Compendium of TID comparative results under X-ray, Gamma and LINAC irradiation

Leonid N. Kessarinskiy, Dmitry V. Boychenko, Andrey G. Petrov, Pavel V. Nekrasov,
Armen V. Sogoyan, Vasily S. Anashin, Pavel A. Chubunov

Abstract--**Compendium of TID comparative results under X-ray, Gamma and LINAC irradiation is presented. The new joint method of X-ray and gamma irradiation employment for TID investigations is proposed. Experiment results successfully confirm the validity of the proposed TID testing approach.**

I. Introduction

THIS work is devoted to the development and verification of the new joint method of X-ray and gamma irradiation employment for TID investigations. The paper reports compendium of TID comparative results for four device types: RAM CY62256N, microcontroller ATMEGA128-16AUAU, video operational amplifier AD829JRZ and N-MOS transistor IRF3710SPBF. Isotopic facilities (Co^{60} and Cs^{137}) and LINACs are the usual tool for the TID hardness assurance tests [1-4]. X-ray facilities are the other powerful tool for TID investigations of modern complex devices, because of low electromagnetic interferences, short measurement lines and compactness. It is possible to control and measure online wider set of informative parameters which leads to a more precise TID hardness level estimation. But proper X-ray's calibration is necessary in each testing order to confirm achieved total dose levels. A new statistically strict calibration method is presented in this paper.

II. Facilities

A new Co^{60}+Cs^{137} facility named "Panorama-MEPHI" was utilized for testing and method verification (fig. 1). It was designed and fabricated for average and low dose rate investigations at SPELS (Moscow, Russia) in 2013. There are two isotopic sources and irradiation chambers with different dose rate range: Co^{60} (0.01 rad/s -0.1 rad/s) and Cs^{137} (0.1 rad/s-25 rad/s). The facility was created for microelectronics irradiation in real conditions. Due to the absence of electromagnetic and electrical interferences it allows measuring precision parameters and operating at real time frequencies [2]. The maximum cable length from irradiation chamber to measurement equipment's box is only 1 meter. It is suitable for 24/7 operation.

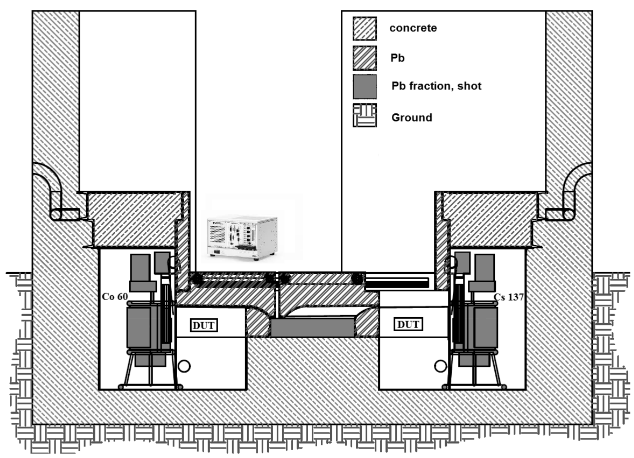

Fig. 1. Scheme of Co60+Cs137 facility (SPELS, Moscow)

Some total dose irradiation was conducted at LINAC "RELUS" and «U-31/33» (SPELS), operating in X-ray mode and at Co^{60} «GU-200». Its average energy is 800 keV and the maximum energy is 4.1 MeV. And finally, X-ray irradiation experiments were done at "PARDUS"(SPELS) 40 keV X-ray facilities.

III. Calibration Method

First two samples in each investigation lot should be irradiated at gamma facility (Cs^{137} or LINAC) with the control of the most TID sensitive "calibration parameter" (q_k, $q_k=q_k(D\gamma)$). At second step all other samples are irradiated at X-ray facility with full parametric control. TID hardness level achieved at X-ray facility (Dx) corresponds to TID hardness level at gamma facility ($D\gamma$) with equal "calibration parameter"

Manuscript received July 11, 2014.
Leonid N. Kessarinskiy, Dmitry V. Boychenko, Andrey G. Petrov, Pavel V. Nekrasov, Armen V. Sogoyan are with the National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow 115409, Russia, 31 Kashirskoe shosse, phone: +7 (495) 323-9034, fax: +7 (495) 324-0420 e-mails: lnkes@spels.ru, dvboy@spels.ru consequently.
Vasily S. Anashin and Pavel A. Chubunov are with the JSC Institute of Space Device Engineering, 53 Aviamotornaya street, Moscow 111250, Russia, e-mail: npk1 niikp@mail.ru.

