

Analysis of radiation effects in trigger front-end electronics with impedance spectroscopy

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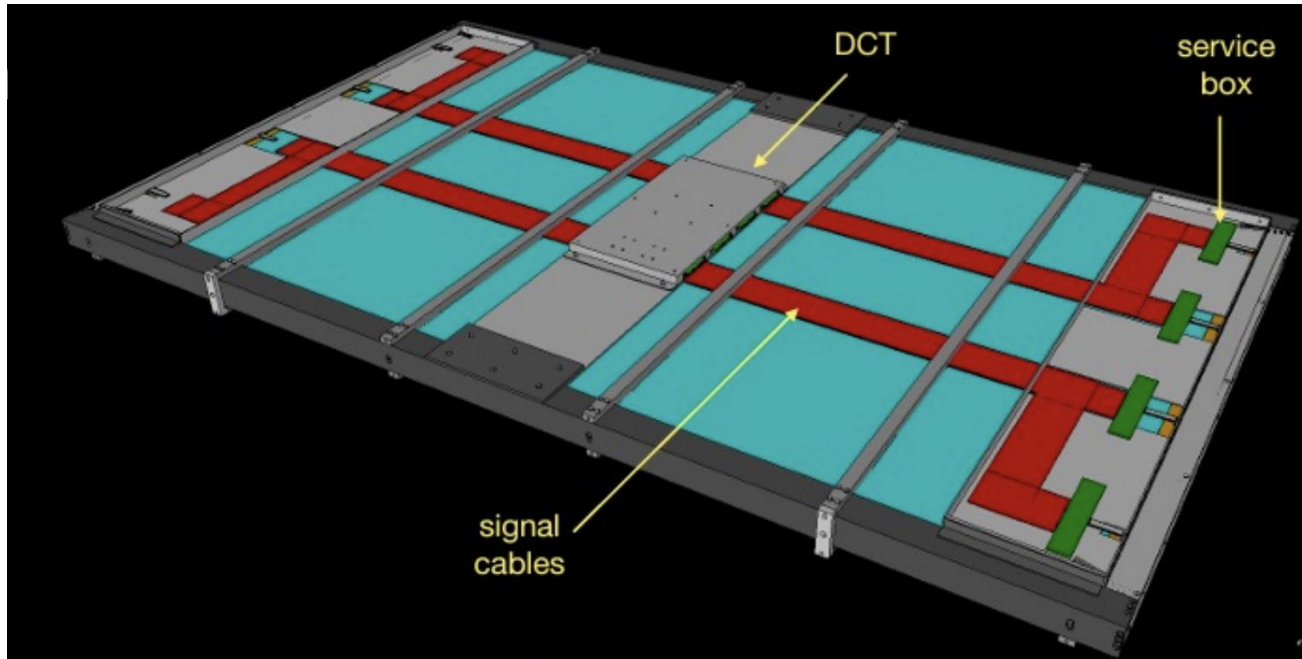
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Outline

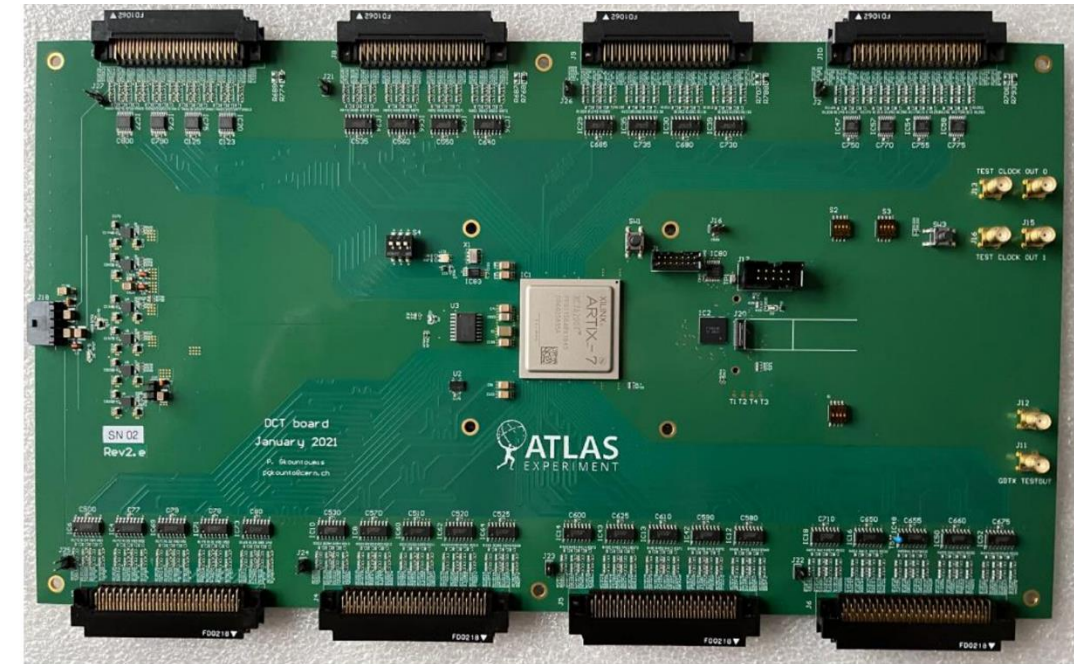
- Radiation qualification for the ATLAS Phase-2 upgrade
- What is Impedance Spectroscopy (IS)?
- Analysis of radiation effects with IS, 2 case studies:
 - LVDS receivers
 - Voltage translators
- Outlook & Conclusions

ATLAS RPC readout system: Phase-II upgrades

PHASE-II RPC LAYOUT



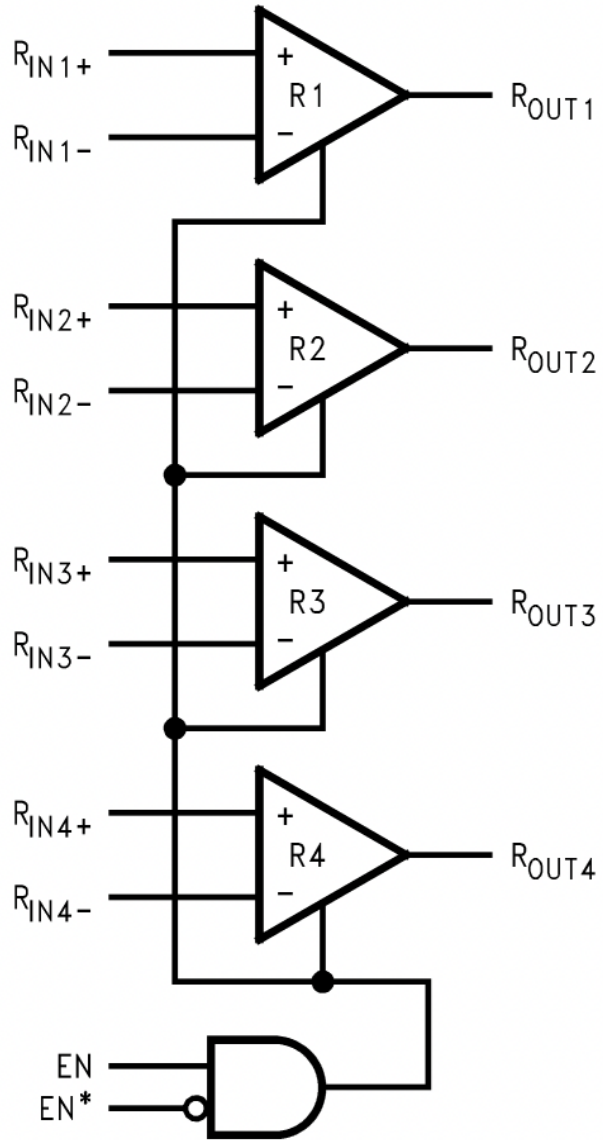
Data-Collector-Transmitter (DCT)



