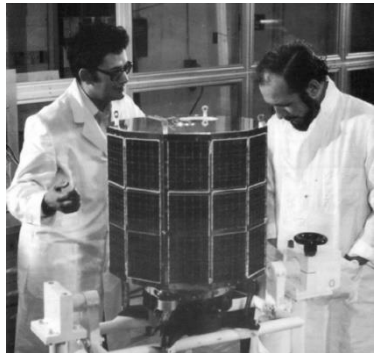
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2000

2010

2020

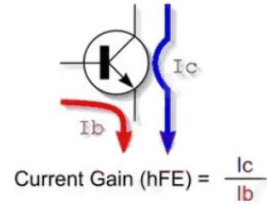
2030?



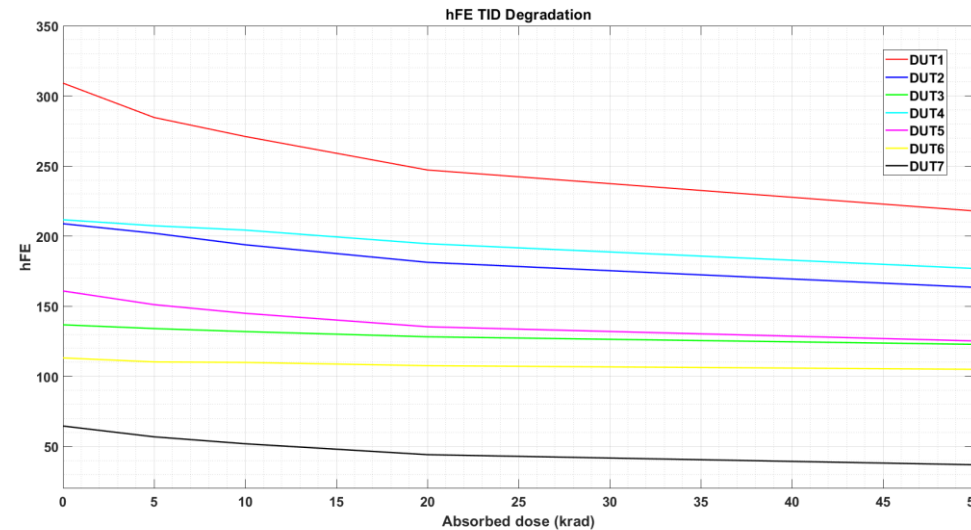
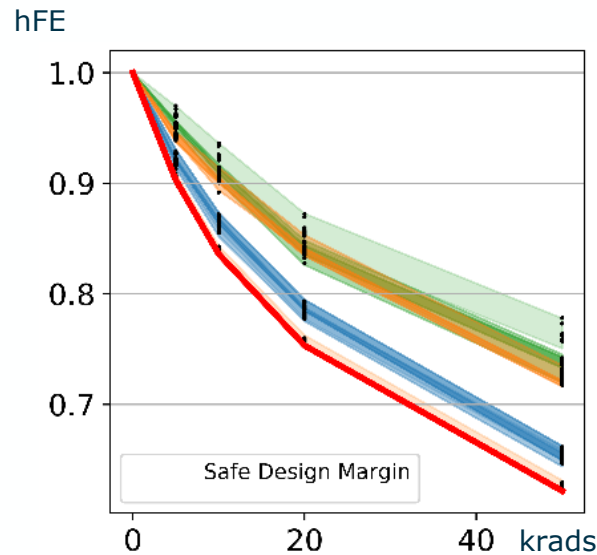
TID tests COTS BJTs (components family)

Effects in TID:

1. hFE
2. Vbe
3. Leakage currents



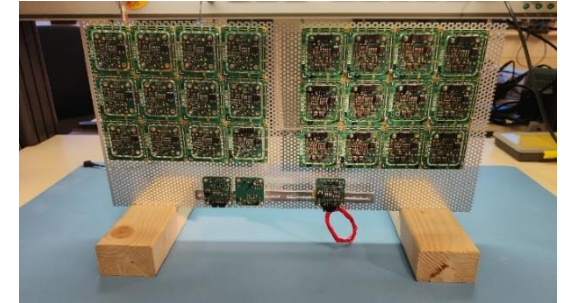
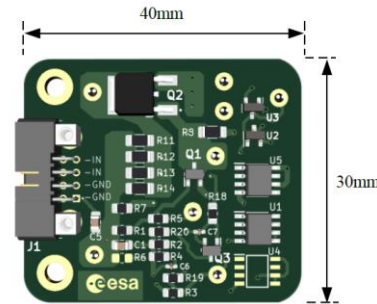
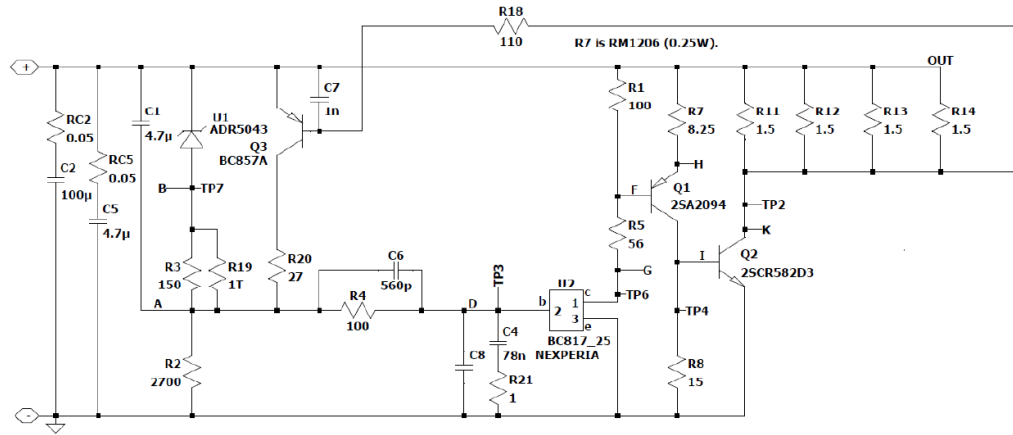
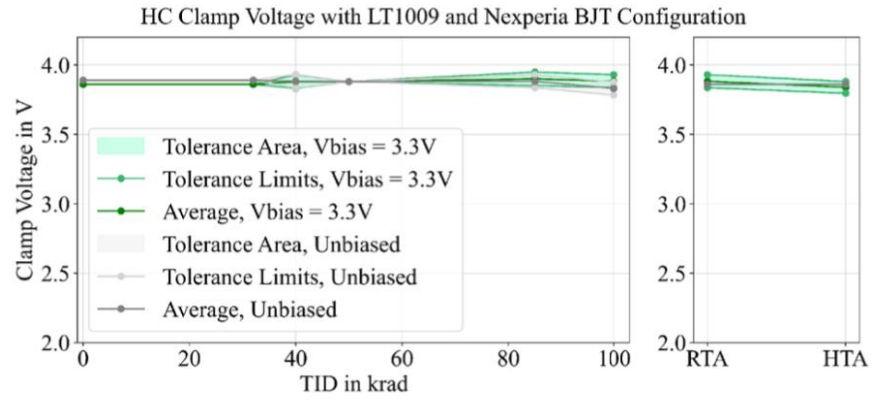
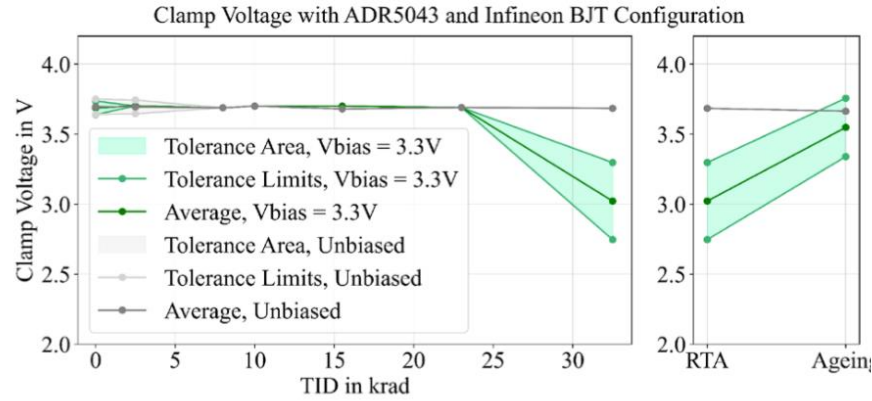
Safe Operating Area (SoA): Derate hFE 5x (~80%) up to 50krad