978-1-4799-5884-9/14/$31.00 ©2014 IEEE

degradation. The next step is in determination of the coefficient (k) between Dx and Dγ ($D\gamma(q_k) = k\cdot Dx(q_k)$). The value of calibration parameter k equals to $k = D\gamma(q_k)/Dx(q_k)$ in point of parametric failure. Then k parameter is calculated for each device irradiated at X-ray facility ($1..n_x$) and gamma facility ($1..n_\gamma$). The mean value of TID hardness level for each lot could be calculated as following:

$$\overline{D_X} = \frac{1}{n_X}\sum_{i=1}^{n_X} D_{Xi}\,, \tag{1}$$

$$\overline{D_\gamma} = \frac{1}{n_\gamma}\sum_{i=1}^{n_\gamma} D_{\gamma i} \tag{2}$$

At next step the error of calibration parameter k should be calculated. It could rather big in case of unstable device radiation behavior. In order to get a statistically correct TID hardness level we should estimate the lowest value of the calibration coefficient (k_L) from equations 3-5.

$$k_L = \frac{k - \sqrt{Q_1 k^2 + Q_2 - Q_1 Q_2}}{(1 - Q_1)}\,, \tag{3}$$

$$Q_1 = \frac{t_{1-\frac{\alpha}{2}, n_X + n_\gamma - 2}}{(n_X + n_\gamma - 2)}\left(\frac{1}{n_X} + \frac{1}{n_\gamma}\right)\frac{\sum_{i=1}^{n_X}\left(D_{Xi} - \overline{D_X}\right)^2}{\overline{D_X}^2}\,, \tag{4}$$

$$Q_2 = \frac{t_{1-\frac{\alpha}{2}, n_X + n_\gamma - 2}}{(n_X + n_\gamma - 2)}\left(\frac{1}{n_X} + \frac{1}{n_\gamma}\right)\frac{\sum_{i=1}^{n_\gamma}\left(D_{\gamma i} - \overline{D_\gamma}\right)^2}{\overline{D_X}^2}\,, \tag{5}$$

where $t_{1-\frac{\alpha}{2},N}$ is quantile of the Student distribution for N variations.

IV. Experimental Data

Proposed calibration method was experimentally verified at four device types.

A. Operational amplifier AD829AR

Six samples of AD829AR were irradiated at X-ray and six at LINAC facility. Offset voltage appeared to be the calibration parameter as most TID sensitive one. Statistically calculated calibration coefficient k equals to 0.297±0.026. This result shows that employment of X-ray irradiation is suitable for TID hardness level investigations and brings in less than 10% error. TID hardness level of AD829AR (with respect of X-ray and gamma lots sizes) equals to $Dx+\gamma = 3.4$ krad. The TID dependence of the AD829AR calibration parameter (offset voltage) is presented in fig. 2.

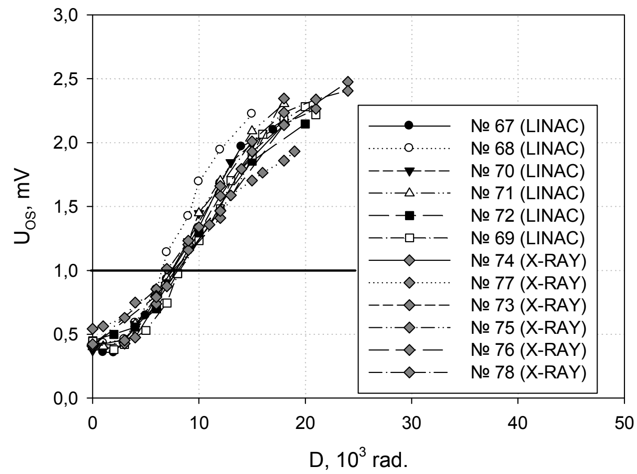

Fig. 2. The TID dependence of the AD829AR calibration parameter (offset voltage).

