Survey of Total Ionizing Dose Tolerance
of power bipolar transistors and Silicon Carbide devices for JUICE

-Status of ongoing activities-

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ESA & CNES Final Presentation Days: Radiation Effects on EEE components

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Power bipolar transistors / SiC devices
Project details

- Project: „Survey of Total Ionizing Dose Tolerance of Power Bipolar Transistors and Silicon Carbide Devices for Juice“
- Contract 4000113976/15/NL/RA
- Price 225 k€
- Original timeframe: 18 months
- Start of project: 01.06.2015
- End of project: November 2017

Power bipolar / Silicon Carbide
Scope of the project

- Power Bipolar Transistors
  - Select and test six power bipolar transistors for ELDRS sensitivity up to 200 krad(Si)
    - Based on industry prefered parts
- SiC device
  - Evaluate TID hardness of commercially available SiC power devices
    - Target dose rate 1 Mrad(Si)
  - Investigate SEE sensitivity up to an LET of 60 MeV cm^2/mg
  - SEE tests with protons to assess sensitivity for LET<15 MeV cm^2/mg
  - (SEE tests to be done, not covered in this presentation)

Part Selection
Power bipolar transistors

Component	Type	Package	V_{CE}	I_C	Lot/Date code
2ST21600 (STMicroelectronics)	PNP	SMD.22	-400 V	0.5 A	33528003ZT
2N7370 (Microsemi)	NPN	TO-254AA	100 V	12A	88115 / 1642 CDWR
2N7371 (Microsemi)	PNP	TO-254AA	-100 V	-12 A	1TWO086021 / 9D1633
BDS16 (Semelab)	NPN	TO-257AB	120 V	8 A	CM1438
BDS18 (Semelab)	PNP	TO-257AB	-120 V	-8 A	AF1615U
BUL54A (Semelab)	NPN	TO-257	500 V	4 A	KF1609Y

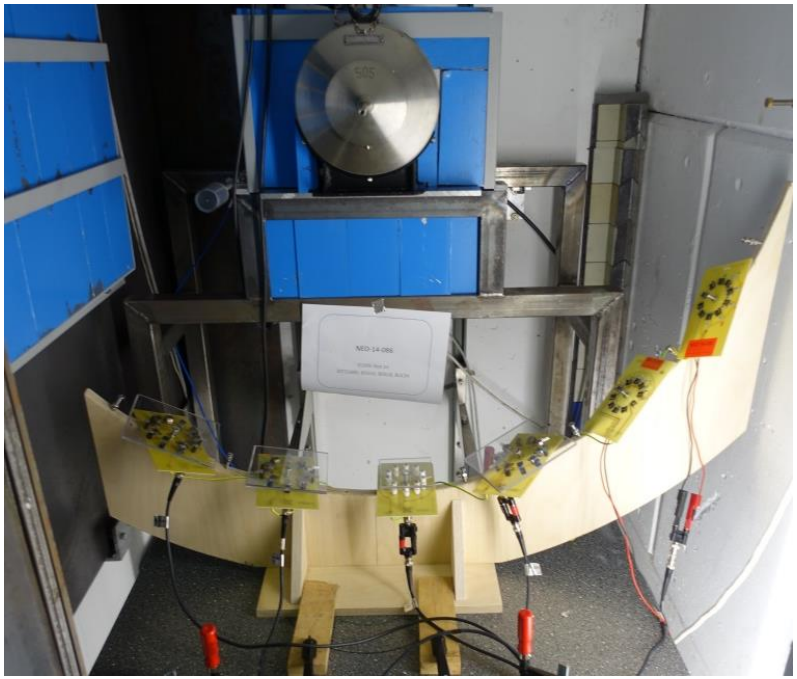
Part Selection
SiC power devices

	Component	Pack.	V	I	Lot / Date code
MOSFET	C2M0080120D (Cree)	TO-247-3	V_{DS} 1200 V	I_D 36 A	W14315
	SCT20N120 (STM)	HIP247	V_{DS} 1200 V	I_D 20 A	GK 06NVY/CHN GK546
Schottky	IDW10G120C5B (Infineon)	TO-247	V_R 1200 V	I_F 5 A	D1012B5 / HAA527
	C4D40120D (Cree)	TO-247-3	V_R 1200 V	I_F 56.5 A	W13714
	SML020DH12 (Semelab)	TO-258AA	V_R 1200 V	I_F 20 A	HM14070
JFET	IJW120RT100T1 (Infineon)	TO-247	V_{DS} 1200 V	I_D 26 A	HAA547

Power bipolar / Silicon Carbide
Procurement

- Procurement initiated 12/2015
- Power Bipolar Transistors
  - Traceability information was not provided for initially proposed Microsemi 2N5154
    - Replaced with STMicroelectronics 2ST21600
  - 08/16: Announcement of large procurement delay of 2 components marked start of ELDRS testing campaign (4/6 components)
  - 2 remaining components started with significant delay (10/16) and (02/17)
- SiC power devices
  - Commercial devices
  - Traceability information available

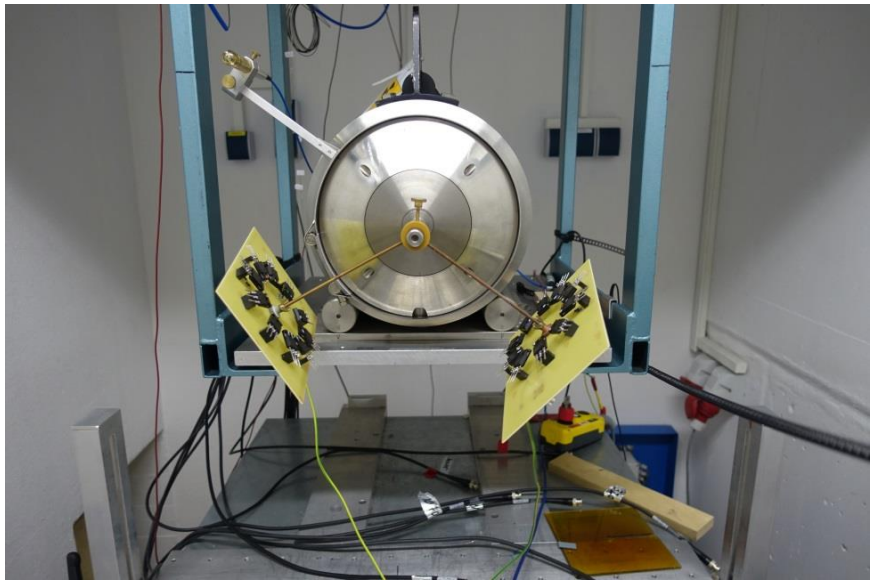
Test Definition
Co-60 Facilities



- TK100 @ INT
  - ELDRS testing up to 200 krad(Si)
  - Initial dose rate @ DUTs: ~35 rad/h
  - Currently ~ 33 rad/h
  - Ongoing since 08/2016
  - Irradiation in fixed geometry
    - Dose rate reduction due to Co60-decay accouted for when calculating irradiation times

Test Definition
Co-60 Facilities

- TK1000B @ INT
  - High dose testing of PBT and SiC-devices
  - Dose rate @ DUTs: 8.8 – 8.6 krad(Si)/h (multiple irradiations)
  - SiC: Co60-Tests finished
    - 168h @ 100°C ongoing for 2 comp.
  - PBT: High dose tests to be performed in the coming weeks



Test Definitions

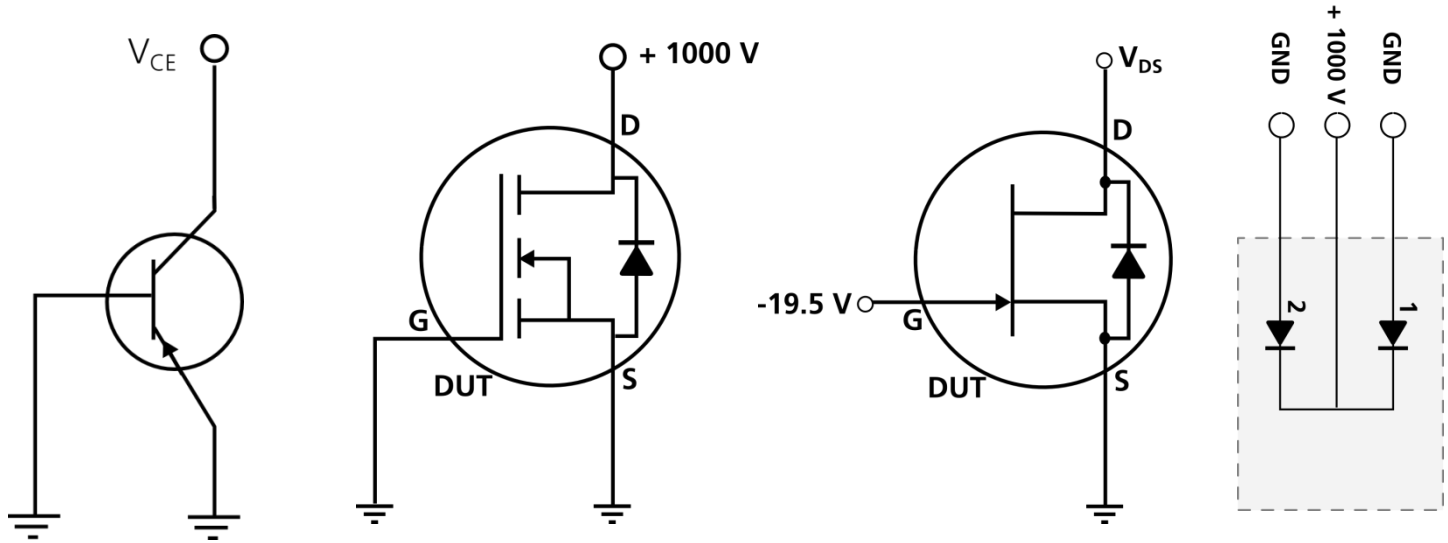
Test steps / Biasing

Power Bipolar Transistors

0 10 20 30 50 100 150 200 krad(Si)