1) P. Martín-Holgado *et al.*, "Lot-to-Lot Variability and TID degradation of Bipolar Transistors Analyzed with ESA and PRECEDER Databases," *2023 IEEE Space Computing Conference (SCC)*, Pasadena, CA, USA, 2023, pp. 13-21
 2) F. Krimmel, et al. "Lot-to-lot variability TID effects on COTS BJT", RADECS, Vienna, 13-17 September 2021

Experiment 1: Over voltage protection

Understanding the COTS BJT Safe Operating Area (SoA) **Voltage clamp** demonstrated is possible using COTS and resilience to TID effects, we tested 24 units up to **100krads**, forcing to operate in the SOA



P. Hernandez, P. Mand, F. Krimmel and F. Tonicello, "Do No Harm: A Novel Methodology to Protect Electrical Failure Propagation in Spacecraft by Applying Safety Barriers," 2023 13th European Space Power Conference (ESPC), Elche, Spain, 2023, pp. 1-14.

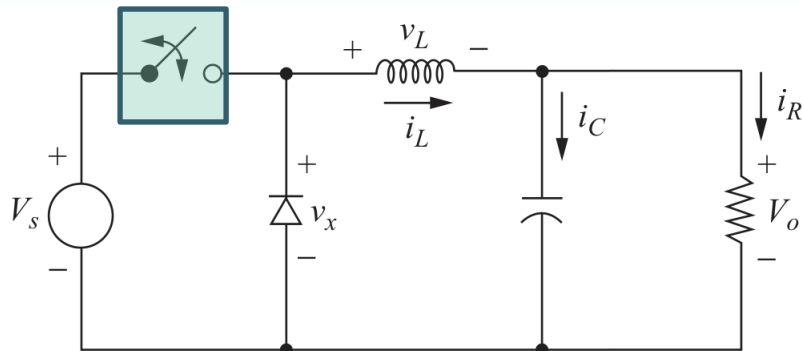
Experiment 2: Driver + Switch DC/DC



Requirements:

- Cost of the basic switching cell (driver+switch) in the order of **10 Euros**
- *Plug and play* driver and switch for DC/DC converters (buck, boost, push-pull...) for 30W-50W in a secondary power supply or even in the solar array regulators.
- Duty cycle from 10% to 80% @ 100 to **200 kHz**.
- Operating temperature range -20 to +80 C.
- Low power consumption (< 20 mA@10 V).
- Turn ON y Turn OFF (rise/fall times) lower than 50ns.
- Low V_{CEMAX} ON state in the order of 0.5V when $I_{ON}=4A$. ($V_{cesat} < V_{cemax}$)
- Low power losses (switching and conductive)
- Full performance up to a of **50 krad TID or beyond**.
- In particular for SEE a conservative V_{CE} derating on the power transistor is applied, on the basis of the mentioned article by Titus.
- For non-power transistors is not required, but derating is anyhow also applied.

Basic switching cell: driver+switch



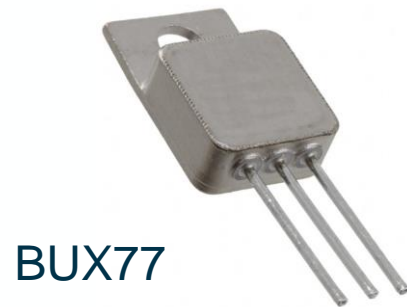
Basic switching cell options DC/DC for small satellites:

Option	Driver	Switch	Cost	Expected radiation performance	Mission Risk
1	COTS driver	COTS MOSFET	Low	Unknown	High
2	COTS driver	COTS GaN FET	Low	Unknown on the driver	High
3	COTS driver (screened)	RH MOSFET	High	Known	Low
4	RH driver	RH MOSFET	Very High	Well Known	Very Low
5	COTS driver (screened)	COTS GaN FET	High	Known	Low
→ 6?	COTS BJT driver	COTS BJT switch	Very Low – not required lot to lot control	Known approach for TID, very likely immune to HI according to ongoing tests after derating	Low ?

RH BJT versus COTS power BJT

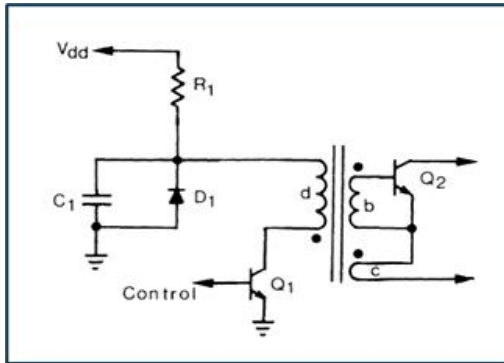
Noting that the corner specification points of the two devices are not the same, the **2SCR583D3** is superior than **BUX77** for thermal impedance, mass and size, hFE , V_{CEsat} , transition frequency, turn on time (<6x).

BUX77 -> 2SCR583D3 Improvements

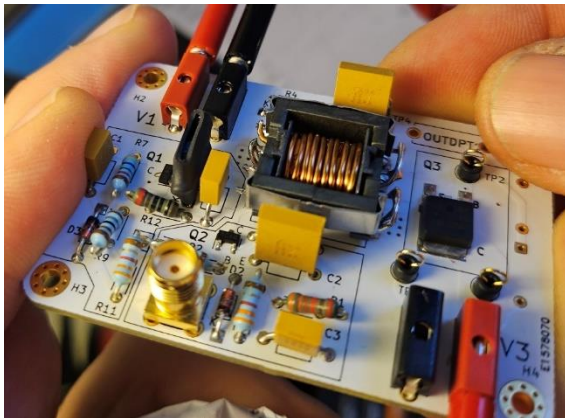
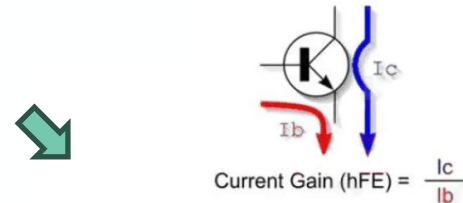


Experiment 2: Proportional Base Drive (PBD)

