Comprehensive Radiation Characterization of Digital Isolators

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***Abstract* – We investigate TID radiation response and SEE susceptibility of six different digital isolators by exposing them to Co-60 gammas with 300 krad$_{(Si)}$ and various proton and heavy ion fields with LET of up to 60 MeV·mg^{-1}·cm^{2}. The type with the least radiation degradation was also exposed to 10 MeV electrons and 14 MeV neutrons.**

I. Introduction

DIGITAL isolators are gaining importance in signal isolation solutions and are challenging the traditional solutions such as those which utilize optocouplers. This is since digital isolators offer various advantages with respect to optocouplers such as their superior performance, reliability and integration. Various isolation techniques are available and commercial solutions are offered by several suppliers. In the course of the presented work we investigate the radiation sensitivity of digital isolators against total ionising dose and single-event effects. Among the devices under study are part types representing various isolation technologies. We will focus on the paramount important electrical parameters that characterize the performance of digital isolators such as the isolation. Following this strategy we will provide a good overview of the digital isolator technologies available on the market that are suited for space applications and their performance in TID and SEE radiation fields.

II. Objectives of the Study

The objective of the study is to investigate the space relevant TID radiation tolerance and SEE susceptibility of different digital isolator technologies, i.e. to perform a detailed radiation evaluation (TID and SEE) of the selected digital isolators allowing an assessment of their suitability for space applications. For that purpose we expose them to Co-60 gammas and for SEE to either high-energetic protons or heavy ions and test those according to test method standards for semiconductor devices as defined in ESCC 22900 [1] and ESCC25100 [2].

Additional electron and neutron exposures are performed with the device type that is the least susceptible to TID degradation.

III. Materials and Methods

A. Test Sample Info

The test candidates selected for the presented study are the ISO15DW and the ISO7220 manufactured by Texas Instruments, the Si8261AAC by Silicon Labs, the MAX14850 by Maxim Integrated, the ADuM1201ARZ and the ADuM1100URZ manufactured by Analog Devices, and the IL715-3E by NVE. These devices use different isolation technologies (see Table 1) like capacitive coupling, an inductive approach that is utilizing a high speed CMOS with a monolithic transformer, or the giant magnetoresistance (GMR) effect.

All the procured test samples are commercial products, however during the procurement process special attention was paid to obtain all the test samples for each device type from a single lot. As this was only partially possible for the Isoloop IL715 from NVE using the GMR effect as isolation technique, this part type is only included for Co-60 TID testing. All the devices but one are assembled in SOIC packages.

B. The Radiation Tests Performed

The digital isolators are exposed to several types of radiation fields that are Co-60 gammas, protons, heavy ions, electrons, and neutrons. The Co-60 gamma radiation field is used to assess the total ionizing dose response of the investigated devices. This is done by characterizing the parameter degradation with an increase of the received dose level. Hereby the most

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important electric parameters of the digital isolators are measured as a function of the dose such as supply currents of the input and the output side at different output voltage levels (i.e. logic high and logic low), rise time, fall time, propagation delay, pulse width distortion and leakage current.

The tests performed with the electrons and neutrons use similar procedures for the characterization of the device degradation as it is the case for the Co-60 gamma tests.

TABLE 1: BASIC PROPERTIES OF THE DUTS USED FOR THE EXPERIMENTS

Part	Manufacturer	Technology	Package type	Lot code
ISO15DW	Texas Instruments	Capacitive	SOIC	404323 2TN4
ISO7220	Texas Instruments	Capacitive	SOIC	4286983TW4
SI8261AC C-C-IP	Silicon Labs	Capacitive	DIP	1333CF600U
MAX14850 ASE+	Maxim Integrated	Capacitive	SOIC	0001755035
ADuM1201 ARZ	Analog Devices	Monolithic transformer	SOIC	1TAK96092.9
ADuM1100 URZ	Analog Devices	Monolithic transformer	SOIC	AJ60138.5
IL715-3E *	NVE	GMR	SOIC	135210

*included for Co-60 TID testing only.

Heavy ion and proton tests are performed to assess the SEE susceptibility of the investigated devices, i.e. the occurrence of Single Event Transients (SET) and Single Event Latch-Up (SEL) is monitored at various values of LET of the incident radiation.

