Investigating radiation effects on LSF0102 level shifters

Pierluigi Casolaro[1,2*], Vincenzo Izzo[2], Riccardo Vari[3], Claudio Principe[2], Antonio Vanzanella[2], Paolo Di Meo[2], Antonio Anastasio[2], Arbab Imtiaz[1,2,4], and Alberto Aloisio[1,2]
[1]Department of Physics “Ettore Pancini”, Università degli Studi di Napoli Federico II, Complesso Univ. Monte S. Angelo, Napoli, I-80126, Italy
[2]INFN Sezione di Napoli, Complesso Univ. Monte S. Angelo, Napoli, I-80126, Italy
[3]INFN Sezione di Roma, Roma, Italy
[4]Dipartimento di Fisica e Astronomia G. Galilei, Università degli Studi di Padova, Padova, Italy
(*) pierluigi.casolaro@unina.it

Abstract— **We present the results of a Total Ionizing Dose (TID) test on Texas Instruments LSF0102 level shifters irradiated with ^{60}Co gamma rays up to a total dose of 20 kGy. Non-monotonic variations were observed in the supply current, high-level output voltage, and output characteristics as a function of dose. Worst-case scenario in terms of highest supply current and lowest high-level output voltage occurs at a specific critical dose. This behavior should be carefully considered when evaluating such devices for use in environments with high radiation levels.**

Keywords —**Total ionizing dose, gamma-ray effects, MOSFET circuits.**

I. INTRODUCTION

LEVEL shifters enable communications between circuits powered with different voltage domains. In complex data acquisition systems presently used in high-energy physics experiments and space applications, level shifters are crucial devices deployed to match logic levels of different integrated circuits, including microprocessors, FPGAs, analog-to-digital converters and other peripherals. Bidirectional level shifters in MOS technologies employ pass transistors which are susceptible to threshold voltage V_t shifts impacting proper voltage translation. Understanding Total Ionizing Dose (TID)-induced degradation in level shifters is therefore essential to ensure the long-term reliability of such devices. In this work, we tested LSF0102 level shifters from Texas Instruments up to a dose of 20 kGy from a ^{60}Co gamma source. Differently from other architectures, LSF family is based on simple MOS transistors, allowing to pinpoint the degradation of the most important device parameters as a function of the dose.

II. MATERIALS AND METHODS

A. *Level shifters*

Fig. 1 shows a schematic layout of the TI LSF0102 under test. In this level shifter [1-5], T1 (MOSFET n-type enhancement) is configured as a MOS diode, with its gate and drain shorted. In this way, T1 sets the gate voltage to the other transistors in the device (all of them being MOSFET n-type enhancement), which translate digital signals across voltage domains. The gates are connected to a capacitance C_f tied to ground, to filter high frequency noise [1]. We studied the translation between 1.2 V and 3.3 V power domains. The input signal V_{in} is fed into the source of T2.

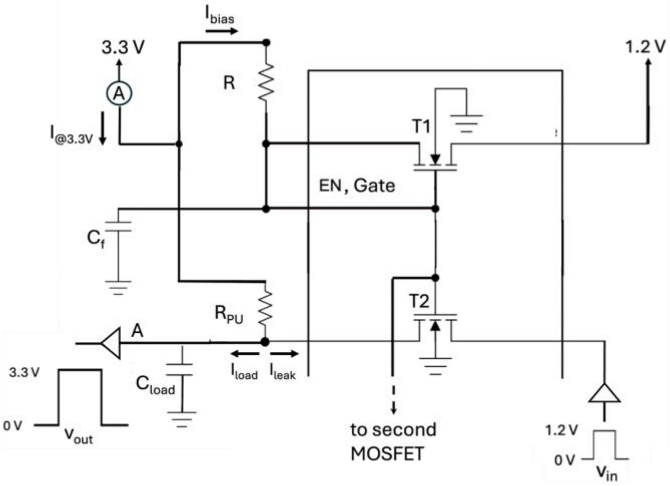

Fig. 1: Schematic layout of a TI LSF0102 level shifter.

