Summary Of mpw2SIdo Test Irradiations

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202608010

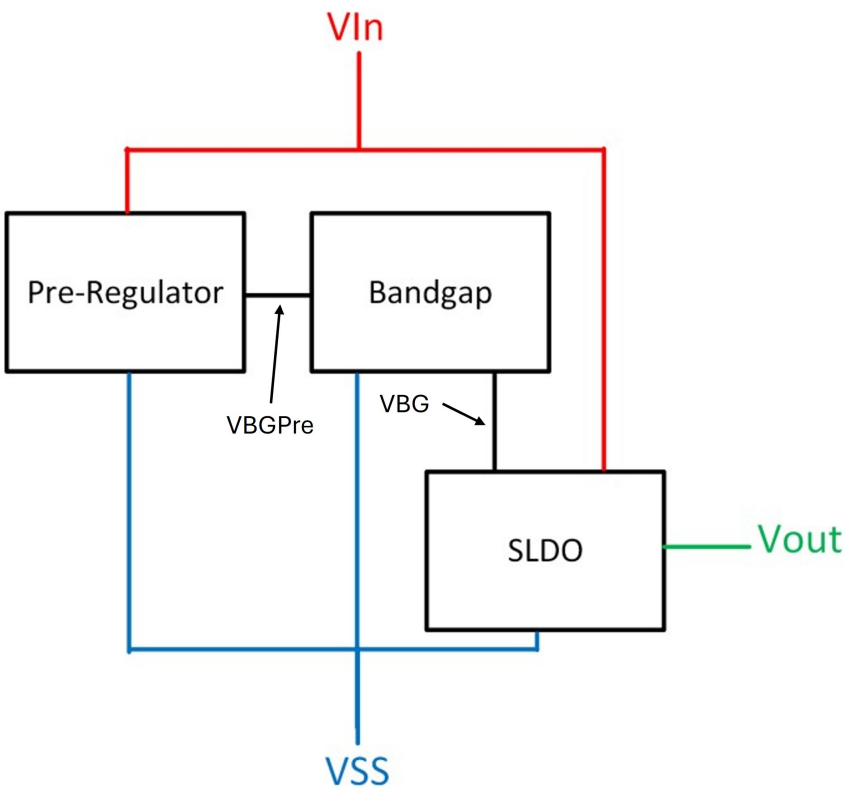
Content:

- 040mA Load Irradiations and Annealing
- 500mA Load Irradiations and Annealing
- 900mA Load Irradiations and Annealing

Overview

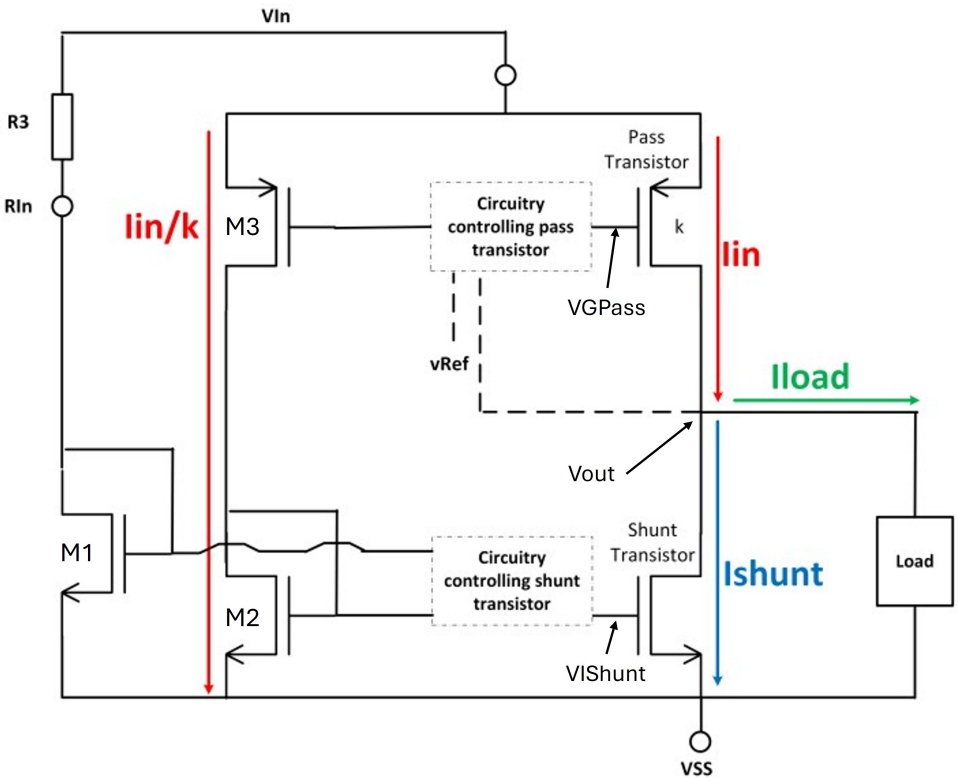
- SLDO Circuit
- Setup
- Test Plan
- Results of Irradiation and Annealing
- Conclusion

SLDO Chip



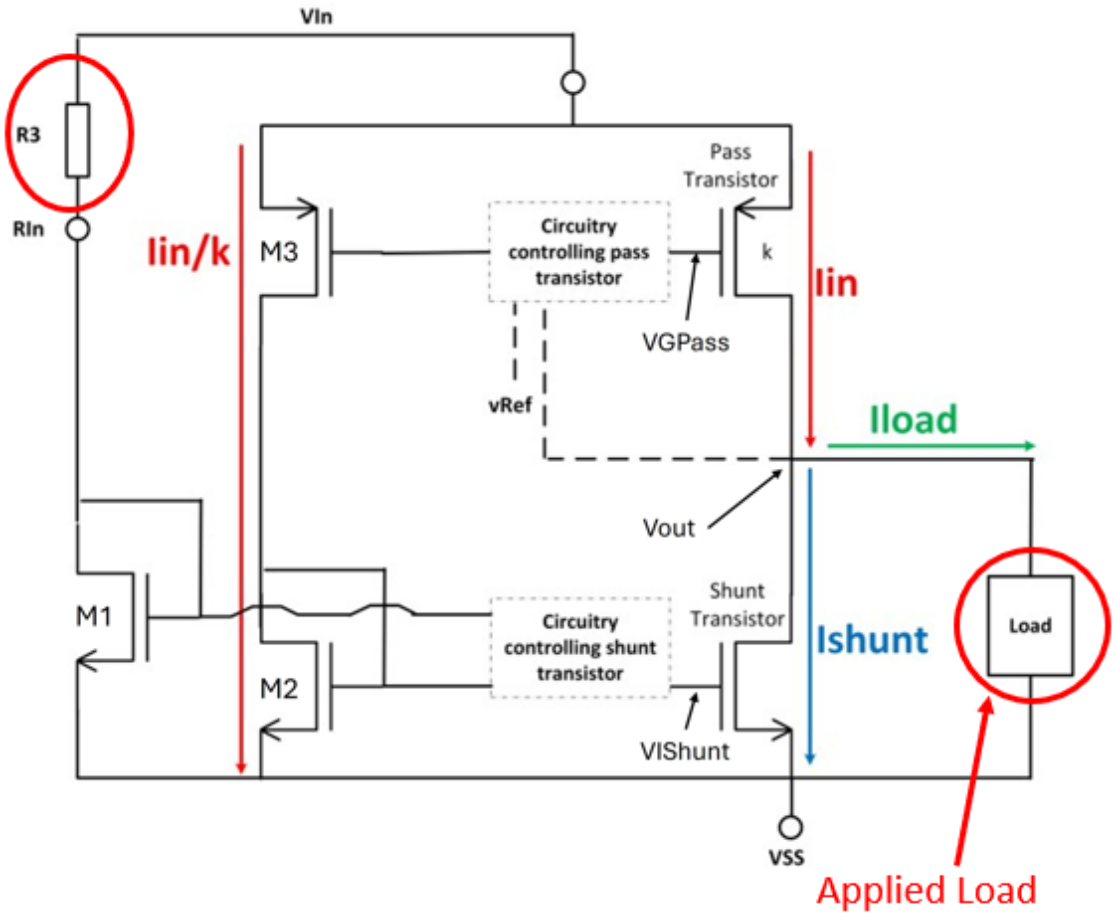
- Made of three main blocks.
- 1st block is a pre-regulator that delivers a clean supply to the main bandgap (2nd block), which provides a reference voltage for the SLDO.
- The 3rd block is the actual SLDO circuit.

SLDO Circuit



- Pass Transistor and its control circuitry form a traditional LDO that regulates the output voltage (Vout) to vRef.
- Shunt Transistor provides an additional path to shunt excess current (I-shunt).
- R3 sets the reference current that is used in combination with Iin/k to regulate the Shunt Transistor (VIshunt).

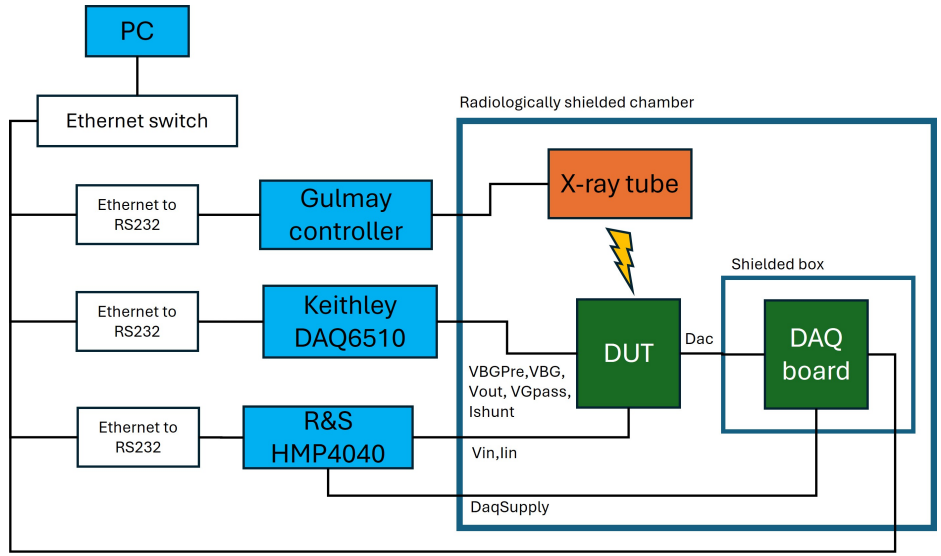
SLDO Operation Modes

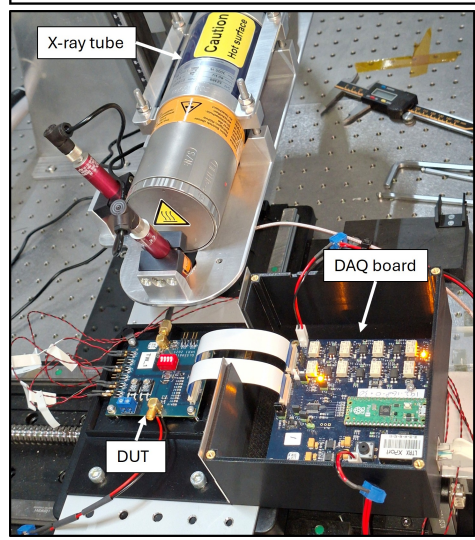


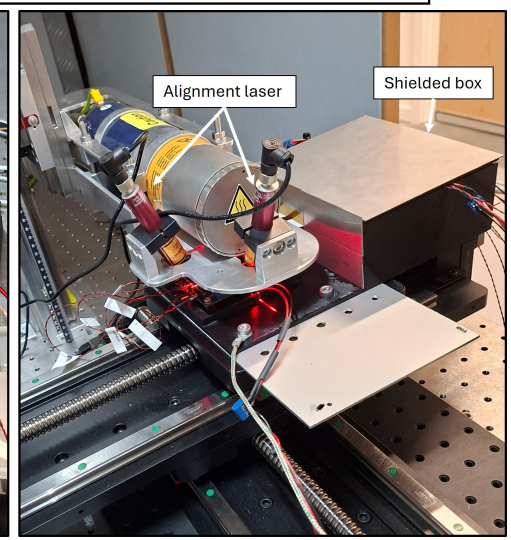
- Operates at 40mA, 500mA or 900mA.
- Device operating range is set via the DAQ board.
- Sets the applied load and rheostat R3.