Silicon Carbide Power Devices

0 30 50 100 300 500 1000 krad(Si)



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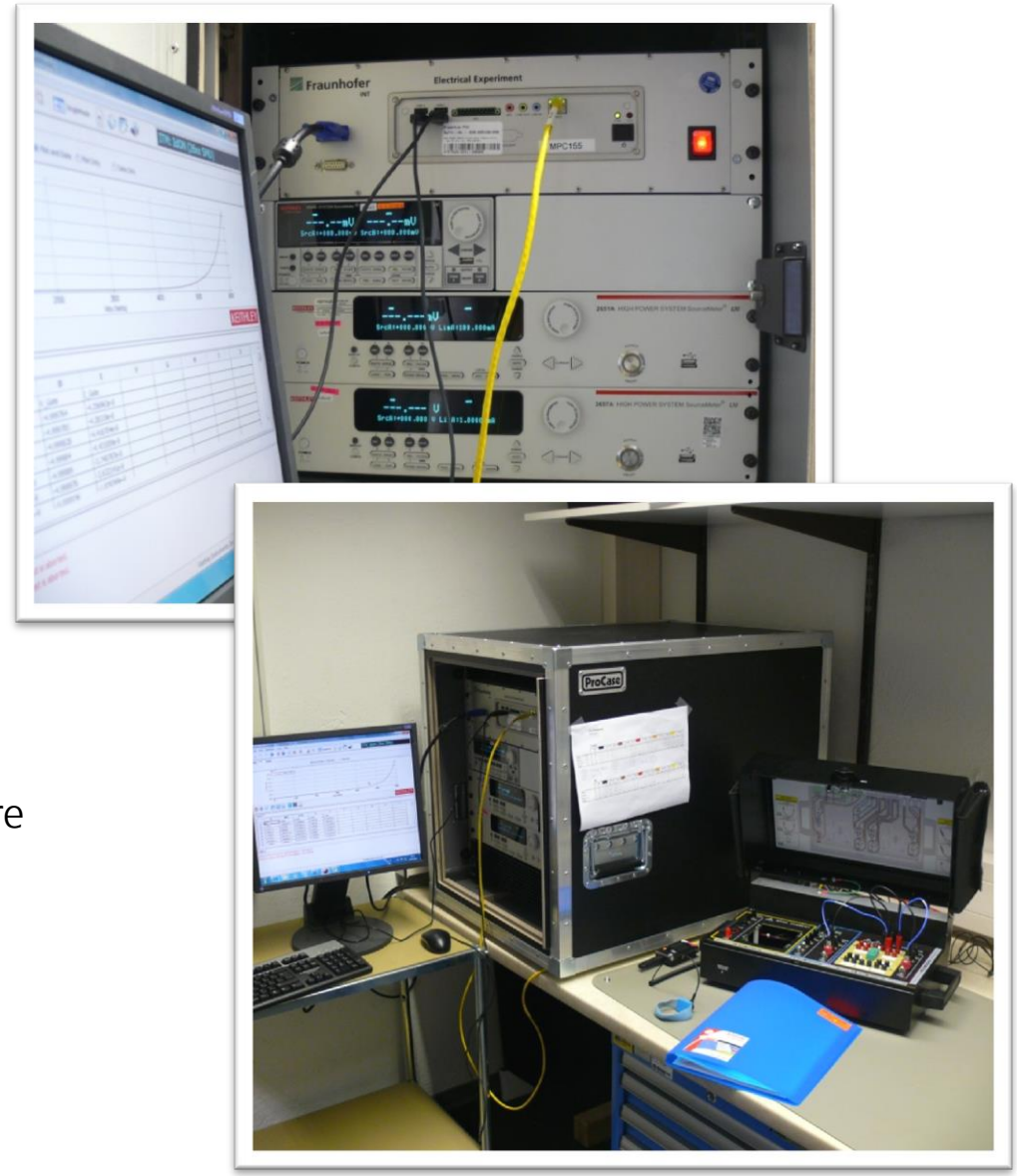
Test Definition
Test setup

- Test setup
  - High Power / High Voltage SMUs
    - Keithley 2657A (1.5 kV @ 120 mA)
    - Keithley 2651A (50 V @ 40 A pulsed)
    - Keithley 2636B (200 V @ 1 A pulsed)
    - Synchronization of pulsed tests
  - Keithley 8010 High Power Test Fixture



Test Definition
Power bipolar transistors

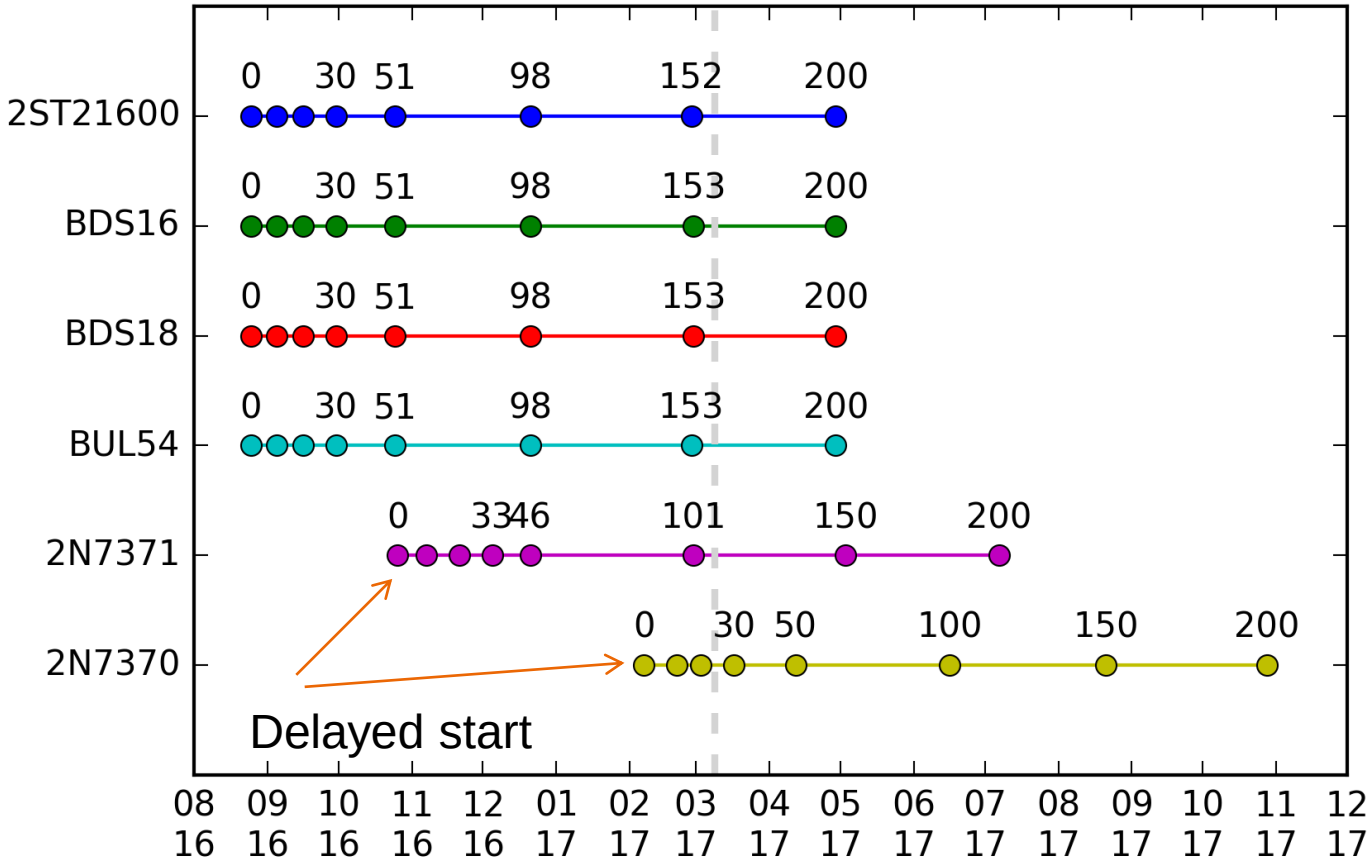
TM	Test	2ST21600	2N7370	2N7371	BDS16	BDS18	BUL54A
3001	Collector-Base Breakdown Voltage	x	--	--	--	--	x
3011	Collector Emitter Breakdown Voltage	x	x	x	x	X	x
3026	Emitter-Base Breakdown Voltage	x	--	--	--	--	x
3036	Collector-Base Cutoff Current	x	--	--	--	--	x
3041	Collector-Emitter Cut-Off Current	--	x	x	x	x	x
3061	Emitter-Base Cutoff Current	x	x	x	x	x	x
3066	Base-Emitter Saturation Voltage	x	x	x	x	x	x
3071	Collector-Emitter Saturation Voltage	x	x	x	x	x	x
3076	Forward Current Transfer Ratio	x	x	x	x	x	x