When the difference between the gate voltage V_g with respect to ground and V_{in} exceeds V_t+V_{OV} [6] (with V_{OV} being the overdrive voltage, which for this technology is typically in the order of 500 mV):

$$V_g - V_{in} > V_t + V_{OV} \tag{1}$$

T2 turns on and transfers the voltage to the drain. Conversely, when

$$V_g - V_{in} \lesssim V_t + V_{OV} \tag{2}$$

T2 turns off and the voltage translation is ruled by the pull-up resistor R_{PU} biased to 3.3 V. The scheme in Fig. 1 shows also an ammeter used to measure the current in the 3.3 V domain, as discussed in the following.

B. *TID test*

TID irradiations were performed at the CERN CC60 facility equipped with a ~3 TBq ^{60}Co gamma source. Fig. 3 shows a picture (left) of the board housing ten DUTs exposed to the ^{60}Co gamma source.

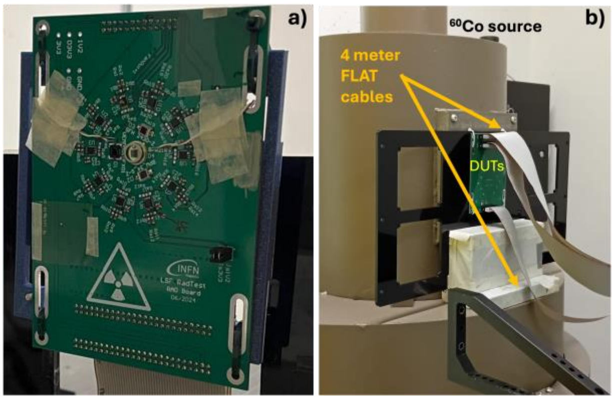

Fig. 2: DUT board (a) exposed to ^{60}Co gamma rays at CERN CC60 facility (b).

The board also hosts two thermocouples and a radiochromic film for both temperature and dose monitoring [7]. During the test, the temperature was constantly measured and found to be 23.5 degrees. As shown in Fig. 3 (right), the board was placed on a stage in front of the gamma source where the dose rate was of 327 Gy/h. We irradiated for about 60 hours yielding a total dose to the DUT of 20 kGy. Following the methodology of our previous irradiation test [8], the DUTs were powered and remotely controlled using a Raspberry Pi 3 Model B+. We used a Tektronix AFG31152 Function Generator, configured to transmit a serial stream at 1.2 V at a frequency of 200 kHz, a Tektronix MSO46 oscilloscope and an Agilent N6705B DC Power Analyzer. During the test, we monitored DUT current consumption, as well as variations in amplitude and rise time of the waveforms translated in the 3.3 V domain. Connections between the DUT board and the input signals and power supplies, as well as between the DUT board and the remote control board, were implemented using 4-meter-long flat cables. Before and after the test, we measured the output characteristics with a B1500A Semiconductor Device Parameter Analyzer.

III. RESULTS

A. Characteristic curves

Fig. 3 shows the I_{bias}-V_{gs} curves of T1 before and after irradiation, taken in configuration shown in the inset (MOS diode).

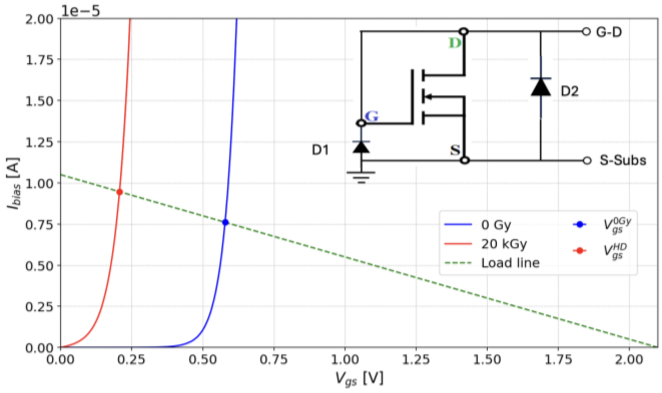

Fig. 3: Characteristic curves, T1 load line and their intersection points. The inset shows the configuration of the level shifter in this measurement.