Test Setup

- Measuring:
  Vin, In, VBGPre, VBG, Vout, VGpass, Ishunt and Temperature.
- Expected TID over 10 year lifetime is $\sim$200krad(SiO_2). The devices were irradiated up to x100 the expected TID.
- Measurements were performed before, during and after irradiation.
- Distance from X-ray tube to DUT: 33.3mm.
- Two Dose rates: Standard and Low.
  (Calibrated with CERN-EP-ESE group's procedure).
- Standard dose rate : 104 krad(SiO_2)/min.
  irradiation step: $\sim$204 krad(SiO_2).
  (i.e. irradiate for 2 mins at $\sim$104 krad(SiO_2)/min).
  X-ray tube settings: 20kV, 20mA
- Low dose rate : $\sim$20.8 krad(SiO_2)/min
  irradiation step: $\sim$60 krad(SiO2).
  (i.e. irradiate for 3 mins at $\sim$20.8 krad(SiO_2)/min).
  X-ray tube settings: 20kV, 4mA
- Data taking automated via python scripts.





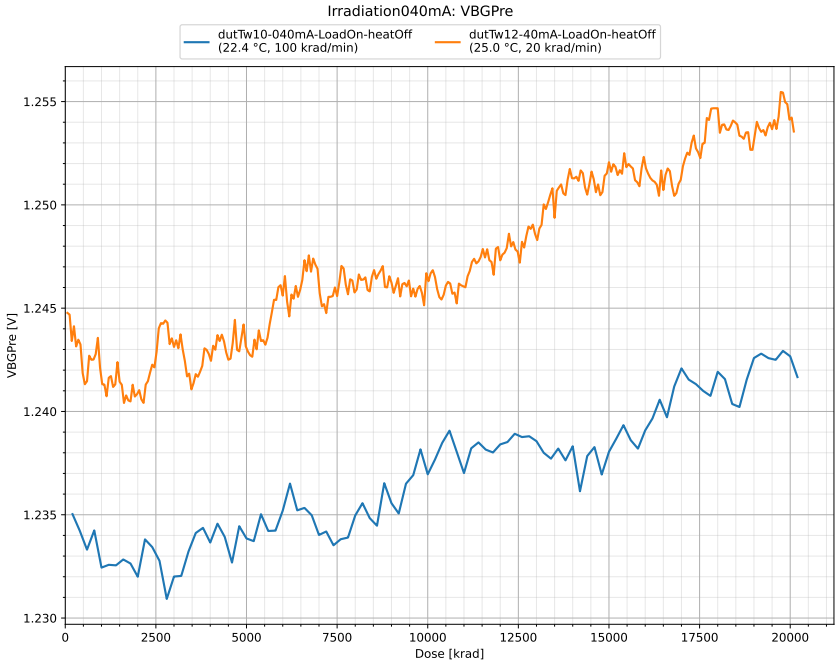


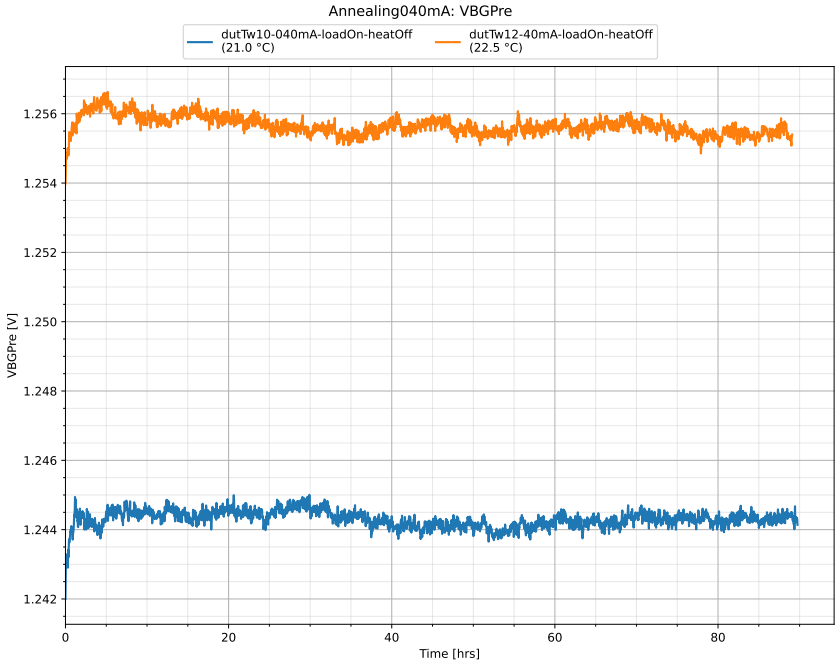
Irradiation Test Plan

#	Dose range	Dose rate	To measure	Conditions	Annealing	DUT
1	**0 - 10 Mrad** Step of 200krad (i.e. 1 point every 2 mins)	100krad/min 20kV;20mA;	Vin, Iin; Vout (steady&DAC scan); VG PASS; VBG; VBGPre; Ishunt (is a Voltage); Temp;	Room-T (i.e. heaters off) (Irrad@DAC const@16 DN) (Load ON)	Keep monitoring every 2 mins for up to 5 days (i.e. 3600 pts)	-DutTw1, 500mA **[under biased];** Done;
2	**0 - 20 Mrad** Step of 200krad (i.e. 1 point every 2 mins)	100krad/min 20kV;20mA;	Vin, Iin; Vout (steady&DAC scan); VG PASS; VBG; Ishunt (is a Voltage); Temp;	Room-T (i.e. heaters off) (Irrad@DAC const@16 DN) (Load ON)	Keep monitoring every 2 mins for up to 5 days (i.e. 3600 pts)	-DutTw4, 500mA **[under biased];** Done; -DutTw5,500mA; Done; -DutTw6,900mA; Done; -DutTw10,40mA; Done;
3	0 - 20Mrad Step of 60krad (i.e. 1 point every 3 mins) (~16hrs total irrad time)	**20krad/min** 20kV;4mA;	Vin, Iin; Vout (steady&DAC scan); VG PASS; VBG; VBGpre; Ishunt (is a Voltage); Temp;	Room-T (i.e. heaters off) (Irrad@DAC const@16 DN) (Load ON)	Keep monitoring every 2 mins for up to 5 days (i.e. 3600 pts)	-DutTw11,500mA;Done -DutTw9,900mA;Done; -DutTw12,40mA;Done;
4	0 - 20Mrad Step of 60krad (i.e. 1 point every 3 mins) (~16 hrs total irrad time)	20krad/min 20kV;4mA;	Vin, Iin; Vout (steady&DAC scan); VG PASS; VBG; VBGpre; Ishunt (is a Voltage); Temp;	**+60C (i.e. heaters on)** (Irrad@DAC const@16 DN) (Load ON or OFF, mixed)	Keep monitoring every 2 mins for up to 5 days (i.e. 3600 pts)	-DutTw13, 500mA; **[w Load off only during irrads];** Done; -DutTw19, 500mA; LoadOn; Done; -DutTw20, 500mA; LoadOff; Done; -DutTw8, 900mA; LoadOn; Done; -DutTw15, 900mA; LoadOff; **[Iin FUSE triggered during Irradiation];** Done; -DutTw16, 900mA; LoadOff; **[Iin FUSE triggered during Annealing];** Done;
5	0 - 20Mrad Step of 60krad (i.e. 1 point every 2 mins) (~16hrs total irrad time)	20krad/min 20kV;4mA;	Vin, Iin; Vout (steady&DAC scan); VG PASS; VBG; VBGpre; Ishunt (is a Voltage); Temp;	Room-T (i.e. heaters off) (Irrad@DAC const@16 DN) **(Load OFF)**	Keep monitoring every 2 mins for up to 5 days (i.e. 3600 pts)	-DutTw17, 500mA; Done; -DutTw18, 900mA; Done;

40 mA Load Region Irradiation and Annealing

Device	Load	Heat	Vin [V]	Dose Rate [krad/min]	Comments
Tw10	On	Off	1.80	104	-
Tw12	On	Off	1.80	20	-


Irradiation040mA: VBGPre
dutTw10-040mA-LoadOn-heatOff (22.4 °C, 100 krad/min)
dutTw12-40mA-LoadOn-heatOff (25.0 °C, 20 krad/min)
VBGPre [V]
Dose [krad]


