Total Ionizing Dose Assessment of a Commercial 200V PMOSFET

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***Abstract* — Total ionizing dose testing of commercial 200 V PMOSFETs. At 100 kRad(Si), observed V_T increase of ~ 3 V for biased ON devices and increase of ~ 1 V for biased OFF devices. The R_{DS_ON} did not degrade with dose.**

I. INTRODUCTION

RADIATION hardened power MOSFETS (PMOSFETs) are critical components in spacecraft power and high voltage switching applications. QML certified RHA components often represent one of the more expensive and long lead-time part categories in a flight product bill of materials (BOM). Commercial power devices are comparatively inexpensive, but these devices have risk for total ionizing dose-induced parametric degradation and catastrophic single event effects (SEE), in particular, single event gate rupture (SEGR).

Previous studies by NASA and coauthors have reported SEE characterization of a commercial PMOSFET device – the Vishay Si7431DP [1] – which is a 200 V, 2.2 A p-channel trench MOSFET. SEGR was observed for certain combinations of bias and linear energy transfer (LET), but the analysis suggests that with appropriate derating, the Vishay Si7431DP may be considered for space applications [1].

In this paper, we present total ionizing dose (TID) test results for the Vishay Si7431DP device. The devices under test (DUTs) were irradiated up to 100 kRad(Si) in OFF state and ON state bias conditions. The gate and drain voltages we used are within the safe operating area implied by the NASA SEE test campaign [1], [2].

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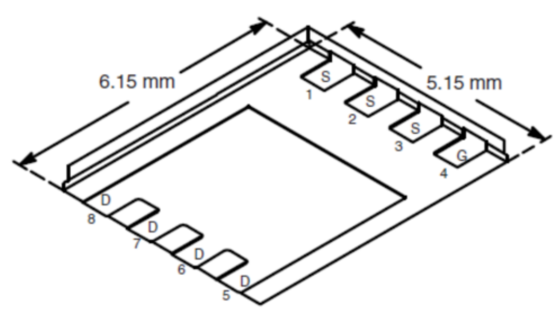
II. PART DESCRIPTION AND EXPERIMENTAL APPROACH

A. Device Under Test

The devices under test (DUTs) are Vishay Si7431DP in PowerPAK SO-8 surface mount packages. Table 1 displays the vendor-supplied electrical parameters of the DUTs [3]. Fig. 1 (left) shows the DUT diagram and Fig. 1 (right) shows the DUTs.

TABLE I.
VISHAY Si7431DP ELECTRICAL PARAMETERS

Parameter	Specification
V_T	- 2 to - 4 V, I_D = - 250 µA
V_{DS}	- 200 V
$R_{DS(ON)}$	0.174 Ω at V_{GS} = - 10 V, I_D = - 3.8 A
$R_{DS(ON)}$	0.180 Ω at V_{GS} = - 6 V, I_D = - 3.6 A



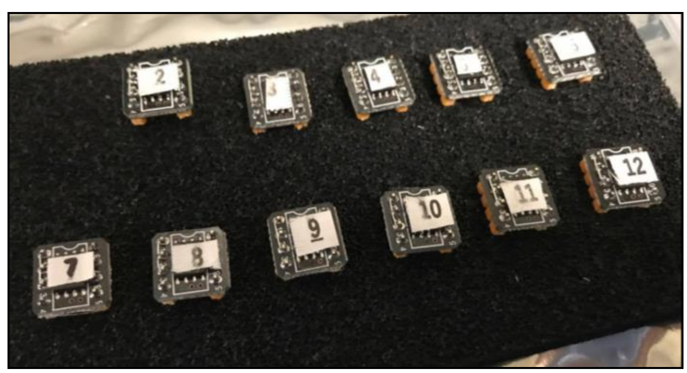


Fig 1. (Top) Vishay Si7431DP block diagram [2]; (Bottom) DUTs.

A total of twelve devices were tested. Six devices were irradiated in a bias ON condition and the remaining six devices were irradiated in a bias OFF condition. Fig. 2 shows the electrical circuit diagram for the bias ON and bias OFF conditions.

