

# Co<sup>60</sup> Gamma-Ray Effects on the DAC-7512E 12-Bit Serial Digital to Analog Converter for Space Power Applications

Goo-Hwan Shin<sup>†</sup>

**Abstract** – The DAC-7512E is a 12-bit digital to analog converter that is low power and a single package with internal buffers. The DAC-7512E takes up minimal PCB area for applications of space power electronics design. The spacecraft mass is a crucial point considering spacecraft launch into space. Therefore, we have performed a TID test for the DAC-7512E 12-bit serial input digital to analog converter to reduce the spacecraft mass by using a low-level Gamma-ray irradiator with Co<sup>60</sup> gamma-ray sources. The irradiation with Co<sup>60</sup> gamma-rays was carried out at doses from 0 krad to 100 krad to check the error status of the device in terms of current, voltage and bit error status during conversion. The DAC-7512E 12-bit serial digital to analog converter should work properly from 0 krad to 30 krad without any error.

**Keywords:** Space power electronics, Total ionizing dose, Digital to analog converter, Data conversion, Co<sup>60</sup> gamma-ray

## 1. Introduction

We have been developing the next generation small satellite-1 (NEXTSat-1) since 2012 for science missions and space core technology verification missions in space with new technology such as data conversion devices to implement the small and a compact design concept [1]. The main missions of the NEXTSat-1 are detecting the plasma and particle energy near the Earth for the study of space storms and the near-infrared (NIR) imaging spectrometer for star formation history and development of space core technologies for space verification. Thus, the NEXTSat-1 has complex system configuration in terms of electrical and mechanical aspects. In addition to configuration, the electrical power isolations are crucial points to perform the missions in a stable manner without any electrical disturbance. The NEXTSat-1 has so many control signals such as telemetries and telecommands to process data considering between a high power unit and a low power unit. In case of the high power unit, the electrical isolation is necessary to avoid any electrical interference in terms of power and white noises to the main processor. Electronic devices such as logics and memories in space environments can contain numerous types of oxides and insulators. Ionizing radiation can induce significant charge buildup in these oxides and insulators leading to device degradation and functional failures [2]. The space missions like National Aeronautics and Space Administration (NASA) and geosynchronous orbit at solar minimum have been used to calculate total ionizing dose (TID) and single event effects (SEE) for 4G NAND and electronic devices [3].

In case of the NEXTSat-1, we have used for the DAC-7512E 12-bit serial digital to analog converter for applying to power and telemetry processing parts[4], which will be placed between high power components and low power component to ensure an electrical isolation. The high reliability shall be required in a space program, because it is unable to fix after launch in space. Therefore, so many tests and analysis shall be required [5]. Of space program tests, the TID test is a dominant factor for providing stable mission operation in space program [6]. The DAC-7512E is the first application by the NEXTSat-1 program. Thus, we have performed the TID test by using Co<sup>60</sup> gamma-ray ranged from 0 krad to 100 krad to check its performance due to irradiations. We have obtained the beneficial results in terms of current variations, voltage variations and waveforms through those TID tests. In this study, we reported the test results of the DAC-7512E serial digital to analog converter which will be applicable for space power applications.

## 2. Experimental Set-up and Test

### 2.1 Experimental configuration and beam source

In this experiment, we have used the Co<sup>60</sup> gamma-ray which has an energy level of 1.17 MeV as an energy source for this test. The Co<sup>60</sup> gamma-ray irradiation facility is located in the Advanced Radiation Technology Institute (ARTI) of Korea Atomic Energy Research Institute (KAERI) in Korea. Table 1 shows the energy level, dose rate per hour, the total dose and the distance between Co<sup>60</sup> gamma-ray rod and the DAC-7512E device under test were used in this experiment.

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**Table 1.** Energy level and dose rate for Co<sup>60</sup> gamma-ray

Energy level (MeV)	1.17
Radiation dose rate (krad / h)	10.00
Total dose (krad)	100.00
Distance from Co <sup>60</sup> gamma-ray rod (cm)	44.80

We have performed TID tests with three samples to obtain and compare the current variations, the voltage variations and the waveforms during irradiation. Table 2 shows the samples used for this TID tests. The DAC-7512E has two types of package such as a small outline transistor 23 (SOT23) and a mini small outline package (MSOP). In this experiment, we have chosen the DAC-7512E SOT23 package type for this TID experiment because it is a very small package and lower mass compared to a parallel digital to analog converter. The SOT23 package has low power dissipation and high junction temperature. With the DAC-7512E, we have prepared the three test samples and designed the Ground Support Equipment (GSE) to check and gather the test results. Table 2 shows the sample allocation under TID test in Advanced Radiation Technology Institute (ARTI) belonging to Korea Atomic Energy Research Institute (KAERI).