Annealing040mA: VBGPre
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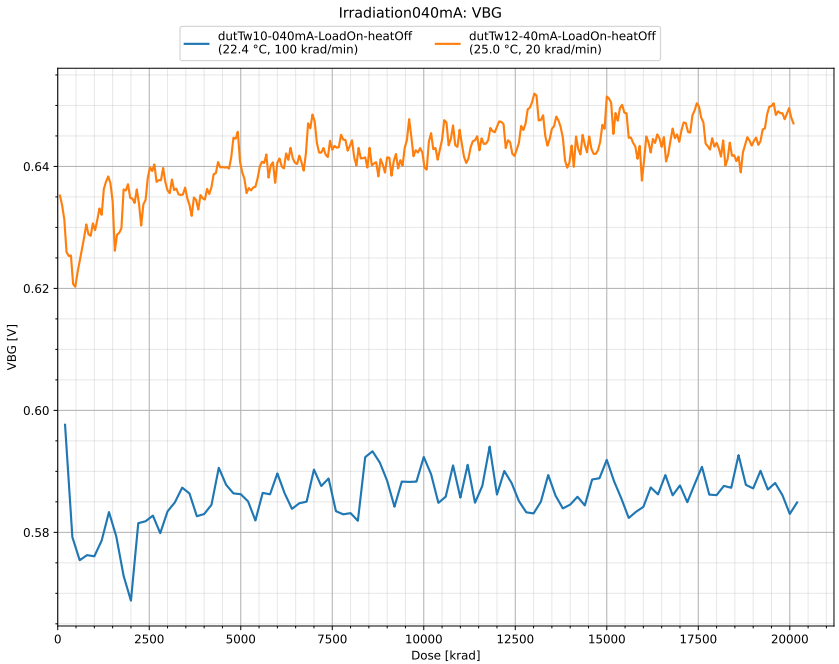
dutTw12-40mA-loadOn-heatOff (22.5 °C)
VBGPre [V]
Time [hrs]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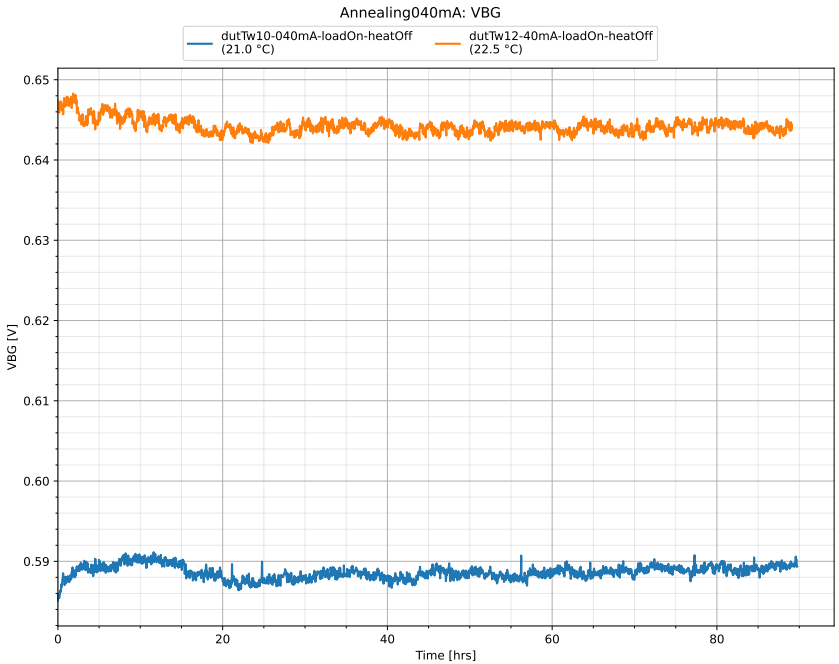
dutTw10-040mA-LoadOn-heatOff (22.4 °C, 100 krad/min)
dutTw12-40mA-LoadOn-heatOff (25.0 °C, 20 krad/min)
VBG [V]
Dose [krad]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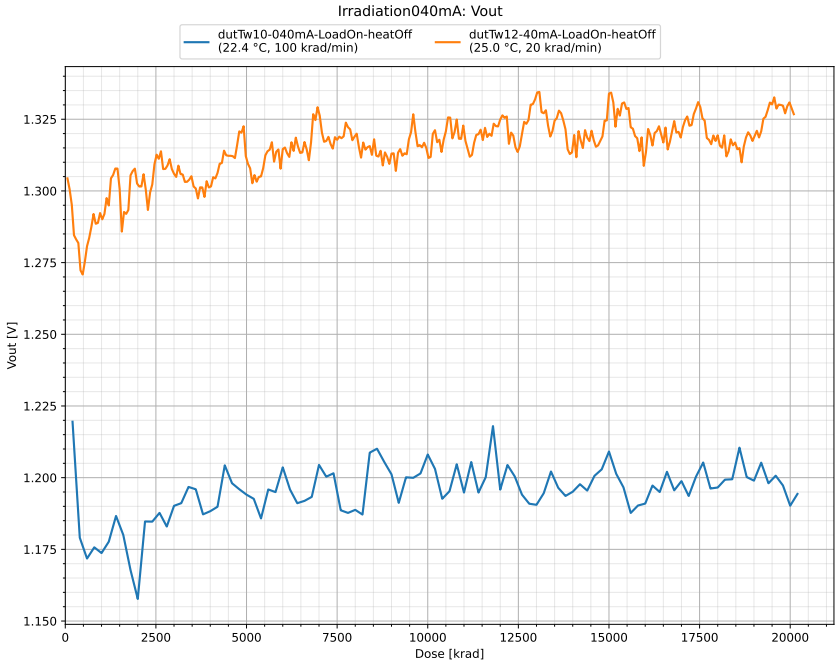
dutTw12-40mA-loadOn-heatOff (22.5 °C)
VBG [V]
Time [hrs]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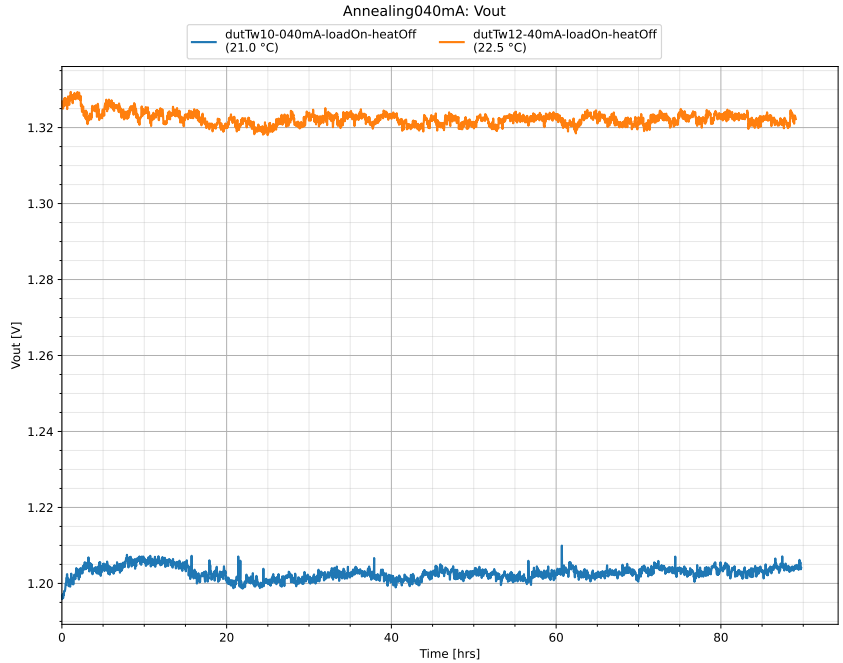
Vout [V]
Dose [krad]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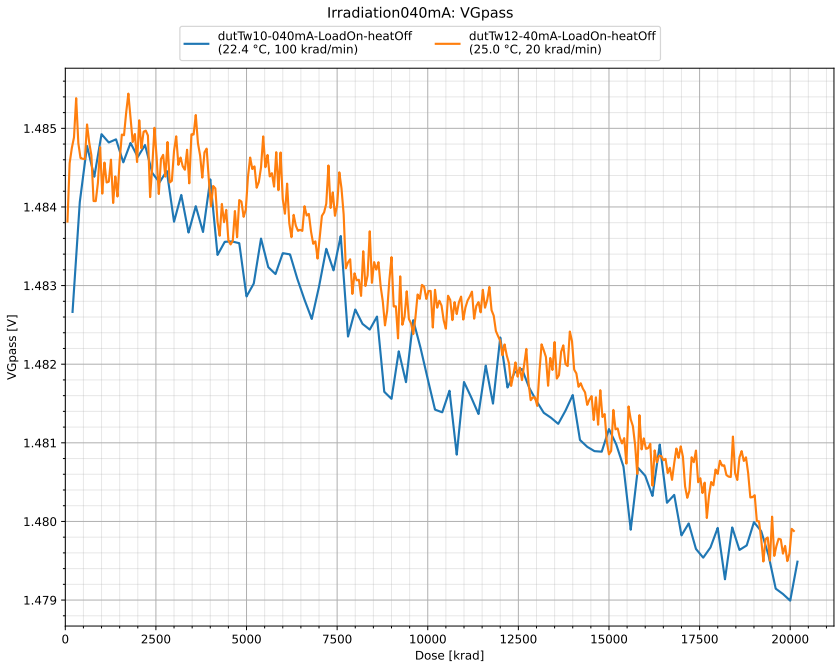
dutTw12-40mA-loadOn-heatOff (22.5 °C)
Vout [V]
Time [hrs]


Irradiation040mA: VGpass
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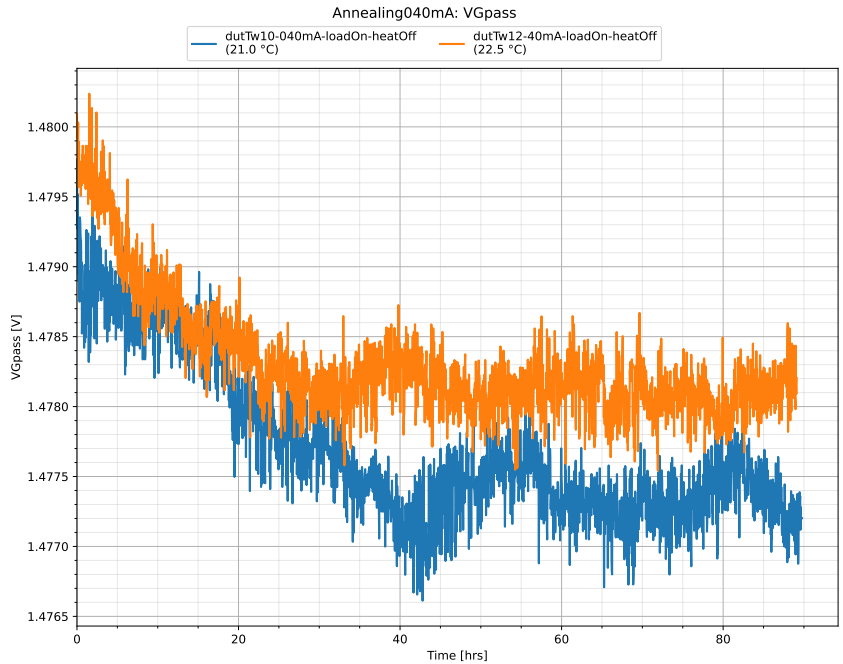
VGpass [V]
Dose [krad]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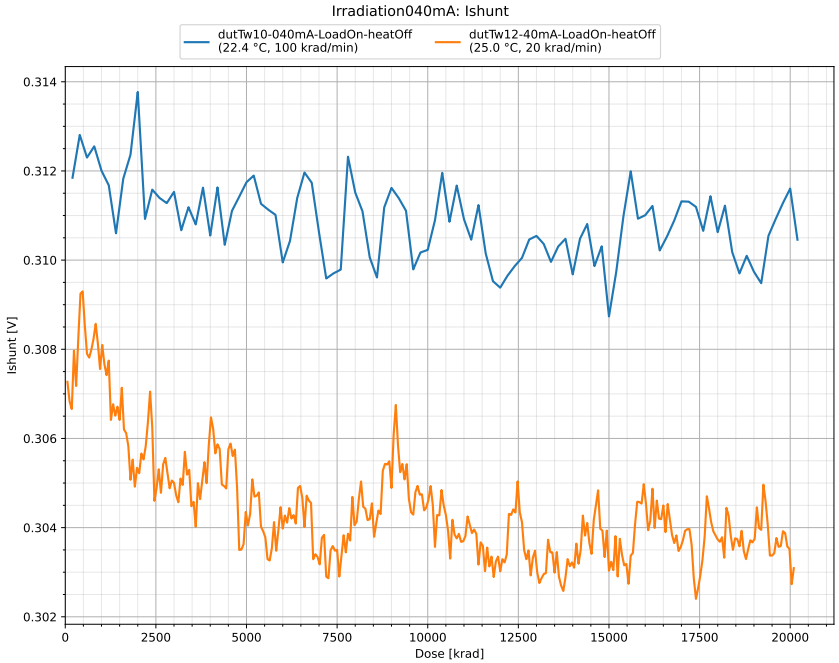
dutTw12-40mA-loadOn-heatOff (22.5 °C)
VGpass [V]
Time [hrs]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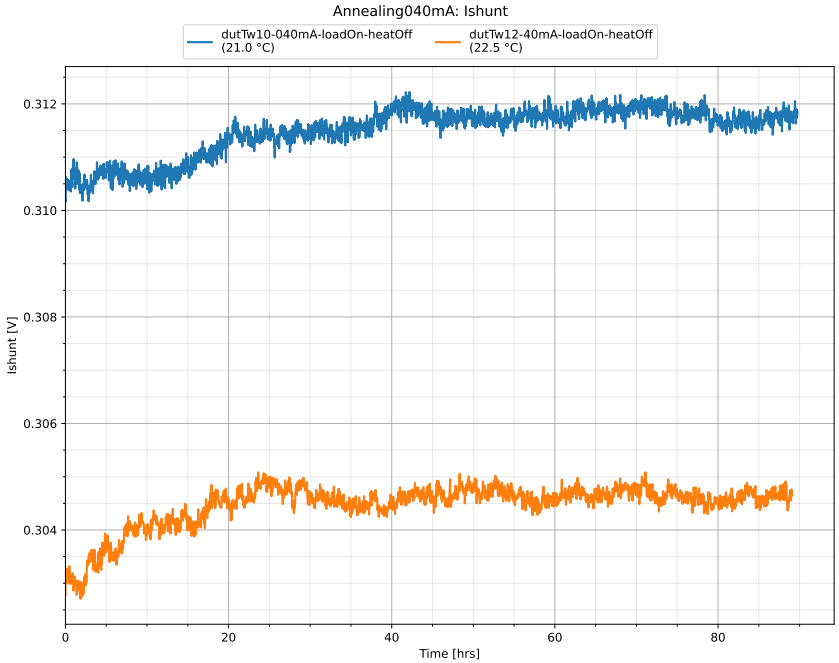
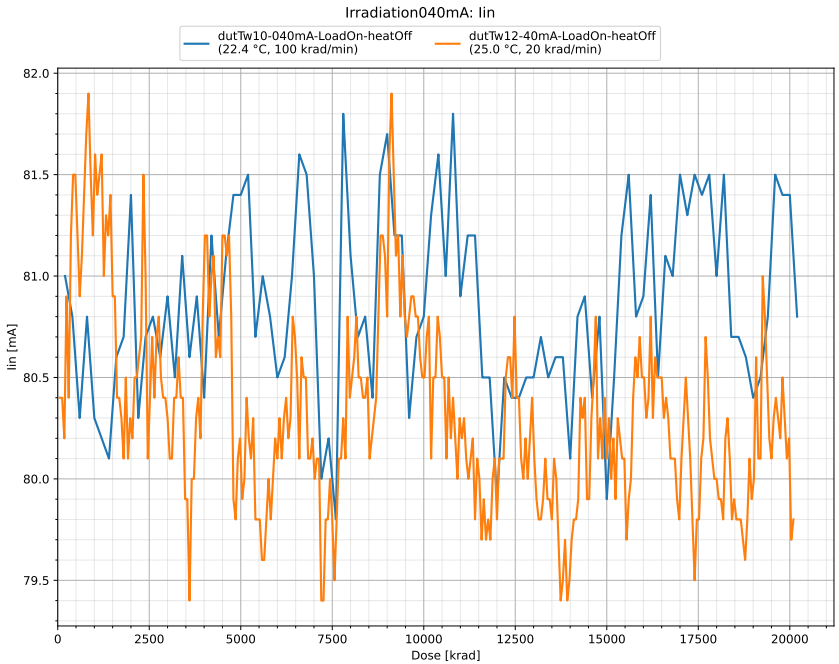
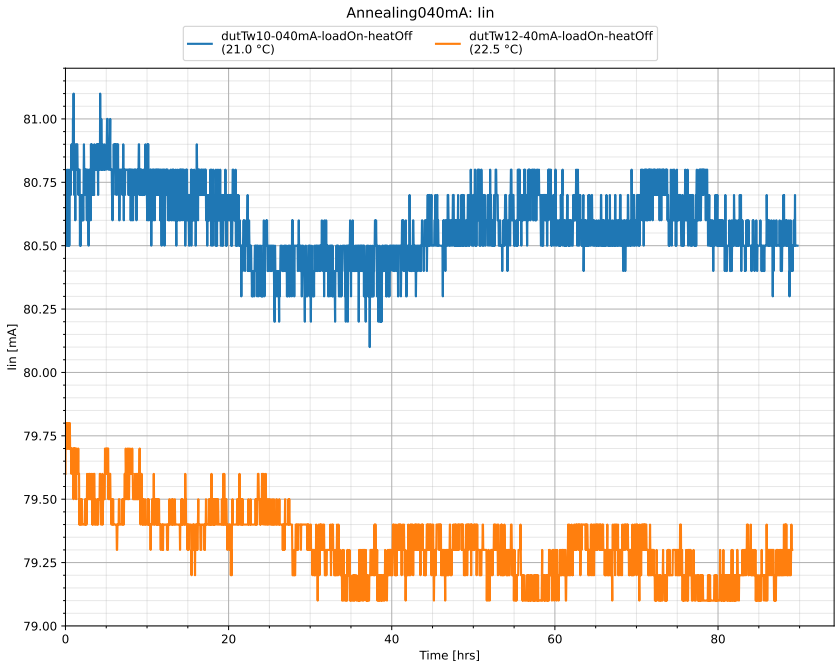
Ishunt [V]
Dose [krad]