Test Definition
SiC Devices

		MOSFET		JFET	Schottky		
TM	**Test**	**C2M0080120D**	**SCT20N120**	**IJW120R100T1**	**C4D40120D**	**IDW10G120C5B**	**SML020DH12**
3407	Drain-Source Breakdown Voltage	X	X	X	--	--	--
3411	Gate-Source Leakage Current	X	X	X	--	--	--
3413	Zero Gate Voltage Drain Current	X	X	X	--	--	--
3403	Gate Threshold Voltage	X	X	X	--	--	--
3421	Drain-Source On-State Resistance	X	X	X	--	--	--
4011	Diode Forward Voltage	X	X	X	X	X	X
4016	Reverse Current	--	--	--	X	X	X

Power Bipolar Transistors

Current Status of ELDRS tests



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Bipolar Power Transistors

Radiation levels (ongoing, ELDRS)

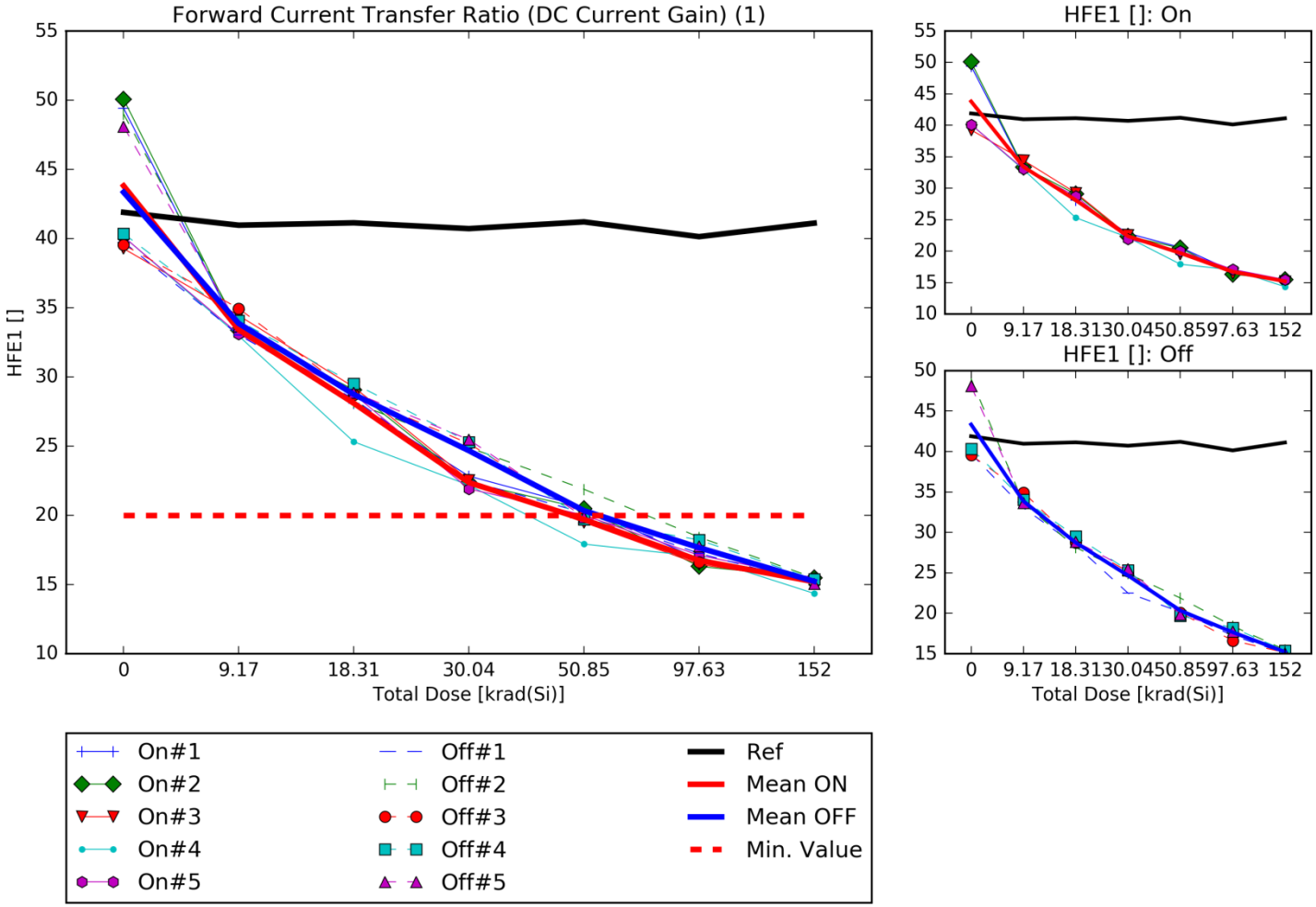
Radiation levels in krad(Si) (Test steps) at which parameters drift out of specs

TM	Test	2ST21600	2N7370	2N7371	BDS16	BDS18	BUL54A
3001	Collector-Base Breakdown Voltage	*					**98**
3011	Collector Emitter Breakdown Voltage	>150	>20	>100	>150	>150	>150
3026	Emitter-Base Breakdown Voltage	>150					>150
3036	Collector-Base Cutoff Current	*					**18**
3041	Collector-Emitter Cut-Off Current		>20	>100	>150	>150	>150
3061	Emitter-Base Cutoff Current	>150	>20	>100	>150	>150	>150
3066	Base-Emitter Saturation Voltage	>150	>20	>100	>150	>150	>150 >150
3071	Collector-Emitter Saturation Voltage	*	>20	>100	>150 >150	>150 >150	**51** **18** **9**
3076	Forward Current Transfer Ratio	*	>20	>100 >100	>150 >150	**18** >150	**51** **30** >150

* Parameters out of specifications were observed, but influence of the setup on the results have to be reviewed, to be confirmed by HDR tests

Current transfer ratio (HFE)

BUL54 #1: V_{CE} = 5V, I_C = 0.1 A



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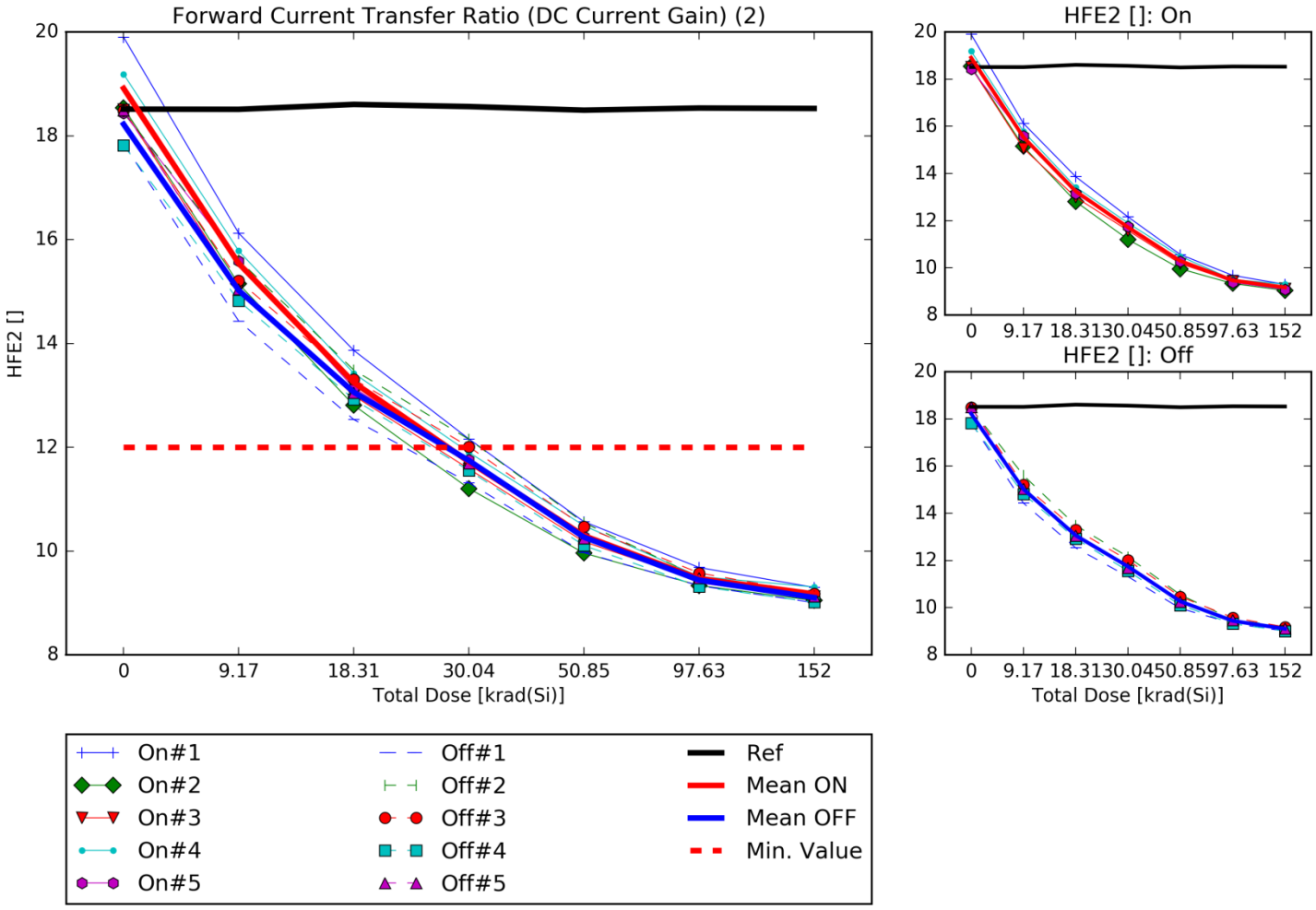
Current transfer ratio (HFE)