B. MOSFET IRF3710SPBF

Six samples of IRF3710SPBF were irradiated at X-ray and six at LINAC facility. Threshold voltage and drain leakage current appeared to be the calibration parameters as most TID sensitive ones. Statistically calculated calibration coefficient k equals to $k\,(V_{GS(th)}) = 0.097\pm0.009$ for threshold voltage and $k\,(I_{DSS}) = 0.084\pm0.008$ for drain leakage current. This results points out that TID hardness level error due to the X-ray employment is less than 10% and calibration coefficients for different IC parameters coincide. TID hardness level of IRF3710SPBF (with respect of X-ray and gamma lots sizes) equals to $D\gamma{+}x(V_{GS(th)})$ = 7.3 krad (for threshold voltage) and $D\gamma{+}x(I_{DSS})$ = 26 krad (for drain leakage current). The dependence of calibration parameter (offset voltage) from TID is presented on fig. 3. The TID dependence of the IRF3710SPBF calibration parameter (threshold voltage) is presented in fig. 3.

C. RAM CY62256N

Six samples of CY62256N were irradiated at X-ray and six at Co^{60} facility, and three at LINAC. Supply current for CMOS, TTL and dynamic operation modes appeared to be the calibration parameters as the most TID sensitive. Statistically calculated calibration coefficient k equals to $k(I_{SB2}) = 0.91\pm0.04$ for CMOS mode supply current, $k(I_{SB1}) = 0.92\pm0.03$ for TTL mode supply current and $k(I_{CC}) = 0.85\pm0.04$ for dynamic mode supply current. This results points out that TID hardness level error due to the X-ray employment is less than 5% and calibration coefficients for different IC parameters coincide. TID hardness level of CY62256N (with respect of X-ray and gamma lots sizes) equals to $D\gamma{+}x$ = 8.1 krad. The TID dependence of the

CY62256N calibration parameter (supply current TTL) is presented in fig. 4.

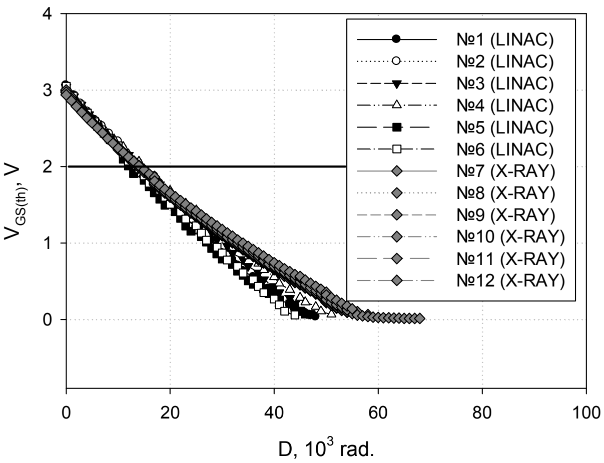

Fig. 3. The TID dependence of the IRF3710SPBF calibration parameter (threshold voltage).

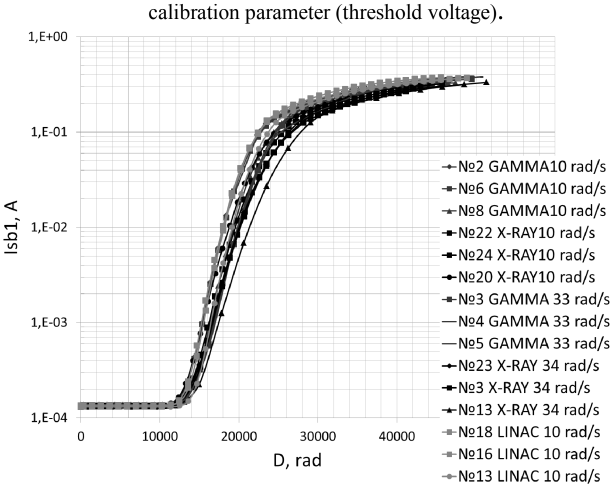

Fig. 4. The TID dependence of the CY62256N calibration parameter (Supply current TTL).

D. *MICROCONTROLLER ATMEGA128-16AU*

Five samples of ATMEGA128-16AU were irradiated at the X-ray and six at the Cs137 facility. Operation without failures, static and dynamic supply current to be the calibration parameters as the most TID sensitive ones, for calibration were used increment currents. Statistically calculated calibration coefficient k equals to $k(FC) = 0.24…0.26$ for operation parameter, $k(I_{CCD}) = 0.25\pm0.01$ for increment dynamic supply current and $k(I_{CCS}) = 0.23\pm0.01$ for increment static supply current. This results points out that TID hardness level error due to the X-ray employment is less than 10% and calibration coefficients for different IC parameters coincide. TID hardness level of ATMEGA128-16AU (with respect of X-ray and gamma lots sizes) equals to $D\gamma+x(FC)$ = 4.9 krad $D\gamma+x(I_{CCD})$ = 17 krad and $D\gamma+x(I_{CCS})$ = 27 krad. The dependence of calibration parameter increment static supply current from TID is presented on fig. 5, the variations static supply currents at TID more then 27 krad related with functional failures of microcontroller.

