Total Ionizing Dose Test of Analog Devices' AD654 Voltage to Frequency Converter

B. Freeman[1], M. Campola[1]

1. NASA Goddard Space Flight Center
Code 561.4, Radiation Effects and Analysis Group
8800 Greenbelt Rd
Greenbelt, MD 20771

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1. Introduction

Analog Devices' AD654 was tested for total ionizing dose (TID) response beginning on February 13, 2017. This device has the Radiation Effects and Analysis Group Identification (REAG ID) number 16-036. This test served as the radiation lot acceptance test (RLAT) for the lot date code (LDC) tested. Low dose rate (LDR) irradiations were performed in this test so that the device susceptibility to enhanced low dose rate sensitivity (ELDRS) could be determined.

2. Devices Tested

2.1. AD654 Voltage-to-Frequency Converter Background

The AD654 is a voltage to frequency converter comprised of an input amplifier, an oscillator system, and a high current output stage. The full scale (FS) input voltage can range from -30 V to +30 V, drive up to 12 transistor-transistor logic loads, optocouplers, or long cables, and outputs a FS square-wave frequency up to 500 kHz.

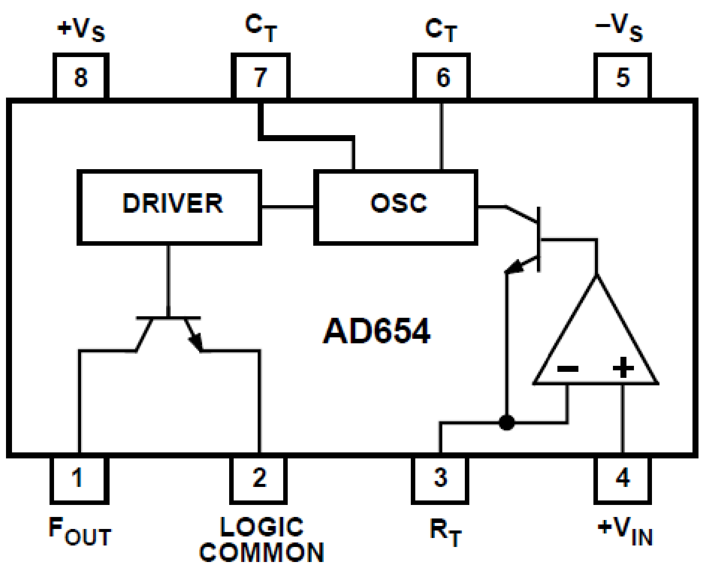

Figure 1: Functional block diagram and pin connections for the AD654.

The maximum output frequency of the device is controlled by a timing capacitor (C_T) and a timing resistor (R_T):

Equation 1. Output frequency

$$f_{out} = \frac{V_{In}}{(10V)R_T C_T}$$

2.2. Device under Test (DUT) Information

Four unbiased AD654s were irradiated at an average dose rate of 8 mrad (Si)/s using a ^{60}Co source with all pins grounded. An additional device was used as a control. These five devices were packaged in an 8-lead standard small outline package (SOIC) with a narrow body.

Table 1: Part Information

Part Number:	AD654
Manufacturer:	Analog Devices
Date Code:	0630
Additional Case Makings:	940388.1
Quantity Tested:	4, Plus 1 Control
Part Function:	Voltage-to-Frequency Converter
Part Technology	Bipolar
Package Style	SOIC 8

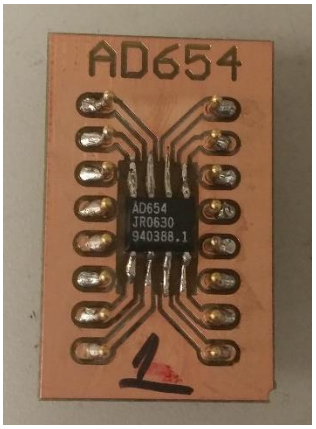

Figure 2: AD654 in an SOIC 8 package soldered to a daughter card for ease of testing.

