NASA/TM–20210009960

Linear Systems LSK389 and LSK489 Dual N-Channel JFET Amplifier Total Ionizing Dose and Single-Event Effects Test Report

Ray Ladbury

March 2021

NASA STI Program ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at http://www.sti.nasa.gov

- E-mail your question to help@sti.nasa.gov

- Phone the NASA STI Information Desk at 757-864-9658

- Write to:
  NASA STI Information Desk
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/TM–20210009960

Linear Systems LSK389 and LSK489 Dual N-Channel JFET Amplifier Total Ionizing Dose and Single-Event Effects Test Report

Ray Ladbury
Goddard Space Flight Center, Greenbelt, MD

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

March 2021

Level of Review: This material has been technically reviewed by technical management.

Available from

NASA STI Program
Mail Stop 148
NASA’s Langley Research
Center Hampton, VA
23681-2199

National Technical Information
Service 5285 Port Royal Road
Springfield, VA 22161
703-605-6000

Linear Systems LSK389 and LSK489 Dual N-Channel JFET Amplifier Total Ionizing Dose and Single-Event Effects Test Report

Ray Ladbury
Principal Investigator
NASA Goddard Space Flight Center

Test Dates: August 27, 2018 (SEE), October 2018 (TID)
Test Report Date: February 3, 2021

1. Purpose

The purpose of these tests was to characterize the susceptibility of the LSK389 and LSK489 Dual N-Channel JFET from Linear Systems to Single-Event Latchup due to heavy ions and to Total Ionizing Dose (TID) degradation at -65 °C and intermediate dose rate. The test was carried out to assess suitability of the amplifiers for the Ocean Color instrument (OCI) on the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) spacecraft.

2. Test Samples

Parts were supplied by Linear Systems as die. In the course of investigating these parts, it was discovered that the two FETs share a common substrate, and so there is a pnpn structure that could be sensitive to latchup. This had two consequences. First, it raised the possibility that the parts could be susceptible to single-event latchup, despite not being CMOS. Second, an application note recommended that the parts be bonded with source tied to substrate. It was decided to test the parts for both SEL and TID susceptibility for two different packages—one with the substrate bonded to the drain and other with the substrate floating. At the same time, it was decided that parts would only be tested in the biased condition, because the amount of time the parts spend unbiased in their application is negligible.
Up to 6 JFET amplifiers (LSK389 or LSK489) were packaged in a 200-pin flatpack (see figure 1). If the substrate was to be tied to the drain of the part, the die was bonded to the package with conductive epoxy.

Two JFET pairs of each part type were supplied in the conductively bonded packages for SEL testing. Four JFET pairs of each part type were supplied for SEL testing in packages that were not conductively bonded. Given what is known about the putative latchup mechanism in these parts the nonconductively bonded parts would be expected to be more likely to be SEL susceptible. For SEL, parts were biased with VDS=3.5 V and VGS between -0.15V and -1V. Tests were conducted at room temperature, which, given the application temperature of -65 °C, should conservatively bound the SEL susceptibility for the application.

For TID, ten (10) samples of each part type from the flight lot of parts in each package configuration were provided by instrument designers, packaged and delivered to the Radiation Group at GSFC. Six (6) of each part/package type were designated test parts, and 4 of each part/package were designated as control parts. The parts were procured as die from Linear Systems and packaged by code 553. It is not expected that the substrate bonding will affect TID performance, but both configurations are being tested out of an abundance of caution. All test parts were irradiated in the biased configuration depicted in figure 2.

Table 1: Part Identification Information

Qty	Part Number	LDC	Source	Package
13 (6 nonconductively bonded, 6 conductively bonded + 2 controls)	LSK389	n/a	Linear Sciences/pkg'd by Code 553	6-die to 200-pin flat-pack
13 (6 nonconductively bonded, 6 conductively bonded + 2 controls)	LSK489	n/a	Linear Sciences/pkg'd by Code 553	6-die to 200-pin flat-pack