Heavy ion testing is a challenge, since the plastic package of the investigated devices needs to chemically etched open before exposure. It was observed that not all digital isolators are functional after this procedure. Another observation was that in case the digital isolator is using an inductive coupling technology the transmission coils might cover a significant portion of the silicon dies and thus shield the 'real' device from being exposed to the heavy ions. In addition, the package provides mechanical stability for these coils. In these cases protons are used for the SEE tests. The LET seen by the device due to a proton exposure is due to the nuclei produced by the protons in silicon and covers the range of from a few MeV·cm^2·mg^{-1} up to approximately 15 MeV·cm^2·mg^{-1} [3].

C. TID and SEE Radiation Fields

Three of the TID exposures are performed in the radiation standard laboratory of the Seibersdorf Laboratories using the Picker C8M/80 Co-60 tele-therapy unit [4] while the other three are performed at the MDS Nordion GammaMat TK1000B facility at Fraunhofer INT. During exposure a PMMA build-up plate with a thickness of 3mm is used to assure that secondary electron equilibrium is established at the test location.

The heavy ion testing is performed at the RADEF facility of the University of Jyväskylä [5] using the following heavy ions (heavy ion energies): Nitrogen (139 MeV), Iron (523 MeV), Krypton (768 MeV) and Xenon (1217 MeV) having surface LETs of 1.8, 18.5, 32.1 and 60 MeV·mg^{-1}·cm$^2_{(Si)}$ respectively.

Neutron exposure is performed at the Thermo Fisher D-711 facility at Fraunhofer INT providing 14 MeV neutrons.

The proton testing is performed at the PIF facility of the Paul Scherrer Institute in Villigen, Switzerland [6]. Monoenergetic protons with energies of 24 MeV to 200 MeV are used for the exposure of the DUTs. The radiation field is homogeneous and of circular shape with a diameter of 4 cm ensuring that the exposed DUTs are entirely covered by the beam.

D. Experimental Methods

Test Set-Up for TID Co-60 and Electron Exposure: The digital isolators are exposed in both unbiased and biased configuration. In the unbiased case all the terminals of the DUTs are held at ground potential. In the biased configuration the device is powered on and a rectangular signal with a frequency of 1 kHz is fed into the input side of the digital isolator causing the output to toggle between its logic-off and logic-on state. A sketch of the circuit diagram of the biased configuration is presented in Fig. 1.

The DUTs are exposed in several dose steps up to a TID dose level of 300 krad$_{(Si)}$. All parts are electronically characterized several times namely prior to exposure, after each dose step, after a subsequent 24 hours anneal phase and finally after the final 168 hours 100°C elevated temperature annealing phase. The exposures are performed according to ESA/ESCC Basic Specification No.22900 "Total Dose Steady-State Irradiation Test Method [2].

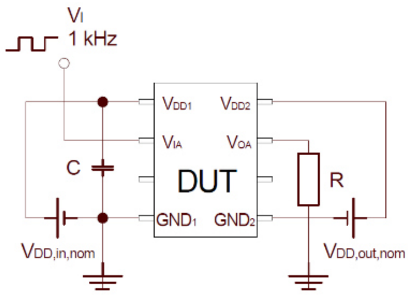

Fig. 1: Schematic circuit diagram of the biased configuration

Test Set-Up for SEE Experiments: Again the DUT is operated with a rectangular input signal (1 kHz) which is fed into the input side of the digital isolator.

The test hardware is controlled via a LabVIEW software and is designed to detect both SET and SEL during exposure of the DUT by monitoring both input currents and the device output.

The SEL detection is based on the occurrence of an unexpected sudden increase of the input and output supply currents. An SEL is considered to have occurred once the input supply current of any side suddenly exceeds a device-specific threshold. After occurrence of a SEL the device is powered down to recover the SEL and subsequently powered on again.

For the detection of SET the output of the digital isolator is monitored. An SET is considered to have been occurred once the output signal deviates approx. 0.5-0.6 Volt from its expected value. The test hardware is designed in such a way to be capable of detecting and recording very short transients with a length in the order of ns. This challenging task requires quick electronics and analysis procedures that are capable of acquiring 100% of the transients induced on a square-wave signal. Consequently tailored hardware and software was developed that can operate at the required speed.

SEE testing is performed at two temperatures namely room temperature and at an elevated temperature of 75°C.