3. Test Setup

In order to test the AD654s, each device was soldered to a daughter card and then the daughter card was placed into a test board containing a timing resistor (R_T) and capacitor (C_T) of 4700 Ω and 330 pF, respectively.

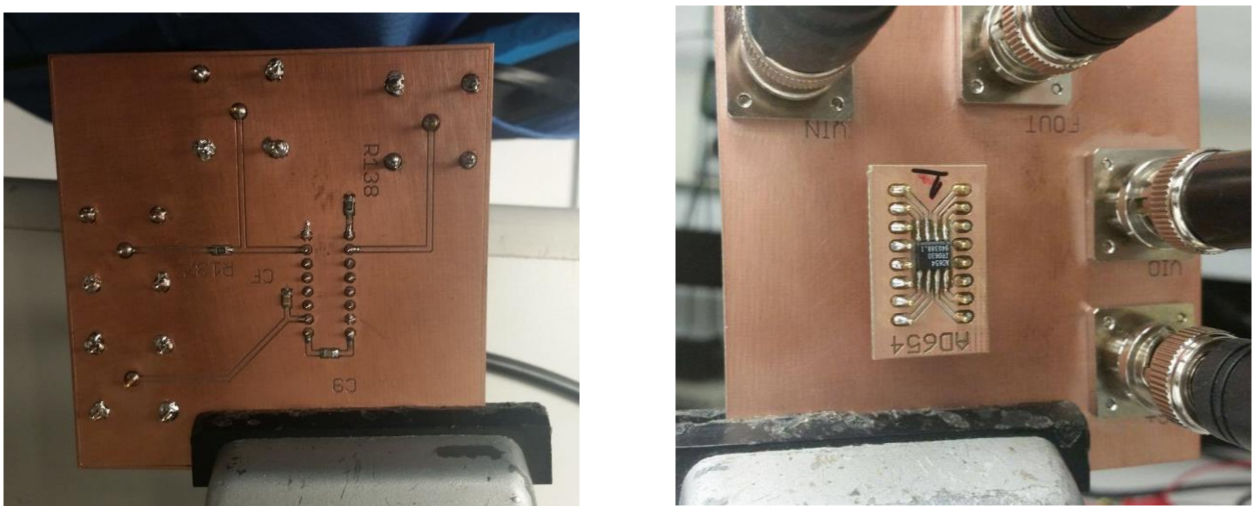

Figure 3. Front and Back of test board

The test setup used a Tektronix oscilloscope to read the frequency output from the device, a Keithley three channel power supply, and a Keithley multimeter to measure the quiescent current. The scope, power supply, and multimeter were connected to the test board via BNC cables.

Figure 4. Tektronix oscilloscope used

Figure 5. Keithley multimeter (top) and three channel power supply (bottom) used

The source voltage used was 12 V, the input voltage was varied between 0-5 V, and the third input/output voltage was 3.3 V in order to replicate the application.

4. Test Description

4.1. Irradiation Conditions and Step Stress

A ^{60}Co source, compliant with MIL-STD-883 Method 1019 Condition D, was used to irradiate the four devices at a LDR with one AD654 being kept as a control. The maximum dose rate was 10 mrad (Si)/s. Prior to the first radiation dose, all five devices were electrically tested to confirm that they were within the specifications given by data sheet. After each exposure level, given in **Error! Reference source not found.**, the samples were tested again. Electrical tests performed are given in Table 3.