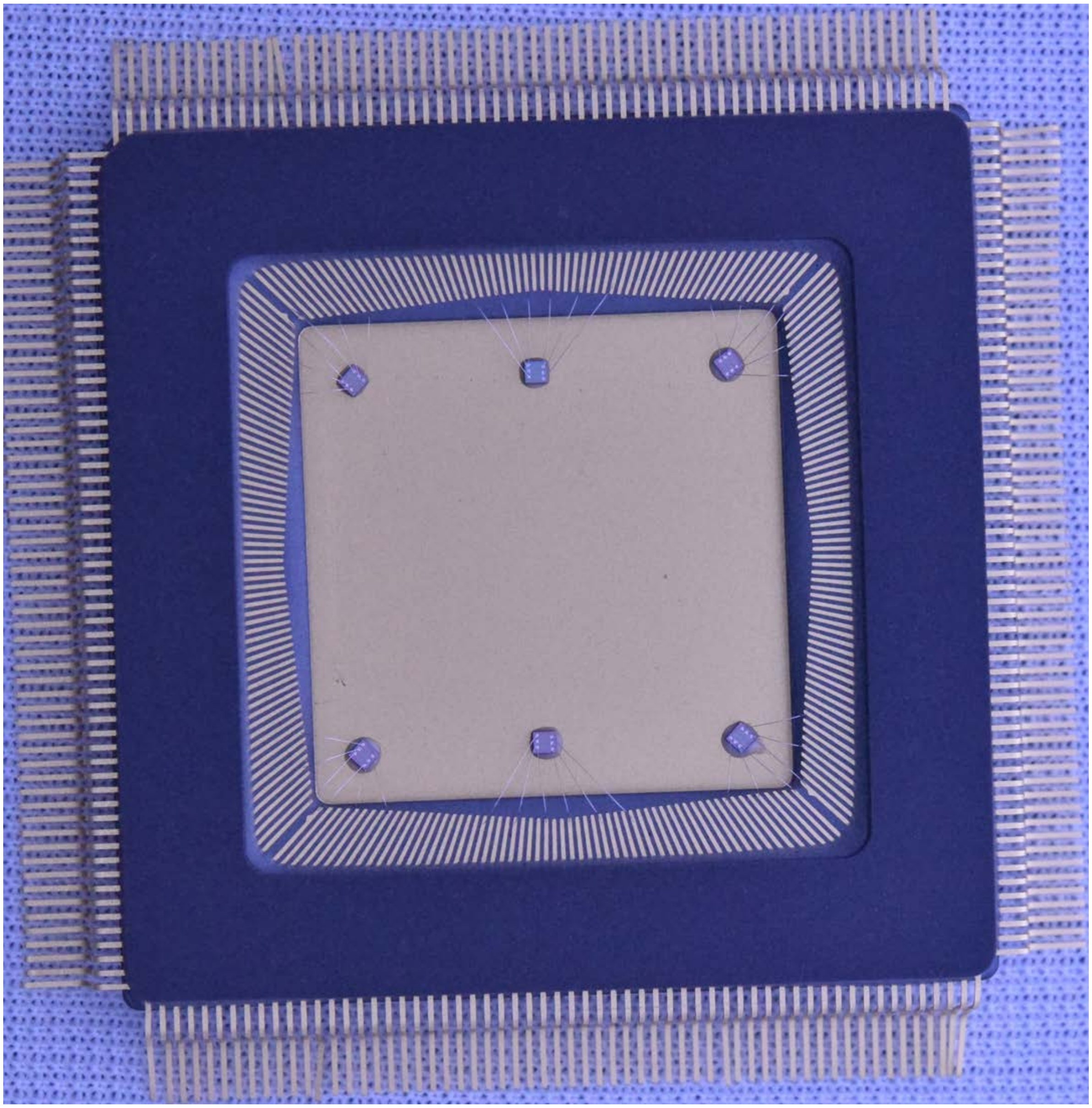

Figure 1 Pinout of the LSK389 and LSK489.

Biased parts were biased as in Figure 2, while unbiased parts were irradiated with all pins grounded.

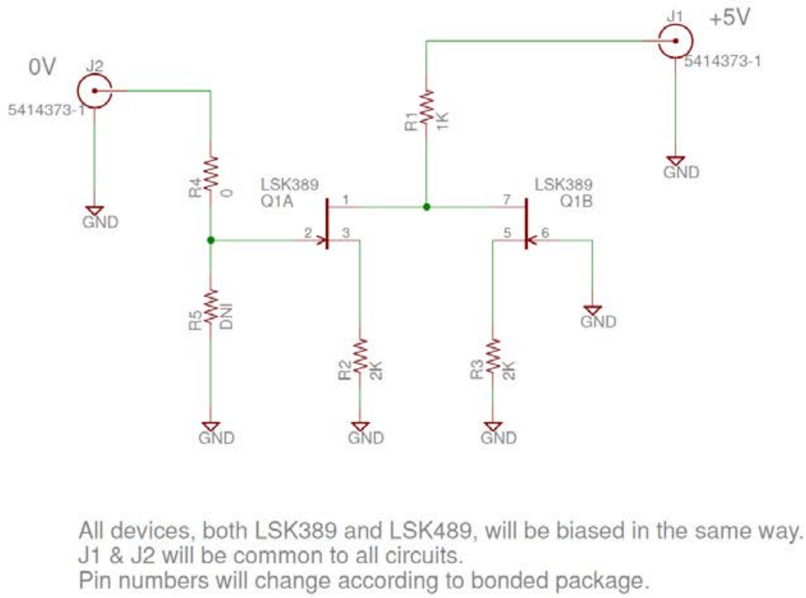

Figure 2 Bias circuit for LSK389 and LSK489 amplifiers.

3. General

SEL testing was done at Lawrence Berkeley National Laboratory using their 88-inch cyclotron. The ion used was Ag with an energy of 1039 MeV (10 MeV per nucleon), an LET of 48.15 MeVcm^2/mg and a range of 90 microns in Si. These beam characteristics more than satisfy the PACE requirements for destructive SEE testing.

TID tests were performed at the Goddard Space Flight Center using their gamma radiation source. Parts were serialized and separated into biased and unbiased test groups and control groups. Two parts of each type were designated controls. The test group were defined as the 5 parts with the closest pre-rad parametric performance. The remaining part served as the control and was not irradiated. The test group was irradiated to doses of 1, 3, 6 10, 20, 30, and 50 krad(Si), and was characterized for functional and parametric degradation along with the control part prior to the first irradiation step and at the end of each subsequent step.

Heavy-Ion Accelerator: Lawrence Berkeley National Laboratory 88-inch cyclotron
Ion: 10 MeV/AMU Ag (1039 MeV)
Ion Range: 90 microns
Ion LET: 48.15 MeVcm^2/mg

TID Facility: Goddard Space Flight Center Radiation Effects Facility (REF)
Dose rate: 1 rad(Si)/s < dose rate < 50 rad(Si)/s
Dose Steps: 1, 3, 6, 12, 25 krad(Si)

4. Test Conditions and Error Modes

Test Temperature: Irradiation, testing and annealing shall be done at room temperature.
Operating Conditions: Test group biased as in Figure 2.
Parameters of Interest: Parametric characteristics for the two part types.

Table II: Matching & Electrical Performance Characteristics from LSK389 Datasheet

Matching Characteristics @ 25°C (unless otherwise stated)

SYMBOL	CHARACTERISTIC	MIN	TYP	MAX	UNITS	CONDITIONS
$\lvert V_{GS1} - V_{GS2} \rvert$	Differential Gate to Source Cutoff Voltage			20	mV	V_{DS} = 10V, I_D = 1mA
$\frac{I_{DSS1}}{I_{DSS2}}$	Gate to Source Saturation Current Ratio	0.9			---	V_{DS} = 10V, V_{GS} = 0V

Electrical Characteristics @ 25°C (unless otherwise stated)

SYMBOL	CHARACTERISTIC		MIN	TYP	MAX	UNITS	CONDITIONS
BV_{GSS}	Gate to Source Breakdown Voltage		-40			V	V_{DS} = 0, I_D = -100μA
$V_{GS(OFF)}$	Gate to Source Pinch-off Voltage		-0.15		-2	V	V_{DS} = 10V, I_D = 0.1μA
I_{DSS}	Drain to Source Saturation Current	LSK389A	2.6		6.5	mA	V_{DS} = 10V, V_{GS} = 0
I_{DSS}	Drain to Source Saturation Current	LSK389B	6		12	mA	V_{DS} = 10V, V_{GS} = 0
I_{DSS}	Drain to Source Saturation Current	LSK389C	10		20	mA	V_{DS} = 10V, V_{GS} = 0
I_{DSS}	Drain to Source Saturation Current	LSK389D	17		30	mA	V_{DS} = 10V, V_{GS} = 0
I_{GSS}	Gate to Source Leakage Current				-200	pA	V_{GS} = -30V, V_{DS} = 0
I_{G1G2}	Gate to Gate Isolation Current				±1.0	μA	V_{G1-G2} = ±45V, I_D = I_S = 0A
G_{fs}	Full Conduction Transconductance		8	20		mS	V_{DS} = 10V, V_{GS} = 0, f = 1kHz
e_n	Noise Voltage			1.9		nV/√Hz	V_{DS} = 10V, I_D = 2mA, f = 1kHz, NBW = 1Hz
e_n	Noise Voltage			4.0		nV/√Hz	V_{DS} = 10V, I_D = 2mA, f = 10Hz, NBW = 1Hz
C_{ISS}	Common Source Input Capacitance			25		pF	V_{DS} = 10V, V_{GS} = 0, f = 1MHz,
C_{RSS}	Common Source Reverse Transfer Cap.			5.5		pF	V_{DG} = 10V, I_D = 0, f = 1MHz,