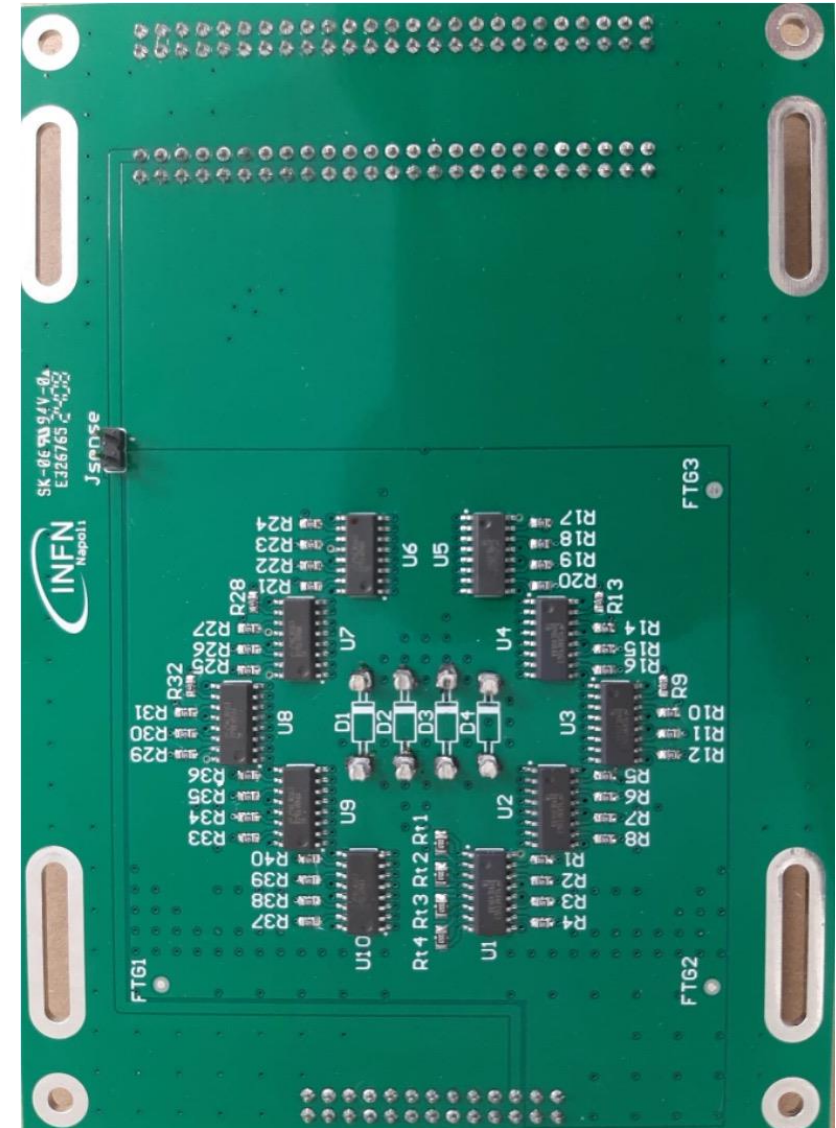
- DCTs adapt RPC signals to LVDS standard and send data to the muon trigger with optical fibers
- ~1600 DCT boards will be part of the Phase-II muon trigger front-end electronic
- Radiation qualification of RPC components is crucial

TID (Gy)	$\Phi_{1\text{ MeV } n.eq.}$ (cm^{-2})	HEH fluence (cm^{-2})
83	4.2×10^{12}	1.2×10^{12}

TI LVDS receiver DS90LV048A

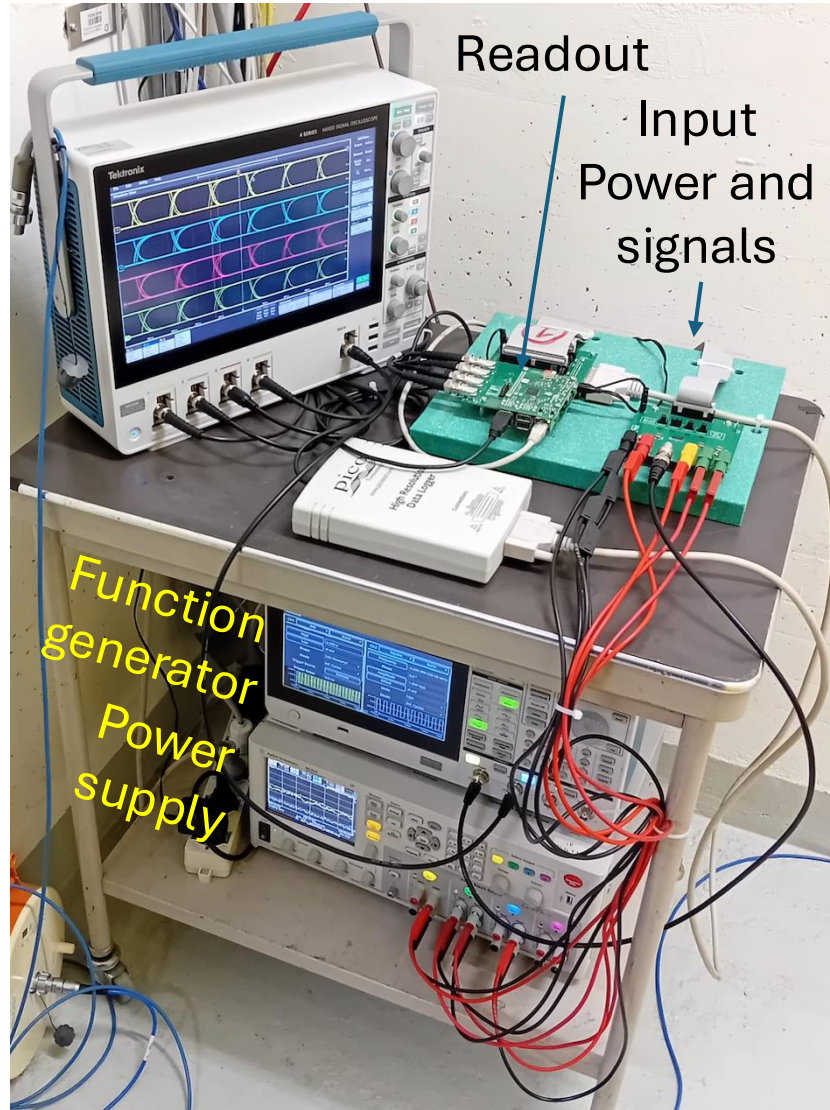
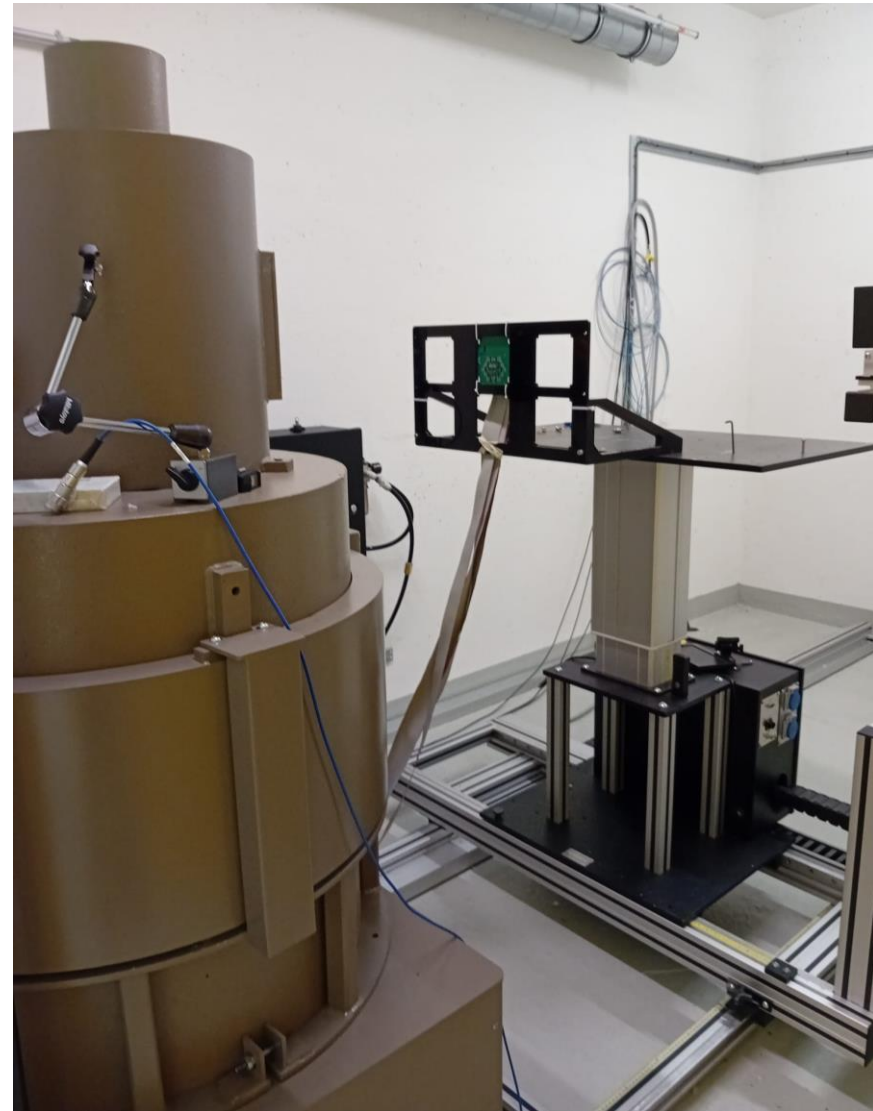


- **> 400-Mbps (200-MHz) switching rates**
- **Powered at 3.3 V**
- **4 independent RXs sharing common EN**
- **When EN is LOW, RX is disabled**
- **Supply current when RXs are disabled is typically 1 mA**
- **Testing board with 10 RXs (DUTs)**