Table 2: Device Grouping and Dose-Stress Instructions

Group	Type	Quantity	Bias	Dose Rate	Exposure Level Steps (krad(Si))
1	AD654	4	Unbiased	LDR 10 mrad(Si)/s	0, 1, 2, 5, 10, 15, 20, 30, 40

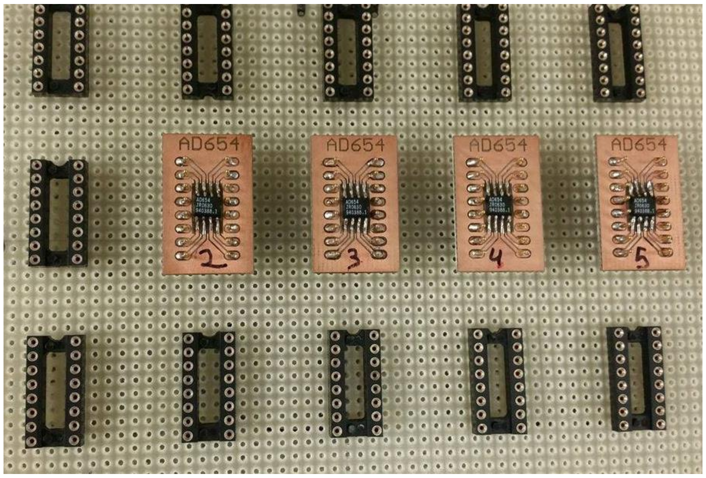

Figure 6. Board used to ground all leads in the test chamber.

Electrical tests were performed in accordance with AD654 datasheet revision C. All test conditions listed for the following parameters were tested.

Table 3: List of Electrical Tests Performed

Test	Symbol	Conditions V_S = +12 V V_{IO} = 3.3 V C_T = 330 pF R_T = 4.7 kΩ	Specifications Min	 Max
Quiescent Current	I_S	V_{In} = 0 V	1.5 mA	3 mA
Output Frequency	F_{Out}	V_{In} = 0 V to 5 V	0 Hz	500 kHz

In addition, the positive signal width (t^+) and rise time (t_{Rise}) were measured for each component.

5. Results

The output frequency, positive pulse width, rise time, and quiescent current of each AD654 were examined. Average values for each dose step have been plotted with error bars calculated using K_{TL}, the one-sided tolerance limit. The K_{TL} value for four samples with a worst case of 99% and 90% confidence was 5.437.

Of the five AD654 voltage to frequency converters, one device was kept as a control while the other four were irradiated. Irradiation was performed under unbiased conditions since bipolar devices experience more degradation with all leads grounded.