Table III: Matching & Electrical Performance Characteristics from LSK489 Datasheet

MATCHING CHARACTERISTICS @ 25°C (unless otherwise stated)

SYMBOL	CHARACTERISTIC	MIN	TYP	MAX	UNITS	CONDITIONS
$\|V_{GS1} - V_{GS2}\|$	Differential Gate to Source Cutoff Voltage			20	mV	V_{DS} = 10V, I_D = 1mA
$\frac{I_{DSS1}}{I_{DSS2}}$	Gate to Source Saturation Current Ratio	0.9		1.0		V_{DS} = 10V, V_{GS} = 0V
CMRR	**COMMON MODE REJECTION RATIO** -20 log $\|\Delta V_{GS1-2}/\Delta V_{DS}\|$	95	102		dB	V_{DS} = 10V to 20V, I_D = 200μA

SYMBOL	CHARACTERISTIC	MIN	TYP	MAX	UNITS	CONDITIONS
e_n	Noise Voltage		2.0		nV/√Hz	V_{DS} = 15V, I_D = 2.0mA, *f* = 1kHz, NBW = 1Hz
e_n	Noise Voltage		3.5		nV/√Hz	V_{DS} = 15V, I_D = 2.0mA, *f* = 10Hz, NBW = 1Hz
C_{ISS}	Common Source Input Capacitance		4	8	pF	V_{DS} = 15V, I_D = 500μA, *f* = 1MHz
C_{RSS}	Common Source Reverse Transfer Capacitance			3	pF	

ELECTRICAL CHARACTERISTICS @ 25°C (unless otherwise stated)

SYMBOL	CHARACTERISTIC	MIN	TYP	MAX	UNITS	CONDITIONS
BV_{GSS}	Gate to Source Breakdown Voltage	-60			V	V_{DS} = 0, I_D = -1nA
$V_{(BR)G1-G2}$	Gate to Gate Breakdown Voltage	±30	±45		V	I_G= ±1μA, I_D=I_S=0 A (Open Circuit)
$V_{GS(OFF)}$	Gate to Source Pinch-off Voltage	-1.5		-3.5	V	V_{DS} = 15V, I_D = 1nA
V_{GS}	Gate to Source Operating Voltage	-0.5		-3.5	V	V_{DS} = 15V, I_D = 500μA
I_{DSS}^2	Drain to Source Saturation Current	2.5	5	15	mA	V_{DG} = 15V, V_{GS} = 0
I_G	Gate Operating Current		-2	-25	pA	V_{DG} = 15V, I_D = 200μA
			-0.8	-10	nA	T_A = 125°C
I_{GSS}	Gate to Source Leakage Current			-100	pA	V_{DG} = -15V, V_{DS} = 0
G_{fs}	Full Conductance Transconductance	1500			μS	V_{DG} = 15V, V_{GS} = 0, *f* = 1kHz
G_{fs}	Transconductance	1000	1500		μS	V_{DG} = 15V, I_D = 500μA
G_{OS}	Full Output Conductance			40	μS	V_{DG} = 15V, V_{GS} = 0
G_{OS}	Output Conductance		1.8	2.7	μS	V_{DG} = 15V, I_D = 200μA
NF	Noise Figure			0.5	dB	V_{DS} = 15V, V_{GS} = 0, R_G = 10MΩ, *f* = 100Hz, NBW = 6Hz

The parameters of interest for the OCI application mainly include IDS and IGS as a function of VDS and VGS, and these were tested prior to irradiation and at each irradiation step. The behavior near the application voltages (VDS = 3 V and VGS = -1V) is of particular interest. In addition, the voltage across a 2 kΩ source resistor were measured as a function of VGS, and IGSS will be measured at VGS = -5V and VGS = -15V.

5. Test Methods

SEL Test: Parts were mounted in sockets on test boards and verified functional prior to the test. The parts mounted on the board were mounted on a fixture in the beam line's vacuum chamber. The vacuum chamber was pumped to the desired pressure, and the parts were again verified functional. From the control room, the desired ion was selected and the beam tune completed. All testing was carried out with angles at normal incidence. Again verifying functionality, the beam-line shutter was opened and the parts were irradiated to the desired fluence. During the irradiation, the part was monitored for any transients. Very few if any were seen. After the irradiation, the part was again tested for functionality. The test was repeated until all test parts had been irradiated.

TID Test: All parts were verified functional prior to commencement of the test. Parametric measurements were made of the parameter of interest and all readings recorded. The test parts were mounted to sockets on bias boards as in Figure 2. An anti-static bag was purged with dry nitrogen, and the parts inserted, the bag being sealed to the extent possible given the wires connected to the parts. The bag-board ensemble was then inserted into a Styrofoam cooler full of dry ice that had also been purged with dry nitrogen. The wires were passed through openings in the cooler, and the ensemble placed in a Pb/Al box and placed a distance from the radiation source such that the dose rate was between 1 and 50 rads(Si)/s. The dose rate was verified using the ionization probe. Once the dose rate was verified, the parts were irradiated to their first dose step. They were then characterized for functionality and degradation of the parameters of interest. All parametric readings were recorded.

Once the parametric testing was concluded, the parts were returned to the TID chamber as before, biased as before, the dose rate confirmed by measurement and irradiated to the next dose step.

Parametric measurement and step irradiation continued until
1) the parts fail functionally, or
2) the parts have been dosed to 25 krad(Si).

Data were made available to the PI as they were collected, so that he could keep the project appraised.

6. Radiation Test execution

- The radiation test engineer was present at the commencement and termination of each dose step to receive the parts for characterization.
- There were no deviations from the above procedure
- After the termination of the test, the parts shall be stored for at least one year in case additional assessment is required.

7. Data Logging

- Data were logged pre-irradiation and at each irradiation step
- An Excel file summarizing the data was provided to the project

8. Results

SEL Test Results: No high-current conditions were seen for any of the parts regardless of part type of package/bonding configuration. Since the test ion LET was 48.15 $MeVcm^2/mg$, well above the PACE requirement, and the parts were tested at room temperature, while the application temperature is -65°C, the parts can be considered SEL immune for the purposes of the OCI application, regardless of part type or package/bonding configuration.

TID Test Results: With two JFETs per part, two part types and two package types and 5 dose steps, and since the data for each part is IDS and IGS over a range of VGS/VDS, the number of plots could easily become unmanageable in this test report. For this reason, we present results for only pre-irradiation and changes from the pre-irradiation levels for the qualification dose of ~6 krad(Si). Since the parts showed little degradation at any dose step, most of the results represent noise from the test equipment, especially around the application voltages of interest. We present average values of all test parts to minimize the noise and fluctuations, although we also investigate part-to-part variability by tracking standard deviations for each part type, as well as the minimum and maximum for all parts for each datapoint.