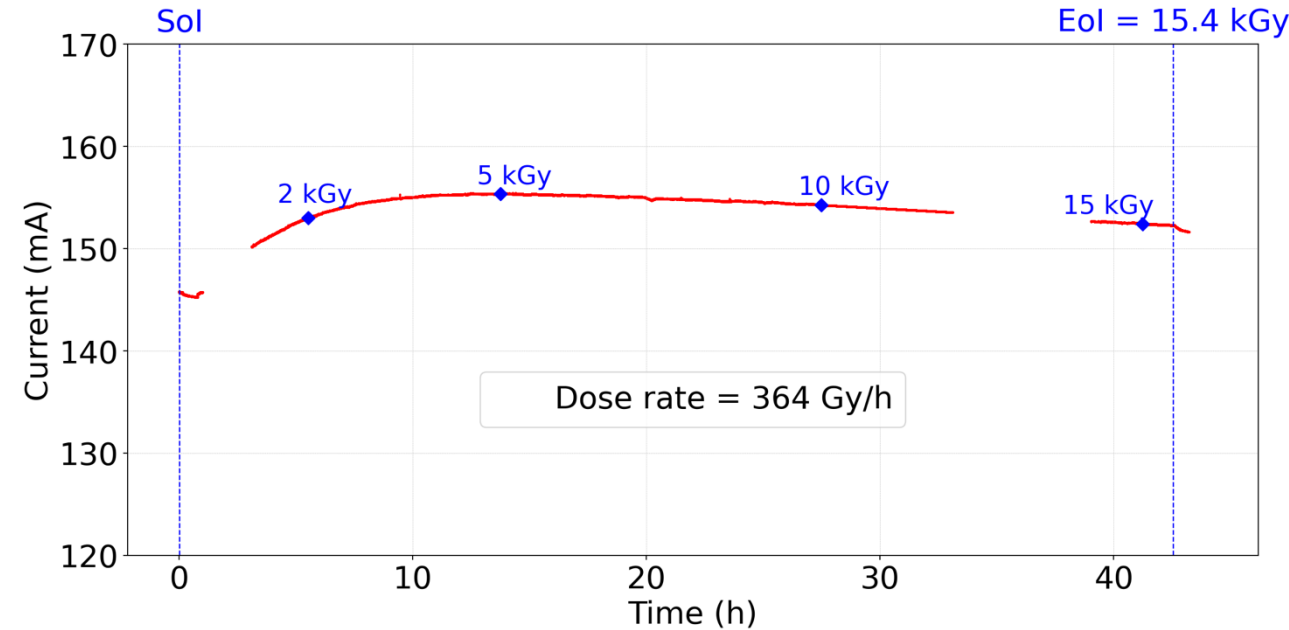
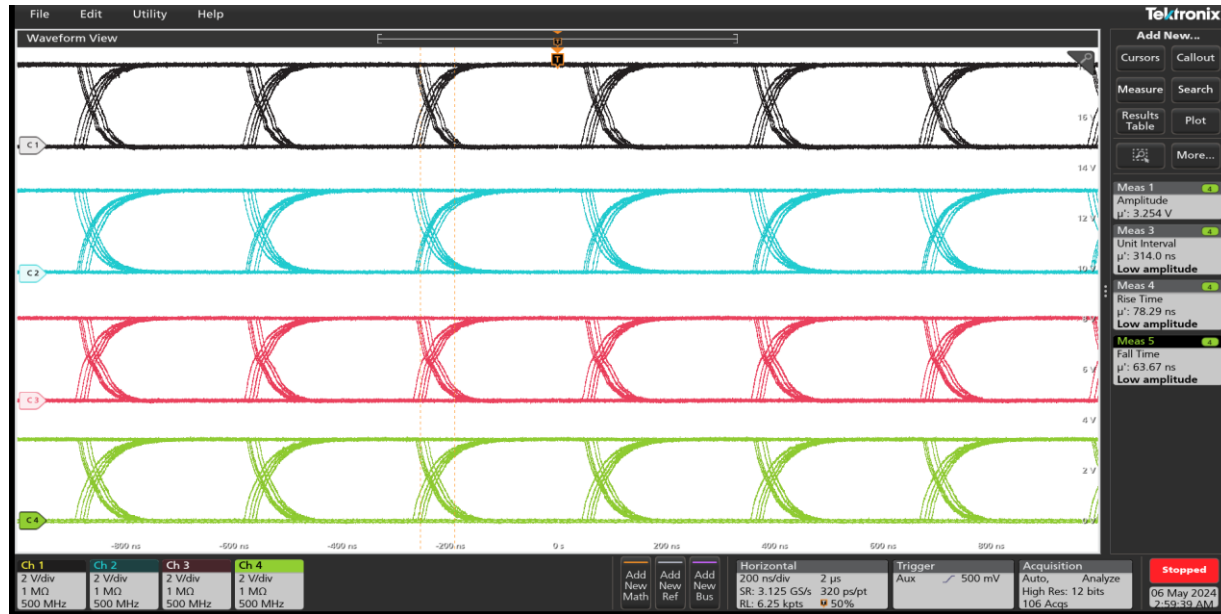
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TID testing setup @ CERN CC60 facility



- **~10 TBq ^{60}Co source**
- **Low dose run (84.6 Gy @ 27 Gy/h)**
- **High dose run (15.4 kGy @ 364 Gy/h)**
- **Design and realization of a suite of 3 boards**
- **4-meter-long cabling for both input and readout**

LVDS RXs: eye diagrams and current consumption



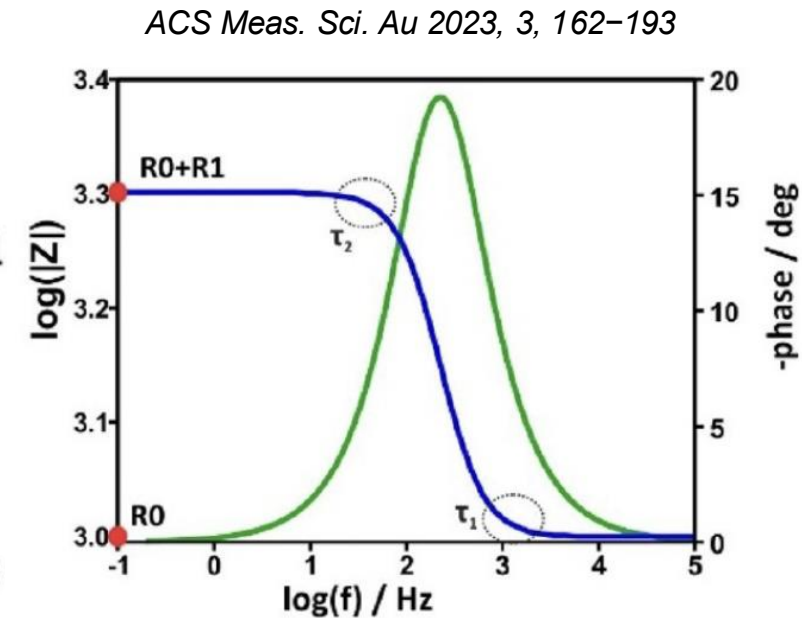
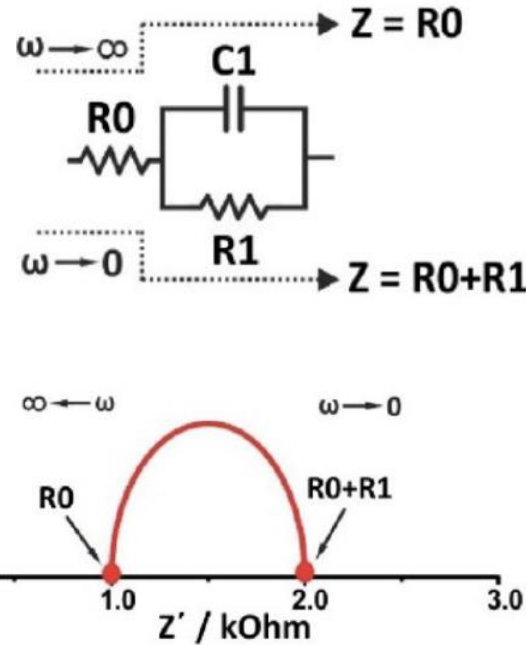
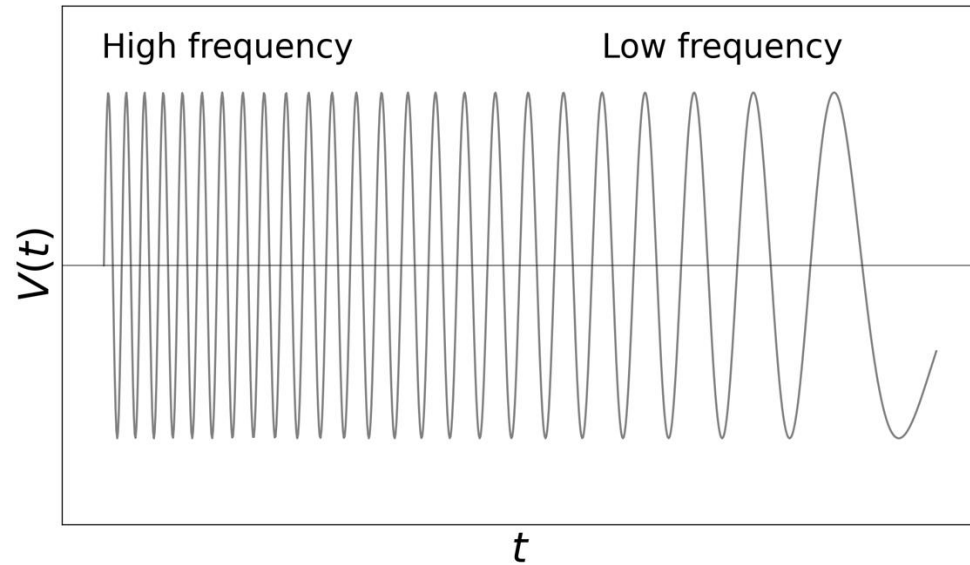
- Eye diagrams key parameters, monitored during and after runs, showed no differences with irradiation

