Total Dose Testing of Advanced Mixed Signal ADC/DAC Microcircuits

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***Abstract*-- Total dose test results are presented for the Maxim 1257/1258 multi-channel ADC/DAC, and the Linear Technology LTC2378-20 low power SAR ADC. The paper discusses radiation testing challenges of complex mixed signal circuits.**

I. Introduction

The availability of highly integrated and precision, mixed signal microcircuits developed by the commercial semiconductor industry offers opportunities for space system designers to improve monitoring and control of analog systems while reducing power and weight. However, these devices were not designed for a radiation environment, and the impact of exposure on their performance and survival are not known. Since the devices are complex and have high levels of precision, the procedures for performing radiation test and characterization can be challenging; particularly, when test time is limited and large amounts of data must be considered in determining the extent of degradation. The following paper describes test procedures and data summarization techniques as applied to total dose testing of the Maxim 1257/1258 multi-channel ADC/DAC and the Linear Technology LTC2378-20, low power, 20 bit ADC. In both cases, commercial evaluation boards and control electronics were used to exercise the devices during test and to evaluate performance during exposure

II. Maxim 1257/1258 Testing

The Maxim 1257/1258 is an integrated system for monitoring and control. It includes a 16 channel, 12 bit ADC, eight 12 bit DACs, and a 12 bit GPIO port. It communicates via a 25 MHz, SPI serial interface. The 1257 is a 3.3 volt part and the 1258 is a 5.0 volt part. Both parts have the same functionality and pinout. Figure 1 illustrates the test configuration used to perform the 1257/1258 pre-rad and post-rad characterization, to set states, and to control the device during irradiation. Control and communication with the 1257/1258 unit were implemented with a laptop computer over a USB connection through a CAT-5 cable from the instrumentation room to the Co-60 test cell. A Bus Pirate, universal bus interface, was used control the SPI bus. It is inexpensive, small, and easily shielded from radiation exposure. The DAC channels were monitored with an Analog Discovery-2 (AD-2) oscilloscope through an analog multiplexer. The AD-2 is an inexpensive instrument with 14-bit resolution, 100MS/s sampling rate, and 30MHz+ bandwidth. It is easily shielded from radiation exposure.

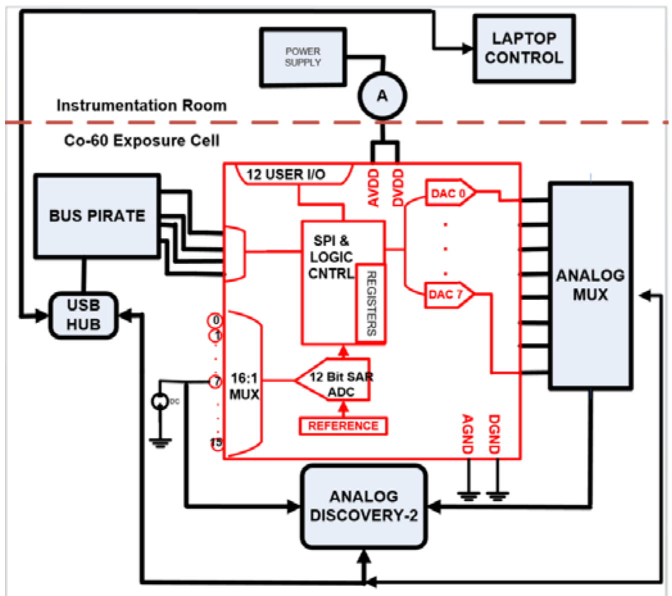

Figure 1. Max1257/1258 configuration for total dose testing

Figure 2 shows the commercial evaluation card used to interface with the microcircuit. The location of the device under test is indicated by the red arrow in the picture. Header pins were relocated to protrude on the back side of the card to facilitate shielding of other electronics on the board.

Testing was performed at the Air Force Research Laboratory ^{60}Co source at Kirtland AFB, New Mexico. A lead collimator was used to restrict the radiation to just the Max 1257/1258 under test. All other components on the board and all instrumentation were shielded. The exposure rate was 70 rad(Si)/s as measured with a RadCal 2026 traceable to NIST standards.