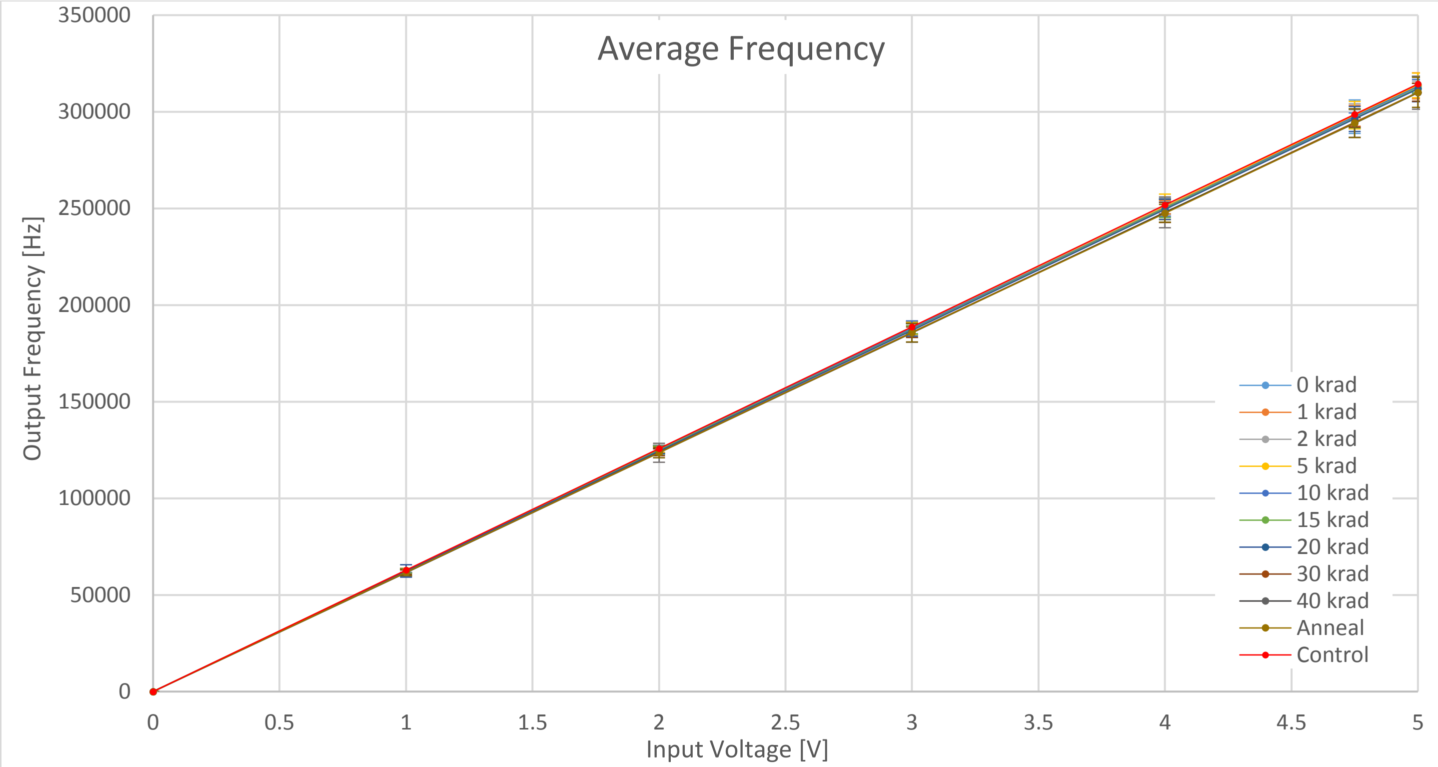

Figure 7. Average output frequency compared to control device.

In general, the measured output frequencies were slightly higher than the calculated output frequency determined from Equation 1 using values measured for the timing resistor and capacitor. Before irradiation, at 0 krad, each device had an output frequency that was higher than the output frequency calculated from Equation 1. The largest percent error occurred for the control device and was calculated to be 1.44%. Unit #3 had the smallest percent error at 0.85%. As the radiation dose increased, the percent error comparing the measured frequency to the calculated frequency gradually decreased. At 40 krad, unit #3 had the smallest percent error at 0.13% while the control stayed about the same with a 1.41% error.

While there was a slight decrease in the average output frequency in Figure 7, the change was respectively small. The error bars also became more spread with increasing voltage.