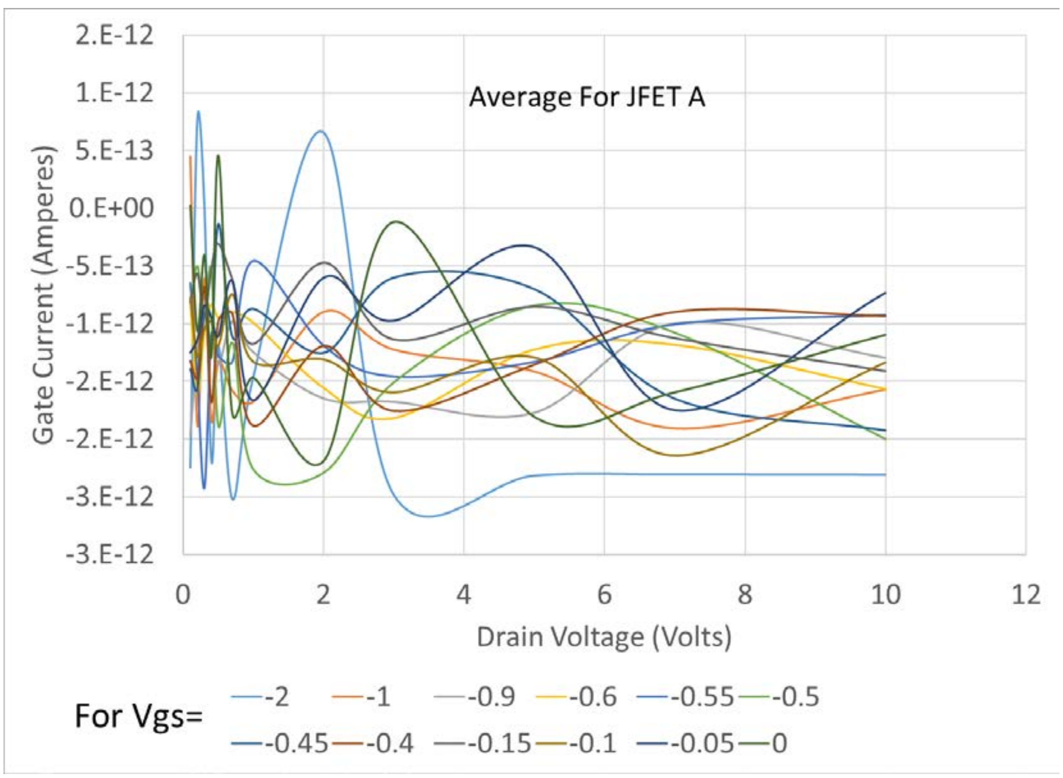

Figure 3 Pre-Irradiation Average Gate Current for Unbonded LSK389 JFET A

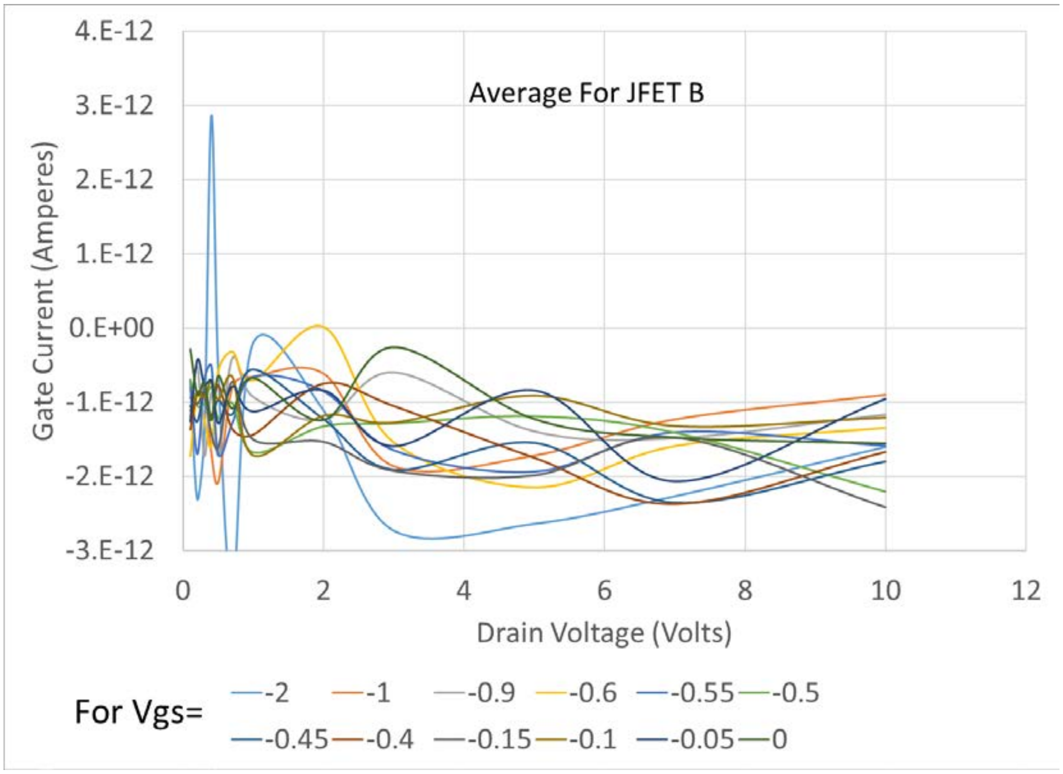

Figure 4 Pre-Irradiation Average Gate Current for Unbonded LSK389 JFET B

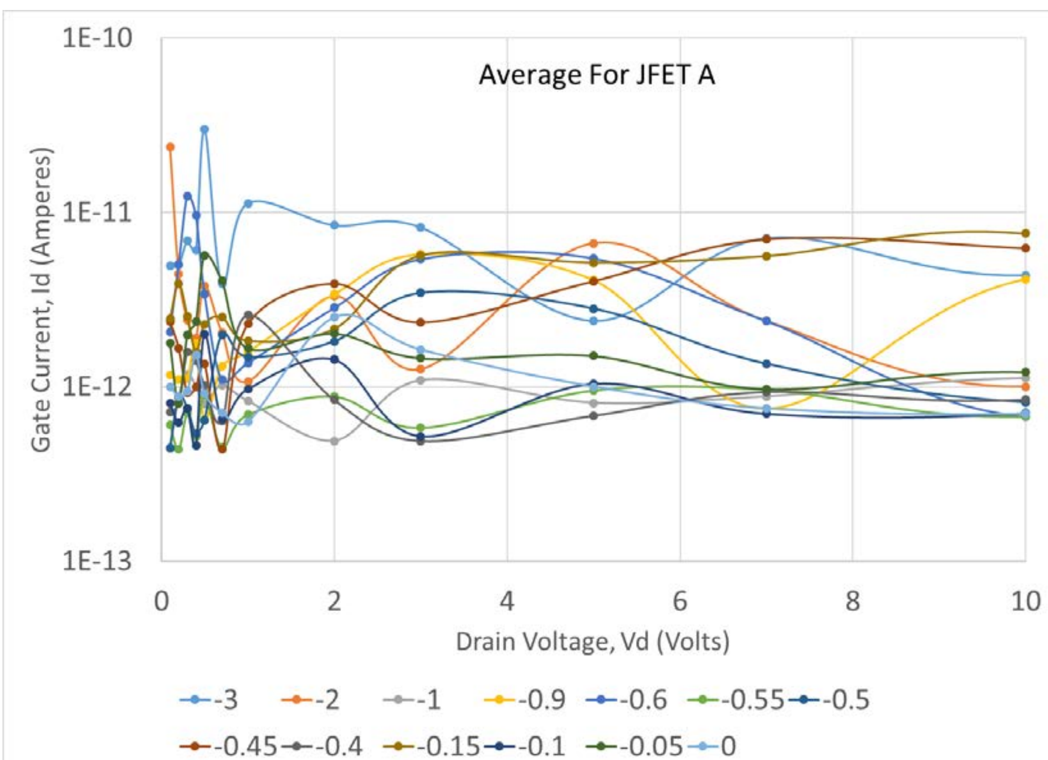