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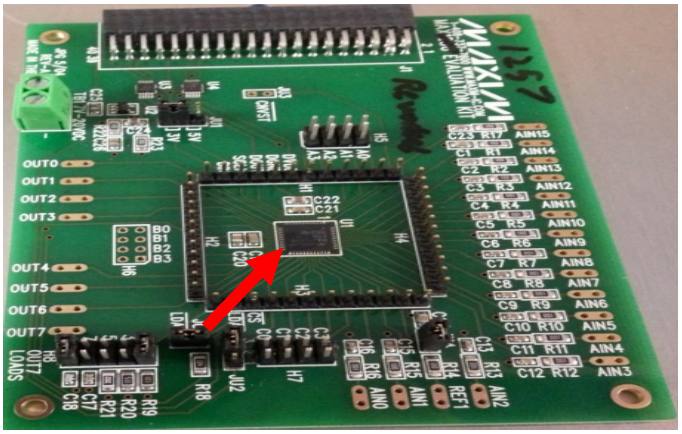

Fig. 2. Max 1257/1258 evaluation board

Power supply current was recorded just prior to all irradiations and monitored during exposure. During irradiation, the ADC input was set to mid-range, and the DACs were set to provide evenly spaced outputs over the voltage range.

For the tests reported here, the radiation response of the DACs was of particular interest. Since the available test time was limited, a technique was required to continuously monitor the DAC non-linearity and present it as a single value indicative of the degradation in performance. Consequently, a Figure of Merit (FOM) was developed as described in the flow chart in Figure 3 and illustrated schematically in Figure 4.