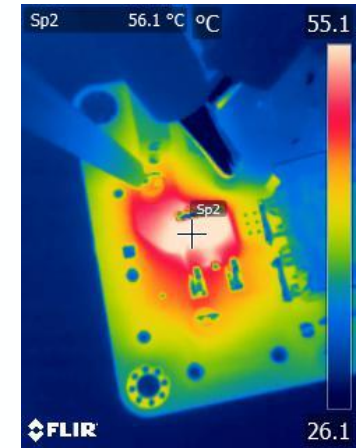
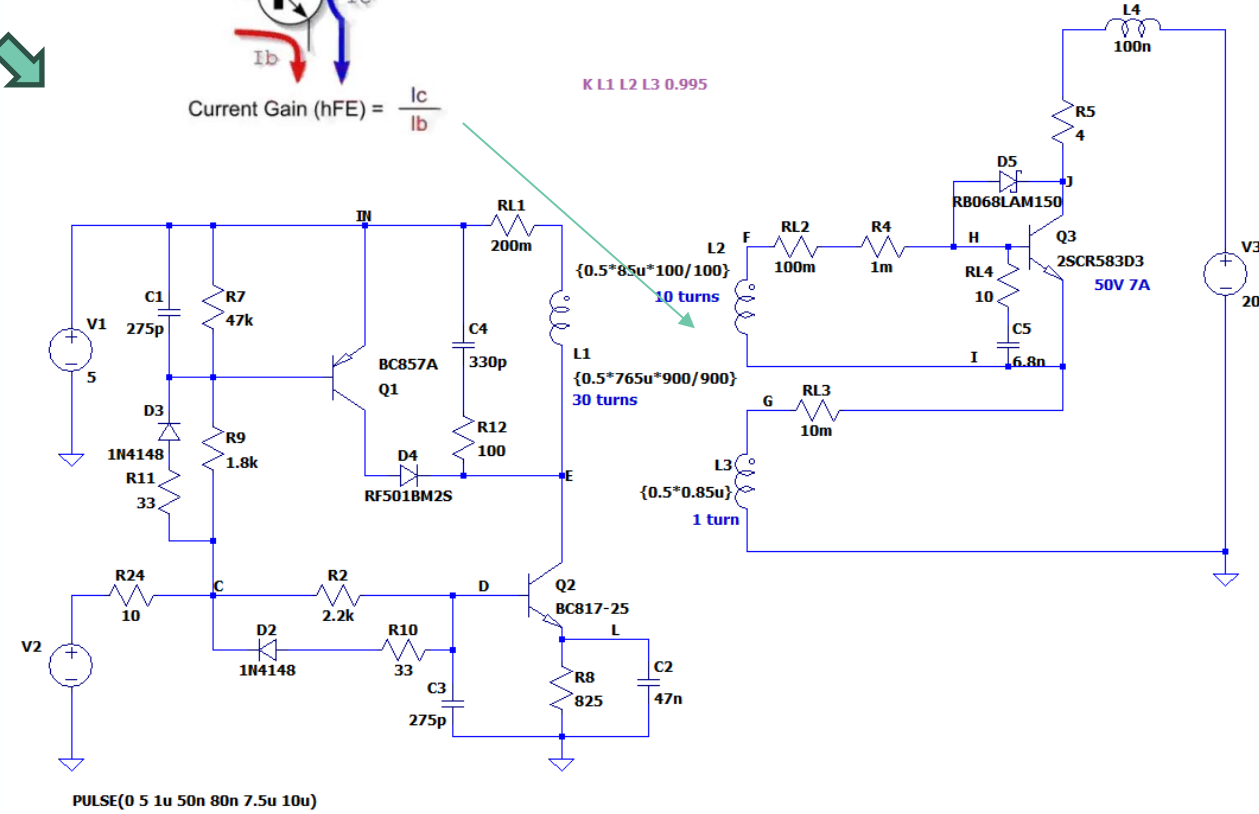
PBD simple concept



"Derating Vce and forcing to operate gain 10, by the ratio of windings selected in the transformer" -> hFE degradation controlled