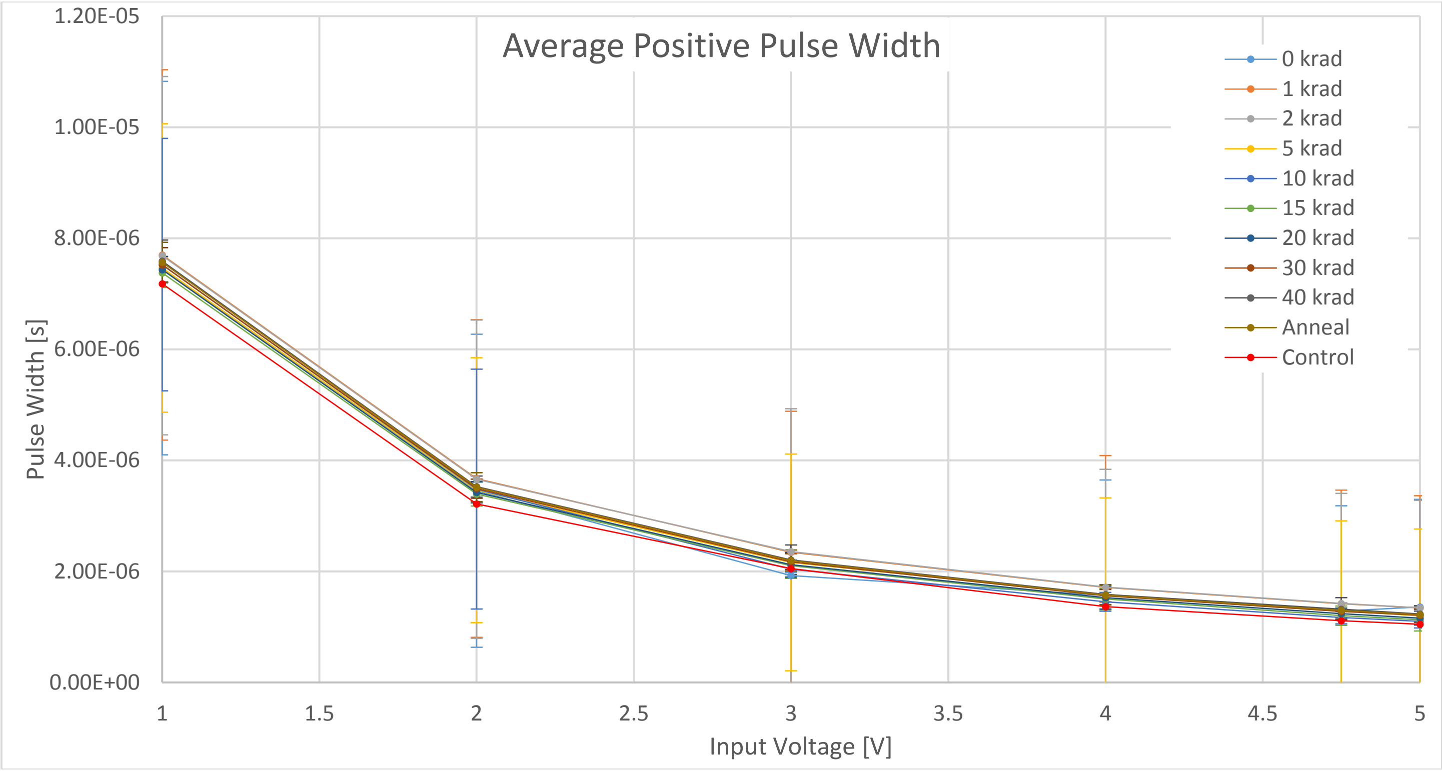

Figure 8. Average positive pulse width compared to control device.

While the average positive pulse width did increase in Figure 8 when the devices were irradiated, the small change did not become larger with increasing dose.