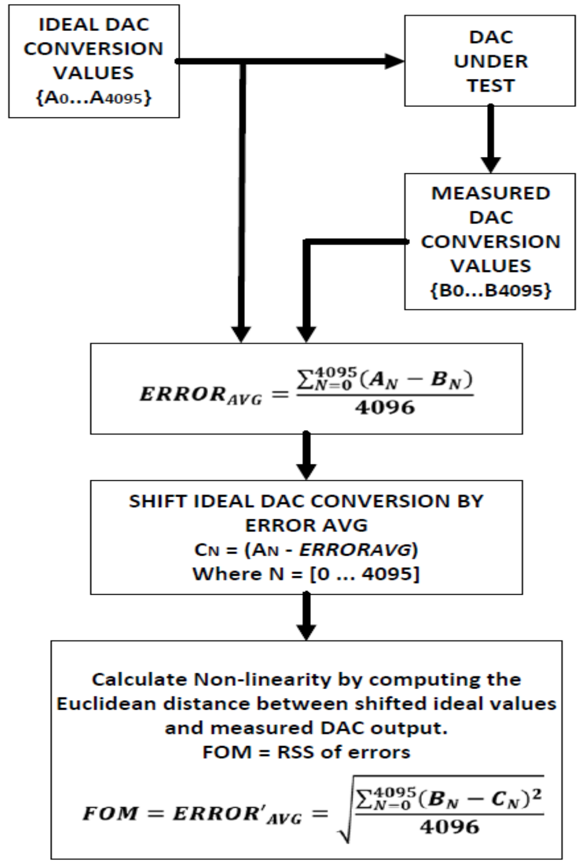

Figure 3. FOM calculation flow chart

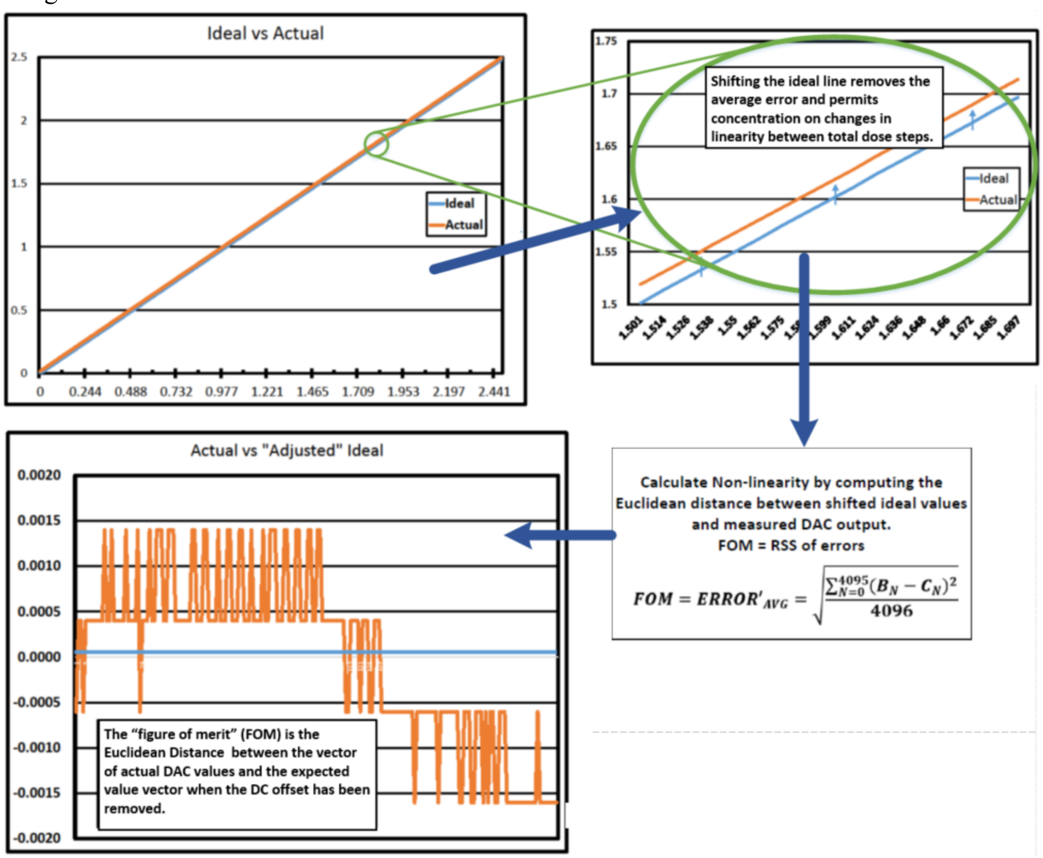

Figure 4. FOM calculation schematic

An ideal conversion curve for a 12 bit DAC was compared with the measured values as recorded by the AD-2, and an average error was calculated over the range of inputs. The ideal conversion curve was then shifted by the average error, which permitted the focus to be placed on increases in non-linearity as total dose affects accumulated. For each subsequent evaluation, a FOM was calculated as the RSS (root-sum-square) of the differences between the shifted ideal conversion curve and the radiation degraded curve.

Figure 5 shows the change in the non-linearity for the MAX 1257 device 1/channel 5 over the first 4 irradiations. Figure 6 shows the pre-radiation values of the FOM over all eight channels of the two 1257 and one 1258 devices. Figure 7 shows the variation in the FOM for all eight channels of 1257 device 1 after 30 Krad(Si) of total dose, and figure 8 shows the increase in FOM for the worst channels of each device over the range of doses. Figure 9 shows the change in power supply current as the dose increased for all three devices.