- Current increases up to ~3 kGy
- After 3 kGy, current decreases up to EoL
- Current variations within 6%

Amp (V)	Unit Interval (ns)	Eye opening (%UI)	Amplitude jitter (mV)
3.2 ± 0.1	312 ± 6	85 %	70 ± 2

Journal of Instrumentation 20.01 (2025): C01023.
10.1088/1748-0221/20/01/C01023

Impedance Spectroscopy (IS)



IS technique

- Studying impedance vs. frequency
- Small AC perturbation
- Potentiostatic IS
- Galvanostatic IS
- Each circuit shows a specific pattern

Applications

- Batteries and fuel cells
- Corrosion studies (to evaluate protective coatings)
- Solar cells
- Biological tissues and cells
- Biosensors
- Semiconductor device characterization

LVDS RXs: power network (1/2)

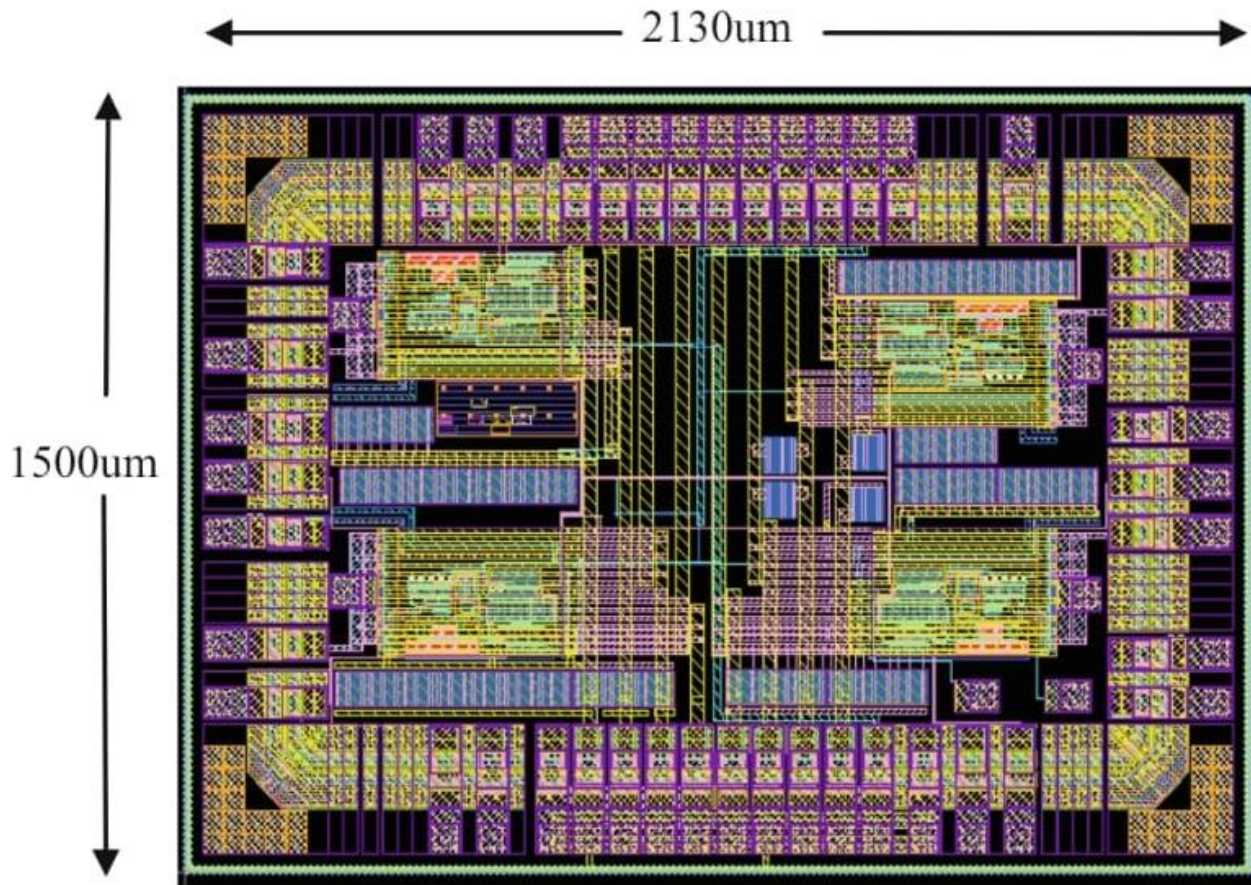
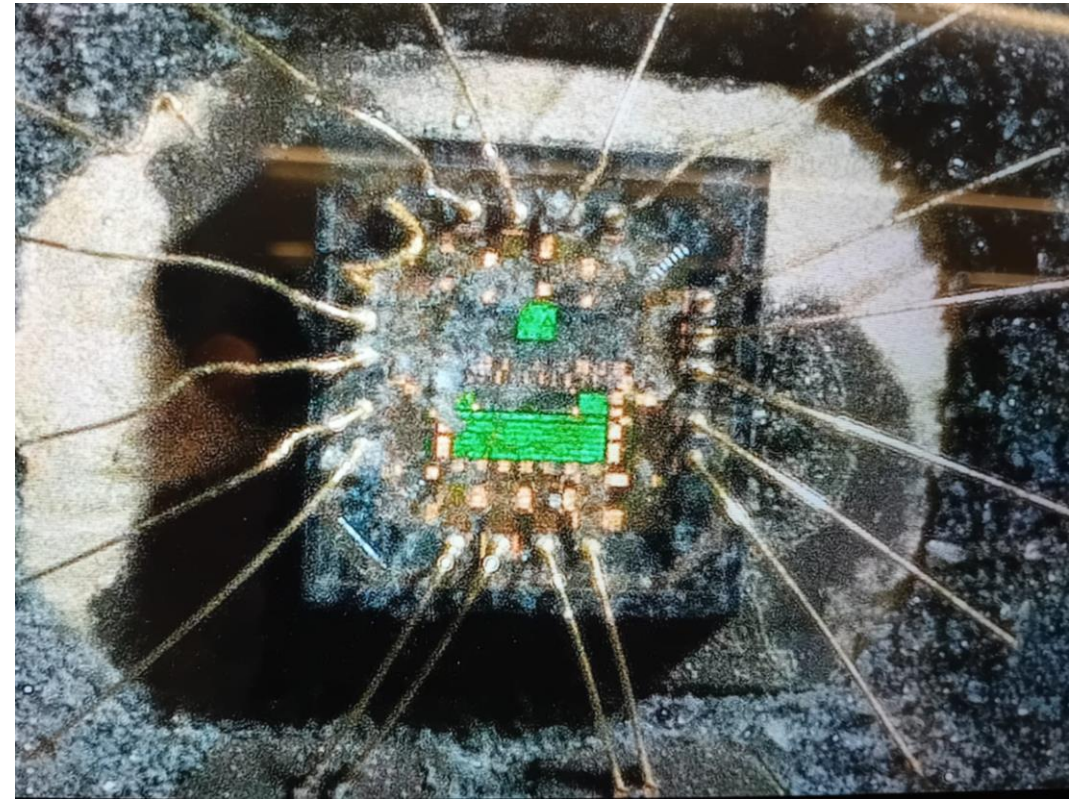


Fig. 7. Layout of LVDS receiver

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B. K. Kaushik et al. (Eds.): VDAT 2017, CCIS 711, pp. 667–678, 2017.
https://doi.org/10.1007/978-981-10-7470-7_63

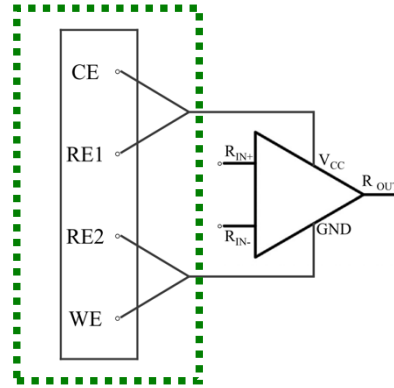


TI DS90LV048A

LVDS RXs: power network (2/2)