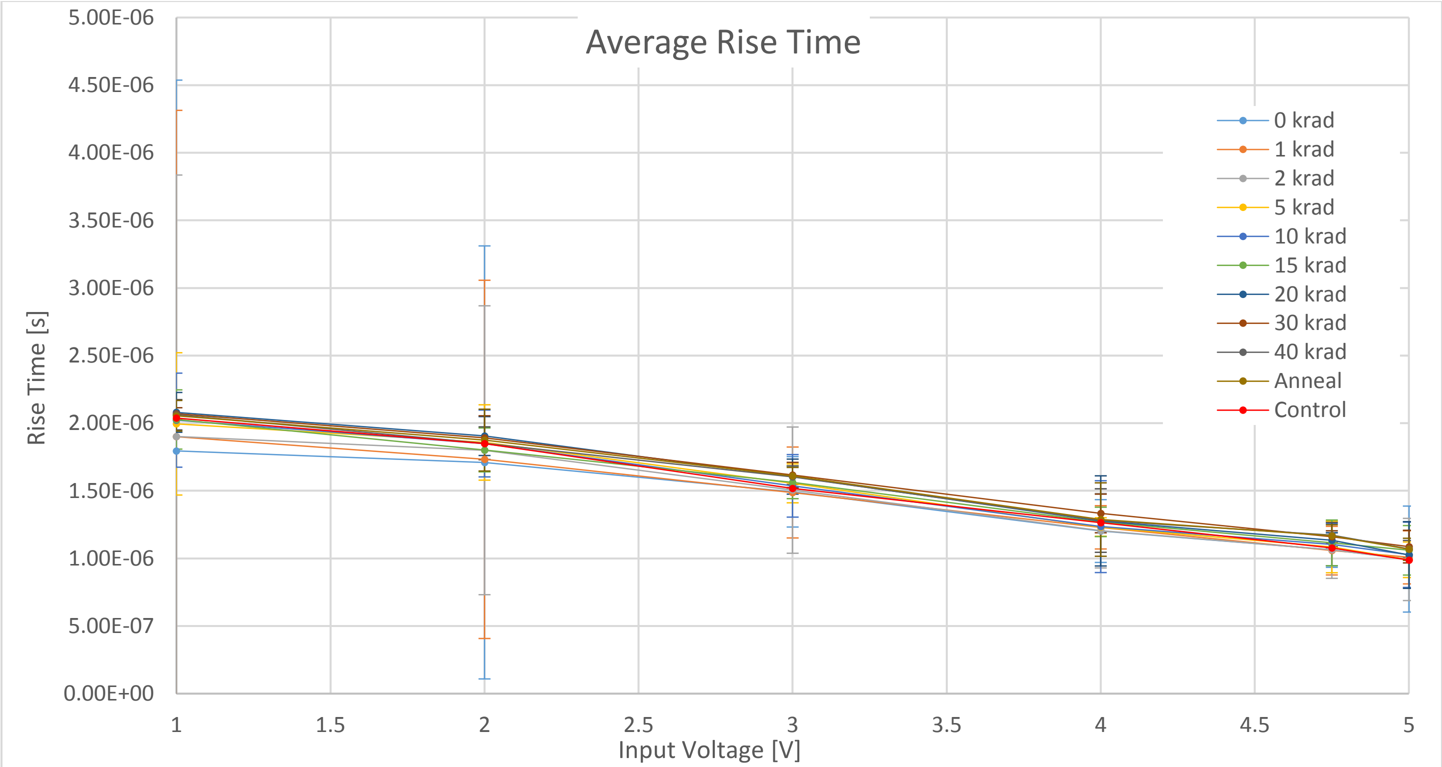

Figure 9. Average rise time compared to control device.

In general in Figure 9, the average rise time increased slightly with increasing dose. It should be noted that the averages given for the lower dose steps, 0 krad to 5 krad, were affected by unit #5, which had a particularly fast rise time, as seen in Figure 10a. This phenomena is seen in the wide range of the error bars.