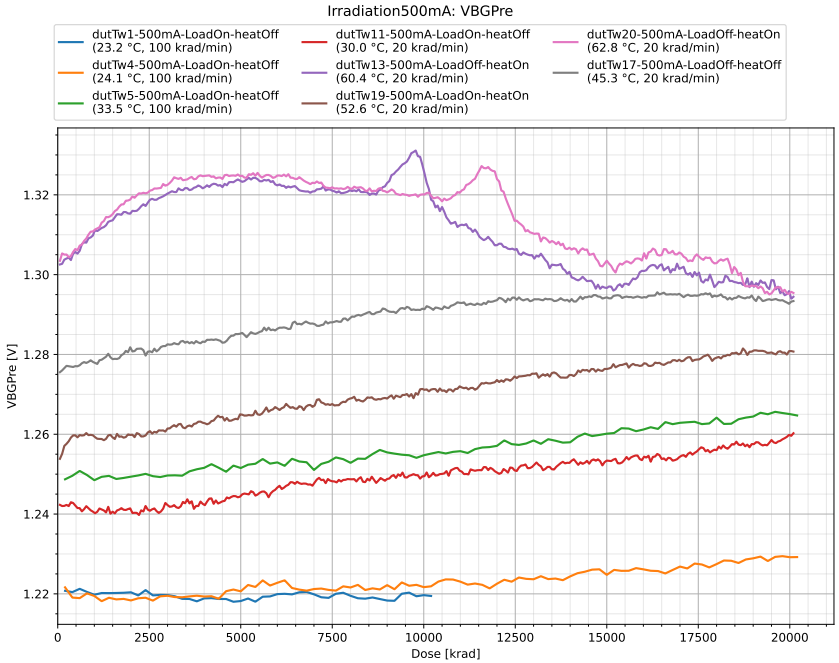

Annealing040mA: Ishunt
dutTw10-040mA-loadOn-heatOff (21.0 °C)
dutTw12-40mA-loadOn-heatOff (22.5 °C)
Ishunt [V]
Time [hrs]

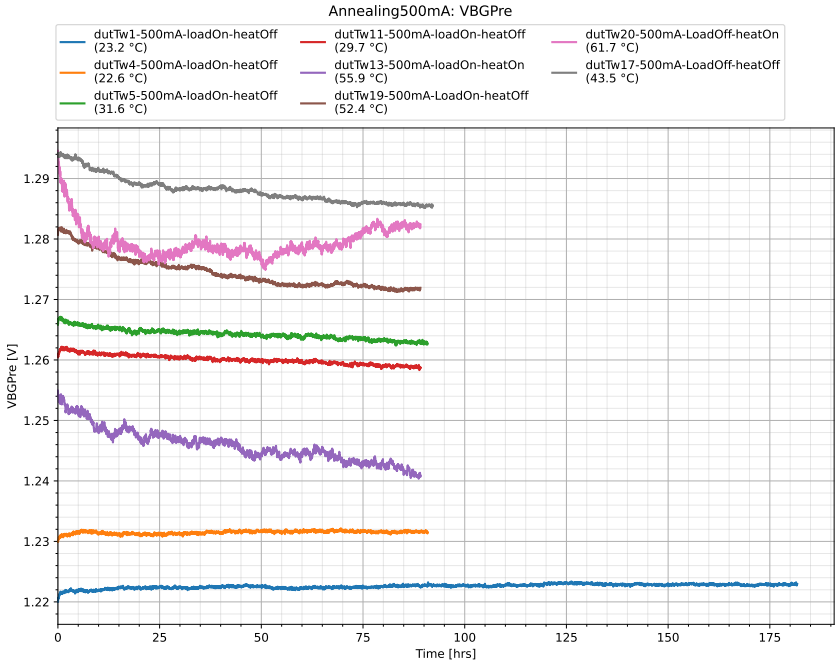

Irradiation040mA: Iin
dutTw10-040mA-LoadOn-heatOff (22.4 °C, 100 krad/min)
dutTw12-40mA-LoadOn-heatOff (25.0 °C, 20 krad/min)
Iin [mA]
Dose [krad]


Annealing040mA: Iin
dutTw10-040mA-loadOn-heatOff (21.0 °C)
dutTw12-40mA-loadOn-heatOff (22.5 °C)
Iin [mA]
Time [hrs]

500mA Load Region Irradiation and Annealing

Device	Load	Heat	Vin [V]	Dose Rate [krad/min]	Comments
Tw1	On	Off	∼1.55	104	- Underbiased due to Vin sense not enabled.
Tw4	On	Off	∼1.55	104	- Underbiased due to Vin sense not enabled.
Tw5	On	Off	1.80	104	-
Tw11	On	Off	1.80	20	-
Tw13	Off/On	Off	1.80	20	- Load Off during Irradiation. Turned On for Annealing.
Tw19	On	On	1.80	20	-
Tw20	Off	On	1.80	20	- ∼4 hrs gap between irradiation and annealing. DUT was powered OFF, with the heat kept ON during this time.
Tw17	Off	Off	1.80	20	-