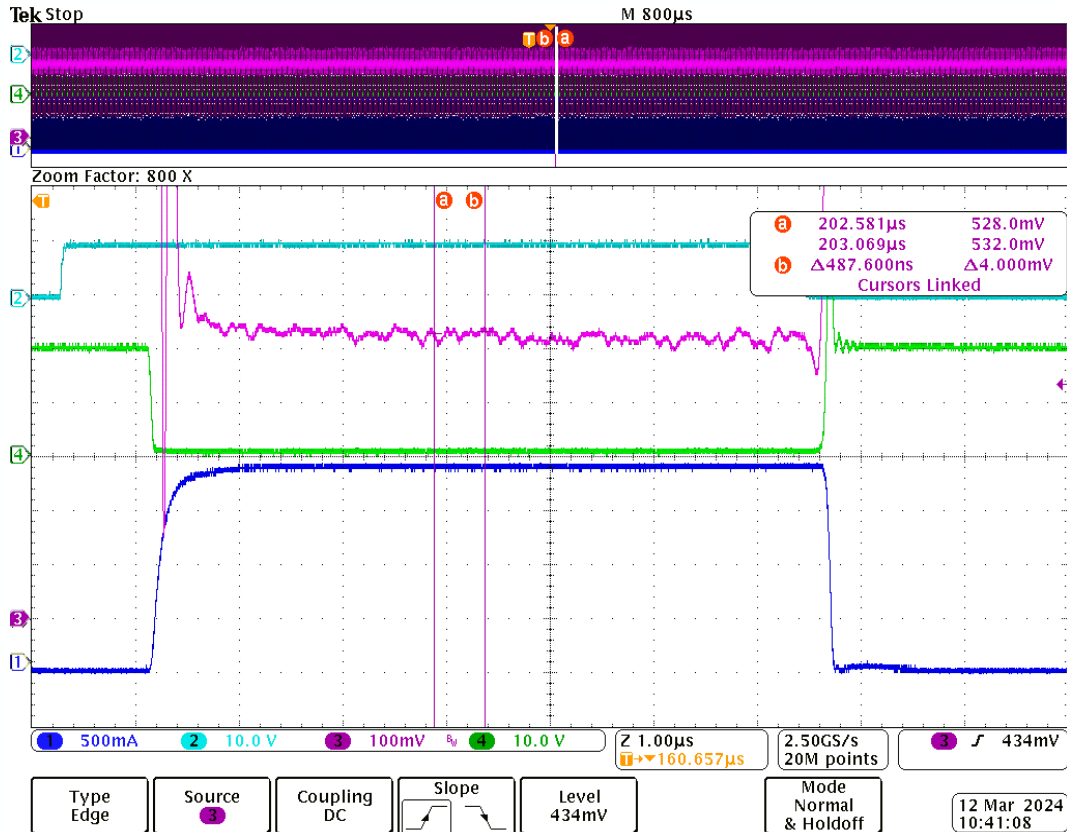


First tested prototype



Thermal test

Experiment 2: PBD test + lesson learnt

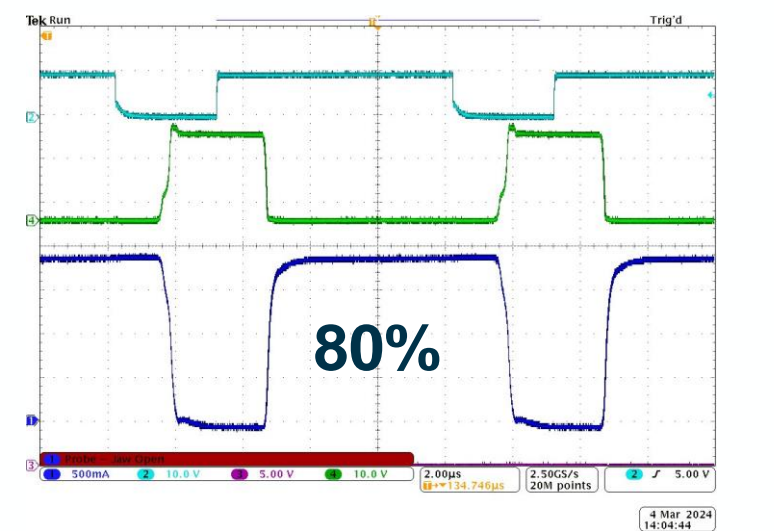
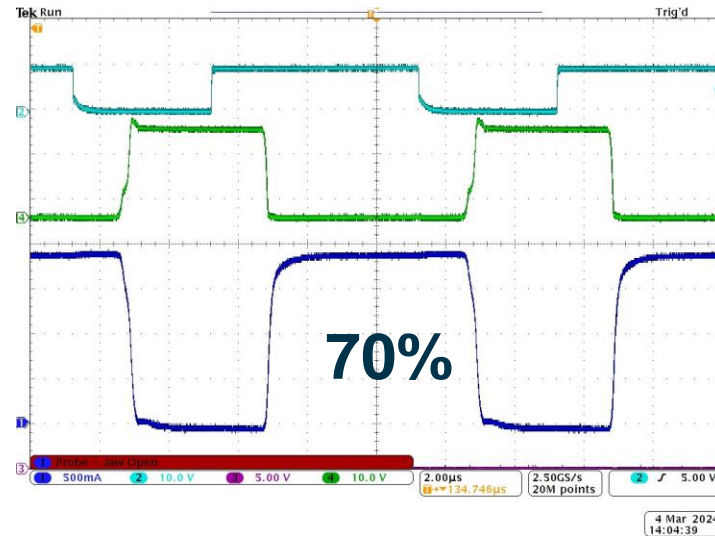
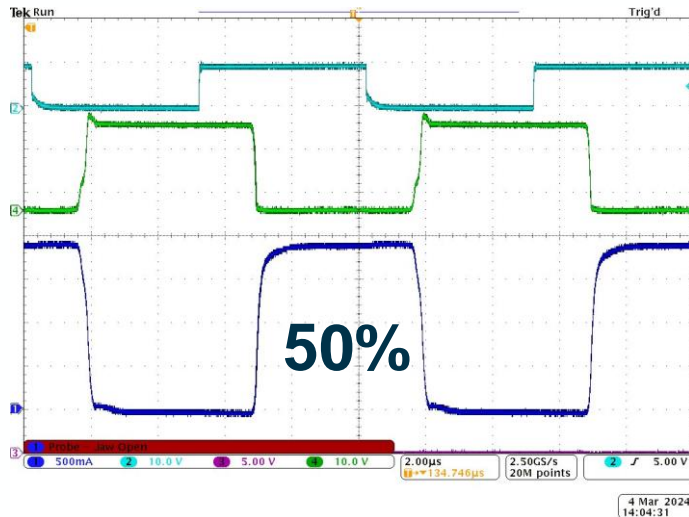
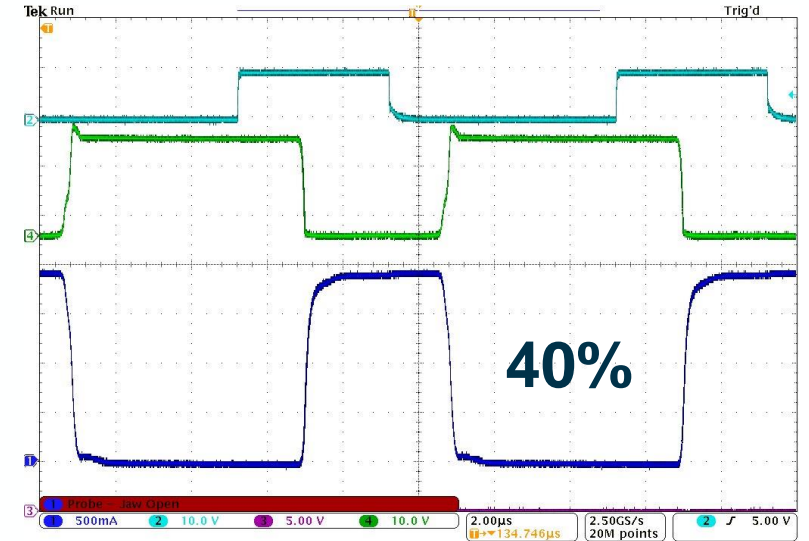
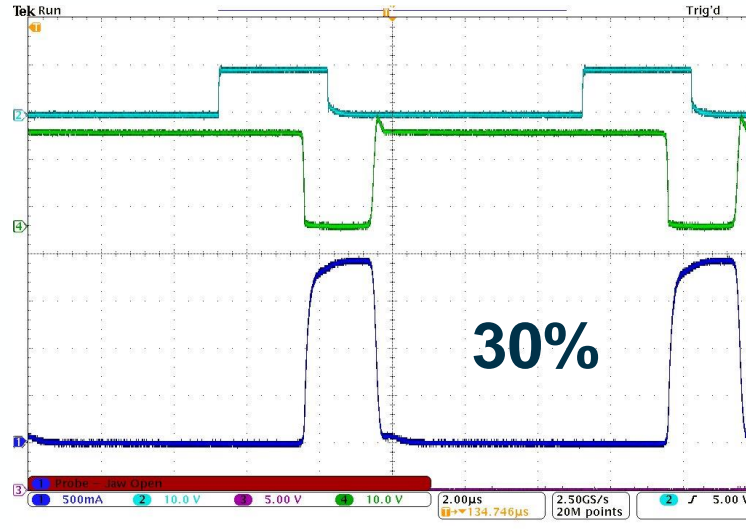
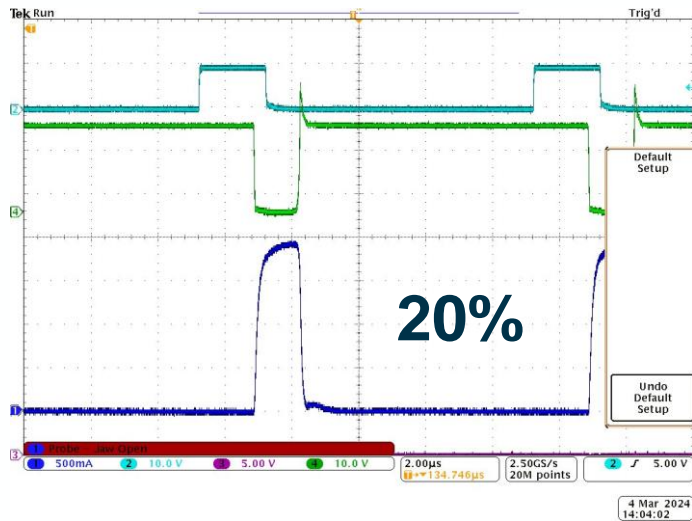


- 1= Current collector Power BJT (Q3)
- 2= Command pulse
- 3= Vce (measured with differential probe) Q3
- 4= Voltage collector Power BJT (Q3)

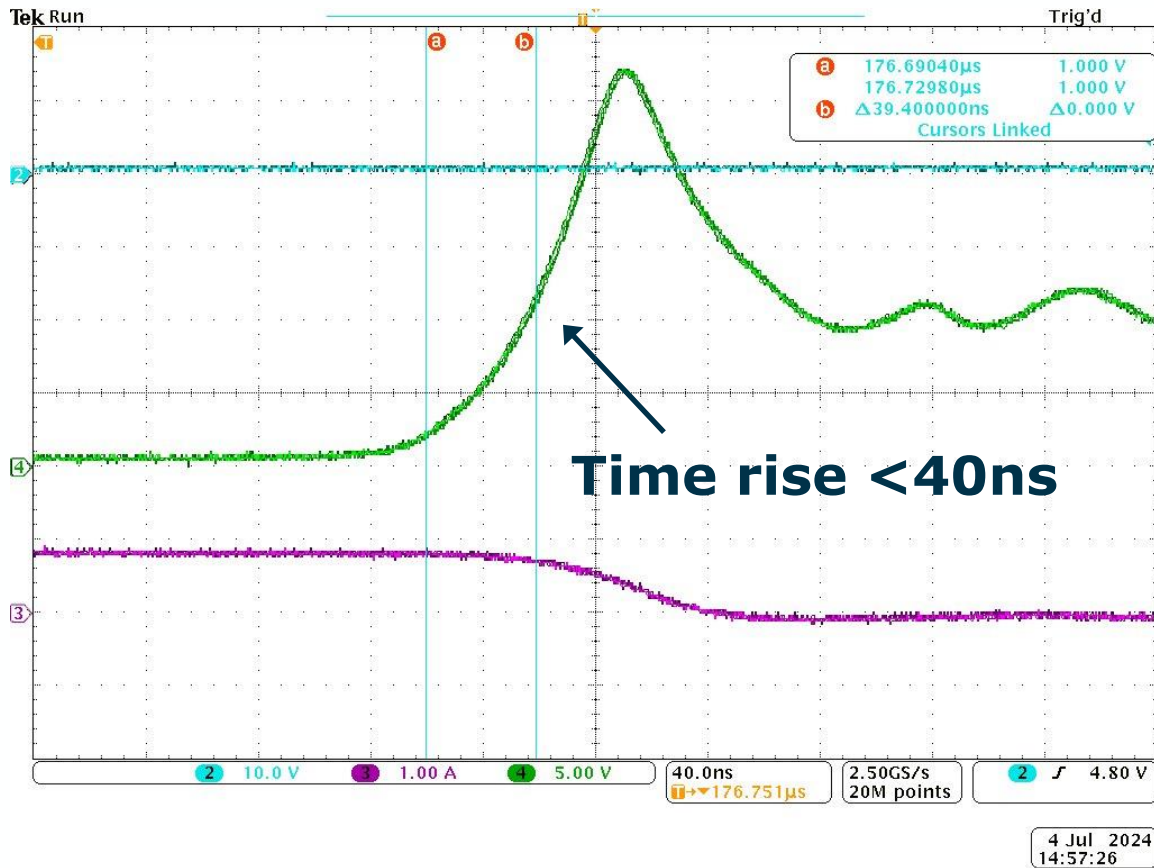
1. BJT spice model is not accurate
2. Baker clamp is needed (Schottky diode b-e)
3. Very fast 30ns time down/rise
4. Duty cycle 20% to 80% confirmed at 200kHz
5. Stable thermal performance
6. Miniaturization can be improved
7. Low power losses (switching and conductive):
max 1.2W at the following envelope conditions:
 $V_{OFF}=30V$, $I_{ON}=4A$.
8. Losses due the baker clamp can be improved
9. PBD forces the design to operate **with gain 10**,
so effects in TID hFE are not seen.