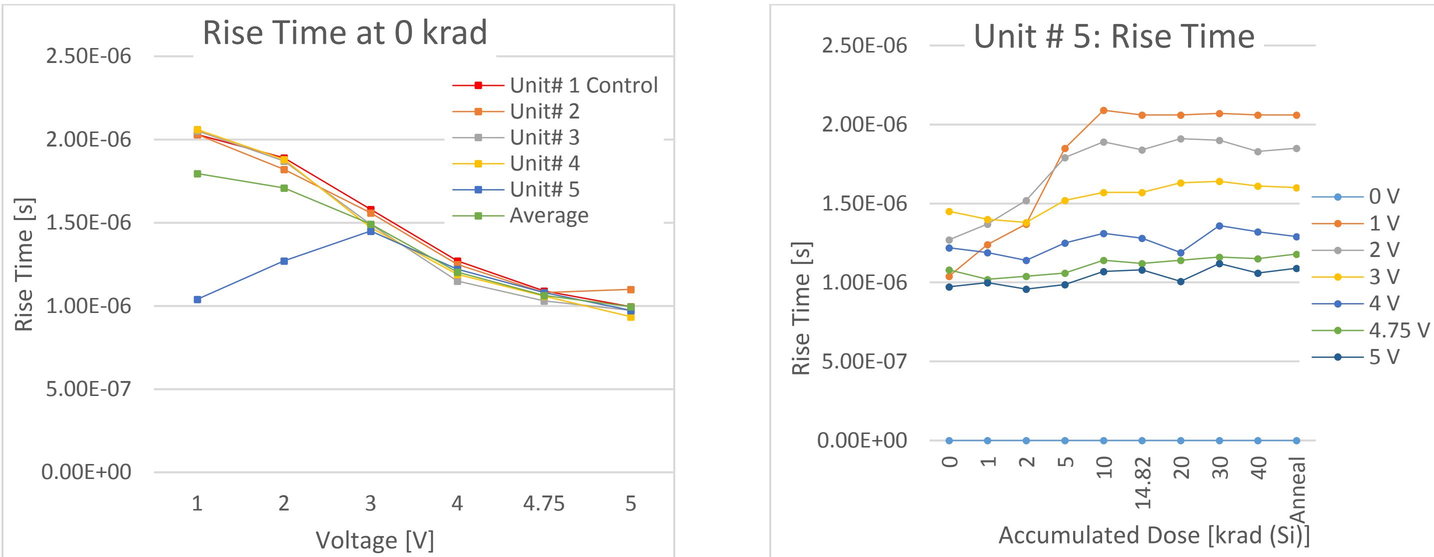

Figure 10a. Rise time of each device before radiation. Figure 10b. Rise time of unit #5 over dose steps.

Figure 10b shows the effect of radiation on unit #5, which was more sensitive, over increasing dose. In general, the radiation caused the device to have a slower rise time. Eventually after 5 krad, unit #5 had a similar rise time when compared to the other devices.

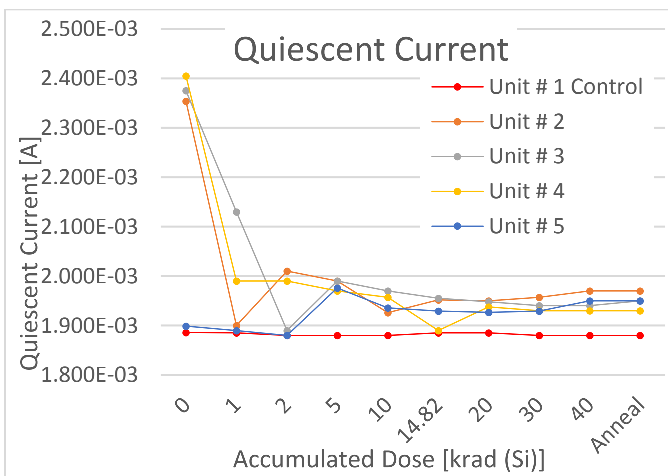

Figure 11. Quiescent current of each device compared to control.

When examining the quiescent current, measured when V_{In} was 0 V, of each device in Figure 11, the radiation did not have a significant effect. At the beginning of testing, there were some cold solder joints that affected the quiescent current of some of the devices. However, since the current was within the range given by the data sheet, the data did not appear to be uncharacteristic at the time. Later in testing, the solder was redone and the problem remedied.

6. Conclusions

Overall, all five devices remained functional throughout the duration of the test. Regardless of the radiation dose, all five devices had output frequencies that were higher than the calculated output frequency determined from the timing resistor and capacitor. The average pulse width slightly increased when the devices were irradiated, but this difference did not increase with increasing dose. The average rise time did increase with increasing dose, but results at lower dose steps were affected by one device with a particularly fast rise time. That one device did experience a slower rise time when radiation was applied, but the unit settled at a rise time similar to the other devices, which were unaffected. The radiation did not have a significant effect on the quiescent current of each device.