Figure 3 Pre-Irradiation Average Gate Current for Unbonded LSK489 JFET A

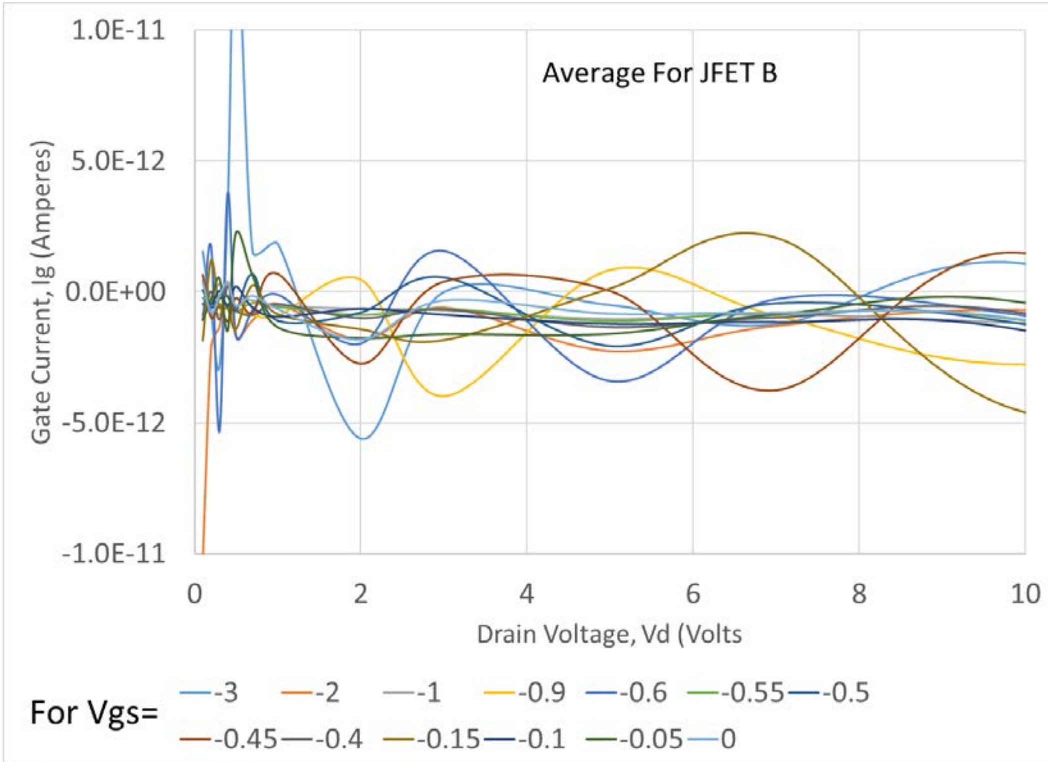

Figure 4 Pre-Irradiation Average Gate Current for Unbonded LSK389 JFET B

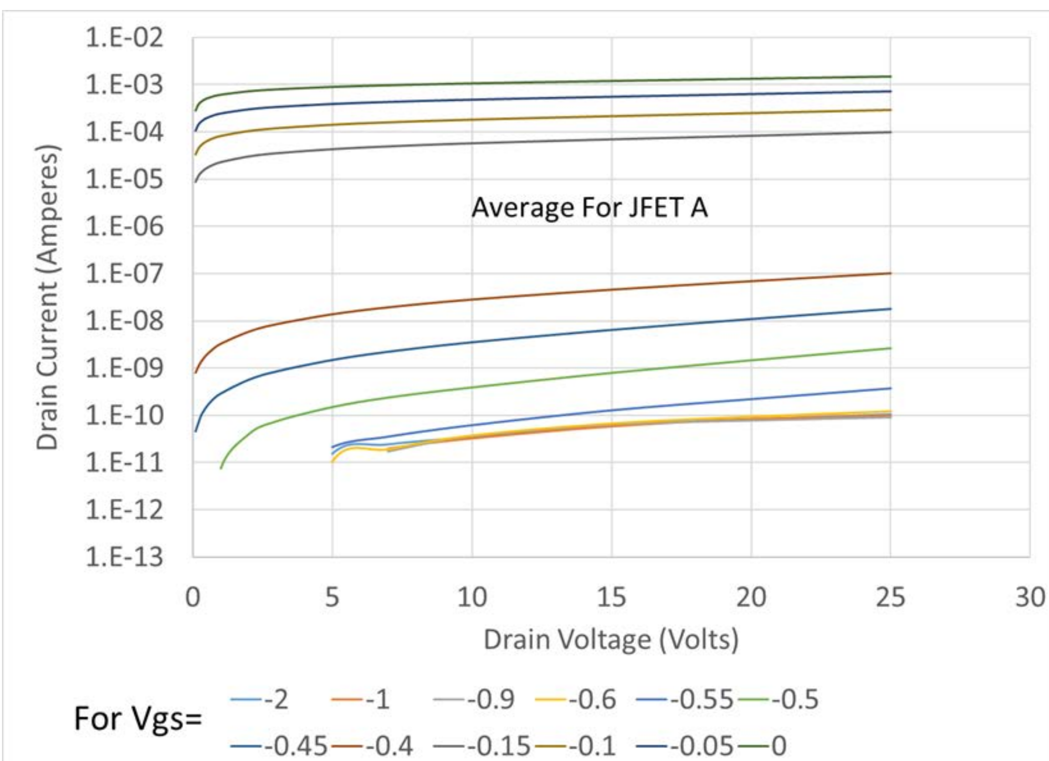

Figure 5 Pre-Irradiation Average Drain Current for Unbonded LSK389 JFET A