Experiment 2: 20%-80% Duty cycle

1= I collector (Power BJT)
2= Pulse command
4= Voltage collector (Power BJT)

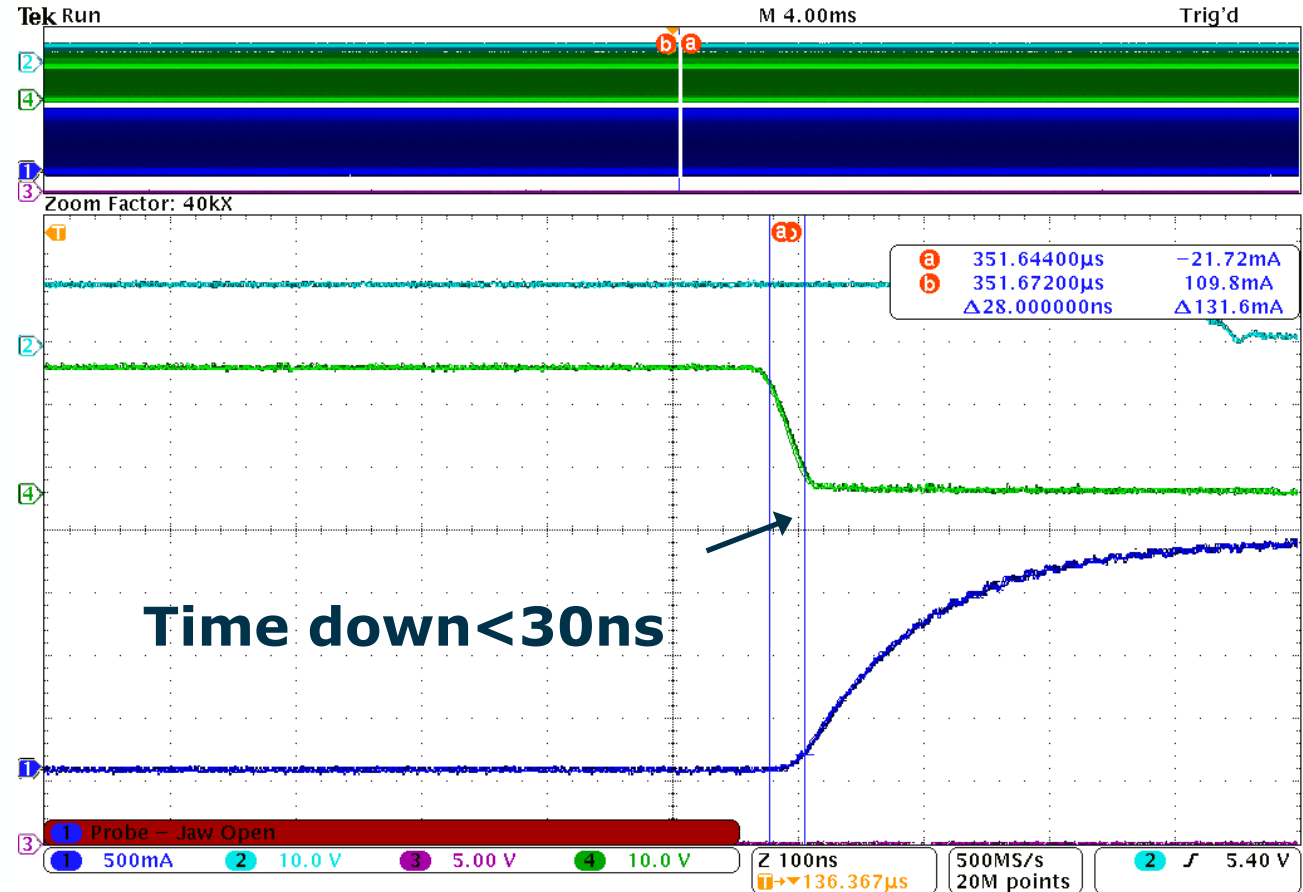


Experiment 2: Time rise/fall measurements



3= I collector (Power BJT)
4= Voltage collector (Power BJT)

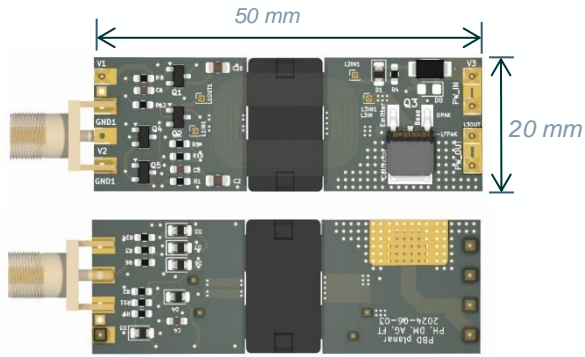
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14:57:26



3= I collector (Power BJT)
4= Voltage collector (Power BJT)

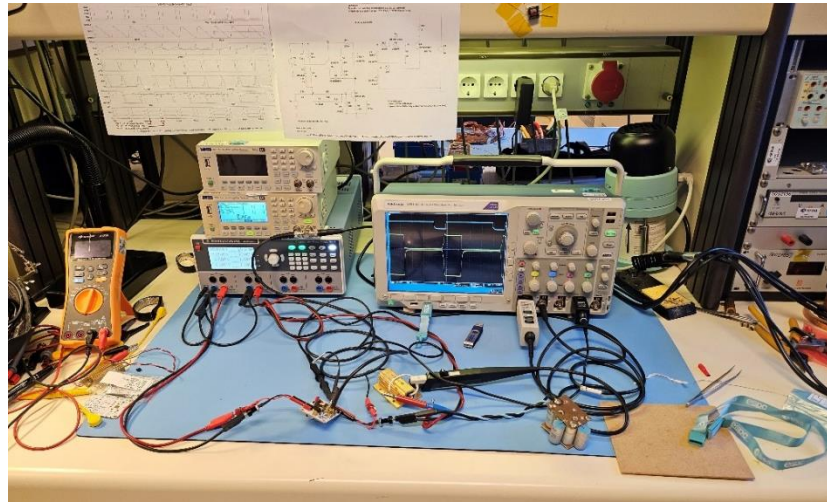
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Experiment 3: miniaturized PBD with planar transformer



Second tested prototype (integrated planar transformer)