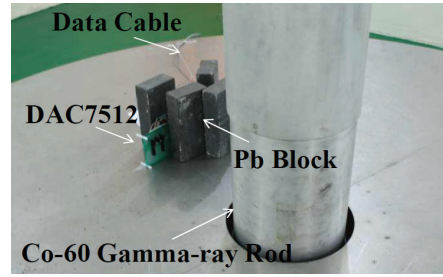
**Table 2.** Samples which were used for TID tests with Co<sup>60</sup> gamma-ray of 1.17 MeV

Sample Lot No.	Parts name	Package type	Operating temperature (°C)
#1	DAC-7512E/250-1	SOT23-6	-40 ~ 105
#2	DAC-7512E/250-2	SOT23-6	-40 ~ 105
#3	DAC-7512E/250-3	SOT23-6	-40 ~ 105

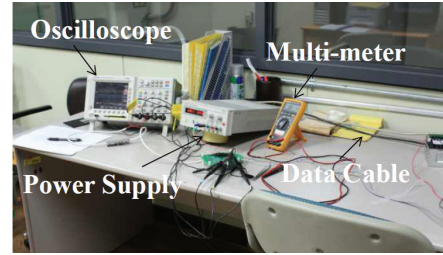
This TID experiment was carried out at the ARTI of KAERI in Korea with a low energy Co<sup>60</sup> gamma-ray. Fig. 1 shows the TID test configuration in ARTI. We prepared three samples for this TID to take average of the experiment results. As you may know, the three DAC-7512E samples were placed on the test printed circuit board (PCB) in Fig. 1. In this Fig. 1, there is a Co<sup>60</sup> gamma-ray rod in the center of test plate, and the EGSE to get test data was placed outside the test chamber. We measured the current, voltage, and waveform for each device under test with a step of 10 krad an hour.

### 2.2 Waveform measurements due to Co<sup>60</sup> gamma ray

The DAC-7512E is a serial digital to analog converter, which consists of data registers and register strings to make analog signal depending on input serial data in terms of binary digit. In Fig. 2, there are three channels for three samples. In other words, the upper signal is for the first sample, the middle signal is for the second sample and the bottom signal is for the third sample, respectively. After writing a data to the data registers in this device, the DAC-7512E will produce analogues as shown in Fig. 2. We have

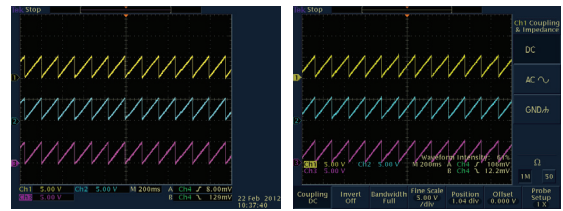


(a)



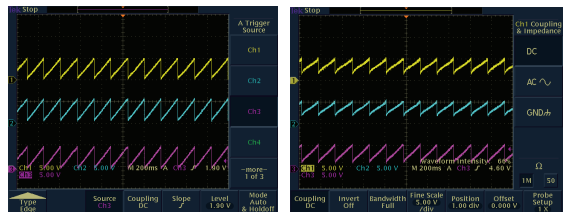
(b)

**Fig. 1.** TID tests set-up and measuring equipment for the DAC-7512E 12-bit digital to analog converter: (a) the DAC-7512E under test in situ and (b) measuring equipment for current, voltage, waveforms using an oscilloscope and a digital multi-meter.



(a)

(b)



(c)

(d)

**Fig. 2.** Output data variation in shape, amplitude and linearity during Co<sup>60</sup> gamma-ray irradiation, which start at 0 krad and stops at 100 krad for test: (a) cumulative dose rate is around 0 krad; (b) cumulative dose rate is around 30 krad; (c), cumulative dose rate is around 60 krad, and (d) cumulative dose rate is around 100 krad.

irradiated the Co<sup>60</sup> gamma-ray from 0 krad until 100 krad to the three DAC-7512E devices by controlling the operation time. Before starting the test, the DAC-7512E's analog outputs were not distorted, which waveforms were captured by oscilloscope. With increasing dose by Co<sup>60</sup>

gamma-ray, the output waveforms of three DAC-7512E devices were begun to change as shown in Fig. 2. Reaching upto 100 krad, the three DAC-7512E devices were completely distorted in shaping after writing data in registers. The amplitude after irradiation to 100 krad was reduced to around 26 % compared to 0 krad. It means that the internal registers were changed in control voltage compared to the original status.