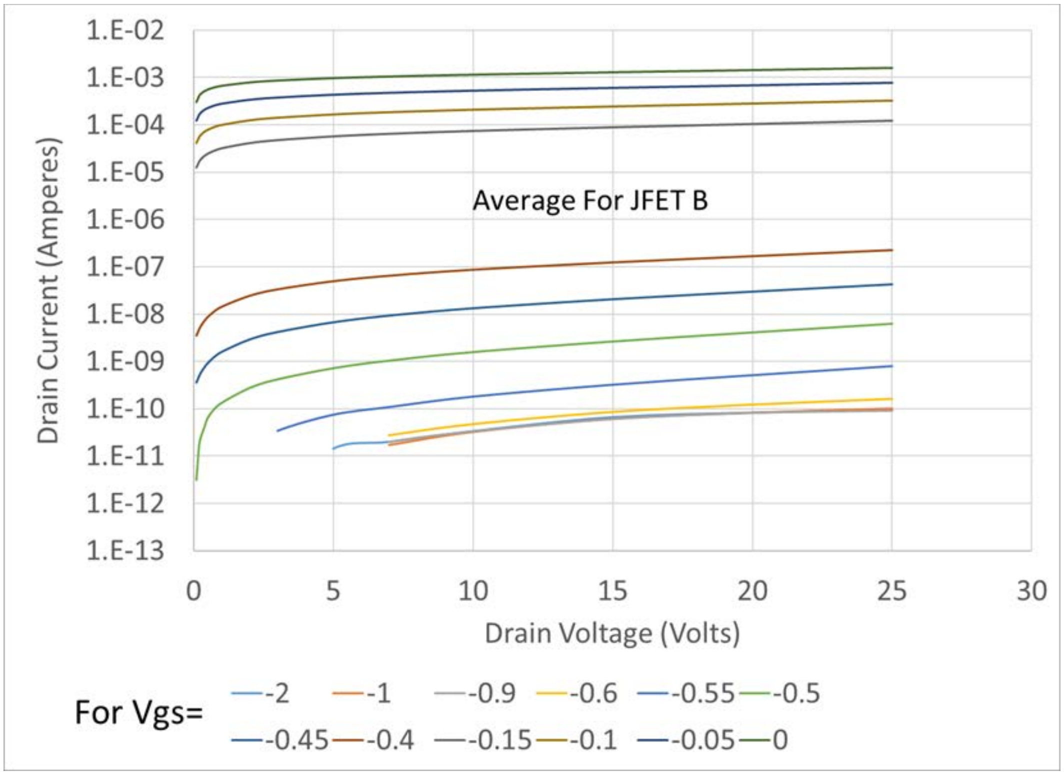

Figure 6 Pre-Irradiation Average Drain Current for Unbonded LSK389 JFET B

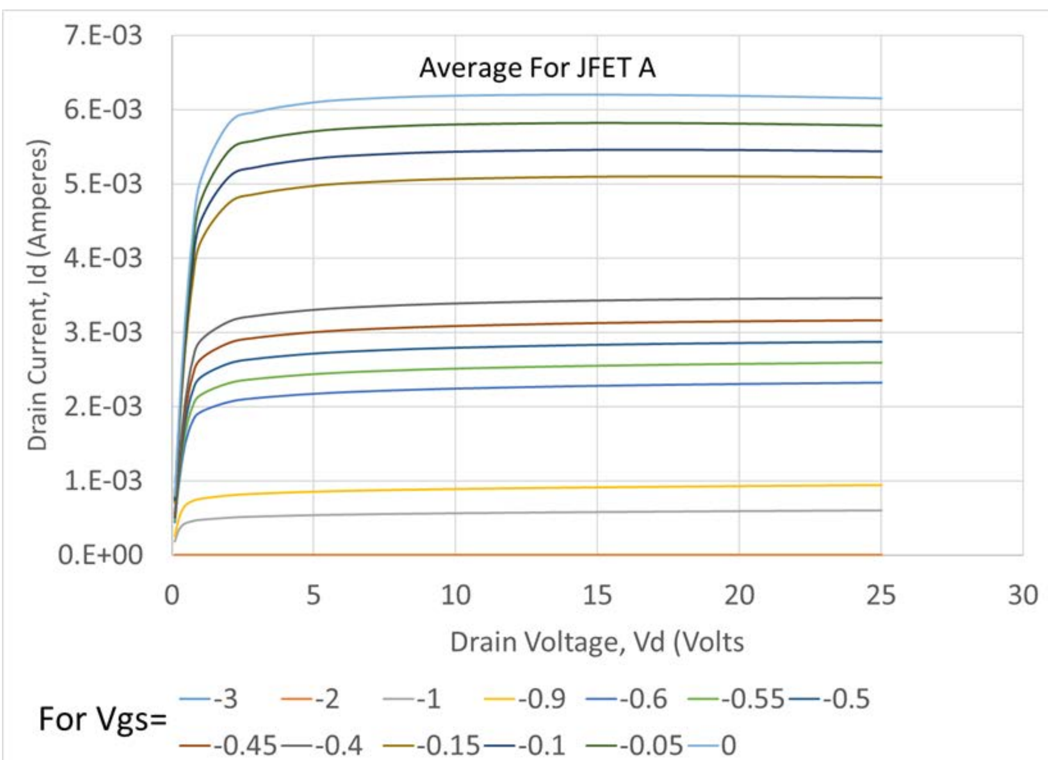

Figure 7 Pre-Irradiation Average Drain Current for Unbonded LSK489 JFET A

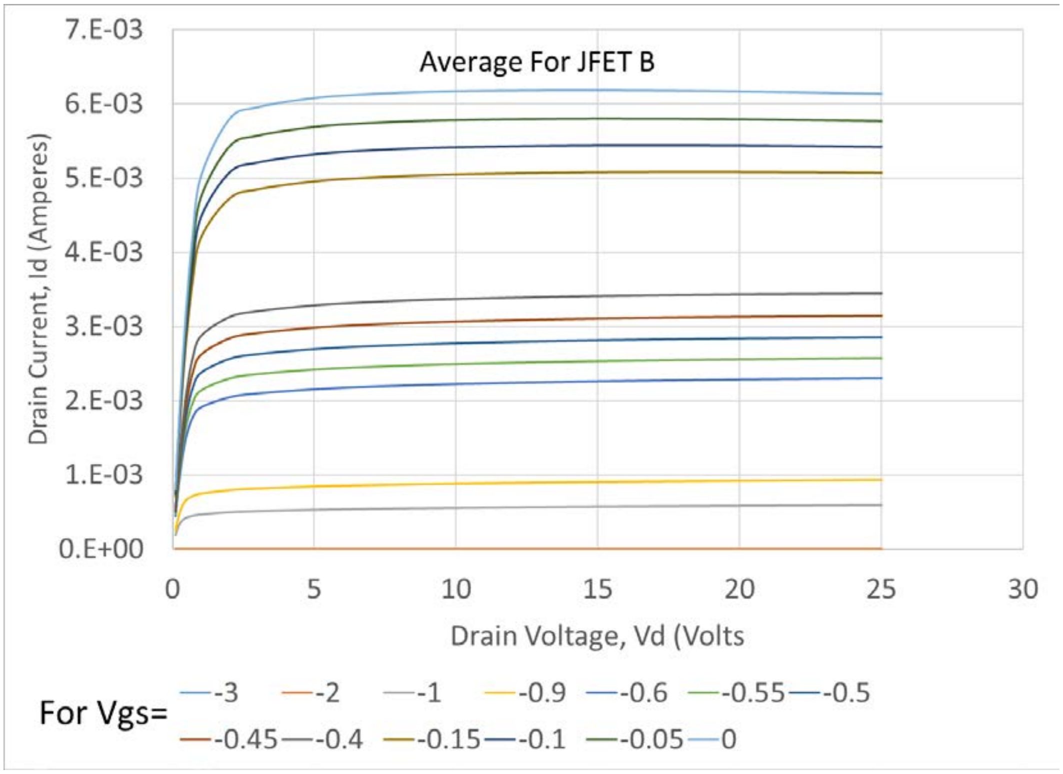