Experimental setup

- Modulab XM ECS
- DUT disabled



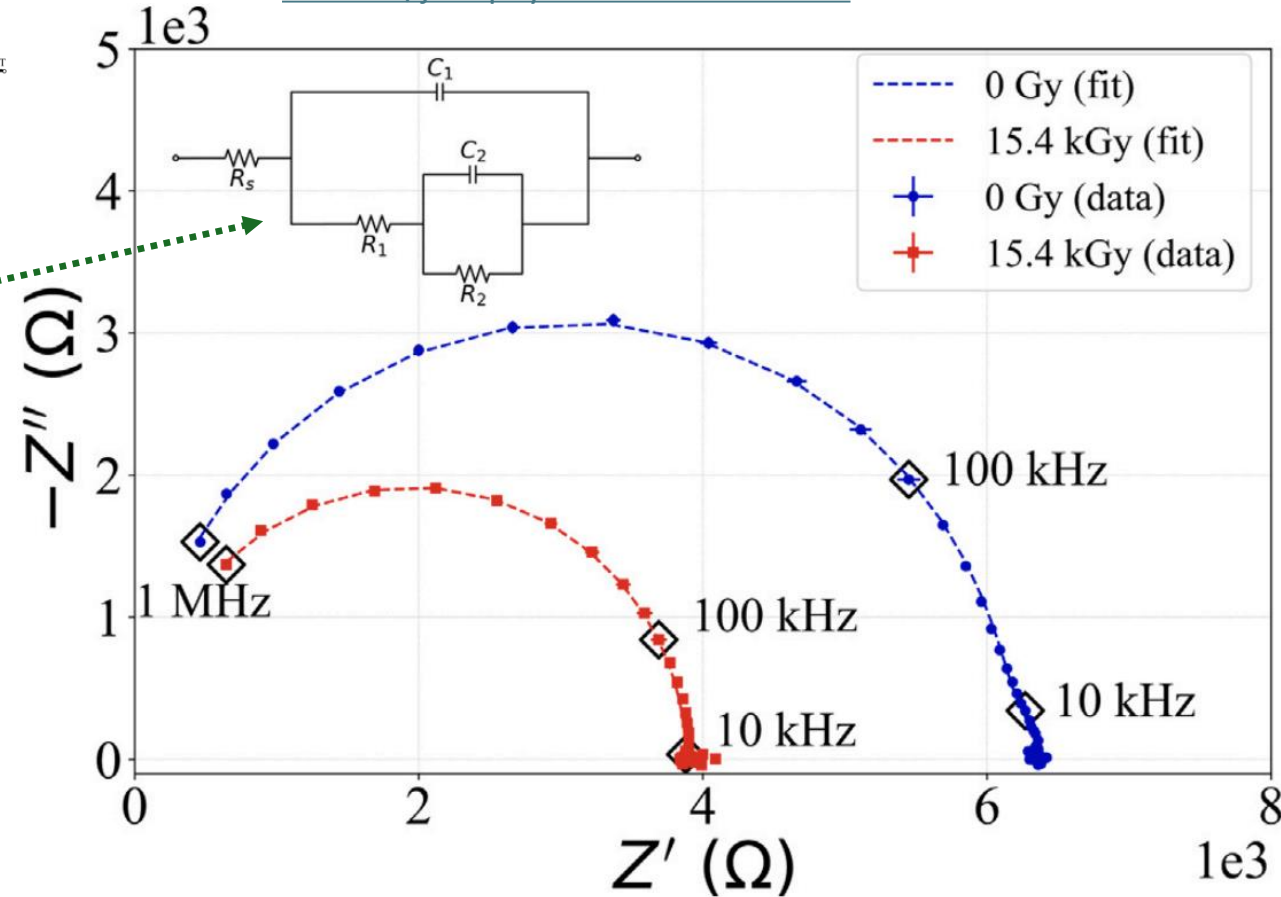
Best fit: 2 RC parallel networks

- R_s : series resistance (pad, contacts, traces)
- Time constants $\tau_1=R_1C_1$ and $\tau_2=R_2C_2$

Results

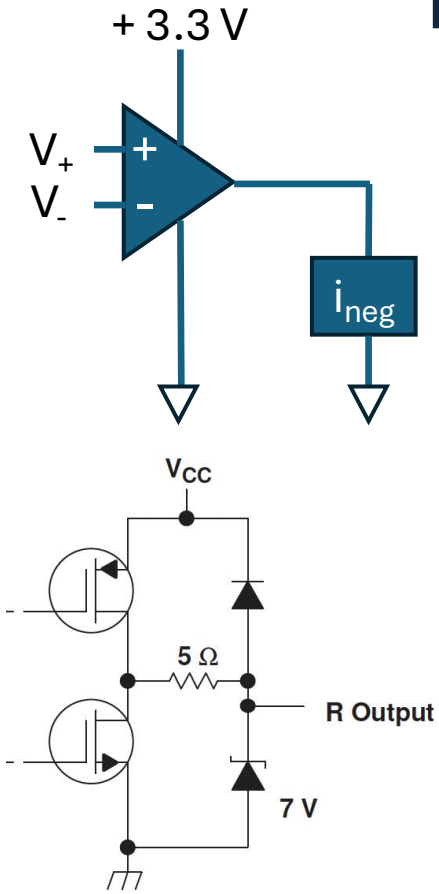
- C_1 : no change after irradiation → *lumped C of power and ground metal rings*
- τ_1 reduction due to leak resistance (R_1) reduction
- τ_2 increases by 3 orders of magnitude → *trap/detrap mechanisms in the bulk*

Radiation Physics and Chemistry (2025): 113367
[10.1016/j.radphyschem.2025.113367](https://doi.org/10.1016/j.radphyschem.2025.113367)



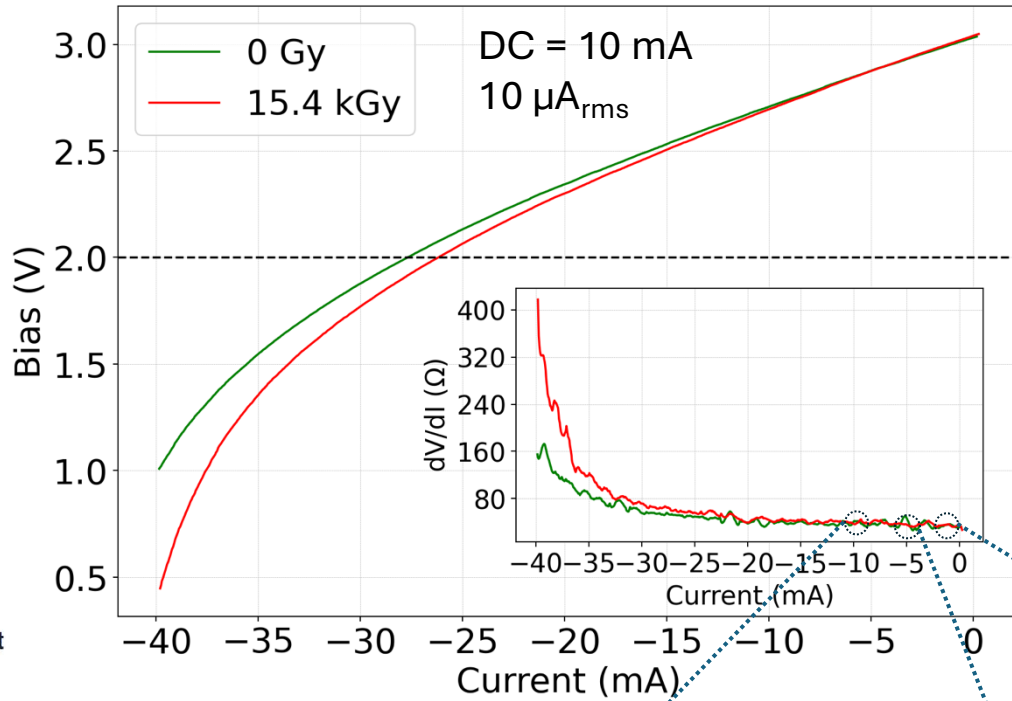
Dose (kGy)	R_s (Ω)	R_1 (Ω)	R_2 (Ω)	C_1 (pF)	C_2 (μ F)	τ_1 (ns)	τ_2 (μ s)	χ^2
0	33 ± 5	6126 ± 8	181 ± 9	95 ± 1	0.081 ± 0.001	584 ± 6	15 ± 1	2.0×10^{-5}
15.4	48 ± 4	3858 ± 14	82 ± 5	96 ± 1	248 ± 1	373 ± 4	$(20 \pm 1) \times 10^3$	8.3×10^{-5}