Diode D1 protects the gate against potentially dangerous voltage surges. Diode D2 is the body diode, typical of MOS structures, between drain and substrate. For $V_{ds} < 0$ V, D1 and D2 are on, while the MOS diode is reverse-biased. For $V_{ds} > 0$ V, D1 and D2 are reverse-biased, while the MOS diode is on. With reference to Fig. 3, the intersection of the I_{ds}-V_{ds} curves with the load line:

$$I_{bias} = \frac{V_{cc}}{R_{PU}} - \frac{1}{R_{PU}} \cdot V_{gs} \tag{3}$$

yields the following operating points before and after irradiation:

$$V_{gs}^{0Gy} = (578 \pm 5)\ mV \text{ at } I_{bias}^{0Gy} = (7.61 \pm 0.03)\ \mu A \tag{4}$$

and

$$V_{gs}^{HD} = (210 \pm 5)\ mV \text{ at } I_{bias}^{HD} = (9.46 \pm 0.03)\ \mu A \tag{5}$$

where the superscripts “0Gy” and “HD” indicate doses of 0 Gy and 20 kGy respectively and $V_{cc} = 2.1\,V$ is the voltage difference between the power domains. V_g is obtained by adding the source voltage, which is fixed at 1.2 V, to V_{gs}. Hence:

$$V_g^{0Gy} = (1780 \pm 5)\ mV \tag{6}$$

and

$$V_g^{HD} = (1410\ \pm 5)\ mV \tag{7}$$

These variations in the operating point result from shifts in the V_t of T1, which are clearly visible in the output characteristics I_{ds}-V_{ds} at different V_{gs} values, as shown in Fig. 4.

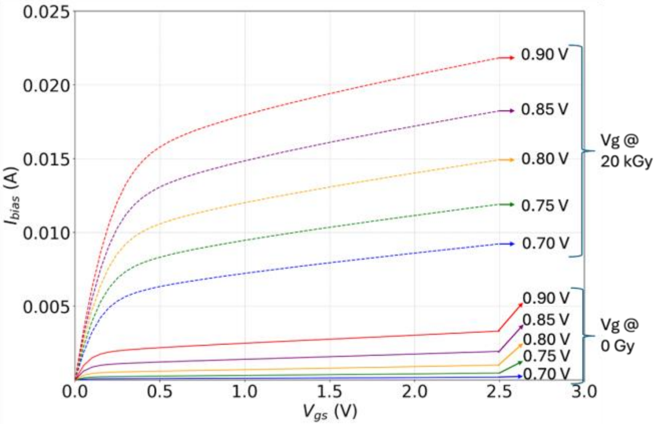

Fig. 4: Output characteristics of T1 MOSFET before and after irradiation.

Ionizing radiation induces charge trapping in the gate oxide and produces interface states, leading to threshold voltage V_t shifts and increased subthreshold leakage in MOSFETs [9]. It should be noted that the characteristics of all transistors are consistent with those presented in Fig. 4, both prior to and following irradiation.

B. Power supply current

The trend of the current $I_{3.3V}$ drawn in the 3.3 V domain by the ten DUTs altogether during the test is shown in Fig. 4.

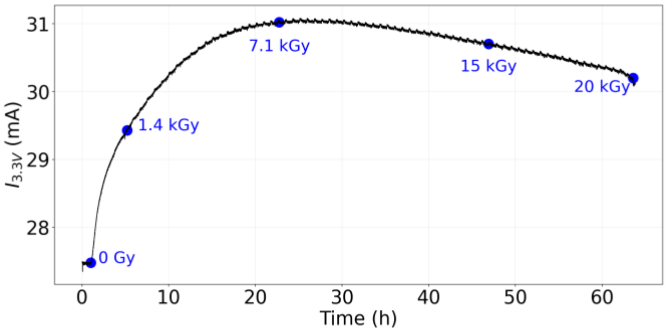

Fig. 5: Current measured by the power supply in the 3.3 V domain.