BUL54 #2: V_{CE} = 5V, I_C = 0.5 A



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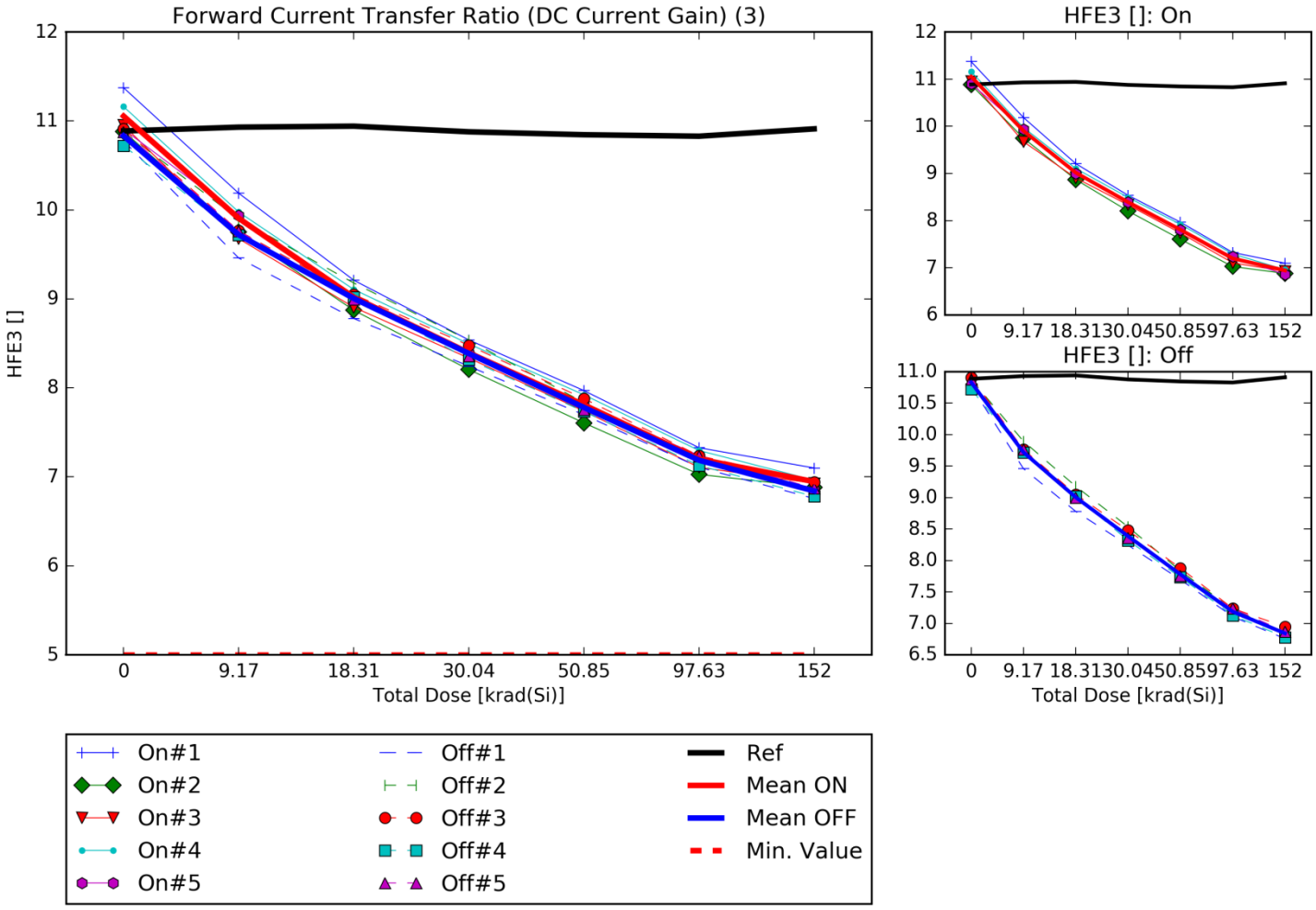
Current transfer ratio (HFE)