LVDS RXs: output driving capability

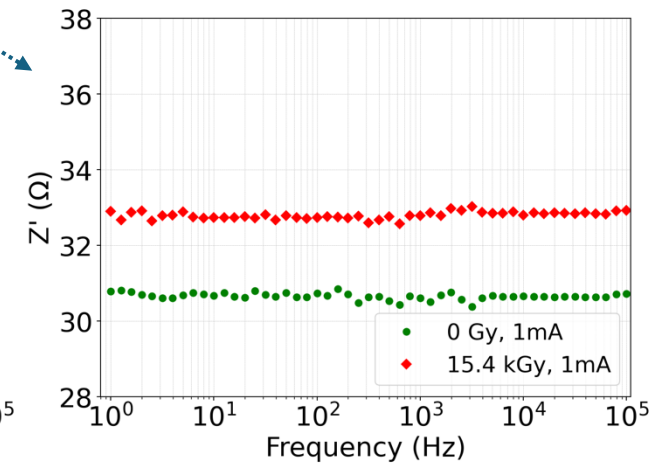
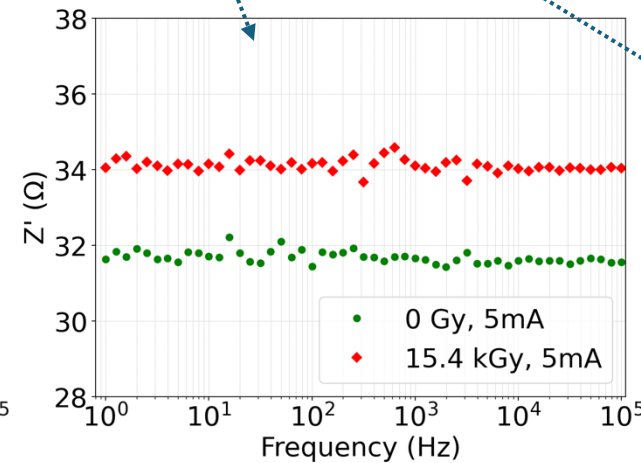
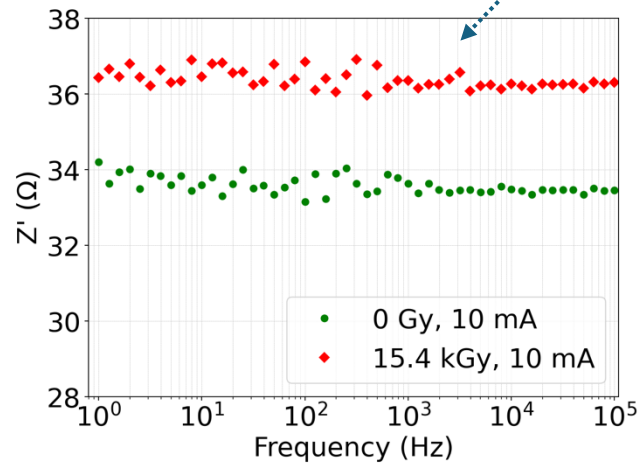


TI Application Report SLLA065

RX output structure is a CMOS inverter with a 7V Zener diode for ESD protection



- $V_{OH} @ I_{OH} = -0.4 \text{ mA}$: 2.7 V (typ), 3.3 V (max)
- Driving capability at the minimum of $V_{OH} = 2 \text{ V}$ reduced by 5% after 20 kGy
- Differential resistance from galvanostatic characteristic increases from $\sim 25 \text{ mA}$
- Bode plots @ 1 mA, 5 mA and 10 mA show that differential resistance does not depend on the freq. and it increases after irradiation



What we learned ?

TI LVDS receiver DS90LV048A

1. Conventional analysis of LVDS RXs

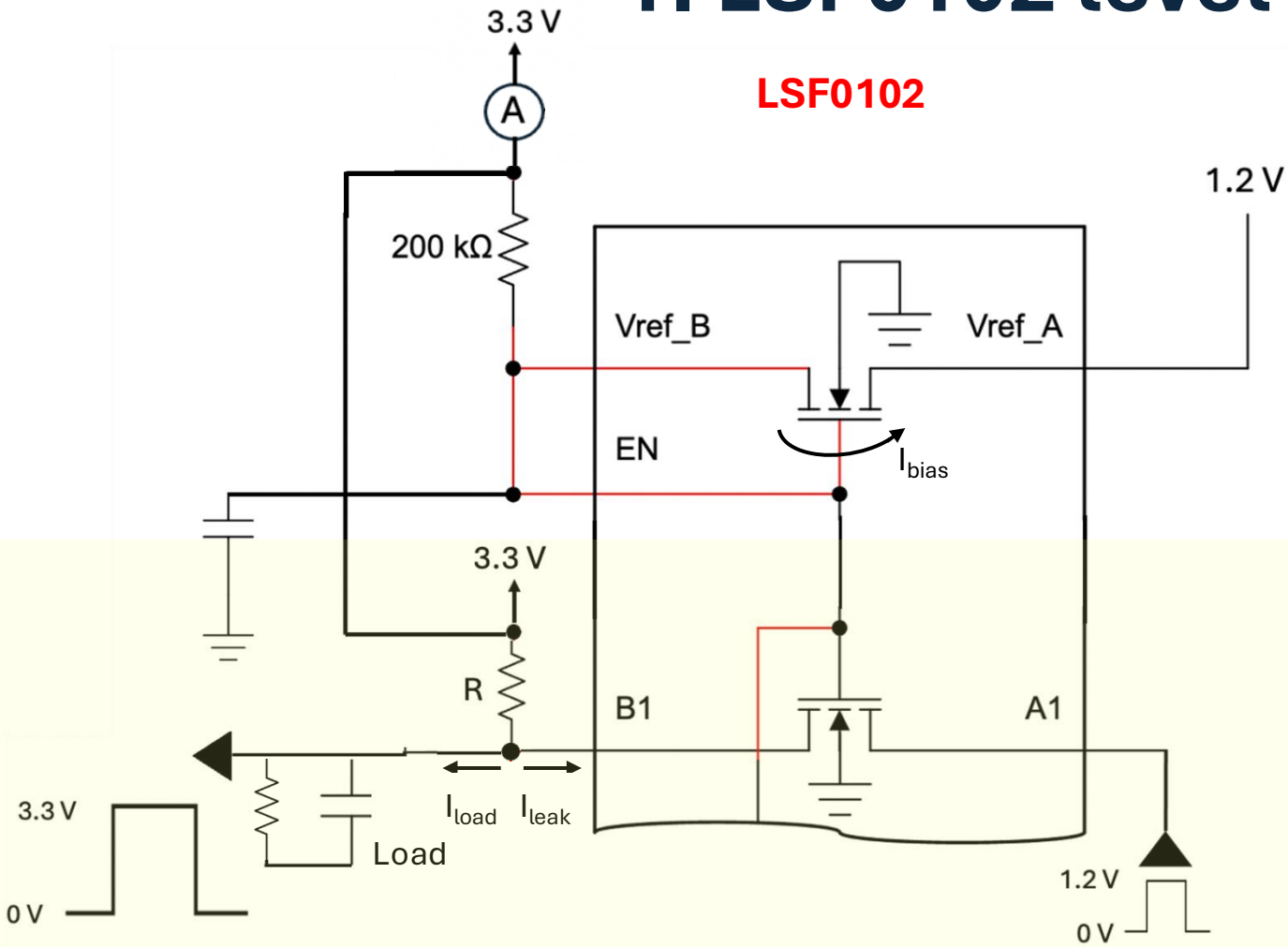
- Current variation during irradiation changed within 6%
- No variation of eye diagrams key parameters

1. IS analysis allowed to identify:

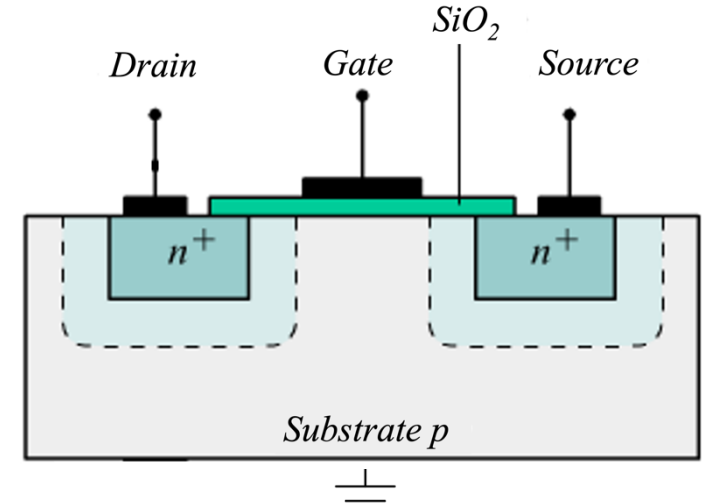
- lumped capacitance of the power ring (not affected by irradiation)
- Its leakage resistance (reduced by $\frac{1}{2}$ by irradiation)
- dynamic processes (trap/detrap) very affected by irradiation

2. Galvanostatic IS on the output driving circuit allowed to evaluate minor changes of differential resistance after irradiation