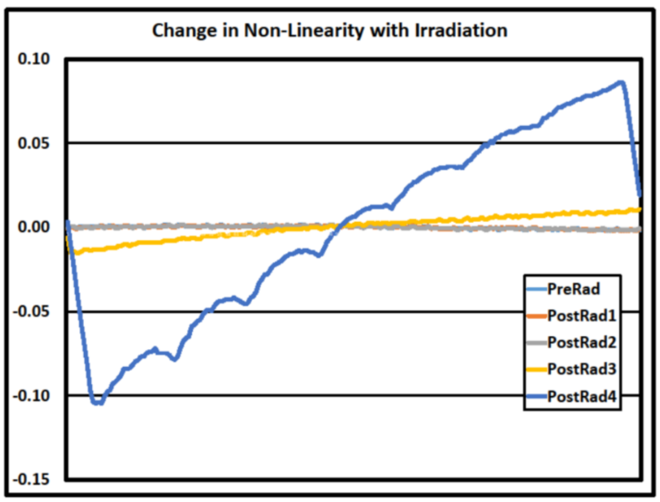

Figure 5. MAX 1257 device 1/channel 5 non-linearity

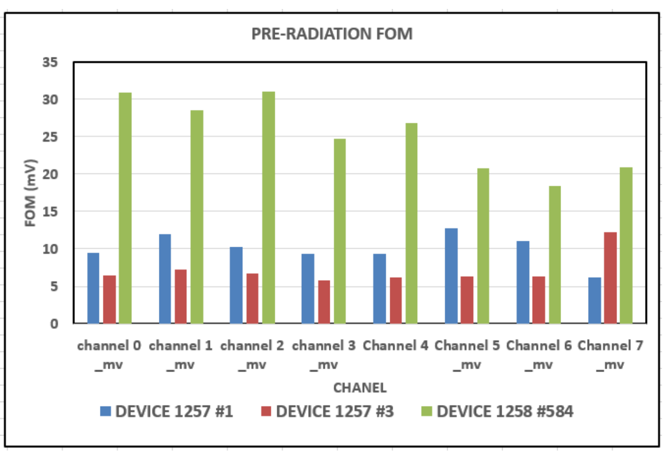

Figure 6. Pre-rad FOM variation

In summary, Two Max1257 units were tested in a step stress method. Both devices were found to be fully functional after exposure to the 5 Krad(Si) and 10 Krad(Si) steps. However, after the 15 Krad(Si) step, the supply current increased by a factor of 2 and the FOM (figure of merit) increased by a factor of 4. Both the supply current and FOM