BUL54 #2: V_{CE} = 5V, I_C = 1.0 A



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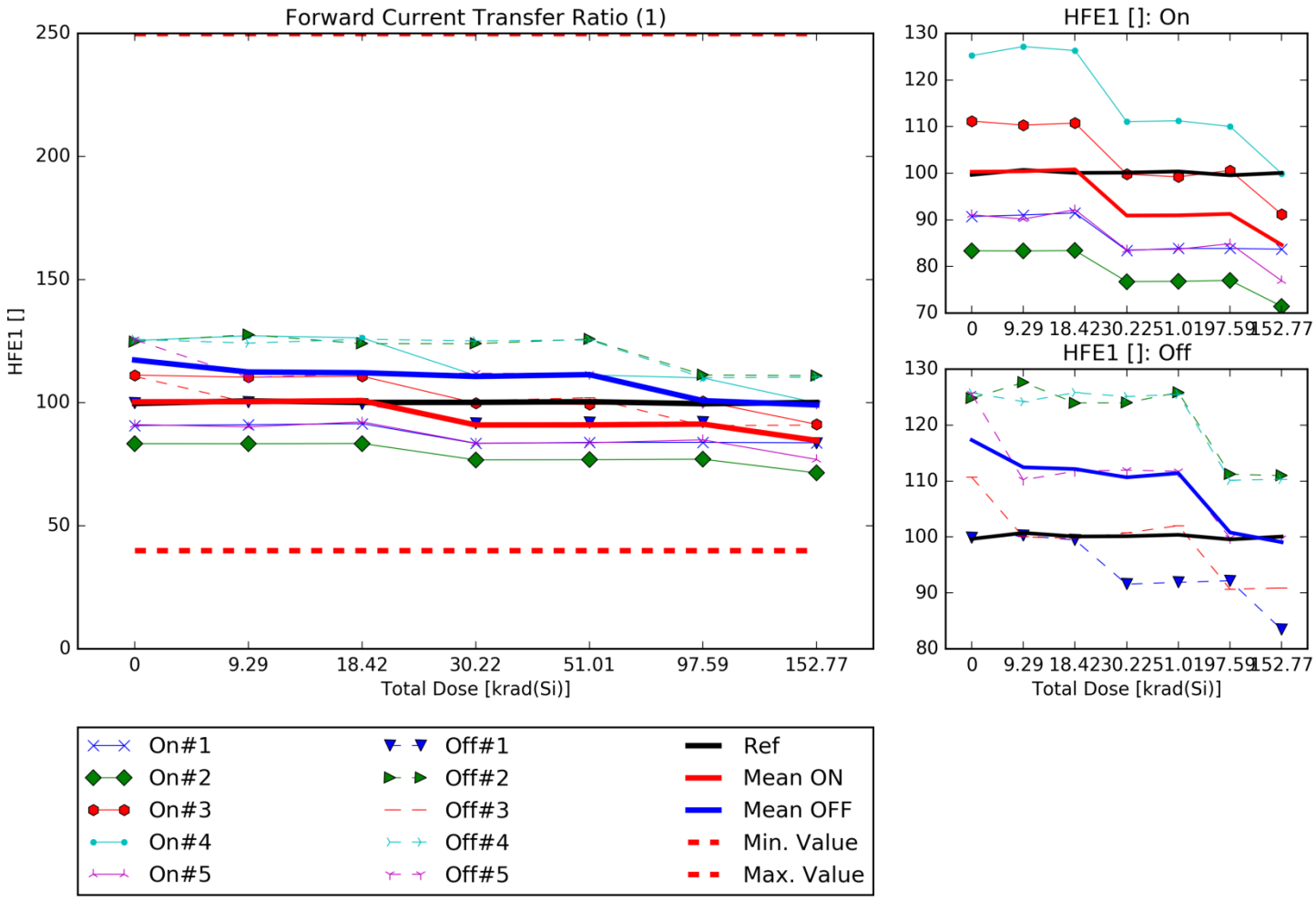
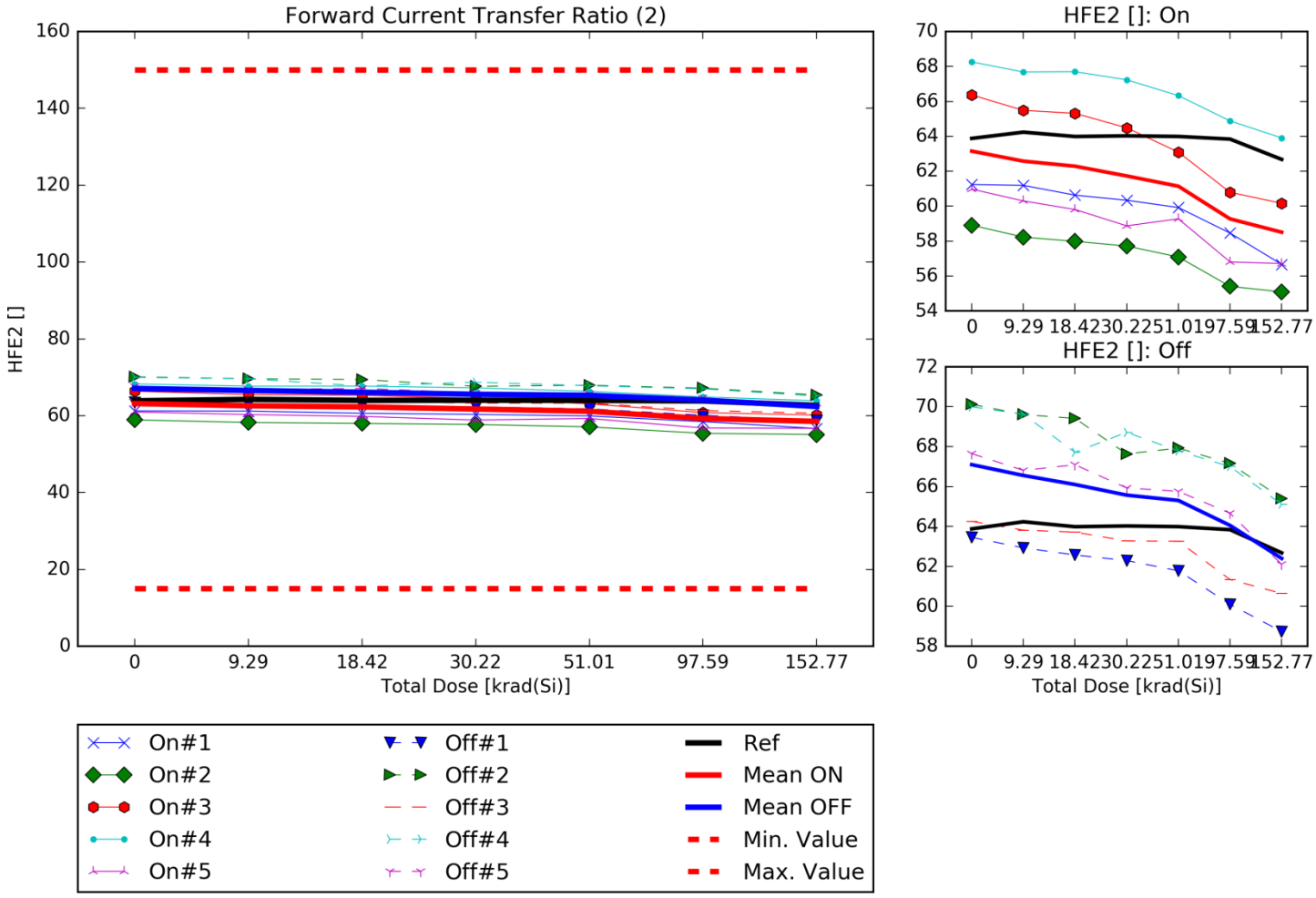
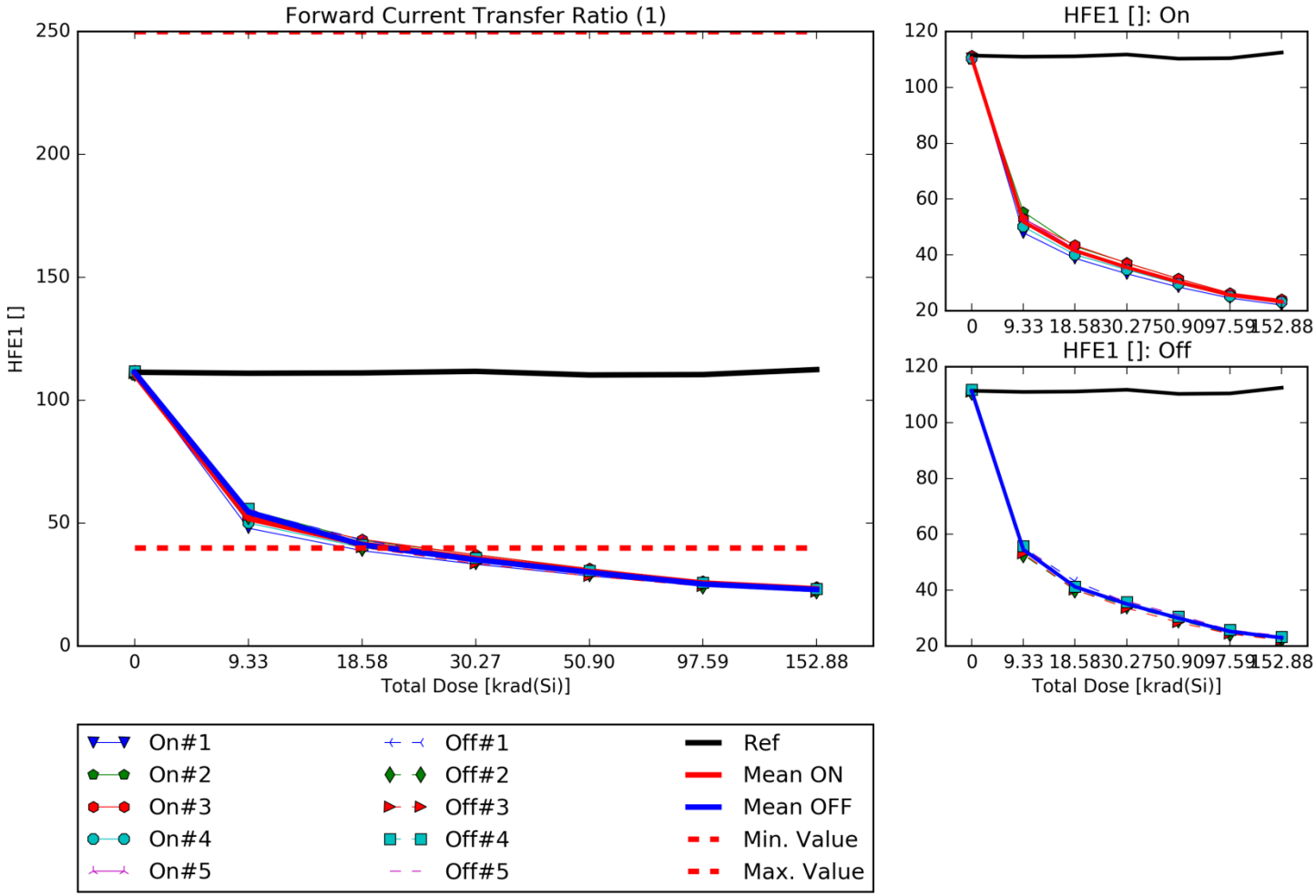
Current transfer ratio (HFE)
BDS16 #1: V_{CE} = 2V, I_C = 0.5 A