Figure 8 Pre-Irradiation Average Drain Current for Unbonded LSK489 JFET B

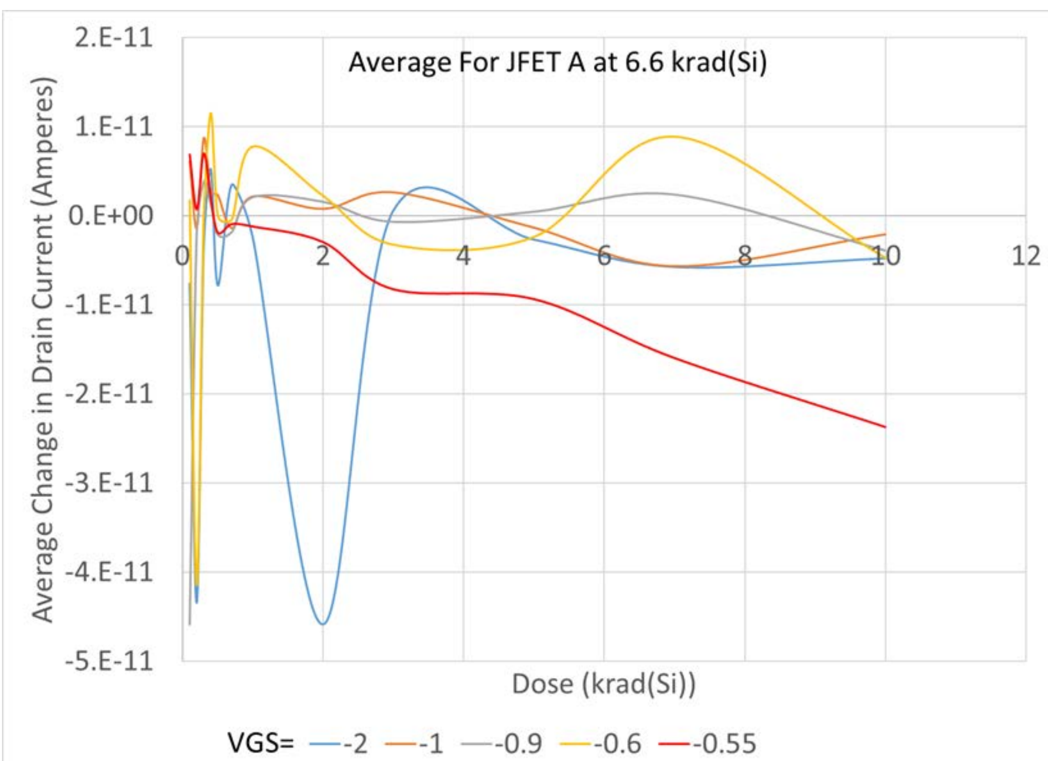

Figure 9 Average Change in Drain Current for Unbonded LSK389 JFET A @6.6 krad(Si)

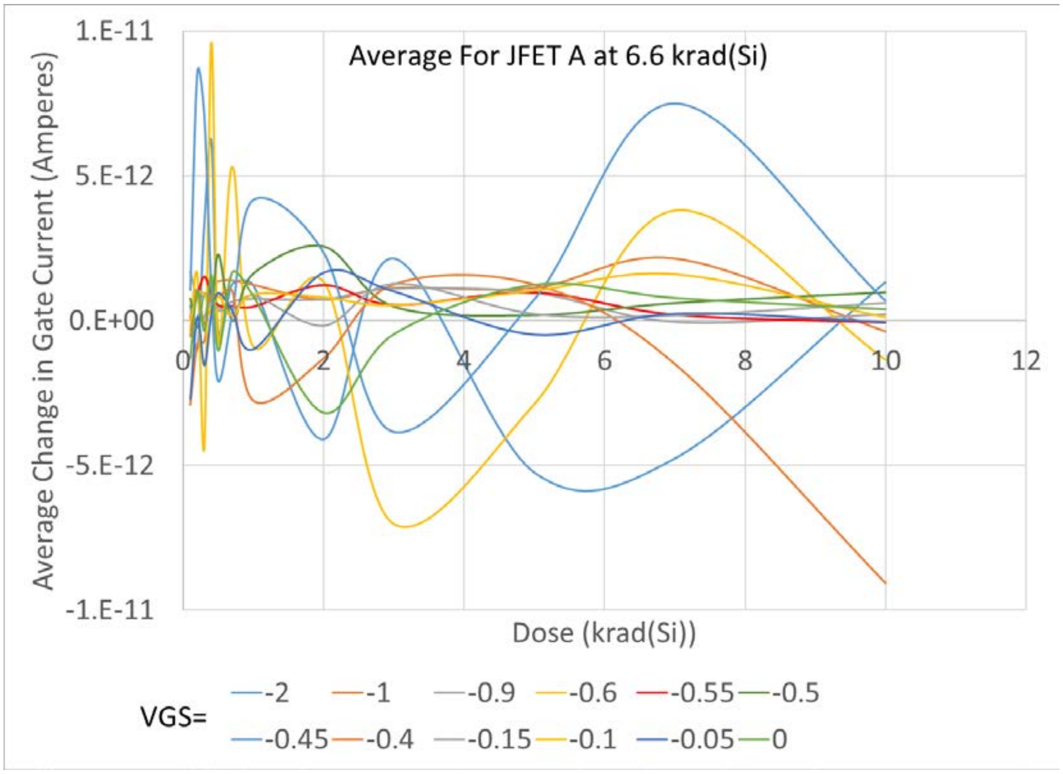

Figure 10 Average Change in Drain Current for Unbonded LSK389 JFET A @6.6 krad(Si)