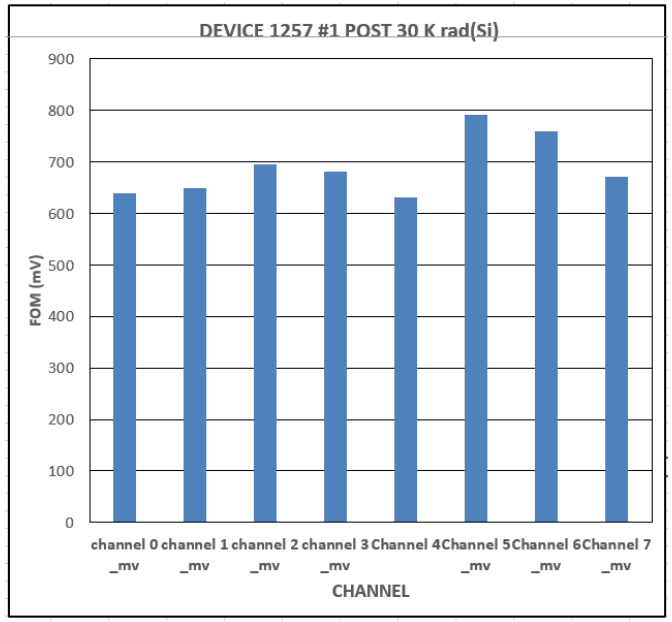

Figure 7. Post-rad FOM variations

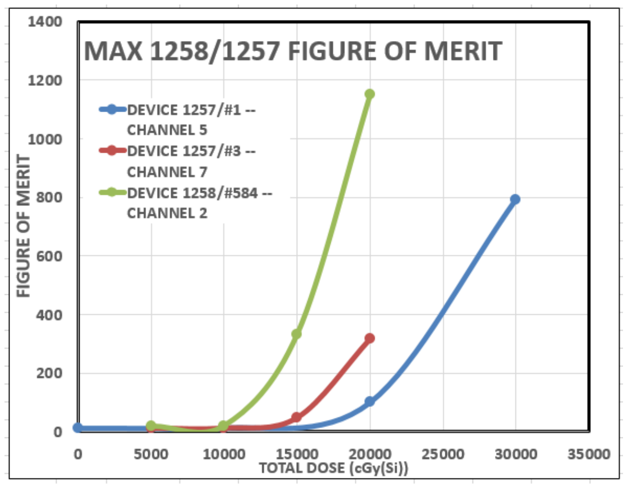

Figure 8. FOM changes with radiation for the worst channel

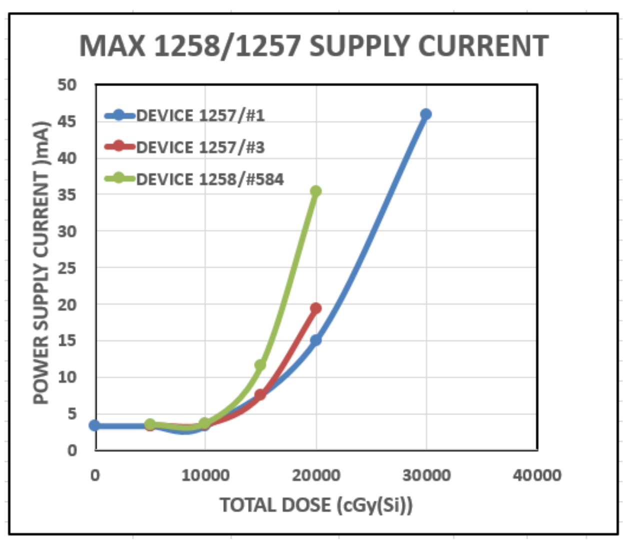

Figure 9. MAX 1257/1258 Supply current change with total dose

continued to increase at 20 Krad(Si). The tests were discontinued after 30 Krad(Si) because the FOM had increased by a factor of 62. A single Max1258 unit was also tested, and was fully functional at 5 Krad(Si) and 10 Krad(Si), but showed the same degradation in supply current and FOM at 15 Krad(Si). All three units were annealed for 168 hours at 100°C, but none of the units recovered functionality.

III. LTC2378-20 Testing

The LTC2378 is a low noise, low power, high speed (1 Msps), 20 bit SAR (successive approximation register) ADC made by Linear Technology. It operates from a single 2.5 V supply and has power down features to permit power saving when not in use. Communication is via an SPI port.

For the radiation tests, the LTC2378 was mounted on a Linear Technology DC1925A evaluation board with connections to a DC590B USB serial controller board. The block diagram of the test assembly is shown in Figure 10 and the test boards are shown in Figure 11. The tests were controlled by a laptop computer in the instrumentation room communicating with a Raspberry Pi computer module and a HiFiBerry 24bit DAC through a USB hub. The outputs were captured with a Bus Pirate and transferred to the laptop through the USB hub. The location of the LTC2378 on the test board is indicated by the red arrow in Figure 11. The position of the LTC2378 and the board connectors complicated the shielding and collimation procedure with the result that the dose rate was limited to 14.2 rad(Si)/s. The parts were fully operational during the radiation exposure, and power supply current and conversion results were actively monitored and recorded.

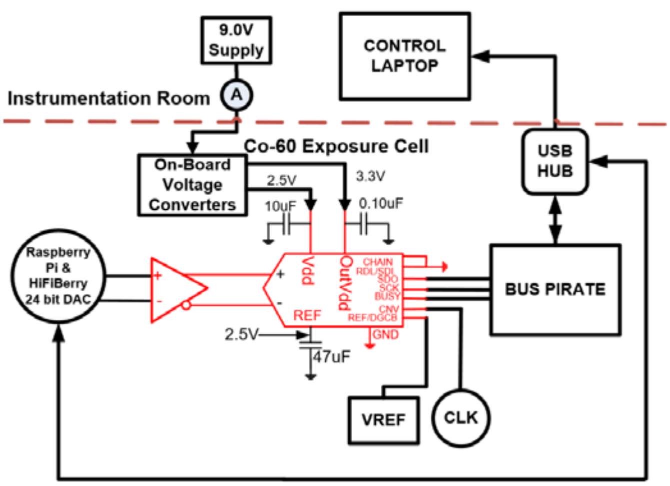

Figure 10. LTC2378-20 Configuration for total dose test

Since test time was limited, the test were conducted with the device under test fully operational during irradiation. The outputs of the conversion were continuously monitored and recorded periodically. The input signal was a saw tooth waveform from the 24bit HiFiBerry with a period of 0.1 seconds. Figure 12 compares the conversions during the first 100 seconds of irradiation with last 100 seconds. Figure 13 shows the conversion history from the beginning of irradiation through 90 Krad(Si). Degradation in the LSB values was observed beginning at 20 Krad(Si) and was progressively worse as the dose increased. Both devices were annealed under bias for 168 hours at 100°C but continued to show loss of LSBs.