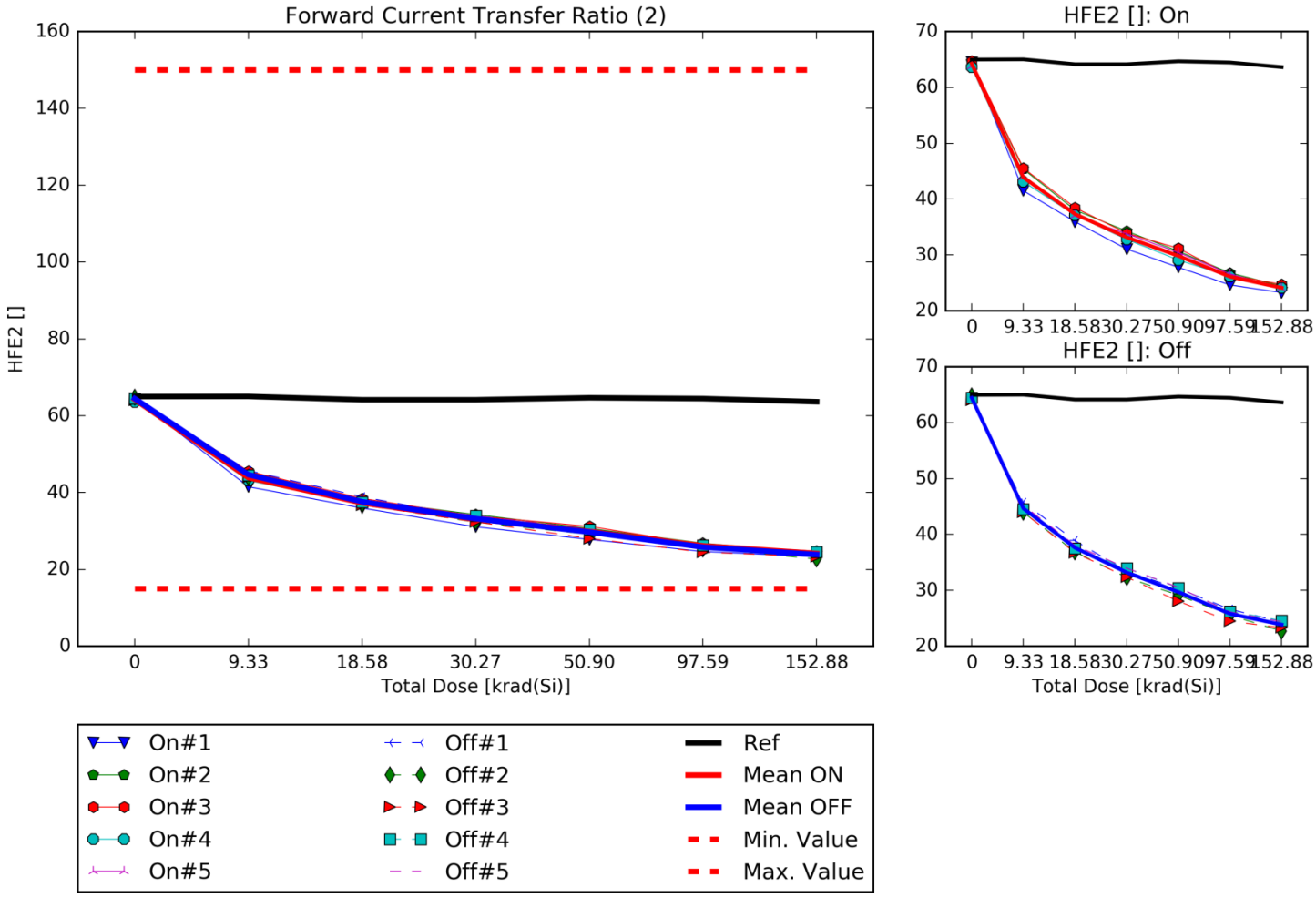
Current transfer ratio (HFE)
BDS16 #2: V_{CE} = 2V, I_C = 4.0 A



Current transfer ratio (HFE)
BDS18 #1: V_{CE} = -2V, I_C = -0.5 A

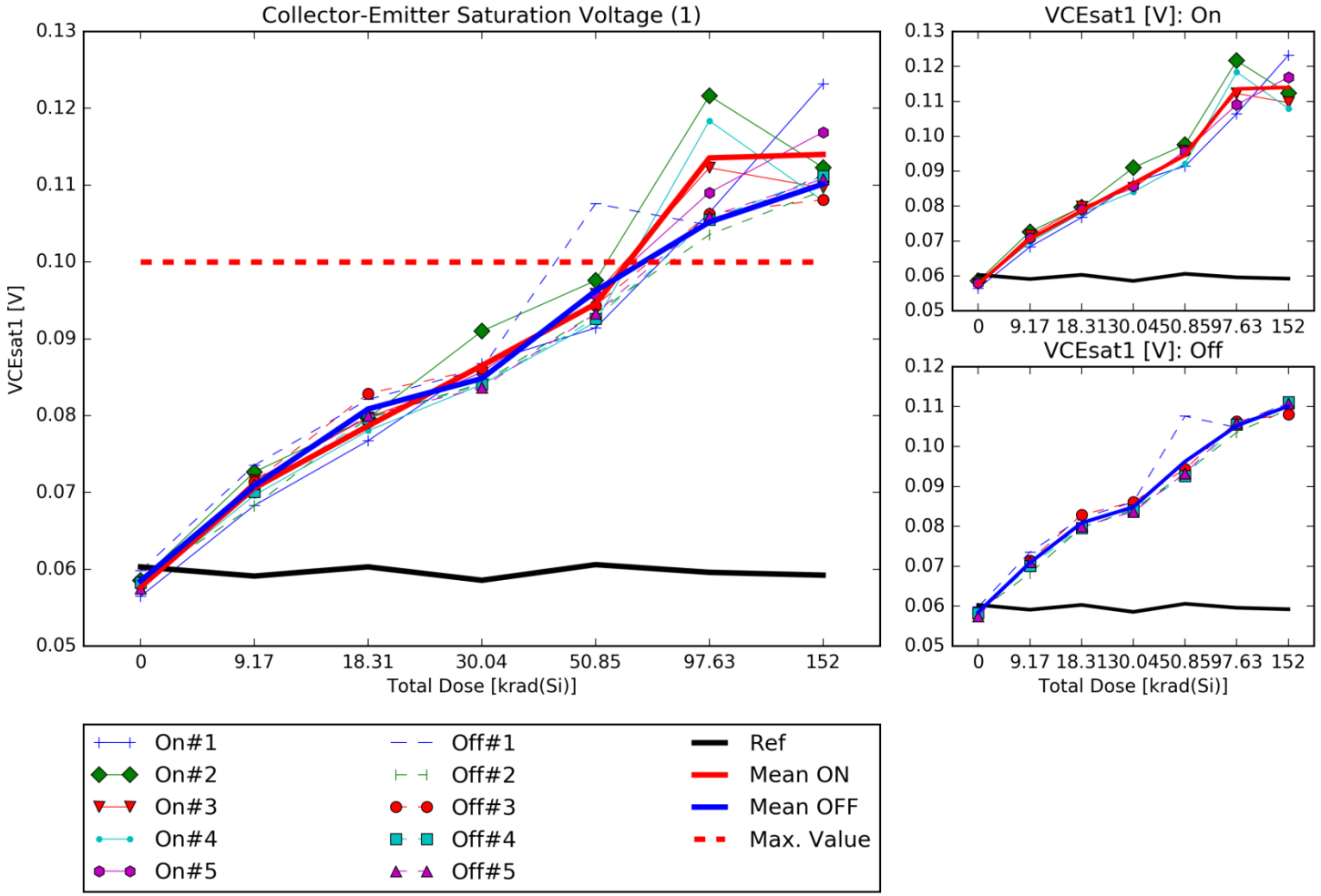


Current transfer ratio (HFE)
BDS18 #1: V_{CE} = -2V, I_C = -4.0 A



Collector-Emitter Saturation Voltage (VCEsat)