Irradiation500mA: VBGPre
dutTw1-500mA-LoadOn-heatOff (23.2 °C, 100 krad/min)
dutTw4-500mA-LoadOn-heatOff (24.1 °C, 100 krad/min)
dutTw5-500mA-LoadOn-heatOff (33.5 °C, 100 krad/min)
dutTw11-500mA-LoadOn-heatOff (30.0 °C, 20 krad/min)
dutTw13-500mA-LoadOff-heatOn (60.4 °C, 20 krad/min)
dutTw19-500mA-LoadOn-heatOn (52.6 °C, 20 krad/min)
dutTw20-500mA-LoadOff-heatOn (62.8 °C, 20 krad/min)
dutTw17-500mA-LoadOff-heatOff (45.3 °C, 20 krad/min)
VBGPre [V]
Dose [krad]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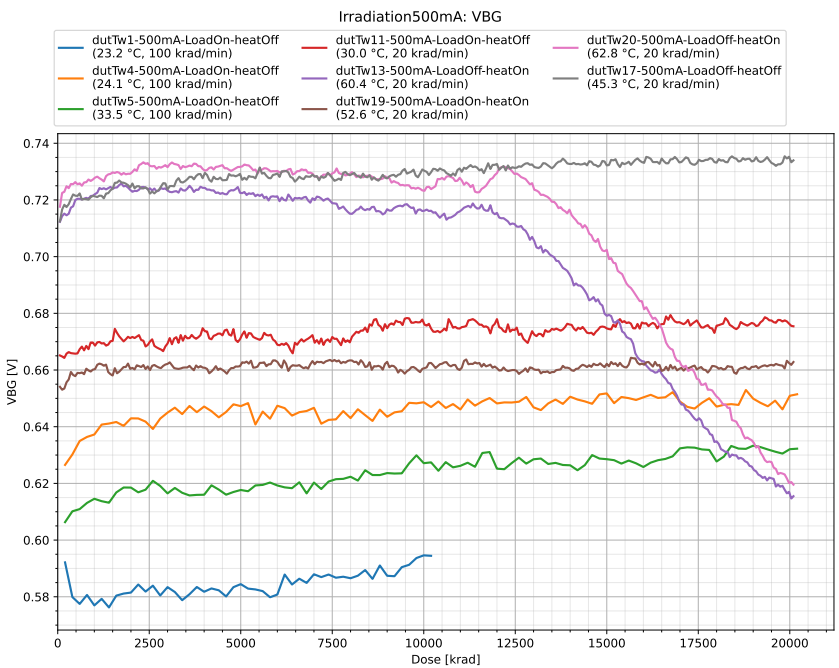
dutTw4-500mA-loadOn-heatOff (22.6 °C)
dutTw5-500mA-loadOn-heatOff (31.6 °C)
dutTw11-500mA-loadOn-heatOff (29.7 °C)
dutTw13-500mA-loadOn-heatOn (55.9 °C)
dutTw19-500mA-LoadOn-heatOff (52.4 °C)
dutTw20-500mA-LoadOff-heatOn (61.7 °C)
dutTw17-500mA-LoadOff-heatOff (43.5 °C)
VBGPre [V]
Time [hrs]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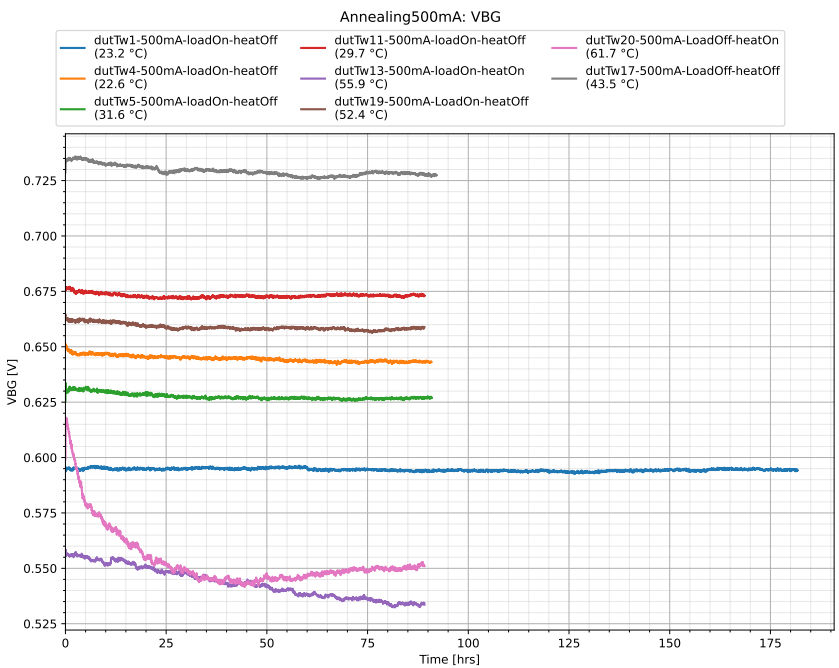
dutTw5-500mA-LoadOn-heatOff (33.5 °C, 100 krad/min)
dutTw11-500mA-LoadOn-heatOff (30.0 °C, 20 krad/min)
dutTw13-500mA-LoadOff-heatOn (60.4 °C, 20 krad/min)
dutTw19-500mA-LoadOn-heatOn (52.6 °C, 20 krad/min)
dutTw20-500mA-LoadOff-heatOn (62.8 °C, 20 krad/min)
dutTw17-500mA-LoadOff-heatOff (45.3 °C, 20 krad/min)
VBG [V]
Dose [krad]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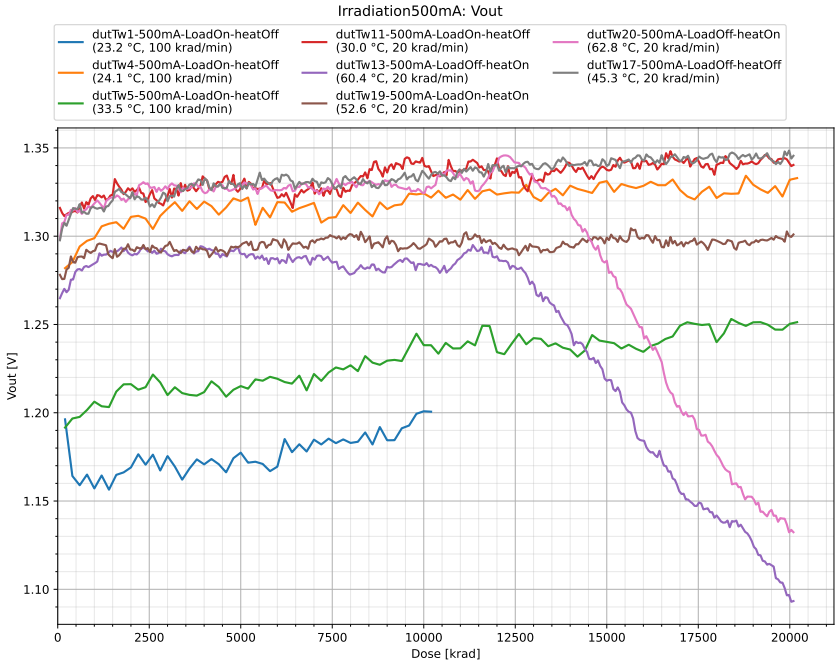
dutTw11-500mA-loadOn-heatOff (29.7 °C)
dutTw13-500mA-loadOn-heatOn (55.9 °C)
dutTw19-500mA-LoadOn-heatOff (52.4 °C)
dutTw20-500mA-LoadOff-heatOn (61.7 °C)
dutTw17-500mA-LoadOff-heatOff (43.5 °C)
VBG [V]
Time [hrs]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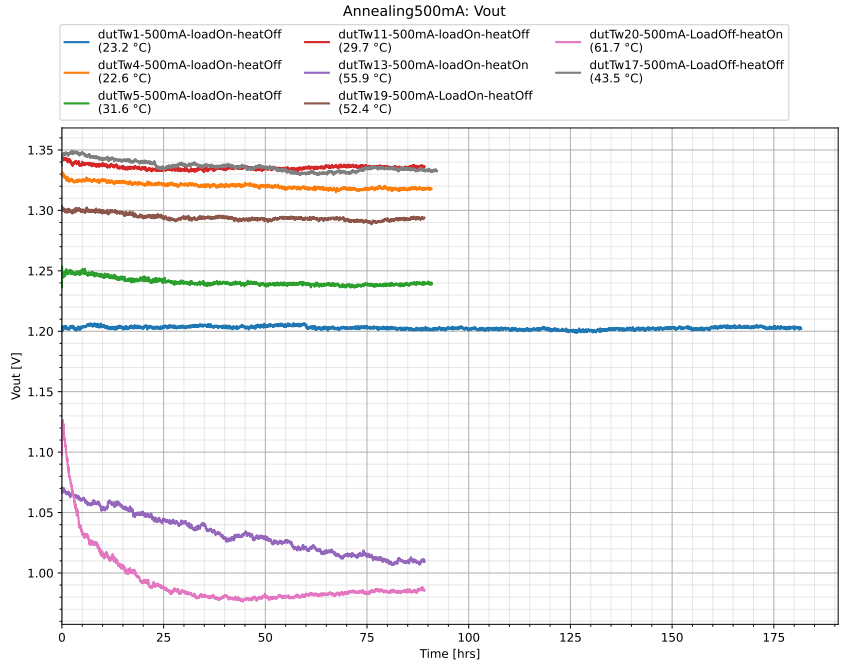
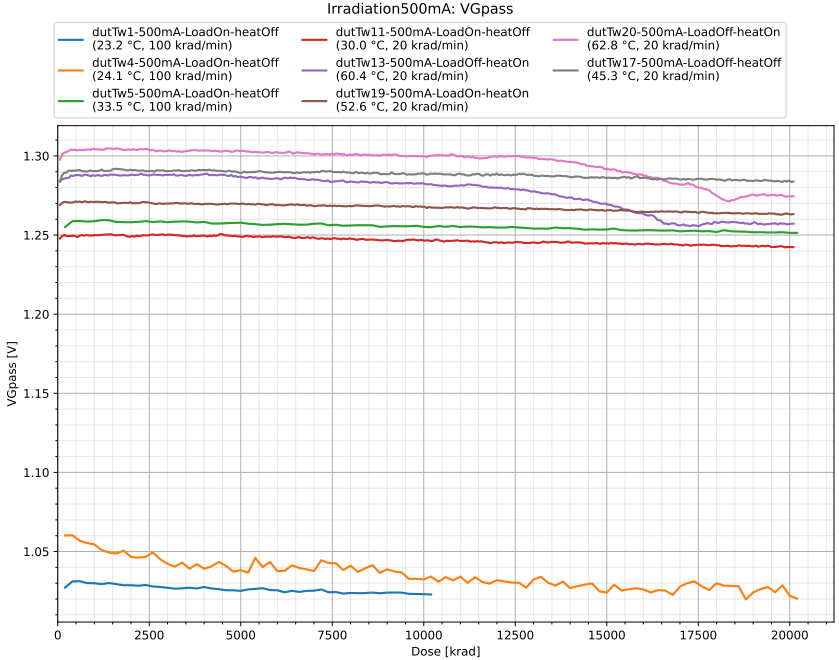
dutTw5-500mA-LoadOn-heatOff (33.5 °C, 100 krad/min)
dutTw11-500mA-LoadOn-heatOff (30.0 °C, 20 krad/min)
dutTw13-500mA-LoadOff-heatOn (60.4 °C, 20 krad/min)
dutTw19-500mA-LoadOn-heatOn (52.6 °C, 20 krad/min)
dutTw20-500mA-LoadOff-heatOn (62.8 °C, 20 krad/min)
dutTw17-500mA-LoadOff-heatOff (45.3 °C, 20 krad/min)
Vout [V]
Dose [krad]


Annealing500mA: Vout
dutTw1-500mA-loadOn-heatOff (23.2 °C)
dutTw4-500mA-loadOn-heatOff (22.6 °C)
dutTw5-500mA-loadOn-heatOff (31.6 °C)
dutTw11-500mA-loadOn-heatOff (29.7 °C)
dutTw13-500mA-loadOn-heatOn (55.9 °C)
dutTw19-500mA-LoadOn-heatOff (52.4 °C)
dutTw20-500mA-LoadOff-heatOn (61.7 °C)
dutTw17-500mA-LoadOff-heatOff (43.5 °C)
Vout [V]
Time [hrs]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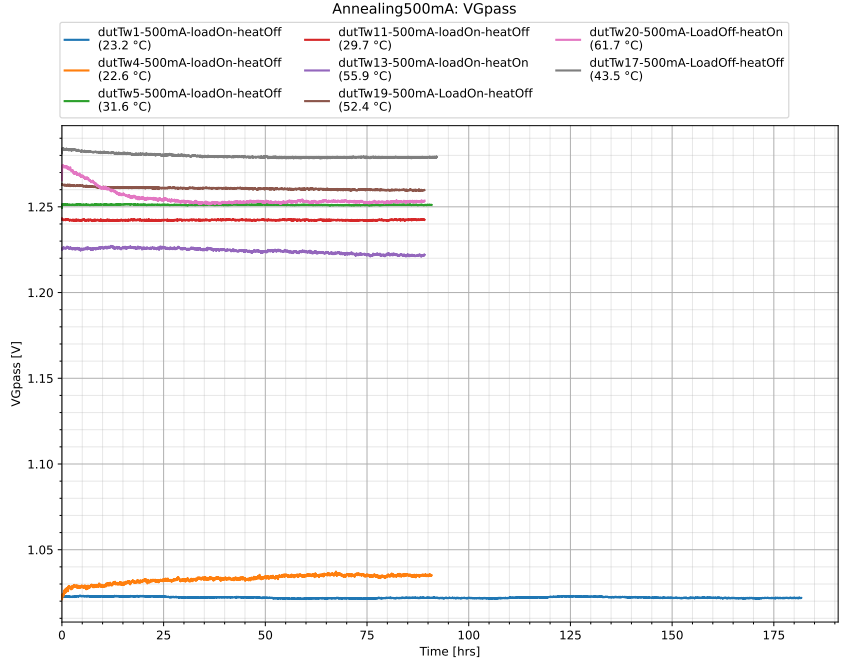
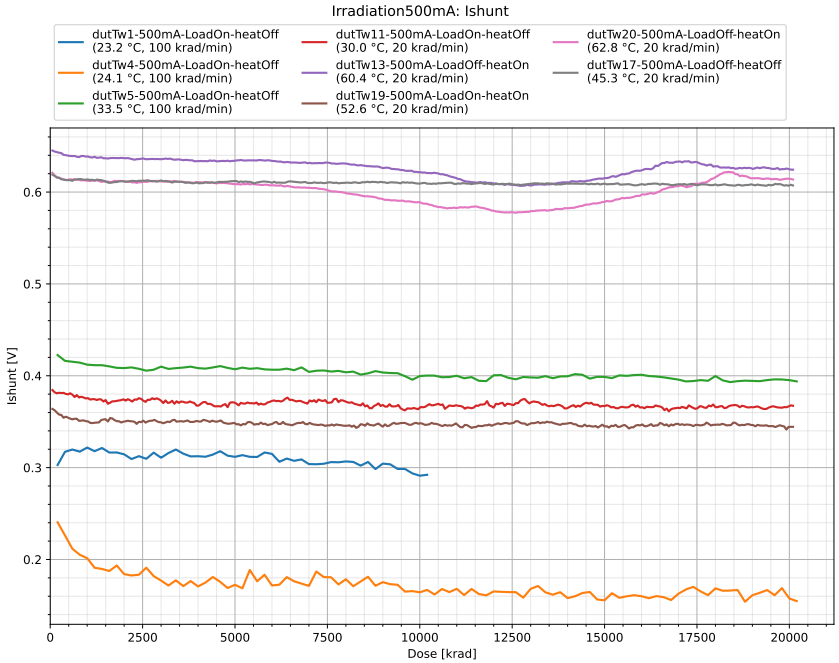
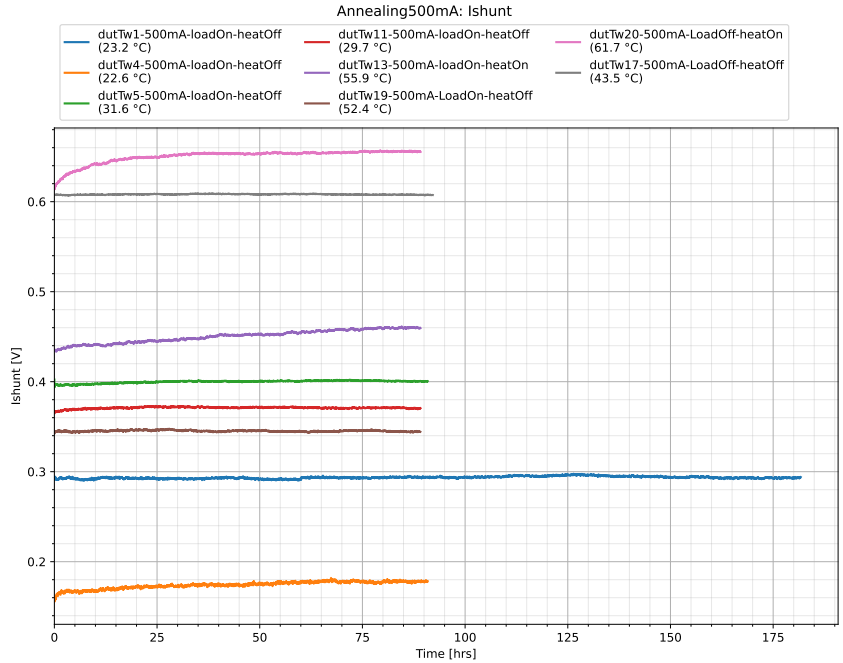
dutTw5-500mA-LoadOn-heatOff (33.5 °C, 100 krad/min)
dutTw11-500mA-LoadOn-heatOff (30.0 °C, 20 krad/min)
dutTw13-500mA-LoadOff-heatOn (60.4 °C, 20 krad/min)
dutTw19-500mA-LoadOn-heatOn (52.6 °C, 20 krad/min)
dutTw20-500mA-LoadOff-heatOn (62.8 °C, 20 krad/min)
dutTw17-500mA-LoadOff-heatOff (45.3 °C, 20 krad/min)
VGpass [V]
Dose [krad]