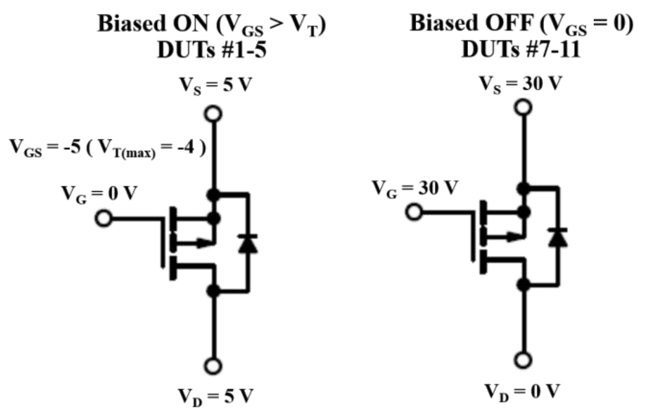
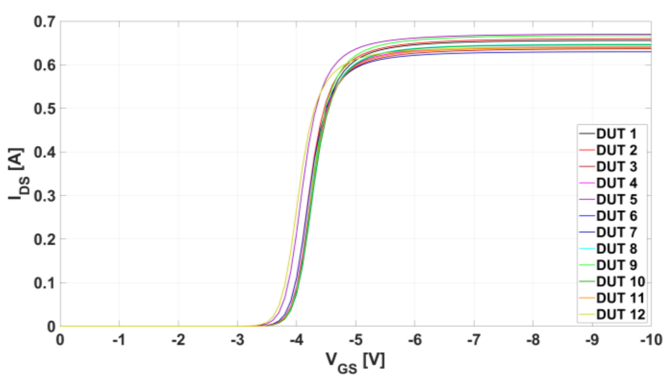


Fig 2. Electrical circuit diagram for devices in bias ON (left) and bias OFF (right) conditions.

Pre-radiation Kelvin measurements were taken prior to the gamma radiation test campaign. During the test campaign, seven rounds of gamma radiation testing were completed with Kelvin measurements taken after each round of radiation. Radiation testing was performed using the Co-60 facility at DMEA, Sacramento with dose rate of 25 rad(Si)/s. Measurements of the samples were also taken after a 24-hour anneal period at the test facility, post shipment from the test facility, and after a 1-week period.

B. *Pre-Radiation Data*

Pre-radiation I_{DS} vs. V_{GS} curves for the tested devices are shown in Fig. 3 for V_D = 0.1 V and in Fig. 4 for V_D = 10 V. The threshold voltages fall between -3.5 V and -4 V, which is consistent with the supplier-provided datasheet limits of Table 1. Note that Fig. 3 (top) shows a linear mode IV curve whereas the datasheet defines V_T using a saturation mode IV. This may explain why our measured V_T trends toward the upper end of the datasheet range.



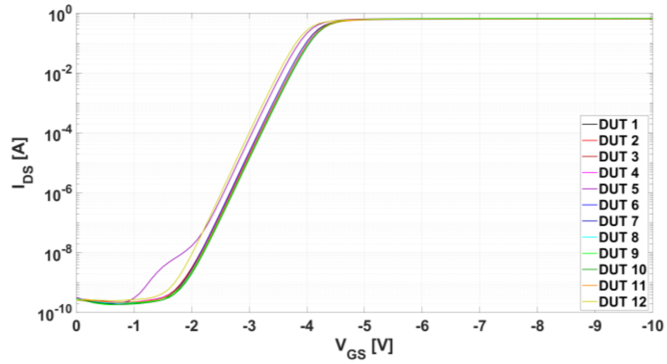
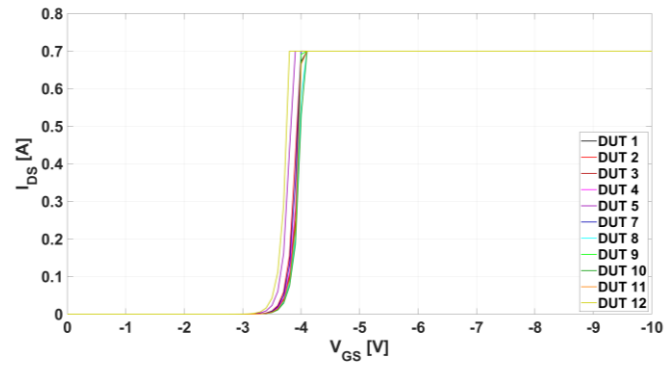


Fig 3. Pre-Radiation I_{DS}-V_{GS} curves with V_D = 0.1V, I_{DS} in linear scale (top) and logarithmic scale (bottom).