BUL54 #1: I_C = 100 mA, I_B = 20 mA



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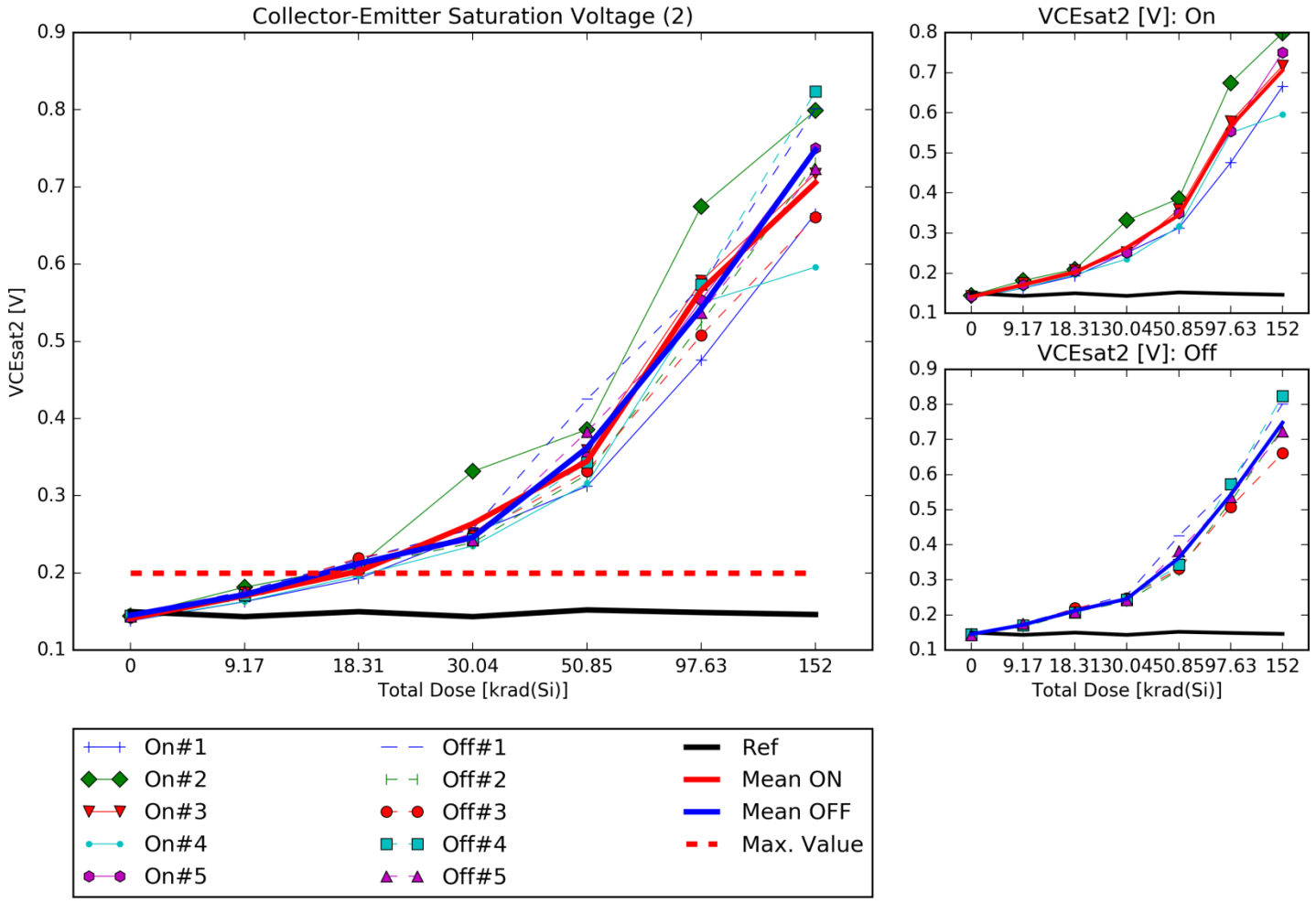
Collector-Emitter Saturation Voltage (VCEsat)

BUL54 #2 I_C = 0.5 A, I_B = 0.1 A



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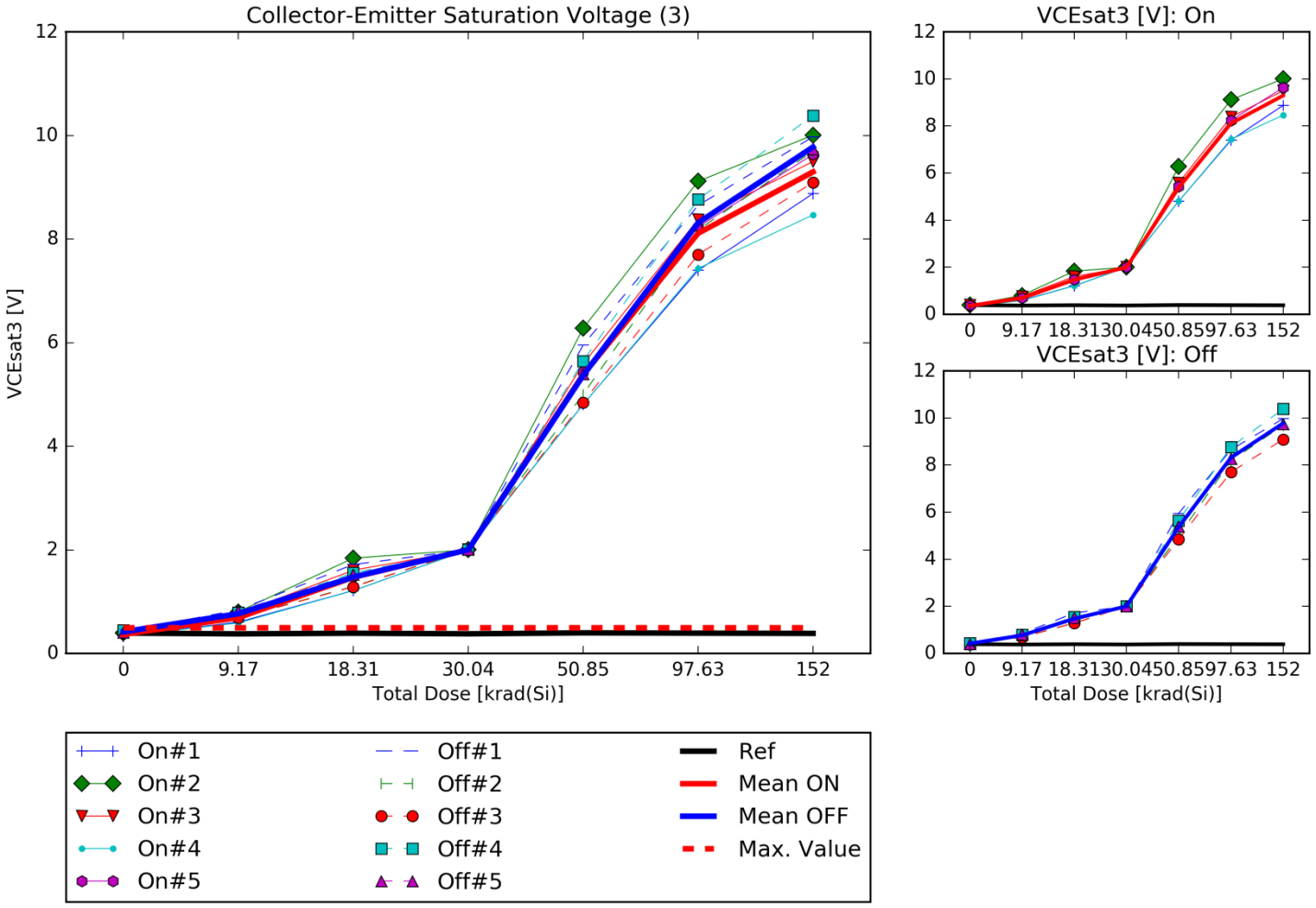
Collector-Emitter Saturation Voltage (VCEsat)

BUL54 #3 I_C = 1.0 A, I_B = 0.2 A



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Parameter tests
SiC Devices

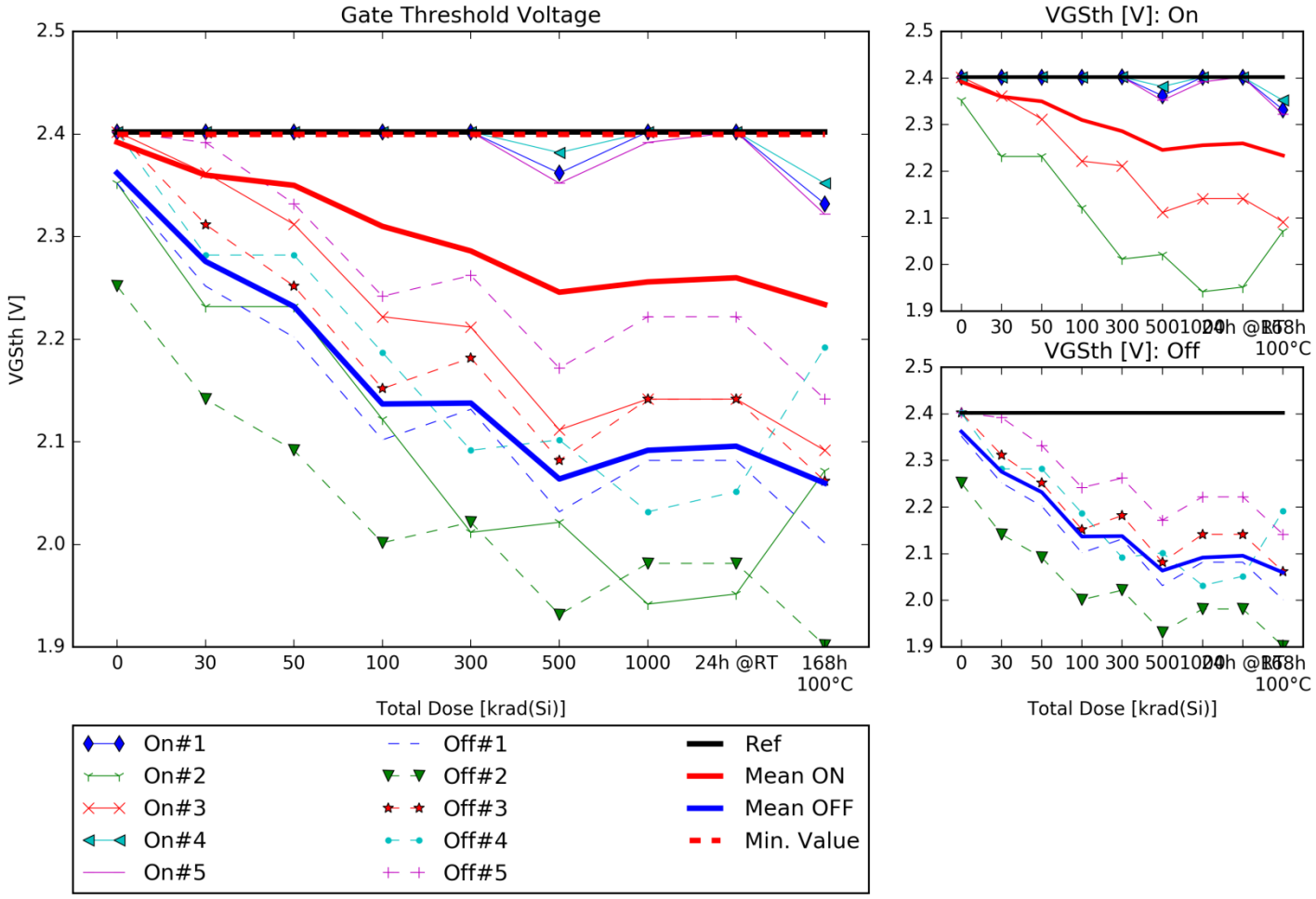
Radiation levels in krad(Si) (Test steps) at which parameters drift out of specs