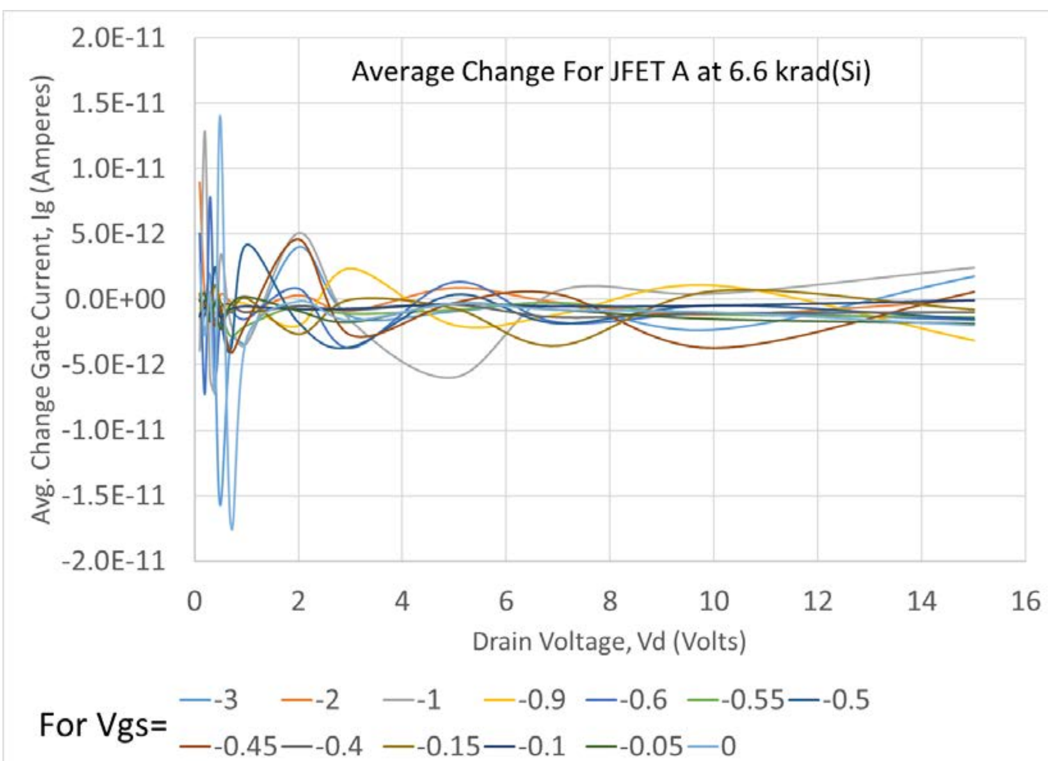

Figure 11 Average Change in Drain Current for Unbonded LSK489 JFET A @6.6 krad(Si)

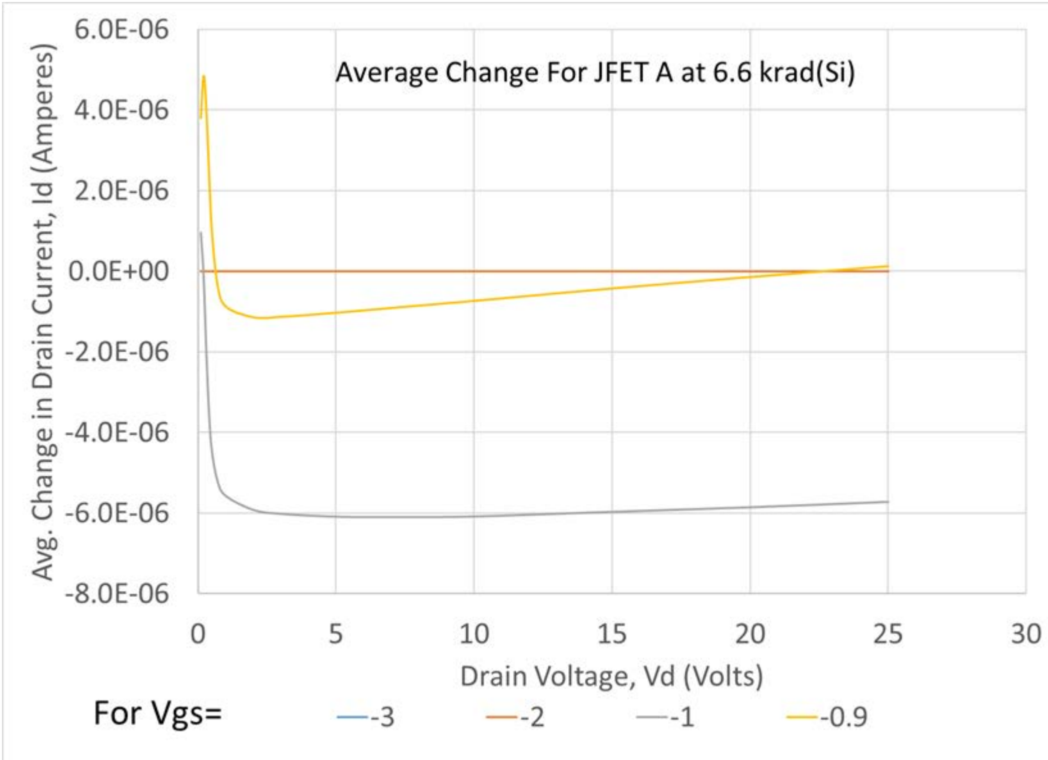

Figure 12 Average Change in Drain Current for Unbonded LSK489 JFET A @6.6 krad(Si)

It is clear that except for the changes in drain current for the LSK489s, the plots represent mainly measurement error and there are few meaningful trends. For this reason, and because the plots for the conductively bonded parts are statistically indistinguishable from the above plots, we do not include plots for the conductively bonded parts. Investigation of whether the two datasets can be combined to further reduce noise and make the data more precise are underway.

However, for the qualification dose of 6.6 krad(Si) for OCI, unless small changes in drain current for the LSK489s are of concern, there are no issues with the use of these parts for the OCI readout application.

9. Conclusion

Based on the SEE and TID results, unless small changes in drain current are of concern for the application, both JFET amplifiers should be suitable for the OCI readout application.