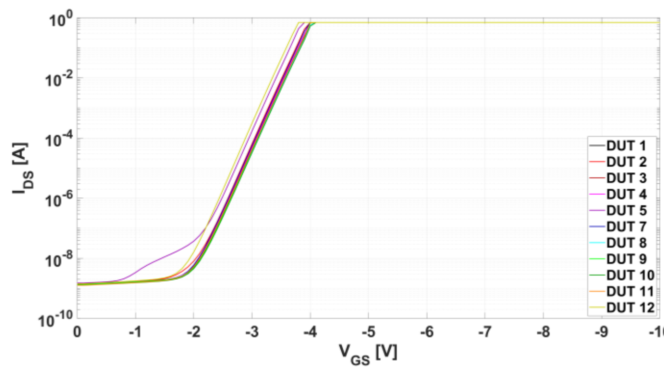


Fig 4. Pre-Radiation I_{DS}-V_{GS} curves with V_D = 10 V, I_{DS} in linear scale (top) and logarithmic scale (bottom).

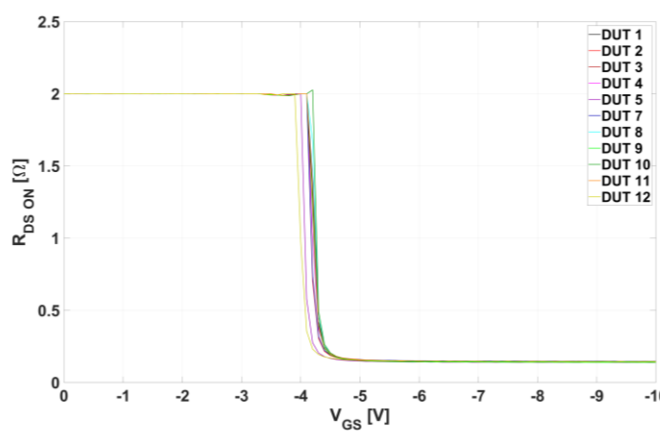


Fig 5. Pre-Radiation R_{DS_ON} vs. V_{GS} curves

C. *Gamma Radiation Test Campaign*

DUT 1, DUT 2, DUT 3, DUT 4, and DUT 5 were irradiated in a bias ON state configuration with V_G = 0 V and $V_D = V_S$ = 5 V (for V_{GS} = -5 V). DUT 11 and DUT 12 were control devices for the Bias ON state radiation testing. Fig. 6 shows the test matrix with dose levels for the five DUTs in kRad(Si)and two controls. Exposures of DUT 3, DUT 4, and DUT 5 were stopped at 50 kRad(Si) and exposure of DUT 2 was stopped after 75 kRad(Si) to observe for annealing of devices exposed to different TID levels. DUT 1 was exposed to a full 100 kRad(Si). Each device was measured after a 24-hour room temp biased anneal, post-shipment anneal, and then again after a 1 week biased anneal.

DUT	Pre Rad	1	3	10	30	50	75	100	24 Hour Anneal	Post Ship + 1 Week Anneal
1	×	×	×	×	×	×	×	×	×	×
2	×	×	×	×	×	×	×	-	×	×
3	×	×	×	×	×	×	-	-	×	×
4	×	×	×	×	×	×	-	-	×	×
5	×	×	×	×	×	×	-	-	×	×
11 (C)	×	×	×	×	×	×	×	×	-	-
12 (C)	×	×	×	×	×	×	×	×	×	×

Fig 6. Test matrix of gamma radiation exposures for DUTs 1-5 and control DUT 11 and 12 in bias ON condition.

Fig. 7 shows the test matrix with dose levels in kRad(Si)for DUT 6, DUT 7, DUT 8, DUT 9, DUT 10, and DUT 11, which were biased on the OFF condition with $V_G = V_S$ = 30 V and V_D = 0 V. DUT 11 was used as a radiation test device to replace a damaged device (DUT 6) in the bias OFF state radiation. DUT 6 was accidentally shorted when attempting to take measurements. Thus DUT 12 was the only control for the bias OFF post-anneal measurements. Exposures of DUT 10 and DUT 11 were stopped at 50 kRad(Si), and exposure of DUT 9 was stopped at 75 kRad(Si). DUT 8 was exposed to the full 100 kRad(Si). DUT 7 was damaged after 75 kRad(Si) – it was accidentally shorted when attempting to take measurements.

DUT	Pre Rad	1	3	10	30	50	75	100	24 Hour Anneal	Post Ship + 1 Week Anneal
6	×									
7	×	×	×	×	×	×	×			
8	×	×	×	×	×	×	×	×	×	×
9	×	×	×	×	×	×	×	-	×	×
10	×	×	×	×	×	×	-	-	×	×
11	×	×	×	×	×	×	-	-	×	×
12 (C)	×	×	×	×	×	×	×	×	×	×

Fig 7. Test matrix of gamma radiation exposures for DUTs 6-11 and control DUT 12 in bias OFF condition.