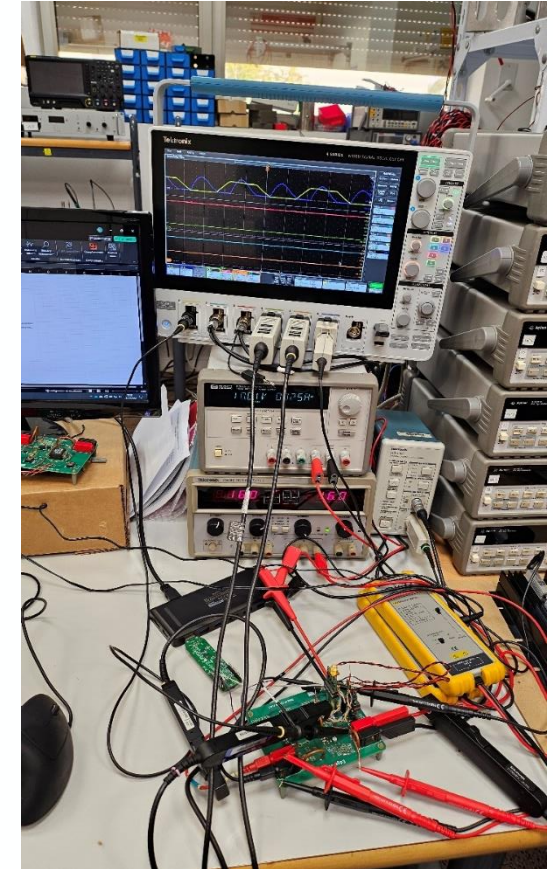
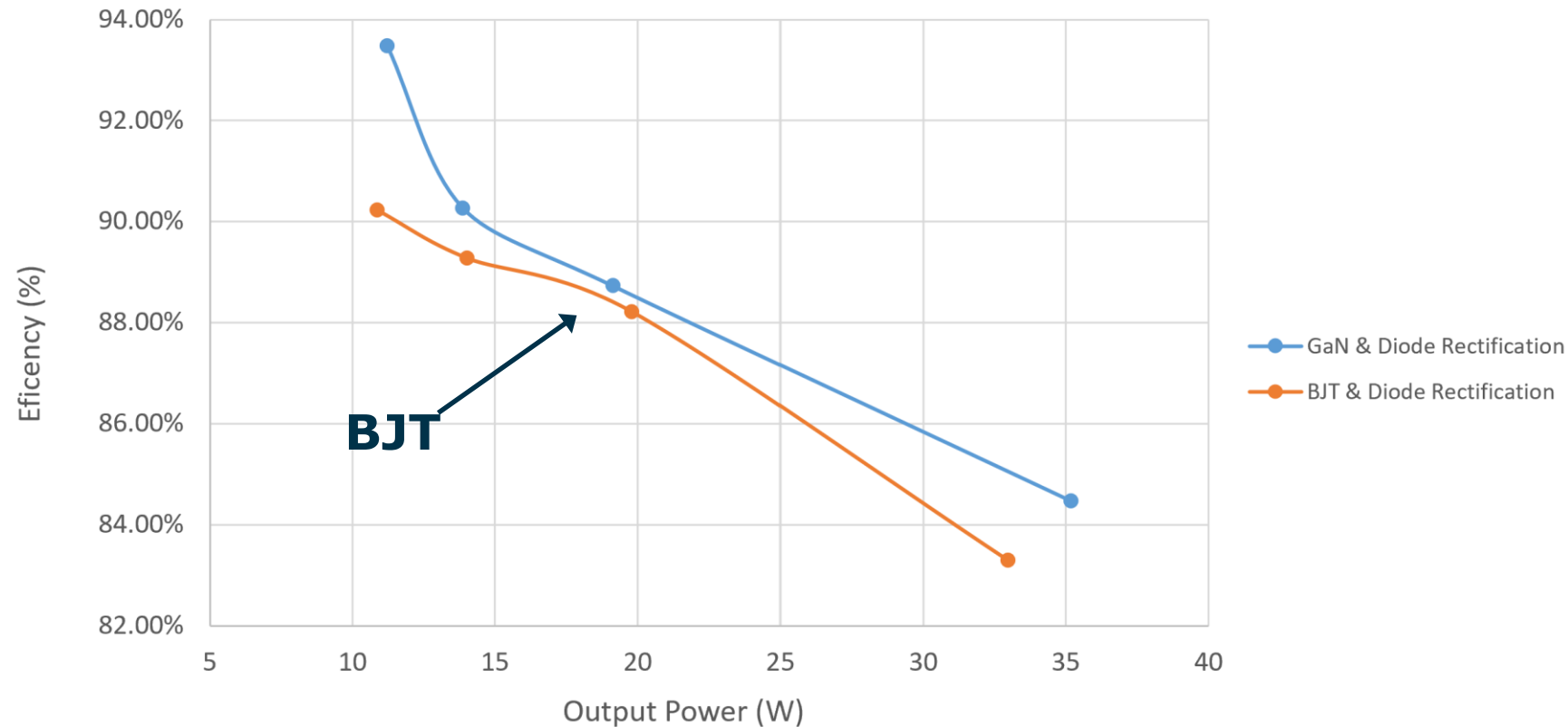
1. With a rated different Schottky is possible to reduce the V_{ceon} from 0.5V to 0.3V
2. Baker clamp is needed (Schottky diode b-e)
3. BJTs is very fast 30ns time down/rise
4. Thermal performance seems good
5. Miniaturization with planar transformer is demonstrated
6. PBD forces the design to operate with gain 10, so effects in TID hFE are not seen.



Laboratory testbench

Experiment 4 – DC-DC efficiency measurements

- ZVZCS Push-pull converter (resonant topology)
- power level: 5W to 40W

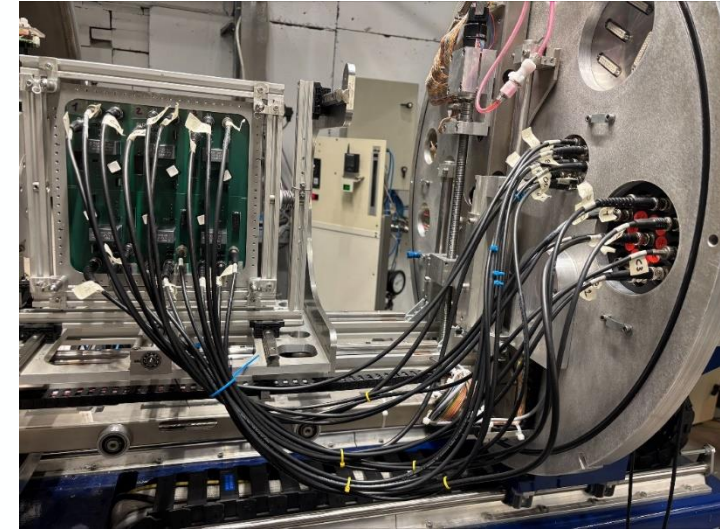


Laboratory testbench

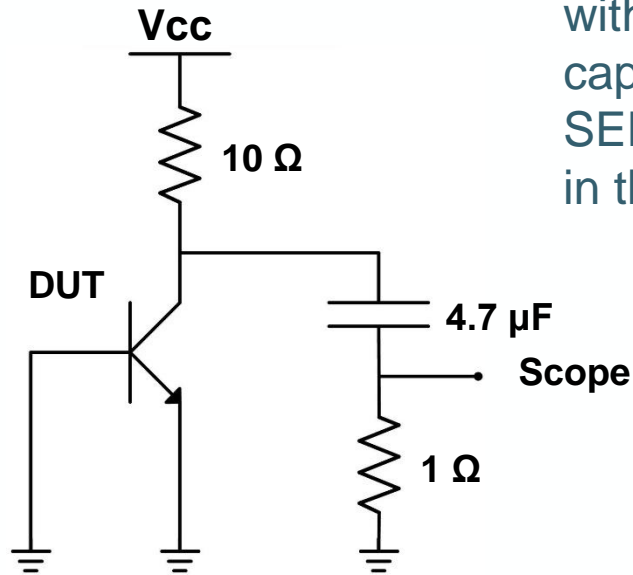
Experiment 5 SEE: Test setup Power BJTs

Seven different part-types with rated C-E breakdown voltage ranging from 50V to 250V were tested with heavy ions: five NPN devices and two PNP devices. The components were tested using ions with energy of 9.3 MeV per nucleon and were irradiated with Krypton (LET = 32.4 MeV·cm²/mg) and Xenon (LET = 62.5 MeV·cm²/mg).