Annealing500mA: VGpass
dutTw1-500mA-loadOn-heatOff (23.2 °C)
dutTw4-500mA-loadOn-heatOff (22.6 °C)
dutTw5-500mA-loadOn-heatOff (31.6 °C)
dutTw11-500mA-loadOn-heatOff (29.7 °C)
dutTw13-500mA-loadOn-heatOn (55.9 °C)
dutTw19-500mA-LoadOn-heatOff (52.4 °C)
dutTw20-500mA-LoadOff-heatOn (61.7 °C)
dutTw17-500mA-LoadOff-heatOff (43.5 °C)
VGpass [V]
Time [hrs]


Irradiation500mA: Ishunt
dutTw1-500mA-LoadOn-heatOff (23.2 °C, 100 krad/min)
dutTw4-500mA-LoadOn-heatOff (24.1 °C, 100 krad/min)
dutTw5-500mA-LoadOn-heatOff (33.5 °C, 100 krad/min)
dutTw11-500mA-LoadOn-heatOff (30.0 °C, 20 krad/min)
dutTw13-500mA-LoadOff-heatOn (60.4 °C, 20 krad/min)
dutTw19-500mA-LoadOn-heatOn (52.6 °C, 20 krad/min)
dutTw20-500mA-LoadOff-heatOn (62.8 °C, 20 krad/min)
dutTw17-500mA-LoadOff-heatOff (45.3 °C, 20 krad/min)
Ishunt [V]
Dose [krad]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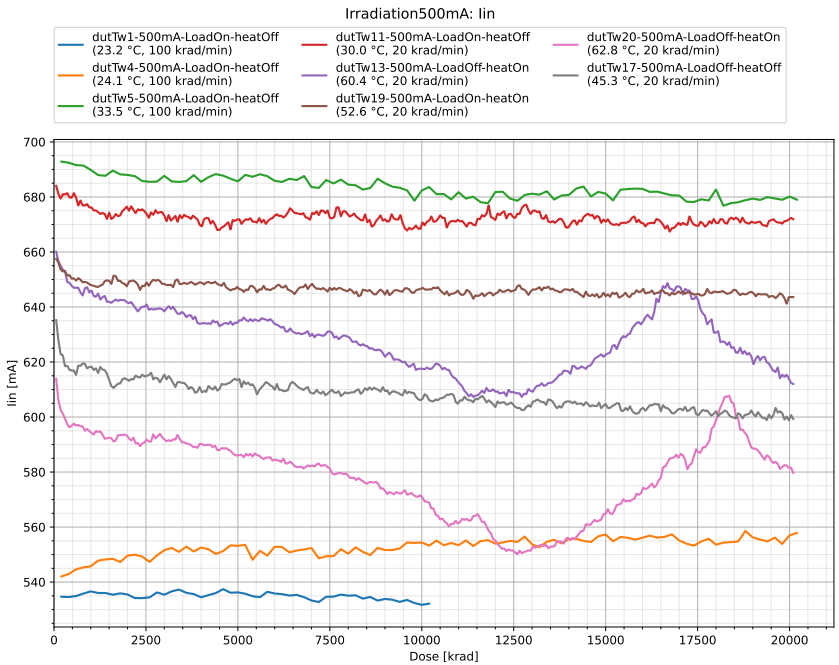
dutTw4-500mA-loadOn-heatOff (22.6 °C)
dutTw5-500mA-loadOn-heatOff (31.6 °C)
dutTw11-500mA-loadOn-heatOff (29.7 °C)
dutTw13-500mA-loadOn-heatOn (55.9 °C)
dutTw19-500mA-LoadOn-heatOff (52.4 °C)
dutTw20-500mA-LoadOff-heatOn (61.7 °C)
dutTw17-500mA-LoadOff-heatOff (43.5 °C)
Ishunt [V]
Time [hrs]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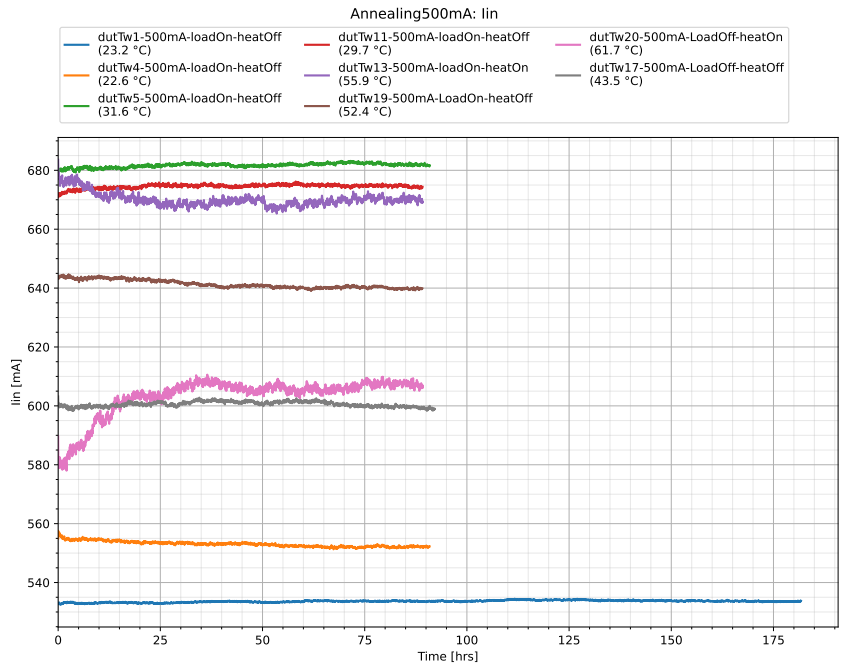
dutTw5-500mA-LoadOn-heatOff (33.5 °C, 100 krad/min)
dutTw11-500mA-LoadOn-heatOff (30.0 °C, 20 krad/min)
dutTw13-500mA-LoadOff-heatOn (60.4 °C, 20 krad/min)
dutTw19-500mA-LoadOn-heatOn (52.6 °C, 20 krad/min)
dutTw20-500mA-LoadOff-heatOn (62.8 °C, 20 krad/min)
dutTw17-500mA-LoadOff-heatOff (45.3 °C, 20 krad/min)
Iin [mA]
Dose [krad]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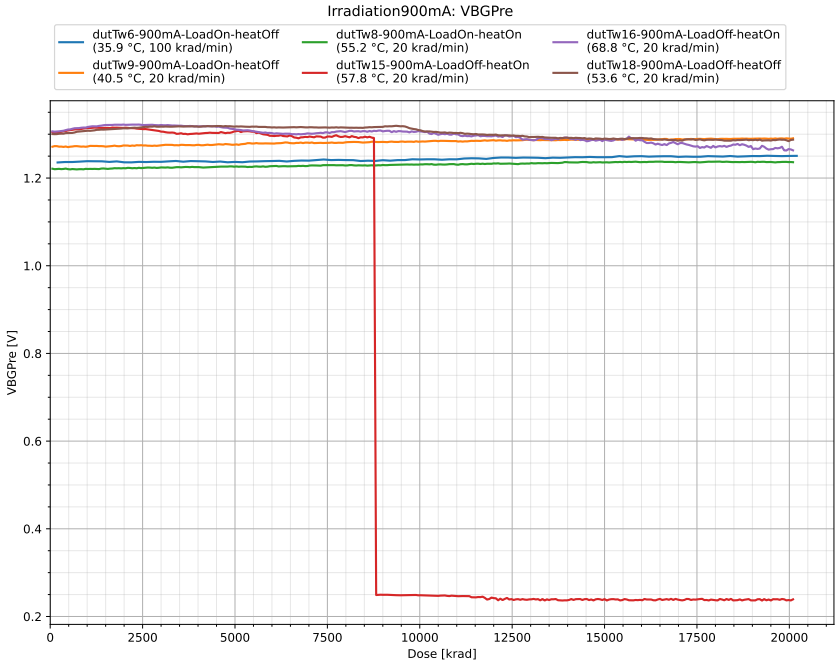
dutTw11-500mA-loadOn-heatOff (29.7 °C)
dutTw13-500mA-loadOn-heatOn (55.9 °C)
dutTw19-500mA-LoadOn-heatOff (52.4 °C)
dutTw20-500mA-LoadOff-heatOn (61.7 °C)
dutTw17-500mA-LoadOff-heatOff (43.5 °C)
Iin [mA]
Time [hrs]

900 mA Load Region Irradiation and Annealing

Device	Load	Heat	Vin [V]	Dose Rate [krad/min]	Comments
Tw6	On	Off	1.80	104	- During post-irrad annealing, data was lost from 1.5 - ∼20hrs
Tw9	On	Off	1.80	20	-
Tw8	On	On	1.80	20	-
Tw15	Off	On	1.80	20	- ∼9Mrad during irradiation: Iin hit compliance, switching off PSU. Vout is not at 0V because the communication pins are enabled, and signals lift the sensor from GND. Post irrad, DUT powers up w/o short.
Tw16	Off	On	1.80	20	- During Annealing Iin fuse triggered Vin∼0.7 instead of 1.8
Tw18	Off	Off	1.80	20	-