The following Fig. 3-(a) and -(b) shows the detailed results of measurement for 60 krad and 100 krad, respectively. According to the test results in Fig. 3, the output waveforms of the DAC-7512Es were shedding compared to non-irradiation condition to the devices. The change rates of the devices after irradiation appeared about 10 % in the slopes of linearity compared to 0 krad. As the irradiation dose rate was gradually increasing, the sample #3 showed not only the different waveforms like non-linear functions, but also a lot of writing errors to register. Detailed waveforms were shown in Fig. 3. In each channel, we can see the differences in voltage level, slope and linearity compared to TID level 0 in Fig. 3-(a). At 60 krad and 100 krad, the amplitude of DAC output voltage was found, which was decreased around 26 % in sample #1, sample #2 and sample #3, respectively. It means that the internal resistor string has a differently applied voltage in the DAC-7512E due to the  $\text{Co}^{60}$  gamma-ray irradiation on internal registers. But also, we can see the linearity and a magnitude of DAC output in Fig. 3-(b) from 60 krad up to 100 krad unlike Fig. 2. Due to the register malfunction, the DAC output was severely fluctuated. As we mentioned, each sample showed the different patterns in slope as the cumulative dose rate was increased as shown in Fig. 3.

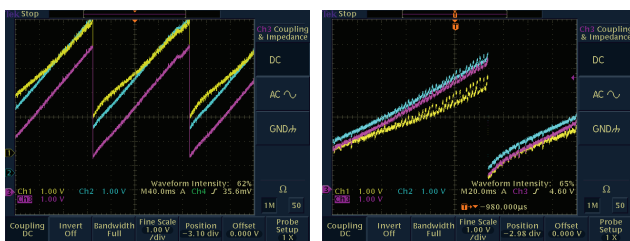
In general, some current changes can be seen due to the dose. Fig. 4 shows the results of current changes in the DAC-7512E devices under test. Until 30 krad, there were little current changes around 0.05 mA per each sample. In other words, the current changes appear almost evenly. After irradiating dose until 40 krad, the DAC-7512E showed a sudden increase in current due to the  $\text{Co}^{60}$

gamma-ray. Compared to the original status at 0 krad, the increase in current at 100 krad after irradiation is around 140 %.

### 3. Test Results and Discussion

There are two types of digital to analog conversion. One is a parallel type converter and the other one is a serial type converter. The two types are different register configuration in data processing. In this experiment, the three DAC-7512E serial conversion devices were used for verification of TID effects. The DAC-7512E is fabricated using a complementary metal oxide semiconductor (CMOS) process [7, 8]. The architecture consists of a string DAC followed by an output buffer amplifier [9-13]. Since there is no reference input voltage, the power supply acts as the reference. From the previous chapter 2, we knew that the current changes of the DAC-7512E appear almost evenly from 0 krad until around 30 krad. The change in current was less than 0.1 % when comparing the original current at 0 krad. However, with an increase of dose by time, the current suddenly increased around 36 krad, around 50 krad. And also, the voltage variations after 100 krad were found around 26 % decreasing when comparing to 0 krad. It means that at 0 krad the DAC output voltage produces +5 V output when writing DAC data to registers. After 100 krad irradiation, the DAC output voltage was dropped to +3.7 V according to TID level.

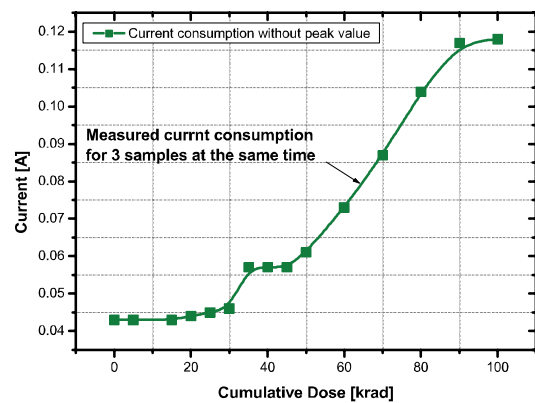
And, the waveforms for three samples were transformed into different slopes and register values as shown in Fig. 3-(a) and Fig. 3-(b). In the point of current change in accordance with  $\text{Co}^{60}$  gamma-ray irradiation, the threshold level of current for each sample was around 40 krad as shown in Figs. 4 and Fig. 5. However, some peak currents were measured at 50 krad and those values were returned to normal current state. Then, the sudden current changes were repeated until 70 krad. It was called the annealing



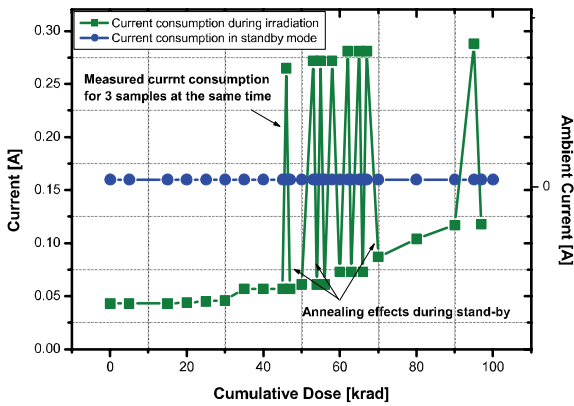
(a)

(b)

**Fig. 3.** Distorted waveforms in accordance with the cumulative dose during  $\text{Co}^{60}$  gamma-ray irradiation: (a) linearity of the DAC-7512E conversion output for device sample #1, sample #2 and sample #3 at 60 krad; (b) an internal register malfunction of the DAC-7512E during digital to analog conversion with a step 1 bit increase at 100 krad.