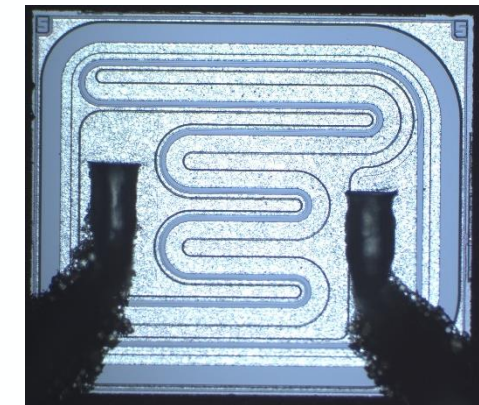
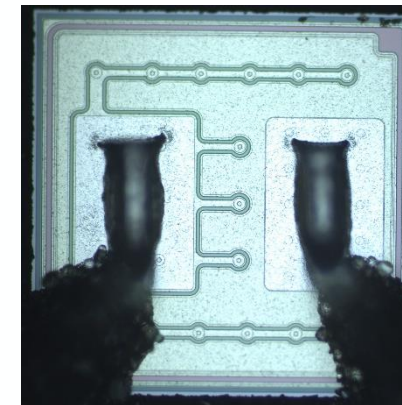
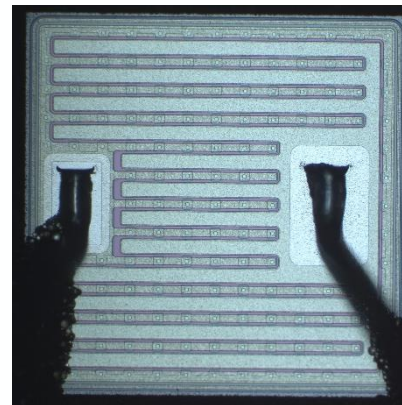
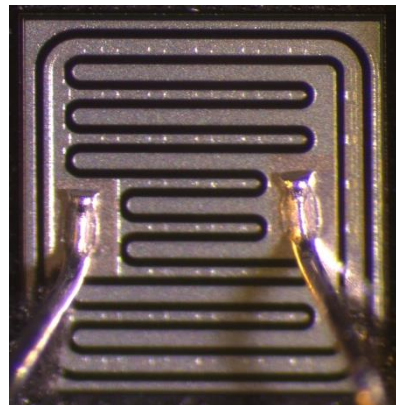
The devices were tested in a worst-case condition: with base and emitter shorted to ground and a capacitor in parallel to accumulate charge to trigger SEB. The 1 Ω resistor is used to convert the current in the BJT in voltage for the oscilloscope.



Testbench – Heavy Ions



Schematic of test setup



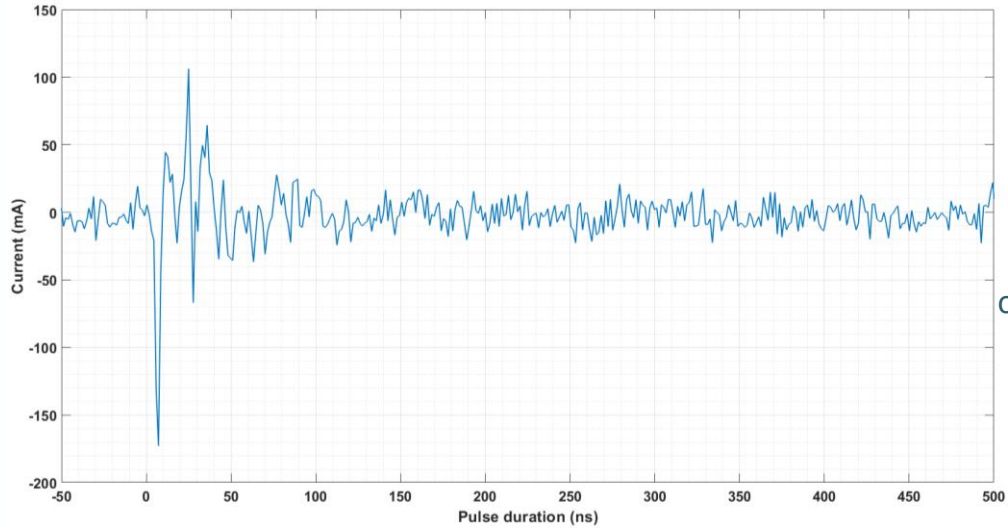
SEE results: summary

Six samples for each of the seven part-types were tested. All the samples showed SETs with a wide range of amplitude (from 100 mA to 45 A) and duration (from 150 ns to 18 μ s). For all the components the SETs increased increasing the collector voltage.

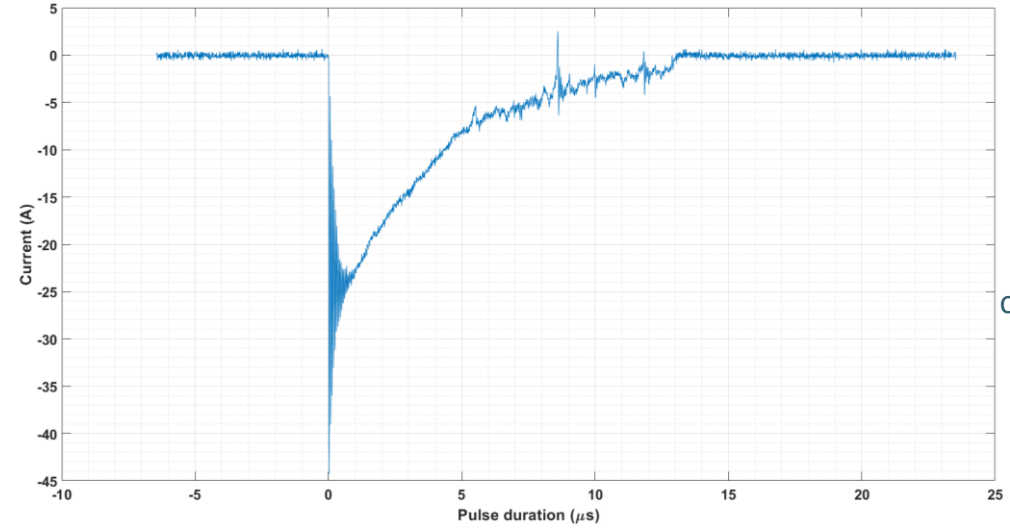
DUT	Voltage rating	Type	Maximum SET amplitude	SEB observed	Minimum Voltage at which SEB happened
1	50 V	NPN	42 A	No	N/A
2	50 V	PNP	400 mA	No	N/A
3	80 V	NPN	45 A	Yes	50V (Xe)
4	80 V	PNP	300 mA	No	N/A
5	100 V	NPN	1 A	Yes	40V (Xe)
6	150 V	NPN	2 A	Yes	50V (Kr)
7	250 V	NPN	1.4 A	No	N/A

PNP transistors appear to be more robust against SET and SEB compared to NPN BJTs.