IV. Results and Discussion

A. TID Test Results

Co-60 TID testing is performed according to ESCC 22900 (exceptions where noted) with a total of 10 DUTs (5 in biased and 5 in unbiased configuration) of each device type. Electrical measurements prior to irradiation, after annealing and at intermediate steps are performed with these DUTs and also with an unirradiated reference sample.

Intermediate steps are taken at 10, 20, 30, 50, 100 and 300 $krad_{(Si)}$ and most part types show parametric failures, i.e. electrical or switching parameters exceeded the limits given in the respective datasheets.

Fig. 2 shows the test results for the output supply current I_{DD} of the SI8261AAC-C-IP, which can be seen as representative for most of the parts. With the exception of the ISO15DW and ISO7220, whose supply currents stayed fairly within limits, supply currents of any other biased device rise to unacceptable levels, several orders of magnitude above rated levels, even after relatively low total doses (30 – 50 $krad_{(Si)}$).

Failure levels, when at least one DUT is beyond limits for at least one parameter, are given in Table 2. For some part types even complete (functional) failures are encountered at certain stages and one part type even had to be derated (i.e. biasing was discontinued at some point).

There may be some instances where the max. limits in the datasheets may be all-too optimistic (e.g. when a maximum limit of 2 ns for a rise time is given and most DUTs settle at 2.2 ns in a setup capable of measuring rise times < 1 ns), but the failure levels given in Table 2 are the ones attributed to radiation effects only.

From all part types investigated in this work, the ISO7220MDR shows the least total dose degradation and is thus selected for further testing with electrons (TID) and neutrons (displacement damage).

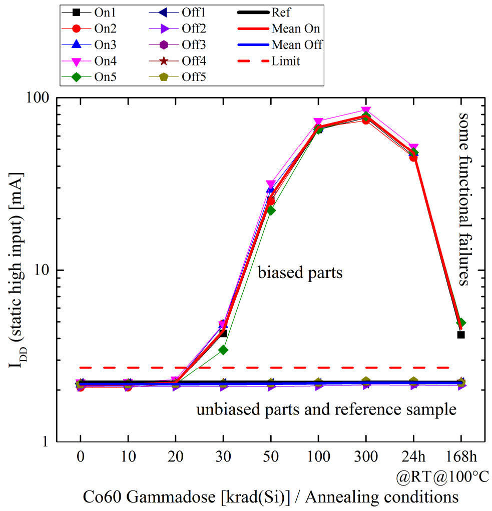

Fig. 2: Output current IDD of Si8261. Parameteric failures already appear after 30 $krad_{(Si)}$ irradiation, additionally after accelerated ageing (168h @ 100°C) some of the biased devices show functional failures.

B. Electron Test Results

The ISO7220MDR is exposed to electrons with an incident energy of 10MeV. The parameter degradation has been characterized at various dose levels that are 23, 47, 95 and 285 $krad_{(Si)}$. The device fails already at a dose level of 23 $krad_{(Si)}$ since the pulse width distortion of the unbiased units exceeds the specification limits already at this dose level. The TID failure levels of the device are presented in Table 2.

Fig. 3 presents a typical result for parameter degradation. Shown is the increase of the input supply current (output in logic-low state during characterisation) when the DUTs are exposed in biased configuration. A degradation of the input supply current was not observed during Co-60 testing.

C. Neutron Test Results

The digital isolator ISO7220MDR is further tested for displacement damage effects at the Thermo Fisher D-711 facility at Fraunhofer INT with a total fluence of $5 \cdot 10^{11}$ cm^{-2} neutrons. This represents a fluence of $9 \cdot 10^{11}$ cm^{-2} of 1 MeV neutrons.

An extensive set of device parameters is tested before and after exposure, and at intermediate steps. No significant parameter variation and therefore no parametric failure is observed. Due to activation of the parts and the lack of displacement susceptibility, no annealing was performed with these DUTs. The lower boundaries of the displacement damage failure levels of the ISO 7220MDR are presented in Table 2.