III. EXPERIMENTAL RESULTS

I_{DS}-V_{GS} characteristics for DUT 1, which was exposed in the ON state configuration to 100 kRad(Si), are shown in Fig. 8 (V_D = -0.1 V) and Fig. 9 (V_D = -10 V). The I_{DS}-V_{GS} curves in Fig. 8 and Fig. 9 show a correlation between increasing shift in threshold voltage V_T with increasing total ionizing dose. The I_{DS} logarithmic scale in Fig. 8 (bottom) shows for increasing TID level exposure, the shift in the I_{DS}-V_{GS} curves yields a decreased leakage current near 0 V, but the leakage current increases and settles to nominal I_{DS} of 10^{-10} A at a higher V_{GS}.

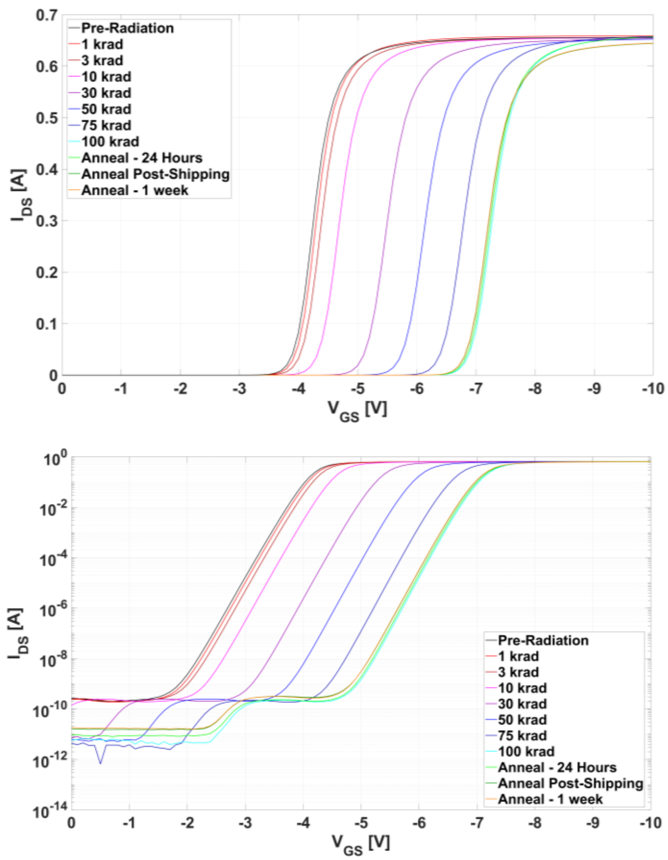
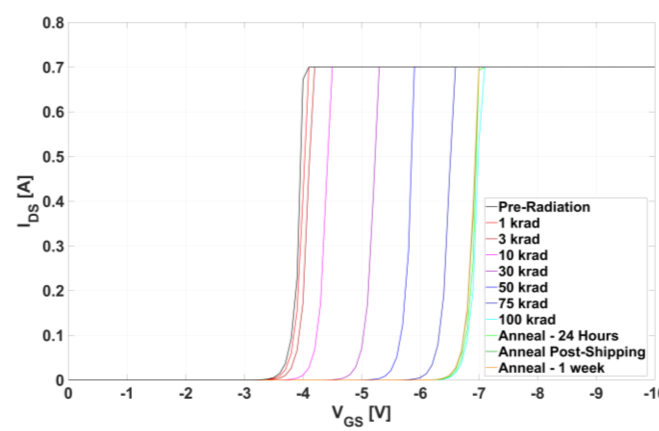


Fig. 8. Device 1 (bias ON configuration) I_{DS}-V_{GS} (V_D=-0.1V) characteristics for pre-radiation, dose levels up to 100 kRad(Si), and anneal data; (top) I_{DS} linear scale, (bottom) I_{DS} logarithmic scale