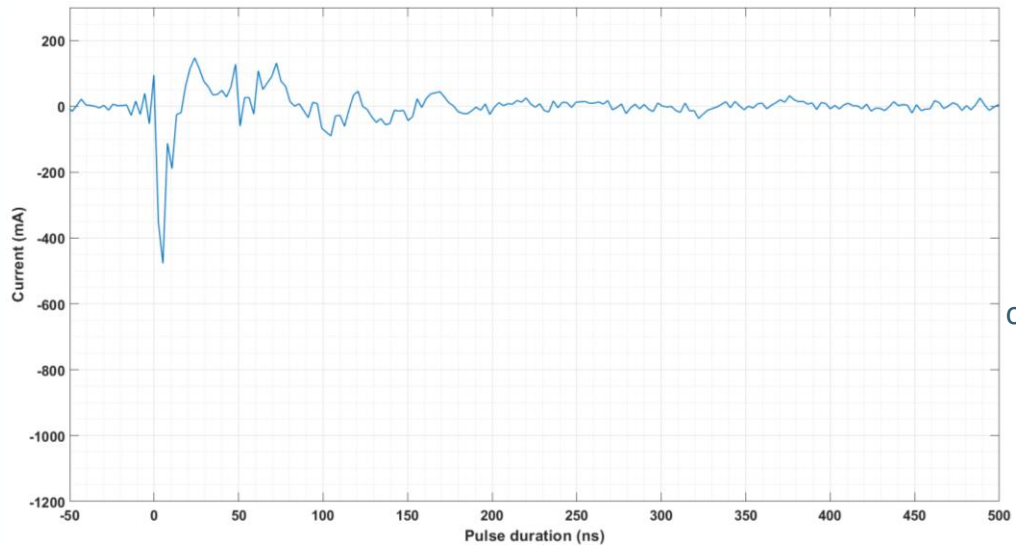
SEE results: SET plots



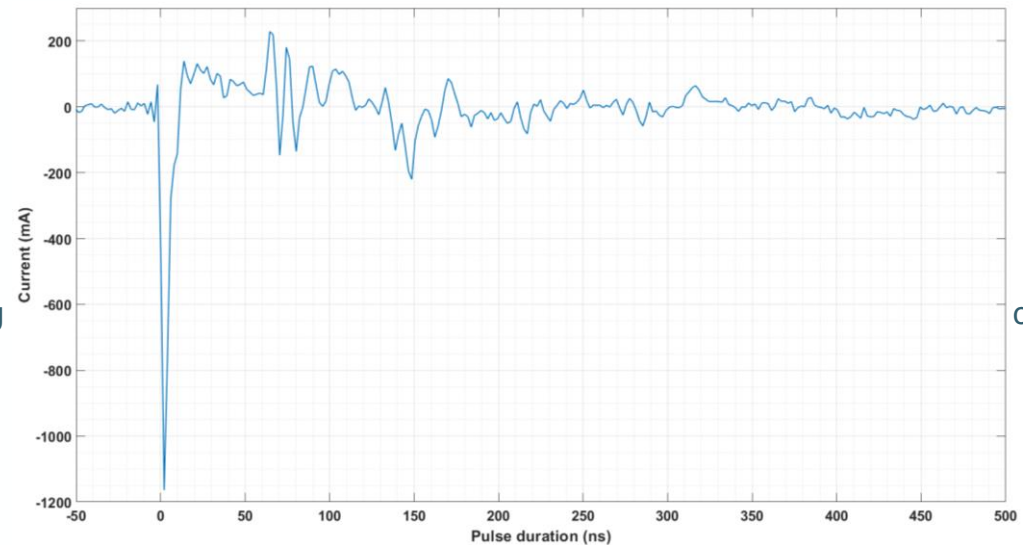
DUT 3 typical
SET at 20 V
collector biasing



DUT 3 typical
SET at 60 V
collector biasing

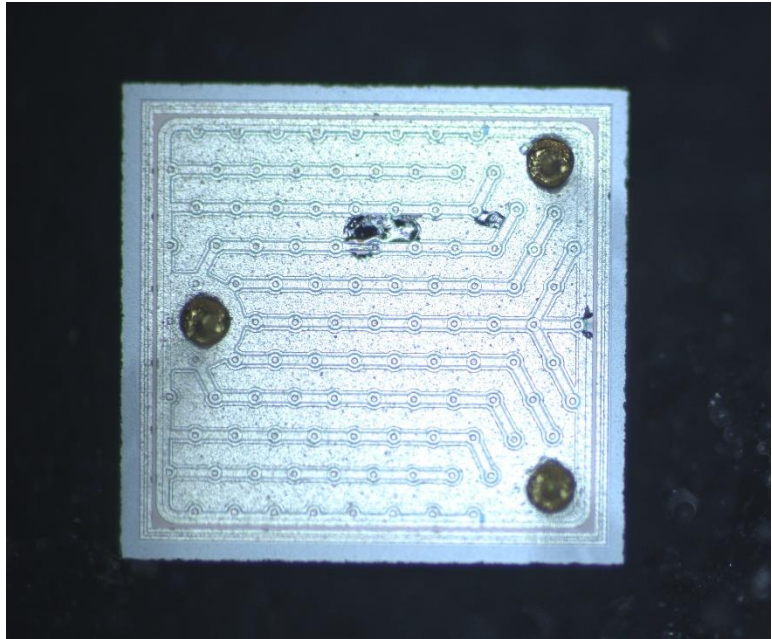
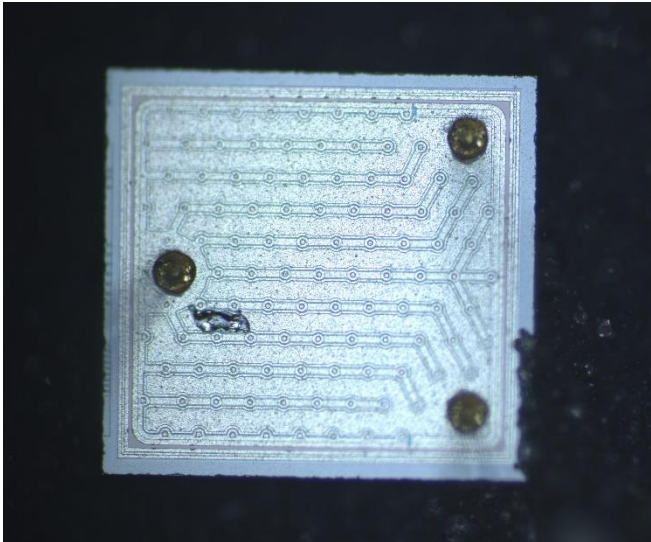
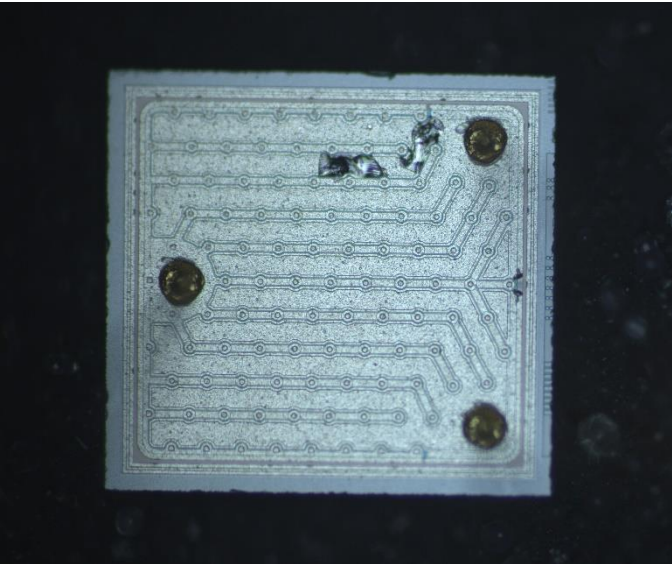
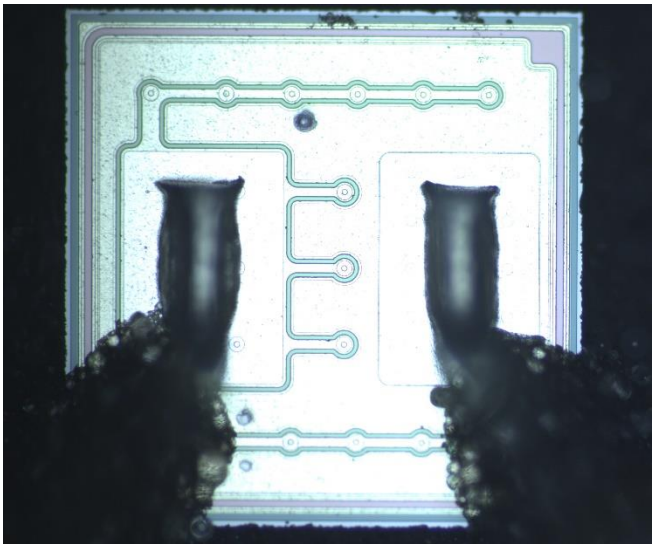
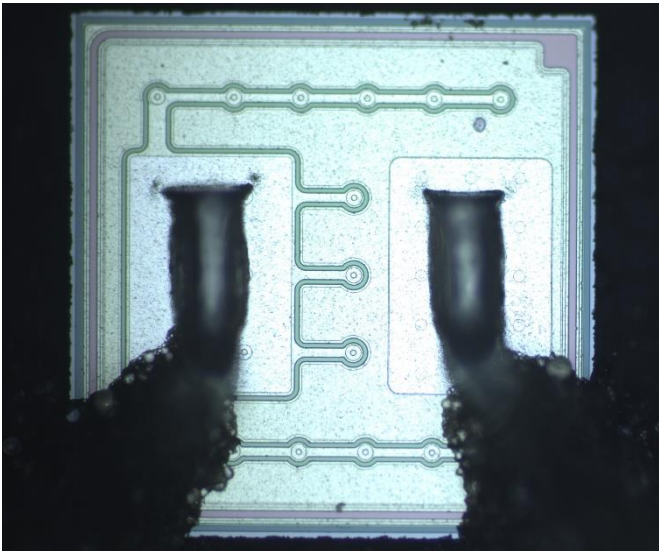


DUT 6 typical
SET at 125 V
collector biasing



DUT 6 typical
SET at 250 V
collector biasing

SEE results: SEBs (ongoing analysis)



Questions?



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The banner features a blue background with a red sun, a satellite dish, and silhouettes of Seville's architecture and a satellite dish.