		MOSFET		JFET	Schottky		
TM	Test	C2M0080120D	SCT20N120	IJW120R100T1	C4D40120D	IDW10G120C5B	SML020DH12
3407	Drain-Source Breakdown Voltage	>1000	>1000	>1000			
3411	Gate-Source Leakage Current	>1000	>1000	>1000			
3413	Zero Gate Voltage Drain Current	>1000	>1000	>1000			
3403	Gate Threshold Voltage	**100?**	>1000	>1000			
3421	Drain-Source On-State Resistance	>1000	>1000	>1000			
4011	Diode Forward Voltage	>1000	>1000	>1000	>1000	**100 - 300**	>1000
4016	Reverse Current				>1000	>1000	>1000

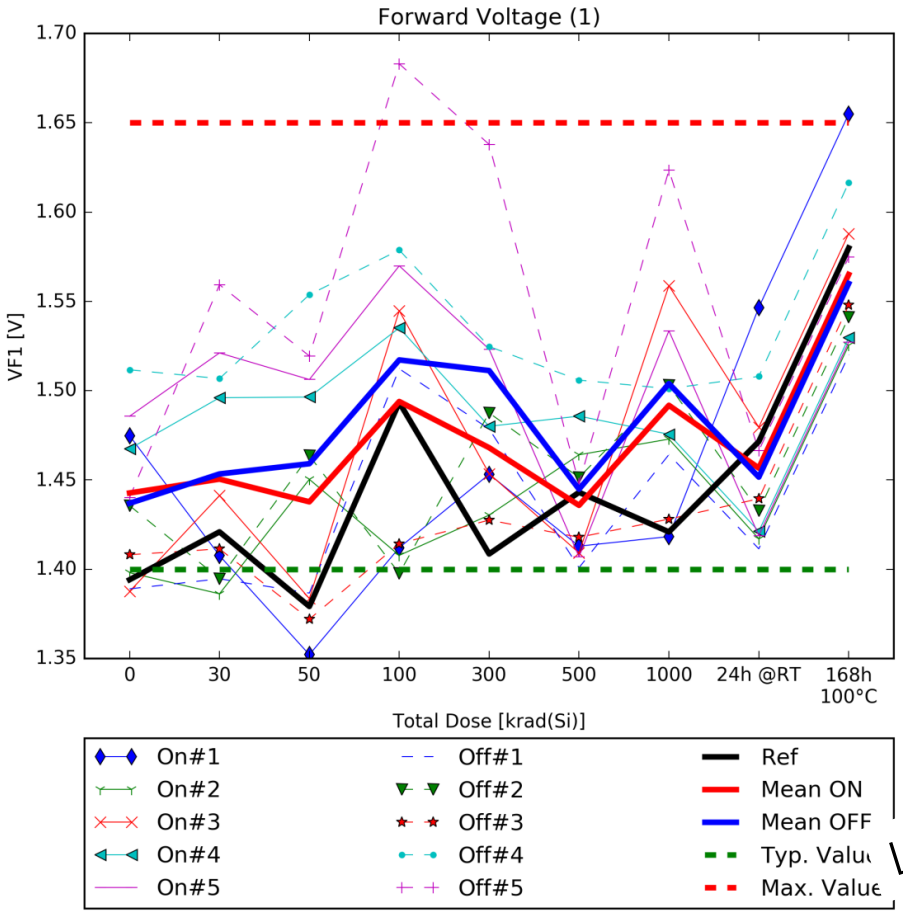
168h @ 100°C currently running

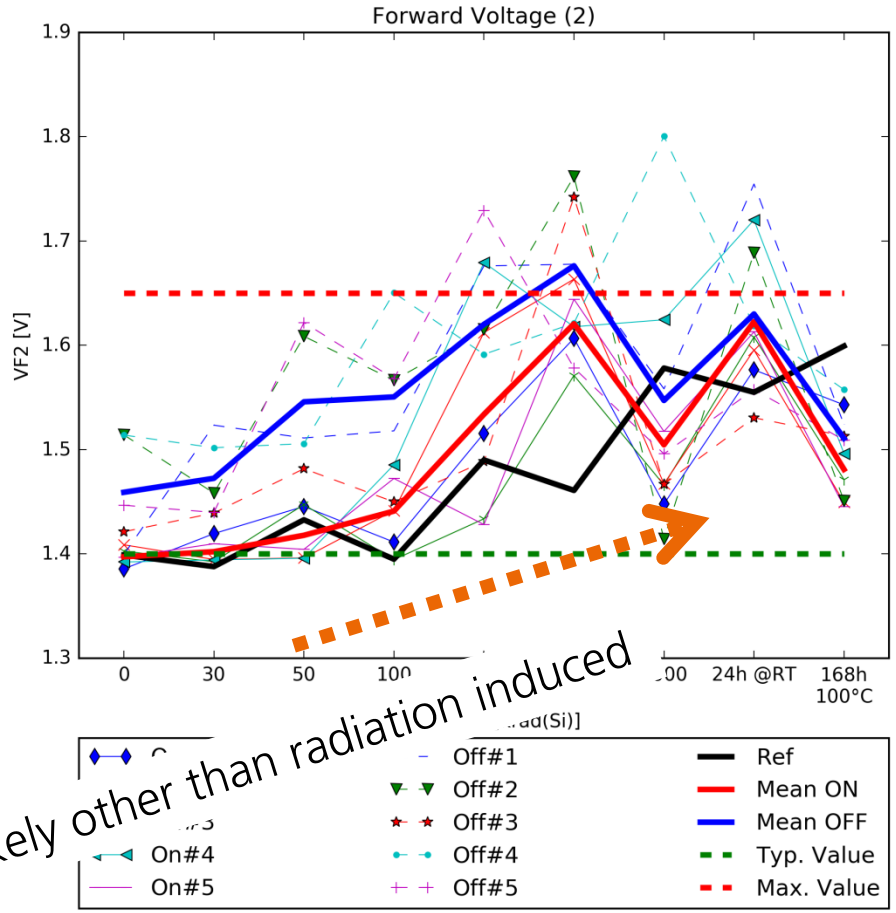
Gate Threshold Voltage ($V_{GS\ th}$)

C2M0080120D: V_{DS}=10V, I_D=5mA (Rev.B Datasheet)



Forward Voltage (V_F)
IDW10G120C5B I_C = 1.0 A, I_B = 0.2 A





Likely other than radiation induced

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Summary / Outlook

- Power Bipolar Transistors
  - ELDRS testing ongoing
    - Three candidates with appropriate radiation hardness identified up to 150 krad(Si)
  - High dose testing will be performed soon
    - LDR sensitivity enhancement can be checked then
- SiC power devices
  - Co60 testing almost finished
    - 168h @ 100°C ongoing for 2 comp.
    - 4 out of 6 devices passed all tests up to 1 Mrad(Si)
    - 2 remaining parts passed all tests up to 100 krad(Si)
  - SEE testing in preparation (approx. June 2017)

Backup
Co60: Accounting for source decay

- Rule of thumb $\mathrm{D(t)} = \dot{D}_0 \cdot t$ not applicable (by far)

$$
\begin{aligned}
D(t_e) &= \int_0^{t_e} \dot{D}_0 \cdot \exp\left(-\ln(2) \cdot \frac{t}{t_{\frac{1}{2}Co60}}\right) dt \\
&= \dot{D}_0 \cdot \frac{t_{\frac{1}{2}Co60}}{\ln(2)} \cdot \left(1 - \exp\left(-\ln(2) \cdot \frac{t_e}{t_{\frac{1}{2}Co60}}\right)\right) \\
\rightarrow t_e &= -\frac{t_{\frac{1}{2}Co60}}{\ln(2)} \cdot \ln\left(1 - \frac{D(t_e)}{\dot{D}_0} \cdot \frac{\ln(2)}{t_{\frac{1}{2}Co60}}\right)
\end{aligned}
$$