TI LSF0102 level translator



Single MOSFET



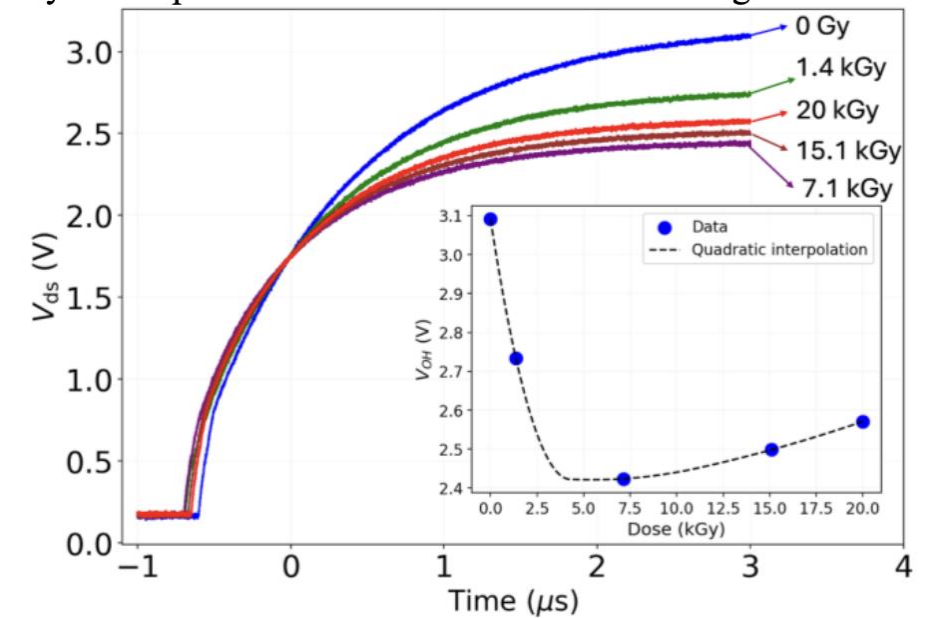
- 3 N-channel MOSFETs (enhancement)
- A master MOSFET sets the threshold for two slave MOSFETs
- Up to 100 MHz for up- or down-translation
- Typical waveforms with different values of pull-up resistors

Waveforms and power supply currents

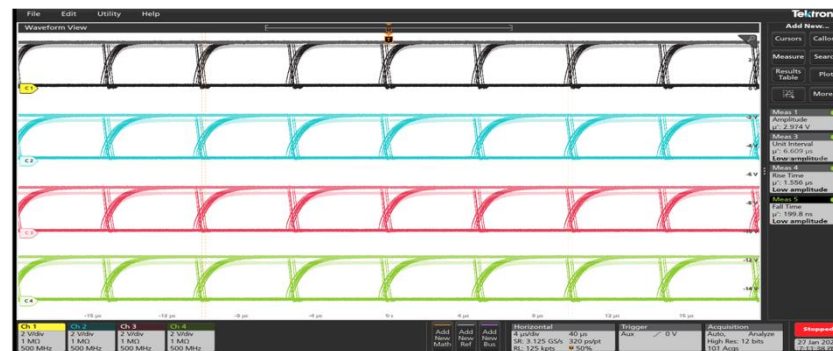
Power supply current ($I@3.3\text{ V}$)



Output waveforms



Eye diagrams (0 Gy and 20 kGy)

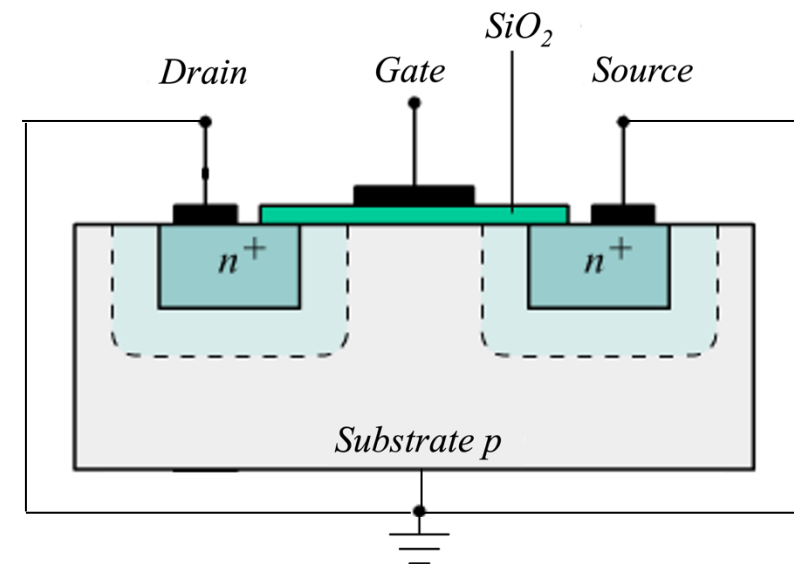
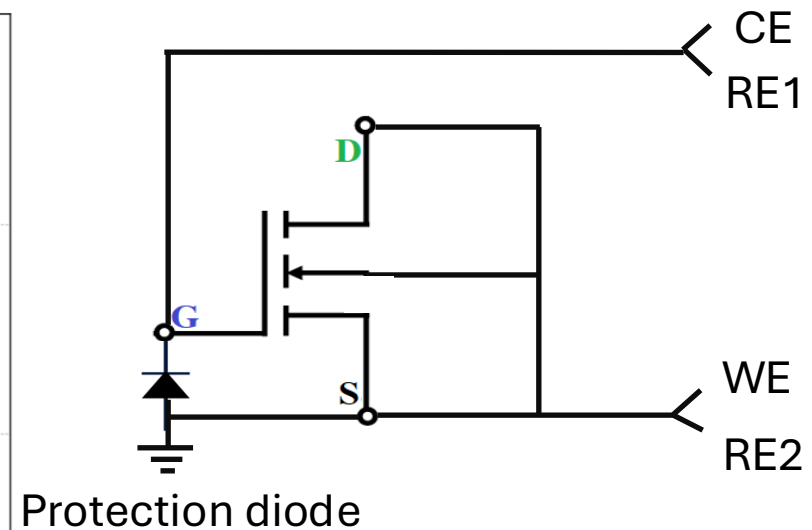
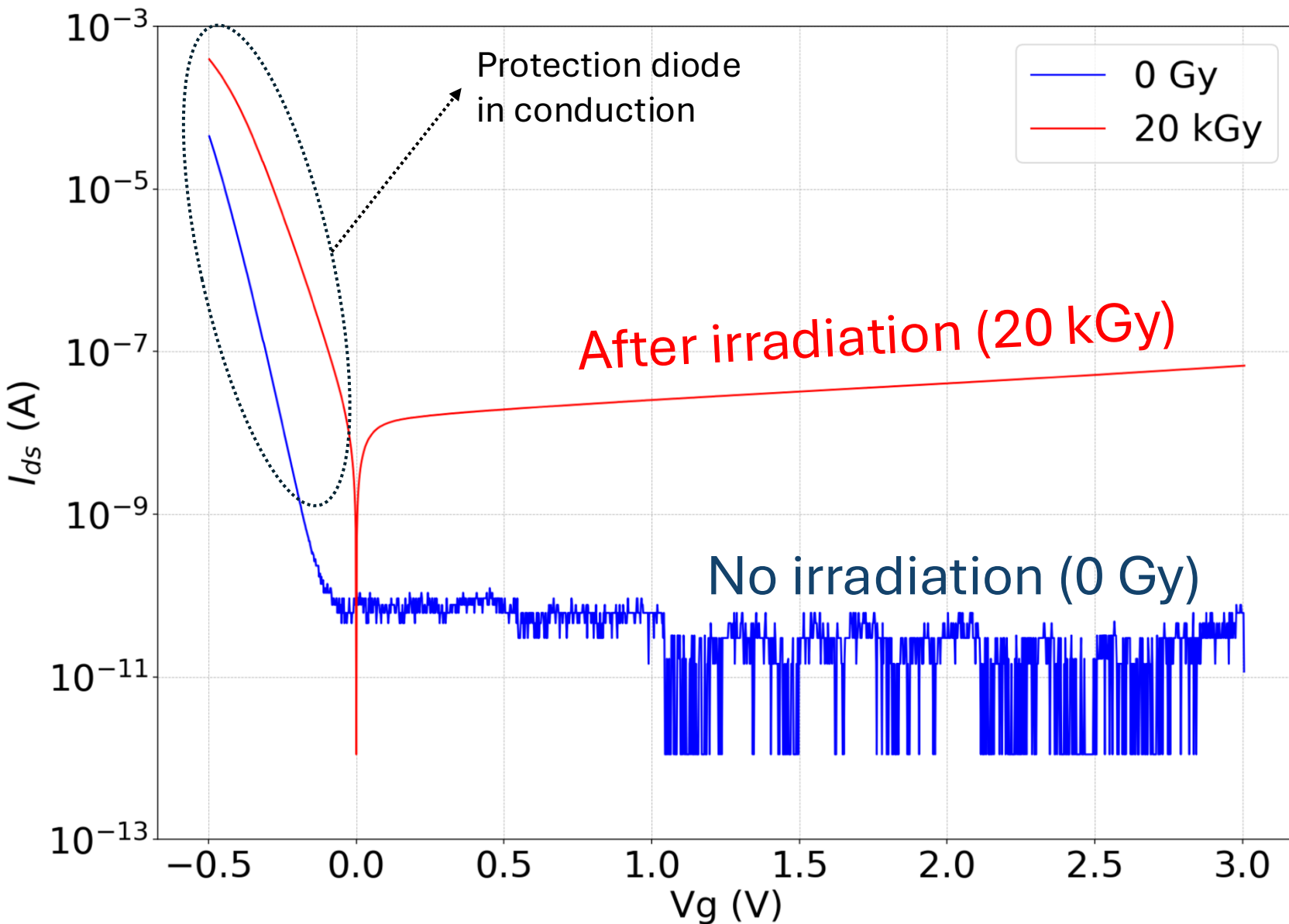