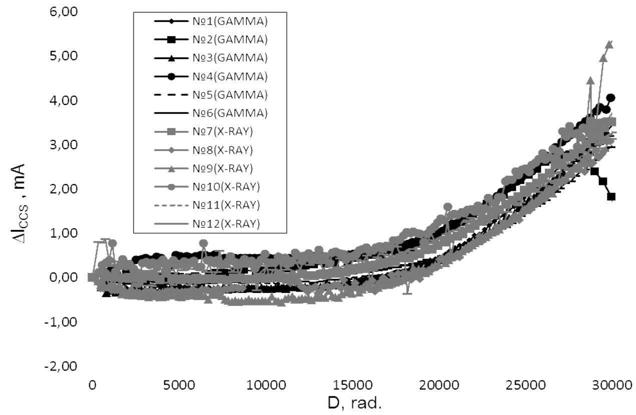

Fig. 5. The TID dependence of the ATMEGA128-16AU calibration parameter (increment static supply current).

V. CONCLUSION

The new joint method of X-ray and gamma irradiation employment for TID investigations is presented. TID experimental results verify the possibility of X-ray irradiation employment for hardness level determination: Admissible additional error and suitable calibration correlation for different IC parameters is revealed.

VI. REFERENCES

[1] E. W. Enlow, R. L. Pease, W. E. Combs, R. D. Schrimpf, R. N. Nowlin, “Response of Advanced Bipolar Processes to Ionizing Radiation,” *IEEE Trans. Nucl. Sci. vol. 38*, pp.1342-1351, 1991.

[2] D.M. Fleetwood, S. L. Kosier, R.N. Nowlin, R.D. Schrimpf, J. R.A. Reber, M. Delaus, P. S. Winokur, A. Wei, W.E. Combs, and R.L. Pease, “ Physical mechanisms contributing to enhanced bipolar gain degradation at low dose rates”, *IEEE Trans. Nucl. Sci*., vol.41, pp. 1871-1883, 1994.

[3] P.C. Adell, R.D. Schrimpf, B.K. Choi, W.T. Holman, J.P. Attwood, C.R. Cirba, K.F. Galloway “Total-Dose and Single-Event Effects in Switching DC/DC Power Converters”, *IEEE Trans. Nucl. Sci.* - 2002. - Vol. NS-49. - № 6. – PP. 3217-3221.

[4] P.C. Adell, R.D. Schrimpf, W.T. Holman, J. Boch, J. Stacey, P. Ribero, A. Sternberg, K.F. Galloway “Total-Dose and Single-Event Effects in DC-DC Converter Control Circuitry”, *IEEE Trans. Nucl. Sci.* - 2003. - Vol. NS-50. - № 6. – PP. 1867-1872.

[5] D.V. Boychenko, L.N. Kessarinskiy, and D.V. Pechenkina “The influence of the electrical conditions on total dose behavior of the analog switches”, *Proc. of 12th European Conf. "Radiation and its Effects on Components and Systems" (RADECS 2011)*, Sept. 19-23, 2011, Spain, pp. 822-824.

[6] L.N. Kessarinskiy, D.V. Boychenko, and A.Y. Nikiforov “An analysis of the radiation behavior of pulse voltage stabilizers” *Russian Microelectronics*, 2012, v. 41, pp. 251-258.

[7] O.A. Kalashnikov, A.A. Demidov, V.S. Figurov, A.Y. Nikiforov, S.A. Polevich, V.A. Telets, S.A. Maljudin, and A.S. Artamonov “Integrating analog-to-digital converter radiation hardness test technique and results”, *IEEE Transactions on Nuclear Science 45 (6 PART 1)* , 1998, pp. 2611-2615

[8] D.V. Gromov, V.V. Elesin, G.V. Chukov, V.V. Repin “Radiation effects in bipolar transistors based on silicon-germanium heterostructures”, *CriMiCo - 2009 19th International Crimean Conference Microwave and Telecommunication Technology*, Conference Proceedings, pp. 726-727.