Table 2: DUT Radiation Failure Levels during TID Testing

Device	Mode	Failure Level (parametric)	Failure Level (functional)
Radiation Type: Co-60			
ISO15DW	Biased	10 krad(Si)	> 300 krad(Si)
	Unbiased	10 krad(Si)	> 300 krad(Si)
ISO7220MDR	Biased	> 300 krad(Si)	> 300 krad(Si)
	Unbiased	> 300 krad(Si)	> 300 krad(Si)
SI8261ACC-C-IP	Biased	30 krad(Si)	168 h@ 100°C **
	Unbiased	> 300 krad(Si)	> 300 krad(Si)
MAX14850ASE+	Biased	50 krad(Si)	100 krad(Si)
	Unbiased	>300 krad(Si)	> 300 krad(Si)
ADuM1201ARZ	Biased	20 krad(Si)	100 krad(Si)
	Unbiased	168 h@ 100°C **	> 300 krad(Si)
ADuM1100URZ	Biased	20 krad(Si)	n/a**
	Unbiased	>300 krad(Si)	>300 krad(Si)
IL715-3E	Biased	30 krad(Si)	> 300 krad(Si)
	Unbiased	> 300 krad(Si)	> 300 krad(Si)
Radiation Type: 10 MeV electrons			
ISO7220MDR	Biased	23 krad(Si)	>285 krad(Si)
	Unbiased	23 krad(Si)	>285 krad(Si)
Radiation Type: 14 MeV neutrons			
ISO7220MDR	Biased	$> 9\cdot10^{11}$ n(1MeV)·cm^{-2}	$> 9\cdot10^{11}$ n(1MeV)·cm^{-2}
	Unbiased	$> 9\cdot10^{11}$ n(1MeV)·cm^{-2}	$> 9\cdot10^{11}$ n(1MeV)·cm^{-2}

* after 300krad(Si) exposure; ** most likely circumvented by unbiasing of all DUTs during irradiation step 50 → 100 krad$_{(Si)}$

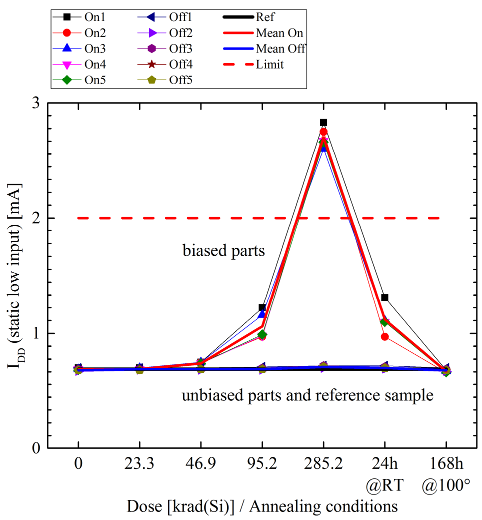

Fig. 3: Increase of the input supply current (output in logic-low state) during electron irradiation.

D. Proton Test Results

Two devices are exposed to protons that are the ADuM1201ARZ and the ADuM1100URZ. Proton tests are performed at room temperature and at 75°C and each at different incident proton energies that are 50, 100 and 200 MeV and additionally 24 MeV for the ADuM1201ARZ. The total proton fluence for each run is set to be 10^{10} p·cm^{-2}; the flux is ~2.1·10^{7} p·cm^{-2}·s^{-1}.

For any of the proton energies neither SET nor SEL is observed. This observation is true for both of the investigated parts at both investigated temperatures (data was taken with two distinctly different test setups). A prolonged exposure with the ADuM1100URZ at a proton energy of 200 MeV (temperature: 75°C) has been performed and gives an upper limit for the SET and SEL cross section of 1.56·10^{-11}cm^{-2} (5.77·10^{-11}cm^{2} for a confidence level of 95%).

Additionally to the SET and SEL test a dielectric rupture test is done (for the ADuM100URZ at room temperature only) at the incident proton energies of 50, 100 and 200 MeV. No increase of the leakage current between input and output side at voltage differences equal to the maximum working isolation voltage is observed. Hence the isolation for none of the devices is ruptured. Upper limits for the SEE cross sections due to proton exposure are presented in Table 3.

TABLE 3: PROTON SEE CROSS SECTION (FOR A CONFIDENCE LEVEL OF 95%)

Device	Condition	Test	SEE Cross Section (cm^2) Nominal Proton Energy (MeV) 200	100	50	24
ADuM1201 ARZ	RT / 75°C	SET / SEL / SEDIR	< 1.85·10^{-10}	< 1.85·10^{-10}	< 1.85·10^{-10}	< 1.85·10^{-10}
ADuM1100 URZ	RT	SET / SEL	< 1.85·10^{-10}	< 1.85·10^{-10}	< 1.85·10^{-10}	n/a
	75°C	SET / SEL	< 0.57·10^{-10}	< 1.85·10^{-10}	< 1.85·10^{-10}	n/a
	RT	SEDIR	< 1.23·10^{-10}	< 1.23·10^{-10}	< 1.23·10^{-10}	n/a