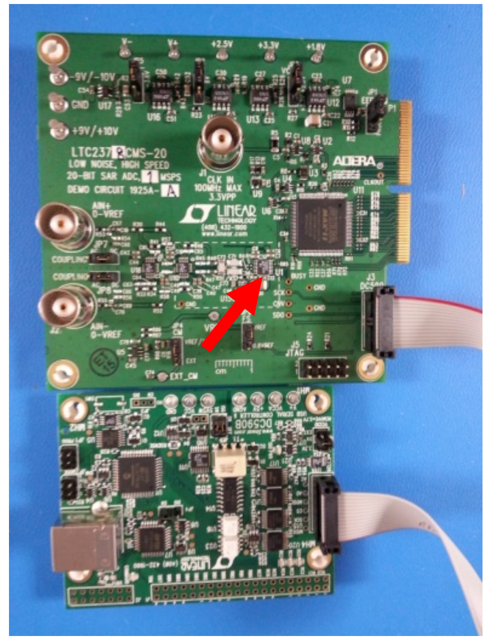

Fig. 11. LTC2378-20 evaluation board

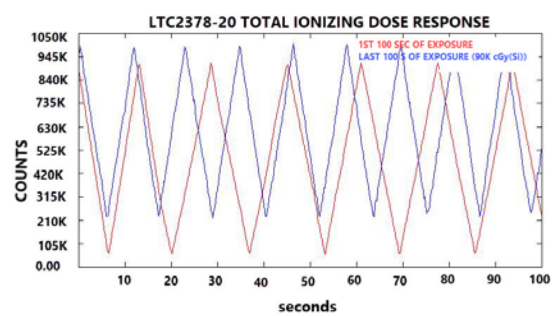

Figure 12. LTC2378 Conversion: 1ST 100 secs compared to last 100 secs

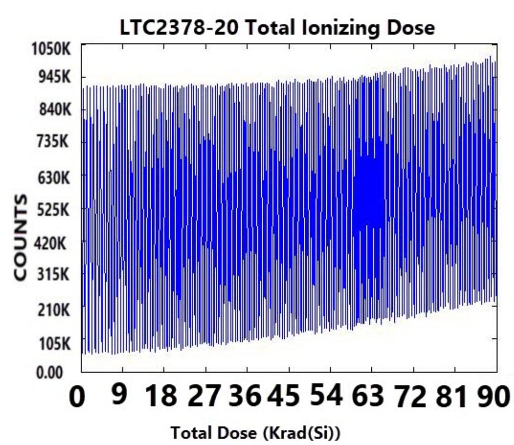

Figure 13. LTC2378-20 Conversion Over 90 Krad(Si) Exposure.

IV. SUMMARY

Total dose tests were conducted on two commercial mixed signal microcircuits with characteristics including low power requirements and advanced functionality. While neither exhibited the radiation tolerance needed for long mission life or the most radiation intensive orbits, both demonstrated a level of hardness consistent with some low earth orbits of limited duration. The use of commercial evaluation boards enabled the hardness evaluation of these parts with a minimal investment in sample preparation. However, compromises in testing dose rate had to be made to accommodate the complexity of collimating the radiation to prevent exposing other parts. Actively exercising and monitoring mixed signal microcircuits can provide improved insight into the radiation induced degradation of the devices as a function of dose. Active monitoring also reduces test time by eliminating the need to stop the irradiation to characterize performance. Examples have been given for the use of a figure of merit for summarizing the increase of non-linearity and for monitoring continuous conversions to identify loss of LSBs.

V. REFERENCES

[1] Maxim Integrated Products, Inc., MAX1220/MAX1257/MAX1258 Data Sheet, 19-3295; Rev 8; 1/15.

[2] Linear Technology Corporation, LTC2378-20 Data Sheet, LT 0315 REV A