Irradiation900mA: VBGPre
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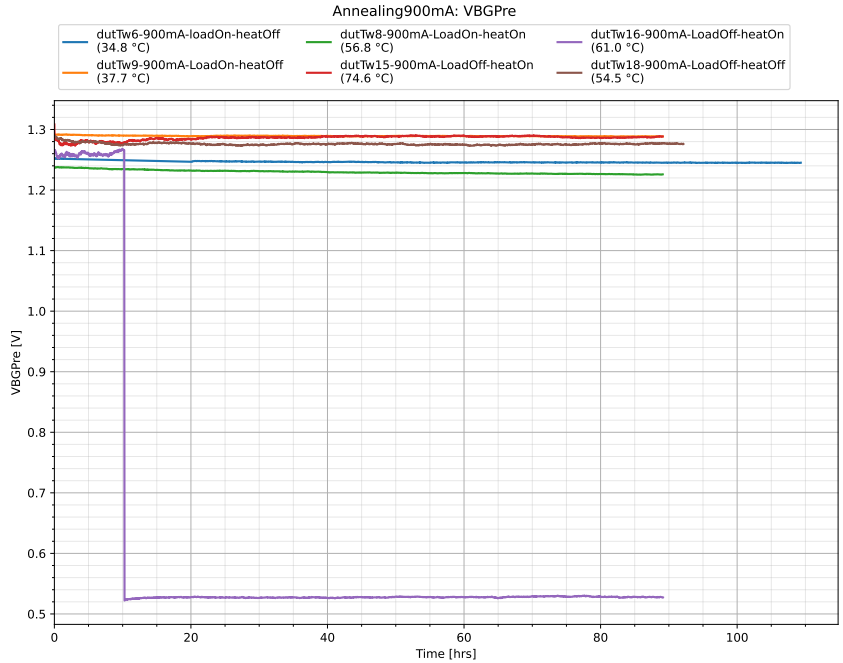
dutTw8-900mA-LoadOn-heatOn (55.2 °C, 20 krad/min)
dutTw16-900mA-LoadOff-heatOn (68.8 °C, 20 krad/min)
dutTw9-900mA-LoadOn-heatOff (40.5 °C, 20 krad/min)
dutTw15-900mA-LoadOff-heatOn (57.8 °C, 20 krad/min)
dutTw18-900mA-LoadOff-heatOff (53.6 °C, 20 krad/min)
VBGPre [V]
Dose [krad]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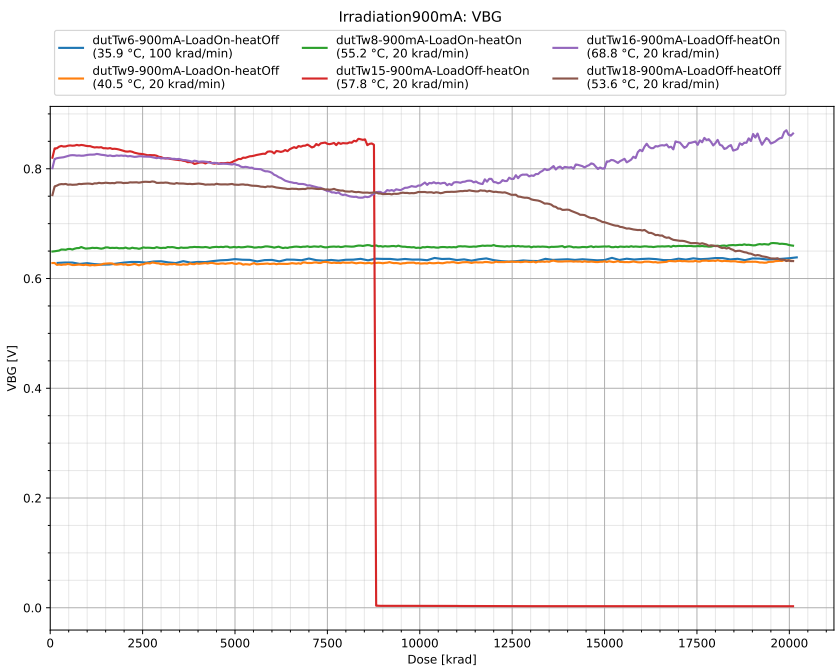
dutTw6-900mA-loadOn-heatOff (34.8 °C)
dutTw8-900mA-LoadOn-heatOn (56.8 °C)
dutTw16-900mA-LoadOff-heatOn (61.0 °C)
dutTw9-900mA-LoadOn-heatOff (37.7 °C)
dutTw15-900mA-LoadOff-heatOn (74.6 °C)
dutTw18-900mA-LoadOff-heatOff (54.5 °C)
VBGPre [V]
Time [hrs]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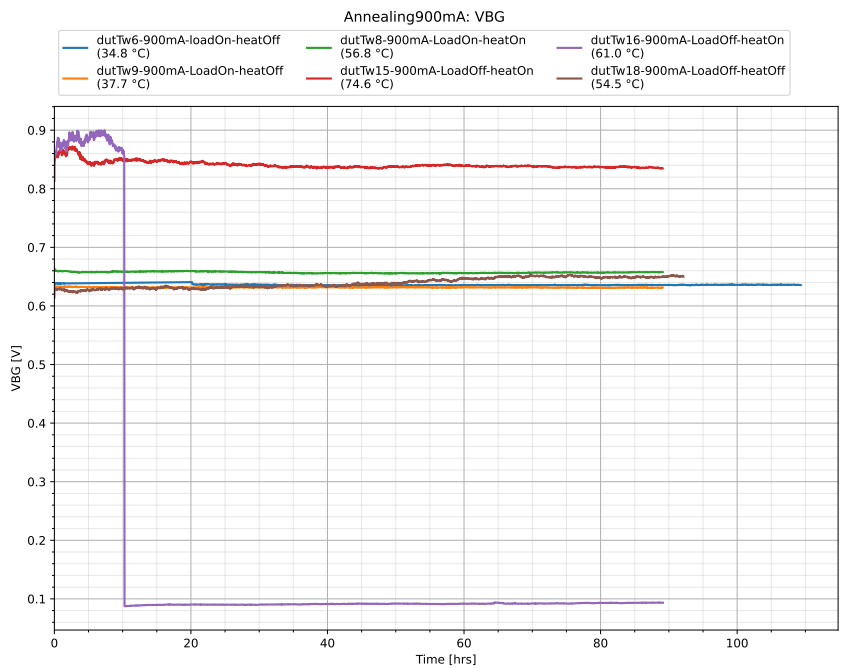
dutTw16-900mA-LoadOff-heatOn (68.8 °C, 20 krad/min)
dutTw9-900mA-LoadOn-heatOff (40.5 °C, 20 krad/min)
dutTw15-900mA-LoadOff-heatOn (57.8 °C, 20 krad/min)
dutTw18-900mA-LoadOff-heatOff (53.6 °C, 20 krad/min)
VBG [V]
Dose [krad]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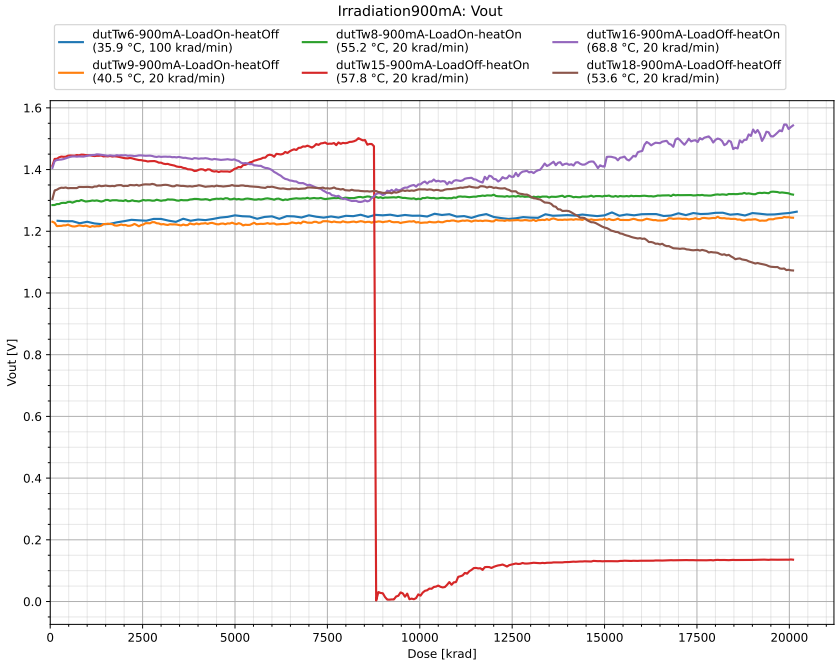
dutTw16-900mA-LoadOff-heatOn (61.0 °C)
dutTw9-900mA-LoadOn-heatOff (37.7 °C)
dutTw15-900mA-LoadOff-heatOn (74.6 °C)
dutTw18-900mA-LoadOff-heatOff (54.5 °C)
VBG [V]
Time [hrs]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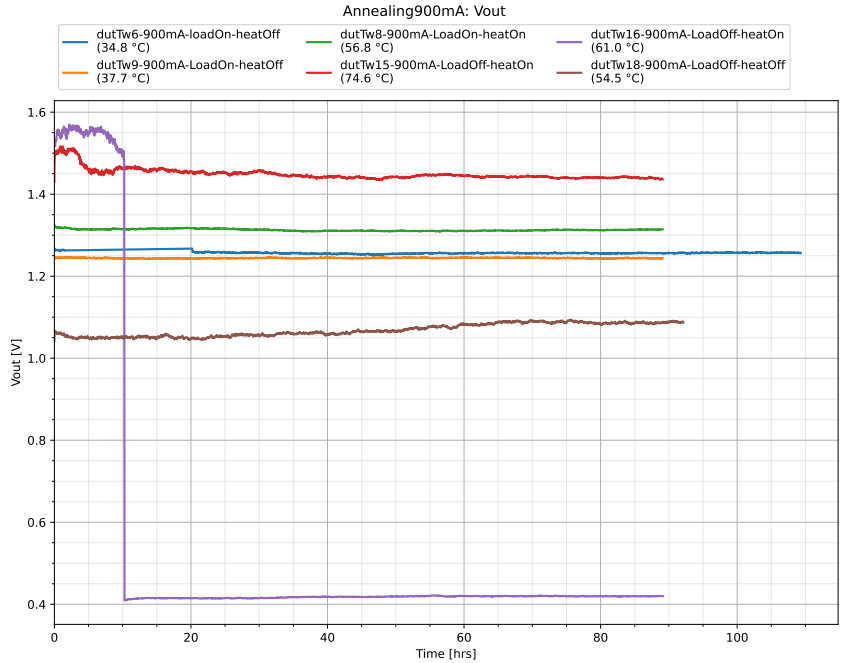
dutTw16-900mA-LoadOff-heatOn (68.8 °C, 20 krad/min)
dutTw9-900mA-LoadOn-heatOff (40.5 °C, 20 krad/min)
dutTw15-900mA-LoadOff-heatOn (57.8 °C, 20 krad/min)
dutTw18-900mA-LoadOff-heatOff (53.6 °C, 20 krad/min)
Vout [V]
Dose [krad]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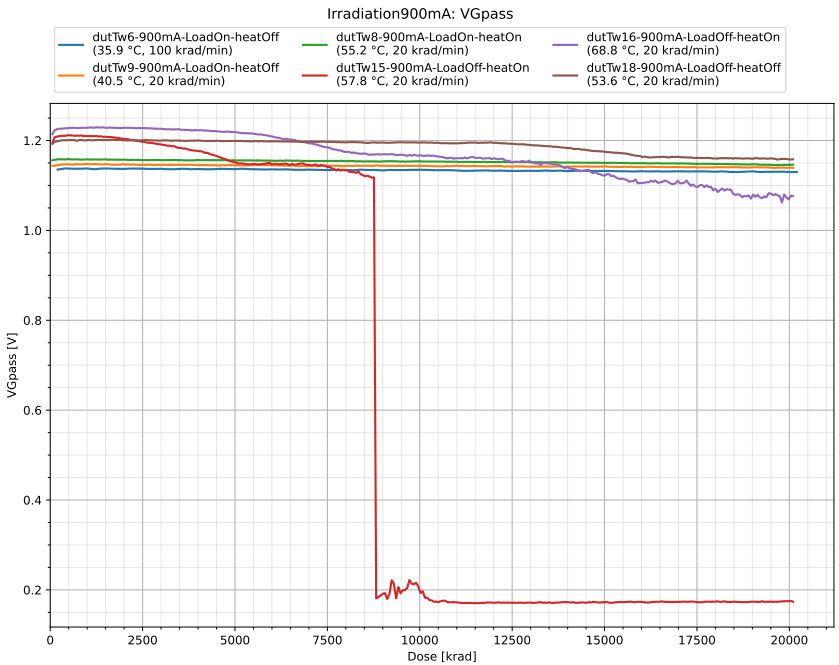
dutTw16-900mA-LoadOff-heatOn (61.0 °C)
dutTw9-900mA-LoadOn-heatOff (37.7 °C)
dutTw15-900mA-LoadOff-heatOn (74.6 °C)
dutTw18-900mA-LoadOff-heatOff (54.5 °C)
Vout [V]
Time [hrs]