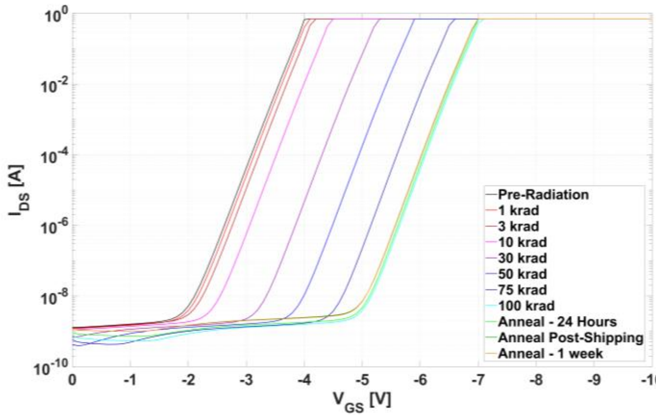


Fig. 9. Device 1 (bias ON configuration) I_{DS}-V_{GS} (V_D=-10V) characteristics for pre-radiation, dose levels up to 100 kRad(Si), and anneal data; (top) I_{DS} linear scale, (bottom) I_{DS} logarithmic scale.

I_{DS}-V_{GS} characteristics for DUT 8, which was exposed in the OFF state configuration to 100 kRad(Si), are shown in Fig. 10 (V_D = -0.1 V) and Fig. 11 (V_D = -10 V). It is evident from these results that bias ON state irradiation produces greater threshold voltage shift V_T in comparison to bias OFF state. We observe insignificant annealing in the devices for both bias configurations.

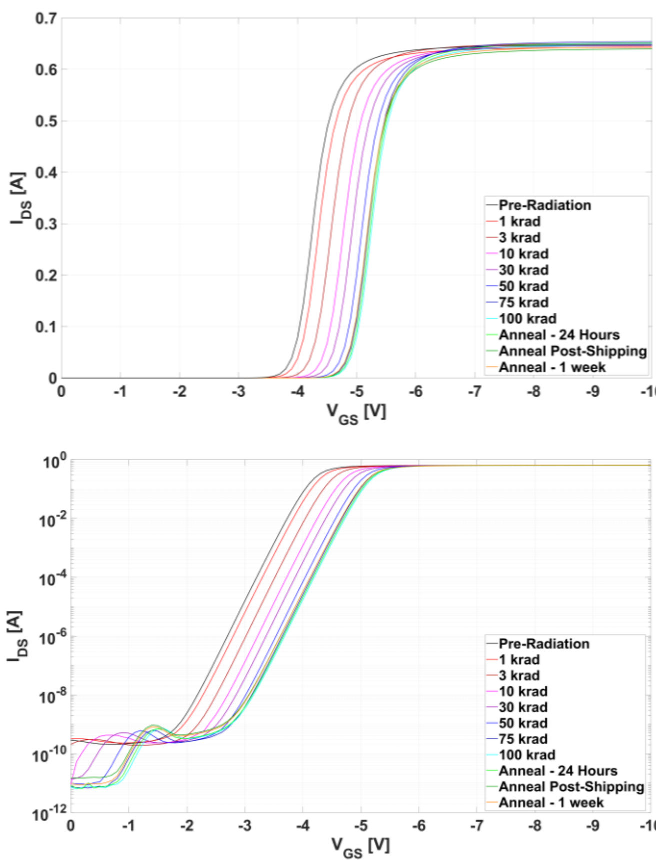


Fig. 10. Device 8 (bias OFF configuration) I_{DS}-V_{GS} (V_D = -0.1 V) characteristics for pre-radiation, dose levels up to 100 kRad(Si), and anneal data; (top) I_{DS} linear scale, (bottom) I_{DS} logarithmic scale