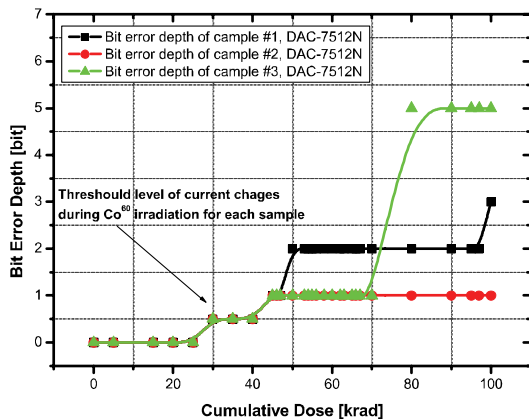
**Fig. 4.** Current variation of the DAC-7512E 12-bit digital to analog converter during  $\text{Co}^{60}$  gamma-ray irradiation, which starts at 0 krad and stops at 100 krad.



**Fig. 5.** Current variation and annealing effects of the DAC-7512E 12-bit digital to analog converter during Co<sup>60</sup> gamma-ray irradiation, which shows the annealing effect just after a fault around 50 krad.

effects during the irradiation of Co<sup>60</sup> gamma-ray. As mentioned regarding a test configuration and beam sources in chapter 2, this TID test was performed with a step by step considering total irradiation dose. Initially, Co<sup>60</sup> gamma-ray was irradiated for one hour. And then after stopping irradiation, we have measured the status of DAC-7512E samples for shape, linearity and amplitude. After that, consecutive test was continued. Therefore, some annealing effects were found during that time. However, there were no annealing effects until around 45 krad. And also, we can see the distorted waveforms depending on the TID level for each sample.

There were some different characteristics for each DAC-7512E sample compared with sample #1, sample #2 and sample #3 in Fig. 2-(b). Moreover, there were much more voltage differences between sample #1 and sample #3 at 60 krad. However, there was slight voltage change between sample #1 and sample #2 in Fig. 2-(a). Nevertheless, we have not found the device malfunction in the performance of electrical characteristics in terms of voltage and current variations as well as waveform’s linearity up to 30 krad as



**Fig. 6.** Bit error measurements of DAC-7512N devices during Co<sup>60</sup> gamma-ray irradiation from 0 krad to 100 krad.

shown in Figs. 2 and Fig. 3.

Fig. 6 shows the bit error counts of each sample from 0 krad to 100 krad. The accumulative bit error count was counted and obtained by manual from Fig. 3-(b). The DAC-7512E is composed of 12-bit depth in internal registers. From Fig. 3-(b), some peak bits were appeared by the Co<sup>60</sup> gamma-ray radiation effects. It consisted on totally 12 bits and a relative bit made an error value as shown in Fig. 6. It means that some bit errors were not affected on converter’s output characteristics, but the current change was founded in this experiment. In other words, a slight change of bit error is not a dominant factor for data conversion from digital to analog.

#### 4. Conclusion

The space industry has gone through with core electronics such as an analog to digital converter (ADC), logics and so on. One of devices such as the DAC-7512E serial digital to analog converter will be applied to NEXTSat-1 program as well as another space program in the future, because it is a useful device for reducing mass and volume. With those devices, the NEXTSat-1 has developed spacecraft bus and payloads since 2012. In addition, the NEXTSat-1 program has a lot of missions to verify space core technologies in space. One of missions for the NEXTSat-1 is technology demonstration of a resistojet propulsion system in space, thus the NEXTSat-1 required the signal isolation to avoid electrical interference for proper operation in space applications. As mentioned, the DAC-7512E 12-bit serial digital to analog converter was conducted for isolating the signals between high power consuming circuits and low power consuming circuits. However, it was not space heritage yet. A reliable system design for space program applications is a crucial point and no space heritage parts should be verified on ground test before launch. As a part of reliability test, we have performed the radiation effects for applying in space power electronics using Co<sup>60</sup> gamma-ray radiation source. In this study, we found and ensured that the DAC-7512E 12-bit serial digital to analog converter should work properly up to 30 krad TID level.

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