E. Heavy Ion Test Results

Heavy ion testing is performed at the RADEF facility of the University of Jyväskylä with the ISO7220MDR and the ISO15DW that are exposed to Xenon, Krypton, Iron and Nitrogen ions having LETs of 60, 32.1, 18.5 and 1.8 MeV·mg^{-1}·cm^{2}$_{(Si)}$ respectively. The devices are tested for the occurrence of Single Event Latch-Ups (SEL), Single Event Transients (SET) and dielectric breakdown (SEDIR). The SEE testing is performed according to ESCC basic specification No. 251000 [2].

SEL testing is done by exposing the digital isolators to a total fluence of 10^{7} cm^{-2}. The number of occurring latch-ups is used to calculate the SEL cross section. It is found that one of the devices, i.e. the ISO7220 MDR, is immune to latch-ups. The SEL cross section curve of the ISO15DW is presented in Fig. 4.

For SET testing the digital isolators are exposed to a total fluence of 10^{6} cm^{-2}. During this exposure the occurring transients are recorded; the number of occurrences is then used for the calculation of the SET cross section. A significant number of transients is observed; the resulting cross section curves are presented in Fig. 5.

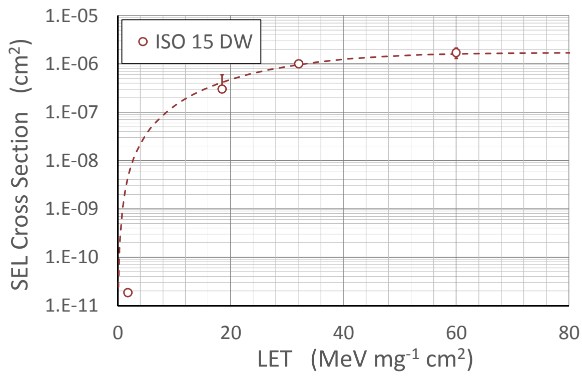

Fig. 4: SEL cross section of the ISO15DW digital isolator as a function of the LET of the incident heavy ions.

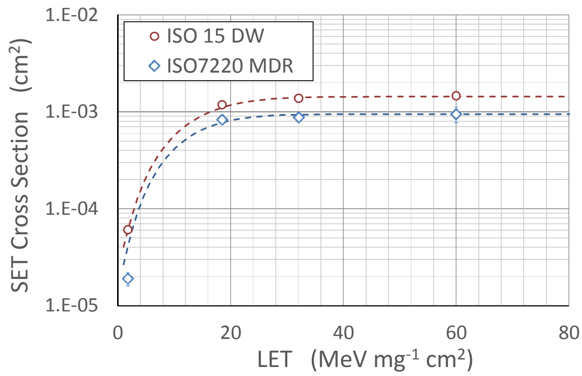

Fig. 5: SET cross section of the ISO15DW and the ISO7220MDR digital isolators as a function of the LET of the incident heavy ions.

The transients observed for the ISO15DW and the ISO7220MDR are analyzed in detail with respect to their duration and their amplitude. Within this context the duration of each transient and its amplitude is determined for every individual event and represented in a scatter plot; hereby each transient is displayed as a point with its duration and amplitude as the abscissa and the ordinate respectively. The resulting scatter plot obtained for the ISO15DW is shown in Fig. 6; the resulting scatter plot for the ISO7220MDR is presented in Fig. 7.

In this representation the transients are arranged according a certain pattern – meaning that the amplitude is not independent from the duration of the transient – and the characteristic of the patterns found for the two digital isolators is very similar. The onset of this observed curve is a linear function with a relatively steep slope. As the digital isolator can only drive the output to its maximum specified level the curve saturates at a certain duration. It is observed that transients with duration longer than 1.5 µs (ISO14DW) or 1µs (ISO7220MDR) drive the output of the digital isolator to its specification limits.