- $I@3.3\text{ V} = I_{\text{load}} + I_{\text{leak}} + I_{\text{bias}}$

- $\Delta I = \frac{I_{20\text{kGy}} - I_{0\text{Gy}}}{I_{20\text{kGy}}} \approx 10\%$

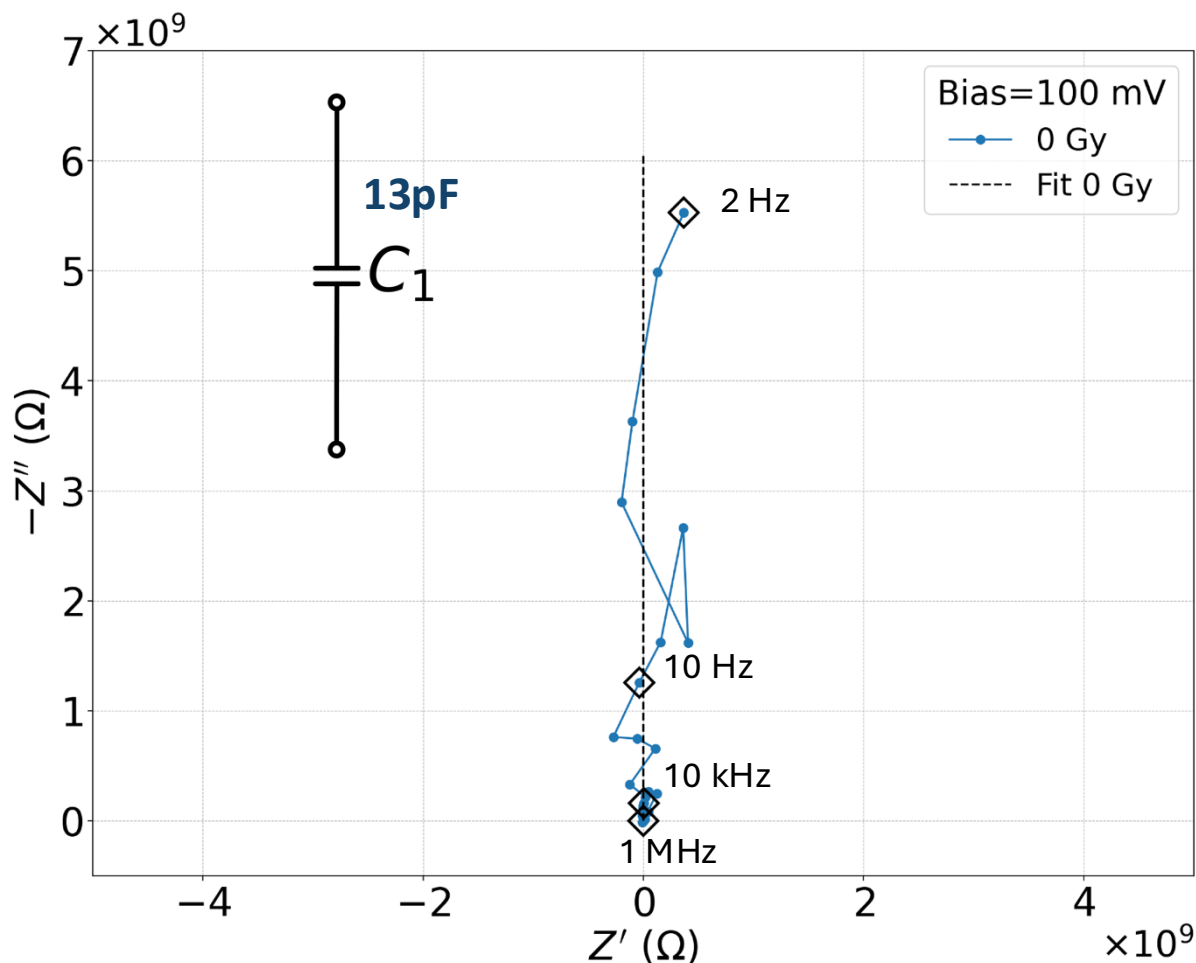
- V_{OH} drops by 0.5 V after 20kGy
- V_{OH} trend compatible with that of $I@3.3\text{ V}$

MOS capacitor / IV curves

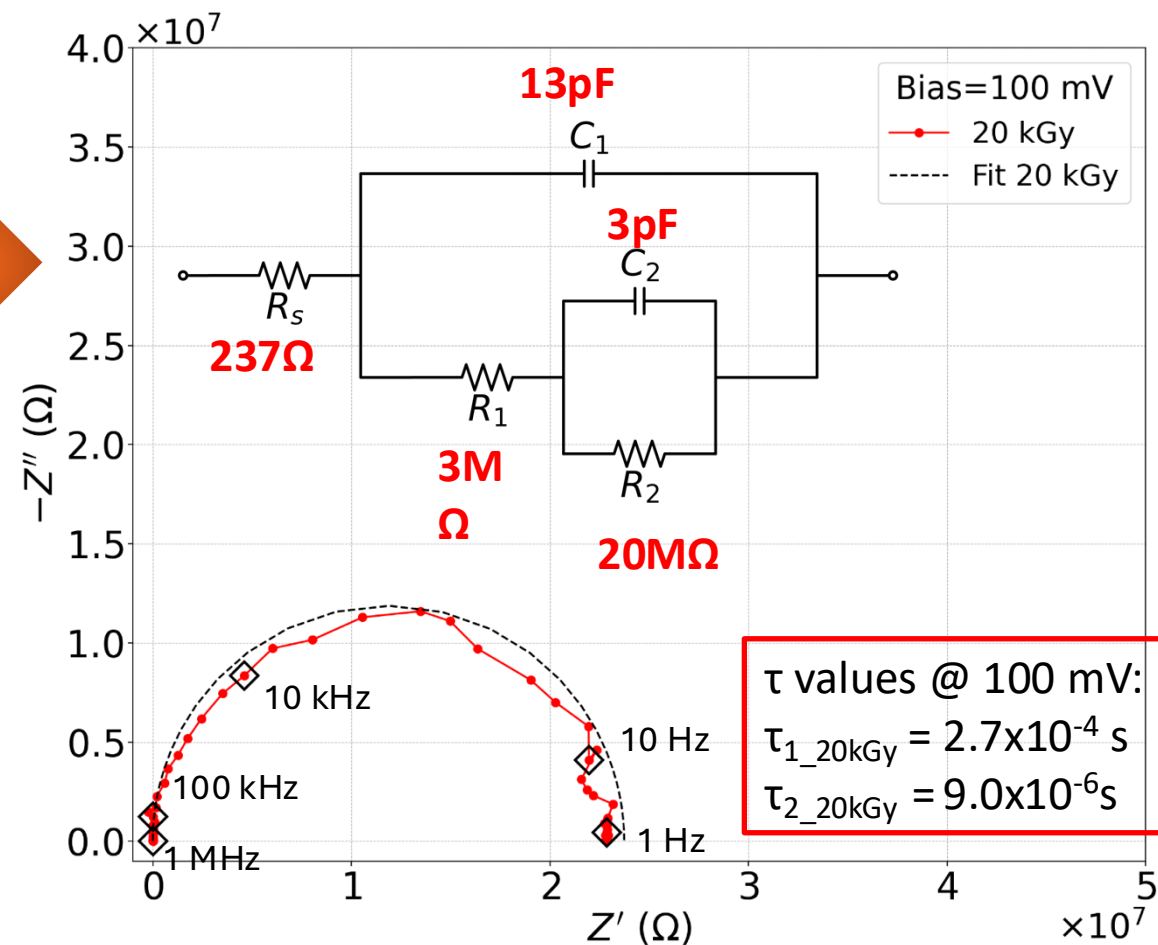


MOS capacitor / Nyquist plot

- At +100 mV and 0 Gy, low leakage current
- The circuit can be modeled by a pure capacitance (13 pF)



- At 20 kGy, current increases by two orders of magnitudes and circuit can be modeled with a two time-constants network
- Presence of a conductive path (about 20 M Ω)



What we learned ?

TI LSF0102 voltage translators

1. Conventional analysis of TI LSF0102

- Current variation during irradiation changed within 10%
- V_{OH} drops by 0.5 V after 20kGy
- Increase of the IV curve of the master MOSFET configured in MOS capacitor

2. IS modelling allows to:

- Model the MOS capacitor as a lumped capacitance before irradiation and as an RC parallel network after irradiation (presence of conductive paths)

Conclusions and outlook

- TID qualification of selected components for the ATLAS muon trigger performed both with conventional analysis and Impedance Spectroscopy (IS)
- For both devices (BiCMOS and MOS technology), the IS approach allowed to study radiation effects not easily accessible with conventional methods
- Overall, IS nicely complements conventional analysis of TID damage
- We plan to increase dose steps, perform online measurements and detailed annealing studies, as well as tests under different radiation types