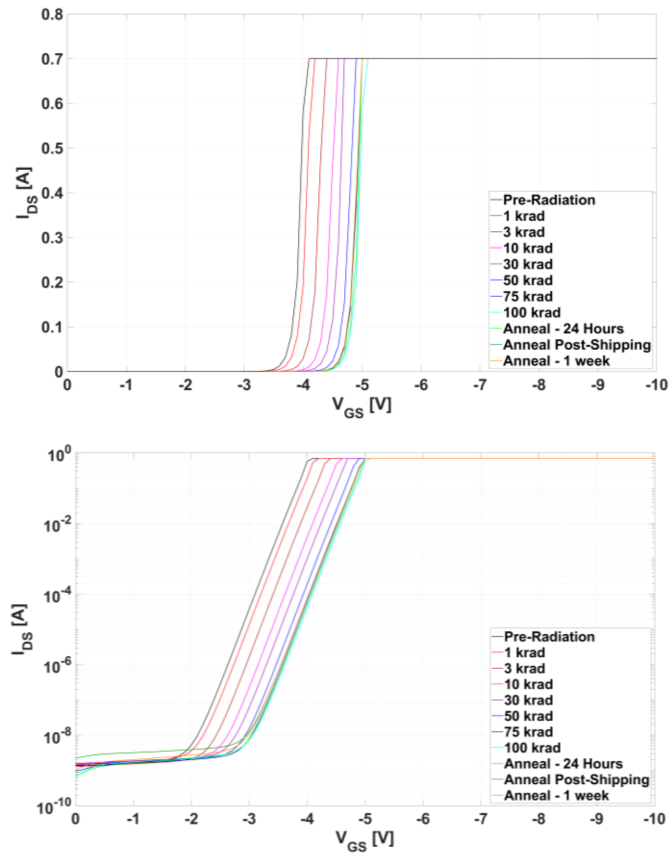


Fig. 11. Device 8 (bias OFF configuration) I_{DS}-V_{GS} (V_D = -10 V) characteristics for pre-radiation, dose levels up to 100 kRad(Si), and anneal data; (top) I_{DS} linear scale, (bottom) I_{DS} logarithmic scale

Fig. 12 and 13 show R_{DS_ON} measurement data for DUT 1 (bias ON configuration exposure) and DUT 8 (bias OFF configuration exposure). Note that the anneal 1 week data was measured with the parameter analyzer set to 3 V compliance instead of 2 V compliance as in the pre-radiation and radiation data. The lateral shift in the curves results from the V_T shift is evident in Fig. 8-11, and the stability of the minimum R_{DS} value indicates that mobility degradation from radiation induced surface states are not an issue for these devices, which is perhaps expected in a vertical trench structure device. Designing with some margin for the turn-on of these devices may enable their use in space environments.

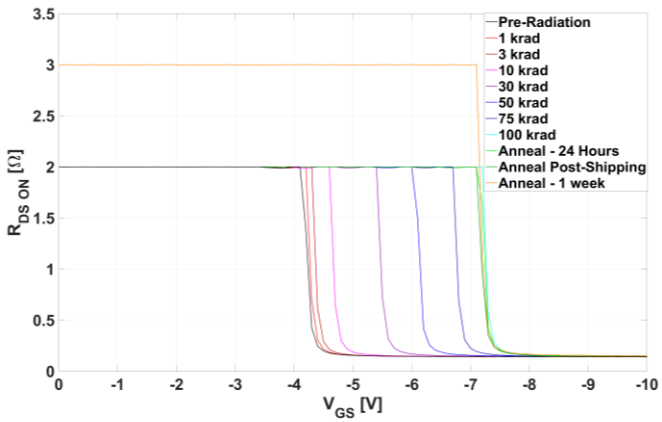


Fig. 12. Device 1 R_{DS_ON} (bias ON configuration) characteristics for pre-radiation, dose levels up to 100 kRad(Si), and anneal data

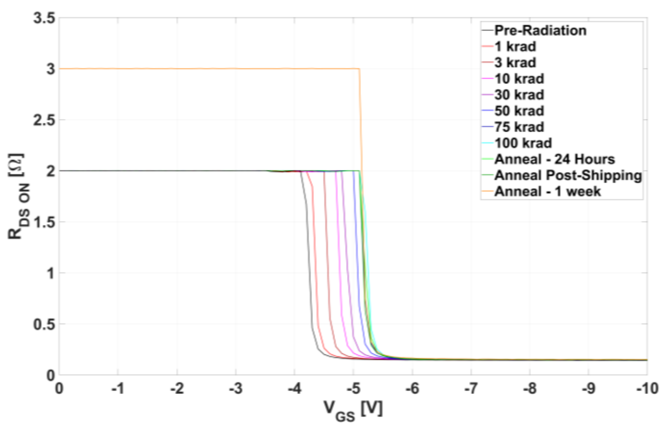


Fig. 13. Device 8 R_{DS_ON} (bias OFF configuration) characteristics for pre-radiation, dose levels up to 100 kRad(Si), and anneal data

IV. CONCLUSIONS AND FUTURE WORK

We have characterized total ionizing dose effects in Vishay Si7431DP 200 V commercial PMOSFETs. At 100 kRad(Si) we observe about a 3 V increase in V_T for devices biased in an ON-state configuration and a 1 V increase in V_T for devices biased in an OFF-state configuration. The R_{DS_ON} did not degrade with dose. Overall, our results suggest that with appropriate headroom in the supply voltage, these devices can be suitable for space applications.

V. REFERENCES

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