$I_{3.3V}$ increases, reaching a maximum at 7.1 kGy, and then decreases slightly toward the end of the irradiation. Despite relatively small percentage difference

$$\Delta = \frac{I_{3.3V}^{20kGy} - I_{3.3V}^{0Gy}}{I_{3.3V}^{20kGy}} \times 100 \sim 10\% \tag{8}$$

in current between the start and end of the irradiation, such a trend reflects the presence of V_t shift in TID damage. From Fig. 1, one can see that:

$$I_{3.3V} = I_{bias} + I_{load} + I_{leak} \tag{9}$$

From (4) and (5), the bias current for the ten DUTs contributes to less than 1% to $I_{3.3V}$ shown in Fig. 5. Since I_{load} is mostly unaffected by irradiation, any change in $I_{3.3V}$ should be attributed to V_t variations in T2, directly affecting I_{leak}.

C. Waveforms

Fig. 6 shows waveforms taken in A (see Fig. 1), at 0 Gy for three different values of the pull-up resistor, R_{PU}=33 kΩ, R_{PU}=68 kΩ and R_{PU}=100 kΩ.

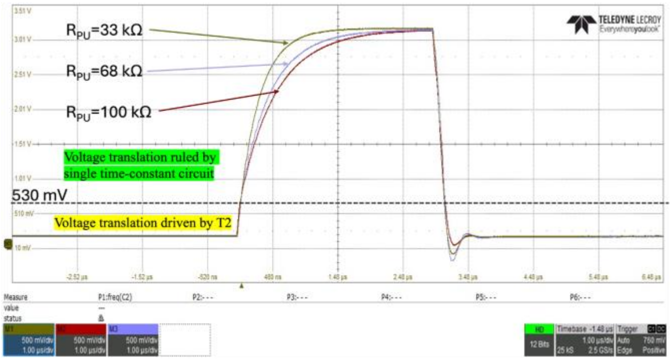

Fig. 6: Output waveforms of the TI LSF0102 level shifter for different values of the pull-up resistor.

Fig. 6 clearly shows the two-stage operation of the level shifter. From (6) and (1), V_t+V_{OV}=1250 mV and V_g=1780 mV, therefore for input voltages up to 530 mV, T2 is on and the voltage translation is actively driven. Beyond this value, T2 goes off and the translation is ruled by a single time-constant circuit with $\tau = R \cdot C_{load}$, where C_{load} is the sum of the receiver input and cable stray capacitances.

Fig. 7 shows the rising edge and high-level voltage V_{OH} reached by the output waveforms at different doses during the TID test.

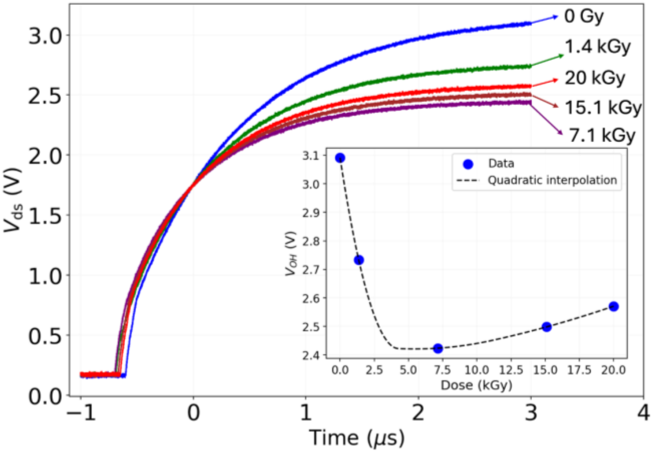

Fig. 7: Output waveforms of the TI LSF0102 level shifter for different doses.

The inset of Fig. 7 shows the non-monotonic trend of V_{OH} as a function of dose. To guide the eye, experimental data are interpolated with a quadratic spline (dashed curve) using the Scipy "interp1d" function. V_{OH} decreases from 3.09 V at 0 Gy to 2.42 V at 7.1 kGy, before partially recovering to 2.57 V at 20 kGy at the end of the irradiation. V_{OH} is given by

$$V_{OH} = Vcc - R \cdot (I_{load} + I_{leak}) \tag{10}$$

therefore the observed trend in Fig. 7 reflects the one followed by $I_{3.3V}$ in Fig. 5. Since I_{load} can be considered nearly constant, V_{OH} variations are proportional to I_{leak} changes. These findings reveal a critical dose threshold at approximately 7.1 kGy, characterized by a minimum in V_{OH} and a corresponding peak in the supply current $I_{3.3V}$.