Irradiation900mA: VGpass
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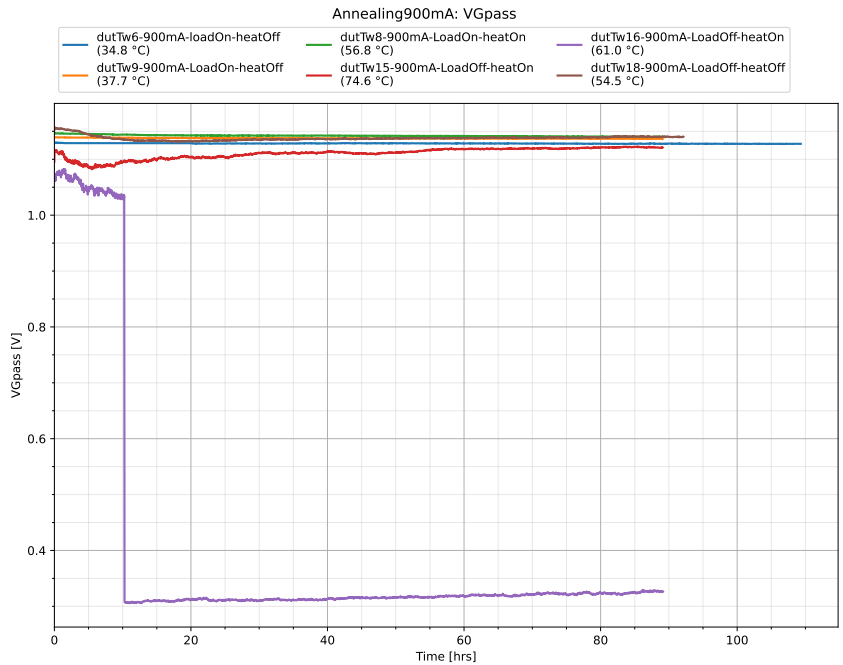
dutTw16-900mA-LoadOff-heatOn (68.8 °C, 20 krad/min)
dutTw9-900mA-LoadOn-heatOff (40.5 °C, 20 krad/min)
dutTw15-900mA-LoadOff-heatOn (57.8 °C, 20 krad/min)
dutTw18-900mA-LoadOff-heatOff (53.6 °C, 20 krad/min)
VGpass [V]
Dose [krad]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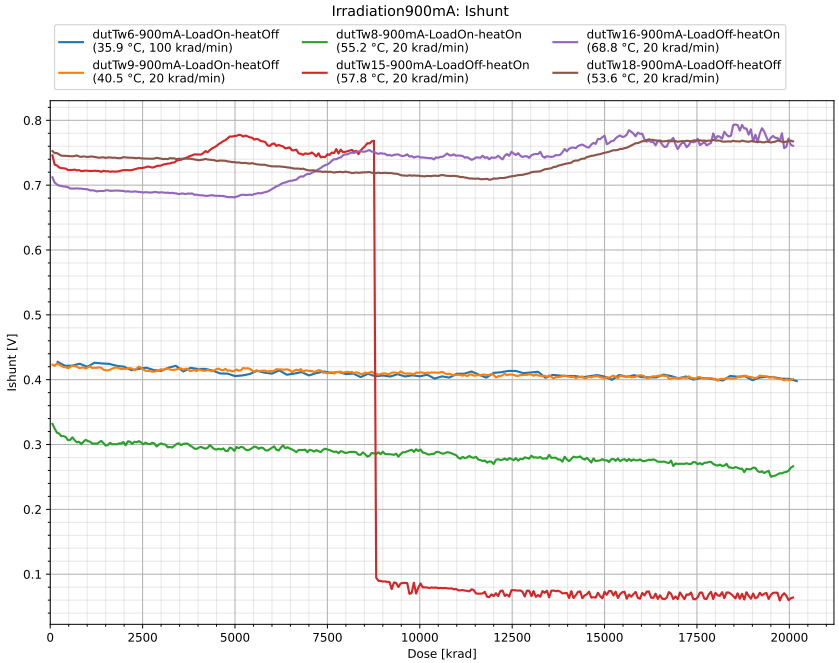
dutTw9-900mA-LoadOn-heatOff (37.7 °C)
dutTw15-900mA-LoadOff-heatOn (74.6 °C)
dutTw18-900mA-LoadOff-heatOff (54.5 °C)
VGpass [V]
Time [hrs]


Irradiation900mA: Ishunt
dutTw6-900mA-LoadOn-heatOff (35.9 °C, 100 krad/min)
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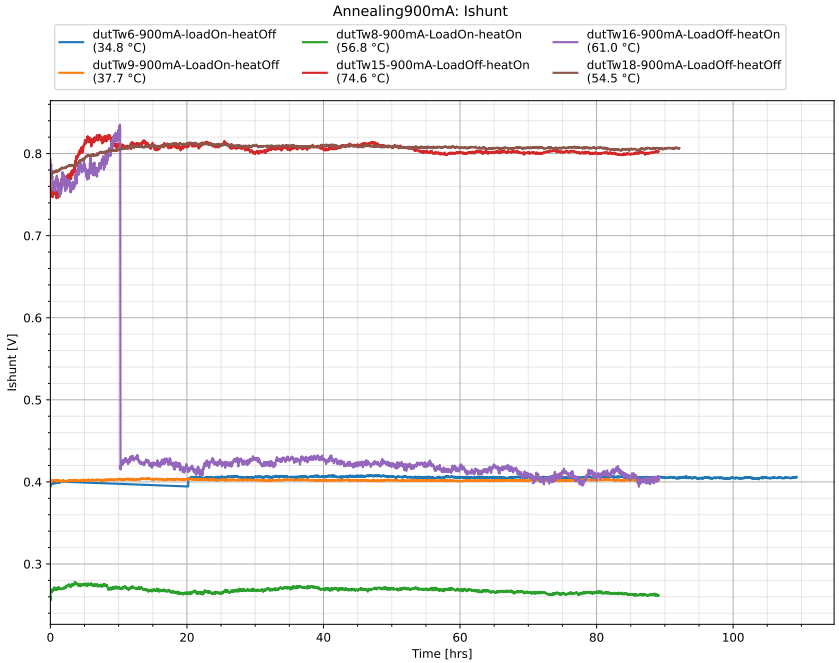
dutTw16-900mA-LoadOff-heatOn (68.8 °C, 20 krad/min)
dutTw9-900mA-LoadOn-heatOff (40.5 °C, 20 krad/min)
dutTw15-900mA-LoadOff-heatOn (57.8 °C, 20 krad/min)
dutTw18-900mA-LoadOff-heatOff (53.6 °C, 20 krad/min)
Ishunt [V]
Dose [krad]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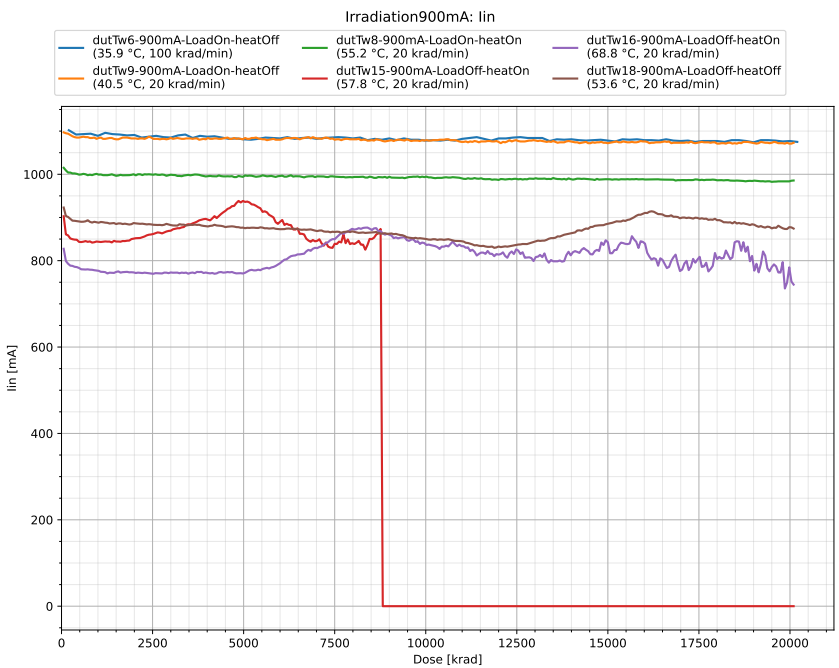
dutTw9-900mA-LoadOn-heatOff (37.7 °C)
dutTw15-900mA-LoadOff-heatOn (74.6 °C)
dutTw18-900mA-LoadOff-heatOff (54.5 °C)
Ishunt [V]
Time [hrs]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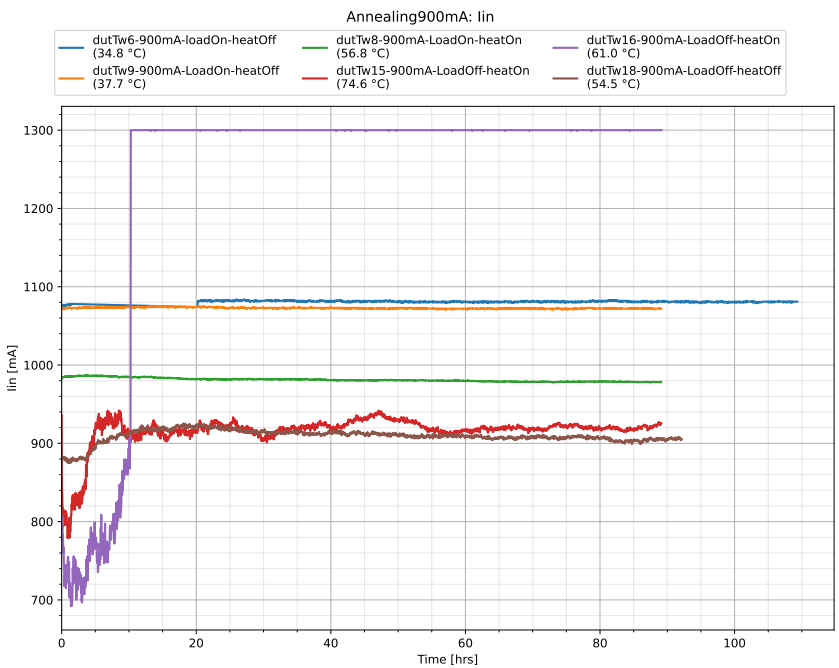
dutTw9-900mA-LoadOn-heatOff (40.5 °C, 20 krad/min)
dutTw15-900mA-LoadOff-heatOn (57.8 °C, 20 krad/min)
dutTw18-900mA-LoadOff-heatOff (53.6 °C, 20 krad/min)
Iin [mA]
Dose [krad]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dutTw9-900mA-LoadOn-heatOff (37.7 °C)
dutTw15-900mA-LoadOff-heatOn (74.6 °C)
dutTw18-900mA-LoadOff-heatOff (54.5 °C)
Iin [mA]
Time [hrs]

Conclusion

- 16 SLDO-chips were irradiated up to 20Mrad(SiO_2) (i.e. x100 more TID than required by SVT 200krad(SiO_2).
- Vin, Iin, Vout, VGpass, VBG, Ishunt, VBGPre and Temperature were measured at regular intervals during irradiation and annealing.
- DUTs show a higher sensitivity to TID when the load was OFF and when heat was ON.