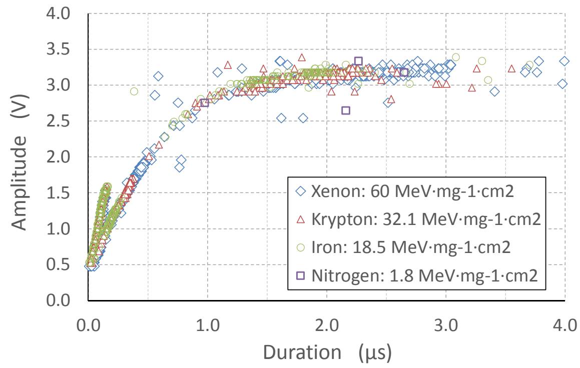

Fig. 6: Scatterplot; presented is the duration and the amplitude of each transient observed with the ISO15DW.

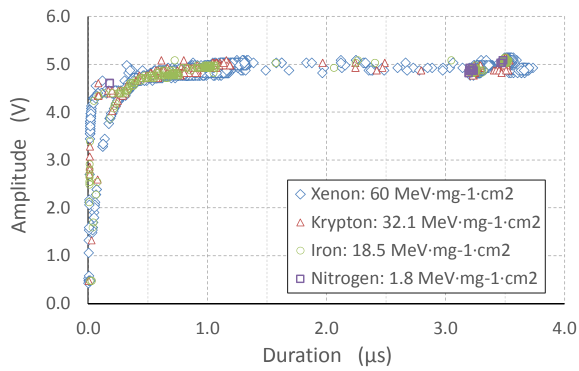

Fig. 7: Scatterplot; presented is the duration and the amplitude of each transient observed with the ISO7220MDR.

To allow for a more detailed analysis of the occurring SETs the shape of the transients was also recorded; hereby the time resolution of the signal recording is 0.67 ns.

Fig. 8 presents an overlay of the time structure of six representatively selected transients (the digital isolator was in low state when the transients occurred) with various durations. The time stamp 0 µs denotes the occurrence of the respective SET – and thus the beginning of the transient. The representation uses a logarithmic time scale that allows also to resolve the time structure of the transients with a duration in the nanosecond regime. From the figure it can be seen that all transients have a very similar characteristic, i.e. they have an identical rising edge.

V. Summary and Conclusions

Six commercially available digital isolator part types have been identified for TID, displacement damage and SEE radiation effects testing. In addition to standard Co-60 TID testing, investigations using 10MeV electrons and 14 MeV neutrons have been carried out.

The Co-60 TID response show good results only for two part types of the Texas Instrument ISO family. All other parts type showed at least an increase in supply currents to intolerable levels, sometimes several orders of magnitude above the rated values, and some part types even showed complete failure and permanent damage. The ISO7220MDR is further tested with neutrons and shows no displacement damage up to an equivalent damage fluence of $9{\cdot}10^{11}$ n(1 MeV)/cm^2.

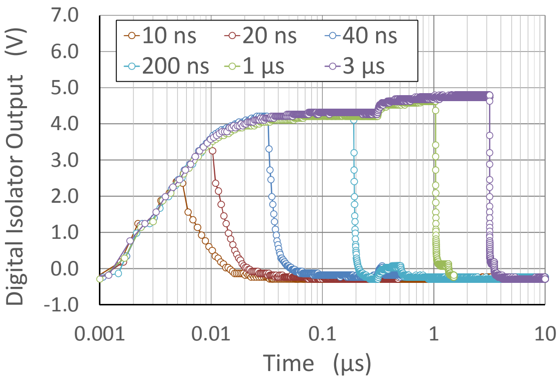

Fig. 8: Overlay sketch of six transients that occurred for the ISO7220MDR; the output of the digital isolator was in logic-low state.

The ISO7220MDR however does not perform as well when exposed to electrons and shows some increase in the supply currents, although less than a factor of 1.5 above the maximum limits.

The ISO15DW and the ISO7220MDR are exposed to heavy ions having an LET range of 1.8 to 60 MeV·mg^{-1}·cm$^2_{(Si)}$. No SEL are observed for the ISO7220MDR while the ISO15DW shows latch-ups for a LET of 18.5 MeV·mg^{-1}·cm$^2_{(Si)}$ and higher. Both digital isolators are susceptible to SET and 97.6% of the transients are found to have amplitudes above the CMOS level. A detailed analysis of the observed transients shows that most of them have a very similar characteristic.

The actual use of digital isolators in a space scenario may be limited to some part types and mission with low radiation requirements. Most devices may be unacceptable due to total dose effects leading to a large increase in supply currents and also due to a distinct susceptibility to SET and/or SEL.

Acknowledgment

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