IV. CONCLUSIONS

We investigated the TID response of TI LSF0102 level shifters exposed to ^{60}Co gamma irradiation up to 20 kGy at the CERN CC60 facility. Our results show that ionizing radiation induces changes in the output characteristics of T1 and T2, as well as in the operating point of T1 configured as MOS diode. The supply current increases as a function of dose up to a maximum at 7.1 kGy and then it slightly decreases toward the end of the irradiation. We found that variations in the supply current are mostly due to changes in T2 I_{leak}, which are in turn proportional to changes in V_{OH}. This behavior is consistent with a shift in V_t, typyically observed in MOS technologies exposed to TID radiation. Our work shows that V_{OH} is non-monotonic with dose, with a critical dose threshold at approximately 7.1 kGy, characterized by a minimum in V_{OH} and a corresponding maximum in the supply current $I_{3.3V}$. This aspect should be taken carefully into consideration when evaluating the maximum dose tolerable by the devices.

ACKNOWLEDGMENT

The authors would like to thank the staff of the CERN CC60 facility. This work was supported by the Italian Research Infrastructure "PRP@CERIC - Pathogen Readiness Platform for CERIC ERIC upgrade" (IR0000028) and by the PRIN 2022 PNRR - OPTICS, both funded by EU - Next Generation EU.

REFERENCES

[1] Texas Instruments, LSF0102 2-Channel Auto-Bidirectional Multi-Voltage Level Translator for Open-Drain and Push-Pull Applications datasheet (Rev. B), Dallas, TX, USA, Apr. 2024. [Online]. Available: https://www.ti.com/lit/pdf/SDLS972

[2] J. Guan, “Top Questions About Auto Bi-Direction LSF Family Translators,” Texas Instruments, Dallas, TX, USA, App. Note SCEA144, Dec. 2024. [Online]. Available: https://www.ti.com/lit/pdf/SCEA144

[3] R. Land, “Voltage-Level Translation With the LSF Family,” Texas Instruments, Dallas, TX, USA, App. Rep. SLVA675B, Dec. 2014, Revised Mar. 2015. [Online]. Available: https://www.ti.com/lit/pdf/SLVA675

[4] S. Rao and A. Ozer, “Biasing Requirements for TXS, TXB, and LSF Auto-Bidirectional Translators,” Texas Instruments, Dallas, TX, USA, App. Rep. SCEA060, Oct. 2017. [Online]. Available: https://www.ti.com/lit/pdf/SCEA060

[5] Texas Instruments, “Translate Voltages for I2C for PCA9306 LSF0102 TXS0102,” Texas Instruments, Dallas, TX, USA, App. Note SCET011, Sept. 2022. [Online]. Available: https://www.ti.com/lit/pdf/SCET011

[6] A. S. Sedra and K. C. Smith, *Microelectronic Circuits*, 7th ed. New York, NY, USA: Oxford Univ. Press, 2015.

[7] P. Casolaro, L. Campajola, and F. Di Capua, “The physics of radiochromic process: one calibration equation for all film types,” *J. Instrum.*, vol. 14, Aug. 2019, Art. no. P08006, doi: 10.1088/1748-0221/14/08/P08006

[8] P. Casolaro, V. Izzo, R. Vari, M. D'Angelantonio, A. Vanzanella, C. Principe, and A. Aloisio, “TID damage assessment on LVDS links for the ATLAS muon barrel spectrometer readout system,” *J. Instrum.*, vol. 20, no. 01, Art. no. C01023, Jan. 2025, doi: 10.1088/1748-0221/20/01/C01023.

[9] J. R. Schwank *et al*., "Radiation Effects in MOS Oxides," IEEE Trans. Nucl. Sci., vol. 55, no. 4, pp. 1833-1853, Aug. 2008, doi: 10.1109/TNS.2008.2001040