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OPS-SAT Phase B2/C/D/E1

Radiation tests results: TID testing of AM26LV31EIDR, AM26LV32EIDR and FM22L16-55-TG

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	Name	Affiliation
Prepared by	Tomasz Rajkowski tomasz.rajkowski@cbk.waw.pl	SRC PAS
Reviewed by		

Institute of Communication Networks and Satellite Communications
Graz University of Technology
Inffeldgasse 12, A – 8010 Graz, Austria

http://www.iks.tugraz.at

E-mail: iks@tugraz.at

Phone: +43 316 873-7441 / Fax: +43 316 463697

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Acronyms and Abbreviations

AD	Applicable Document
ADCS	Attitude Determination and Control System
AIT	Assembly, Integration and Test
AIV	Assembly, Integration and Verification
ARM	Advanced RISC Machines
ASIC	Application-Specific Integrated Circuit
ATX	Advanced Technology Extended
BCR	Battery Control Regulator
BSP	Board Support Package
CADU	Channel Access Data Unit
CAN	Controller Area Network
CCSDS	Consultative Committee for Space Data Systems
CDF	Concurrent Design Facility
CDR	Critical Design Review
CEDR	Concurrent Design Facility Evolution Design Review
CFDP	CCSDS File Delivery Protocol
CFI	Customer Furnished Item
CLTU	Command Link Transfer Unit
CMOS	Complementary Metal Oxide Semiconductor
C/N	Carrier to Noise Ratio
CNES	Centre national d'études spatiales
CoG	Centre of Gravity
COTS	Commercial off-the-shelf
CPDU	Command Pulse Distribution Unit
CPU	Central Processing Unit
DDR	Double Data Rate
DMA	Direct Memory Access
ECC	Error Correction Coding
ECF	Earth-Centered Earth-Fixed
ECSS	European Cooperation for Space Standardization
EGSE	Electrical Ground Support Equipment
EMC	Electromagnetic compatibility
EME	Experiment Management Environment
EPA	Electrostatic Protected Area
EPS	Electrical Power System
ESA	European Space Agency
ESD	Electrostatic discharge
ESOC	European Space Operations Centre
ESTEC	European Space Research and Technology Centre
ESTRACK	European Space Tracking Network
F2FS	Flash-Friendly File System
FAR	Flight Acceptance Review
FAT	File Allocation Table
FCT	Flight Control Team
FDIR	Fault-Detection, Fault-Isolation and Recovery

FEA	Finite Element Analysis
FOV	Field of View
FPGA	Field Programmable Gate Array
GENSO	Global Educational Network for Satellite Operations
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSE	Ground Support Equipment
GSTP	General Support Technology Programme
HPS	Hard Processor System
HSMC	High Speed Mezzanine Card
HW	Hardware
I2C, IIC, I^2C	Inter-Integrated Circuit
IADC	Inter-Agency Space Debris Coordination Committee
ICD	Interface Control Document
IDE	Integrated Development Environment
IKS	Institute of Communication Networks and Satellite Communications
IOD	In-Orbit Demonstration
IP	Intellectual Property
ISIS	Innovative Solutions In Space
ITAR	International Traffic in Arms Regulations
ITT	Invitation To Tender
JFFS2	Journalling Flash File System version 2
JTAG	Joint Test Action Group
KO	Kick-Off
LAN	Local Area Network
LEO	Low-Earth Orbit
LEOP	Launch and Early Orbit Phase
LIDAR	Light Detection and Ranging
LTAN	Local Time of Ascending Node
LVDS	Low Voltage Digital Signalling
MA	Mission Analysis
MAR	Mission Analysis Report
MGSE	Mechanical Ground Support Equipment
MICONYS	Mission Control System
MO	Mission Operations
MOCD	Mission Operations Concept Document
MMC	Multimedia Card
MPPT	Maximum Power Point Tracking
MRR	Mission Requirements Review
MRD	Mission Requirements Document
MSK	Minimum Shift Keying
MTQ	Magnetorquer
MUST	Mission Utility and Support Tools
NIS	Network Interface System
OBC	On-Board Computer
OBDH	On-Board Data Handling
OoL	Out of Limits
OS	Operating System

PCB	Printed Circuit Board
PCI	Peripheral Component Interconnect
PCM	Power Conditioning Module
PDM	Power Distribution Module
PDR	Preliminary Design Review
PFM	Protoflight Model
PoC	Point of Contact
POD	Picosatellite Orbital Deployer
PoP	Package on Package
PUS	Packet Utilisation Standard
QA	Quality Assurance
QPSK	Quadrature Phase-Shift Keying
RAAN	Right Ascension of Ascending Node
RAM	Random-Access Memory
RD	Reference Document
RF	Radio Frequency
RX	Receive
RISC	Reduced Instruction Set Computer
SATA	Serial Advanced Technology Attachment
SCOE	Satellite Check Out Equipment
SCOS-2000	Satellite Control and Operation System 2000
SD	Secure Digital
SDHC	Secure Digital High Capacity
SDR	Software Defined Radio
SDR	System Design Report
SDRAM	Synchronous Dynamic Random Access Memory
SEE	Single Event Effect
SEL	Single Event Latchup
SEU	Single Event Upset
SLE	Space Link Extensions
SLR	Satellite Laser Ranging
SMILE	Small Mission Infrastructure Laboratory Environment
SoC	System-on-Chip
SoM	System-on-Module
SoW	Statement of Work
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
SRD	System Requirements Document
SRDB	Satellite Reference Database
SRR	System Requirements Review
SSO	Sun-Synchronous Orbit
SSPA	Solid State Power Amplifier
SSTL	Surrey Satellite Technology Ltd
STK	Systems Tool Kit
SVF	Software Validation Facility
SW	Software
TBC	To Be Confirmed
TBD	To Be Defined

TC	Telecommand
TID	Total Ionizing Dose
TLE	Two Line Elements
TM	Telemetry
TMTC	Telemetry and Telecommand
TN	Technical Note
TNC	Terminal Node Controller
TRL	Technology Readiness Level
TRP	Thermal Reference Points
TUG	Graz University of Technology
TX	Transmit
UBIFS	Unsorted Block Image File System
UHF	Ultra High Frequency
USB	Universal Serial Bus
VC	Virtual Channel
VHDL	VHSIC Hardware Description Language
VHSIC	Very-High-Speed Integrated Circuits

1 Introduction

1.1 Scope of the Document

Document describes test results of TID testing of AM26LV31EIDR, AM26LV32EIDR and FM22L16-55-TG in ESTEC Cobalt-60 facility.

1.2 Applicable Documents

AD1	RADIATION TEST SUMMARY Number: TEC-QEC/RP 20380 Version 1.0

1.3 Reference Documents

2 Scope and Objectives

Scope of TID tests was to evaluate suitability of AM26LV31EIDR, AM26LV32EIDR and FM22L16-55-TG chips for use in LEO OPS-SAT mission. Devices were irradiated up to 15krad in Cobalt-60 facility, their parameters were measured in two intermediate measurements and in final post-irradiation measurement.

3 General Overview of the Measurements

3.1 Irradiation setup

DUTs are irradiated in three runs lasting 17 hours, 6 hours and 14 hours, during each run units receive about 5.6krad of total dose. After each run there is a break in irradiation for electrical measurements, each break lasts about 2 hours.

Three samples of each chip are tested. All units are mounted on one PCB (see Figure 3.1) and they are all biased with nominal voltage of 3.3V during irradiation.

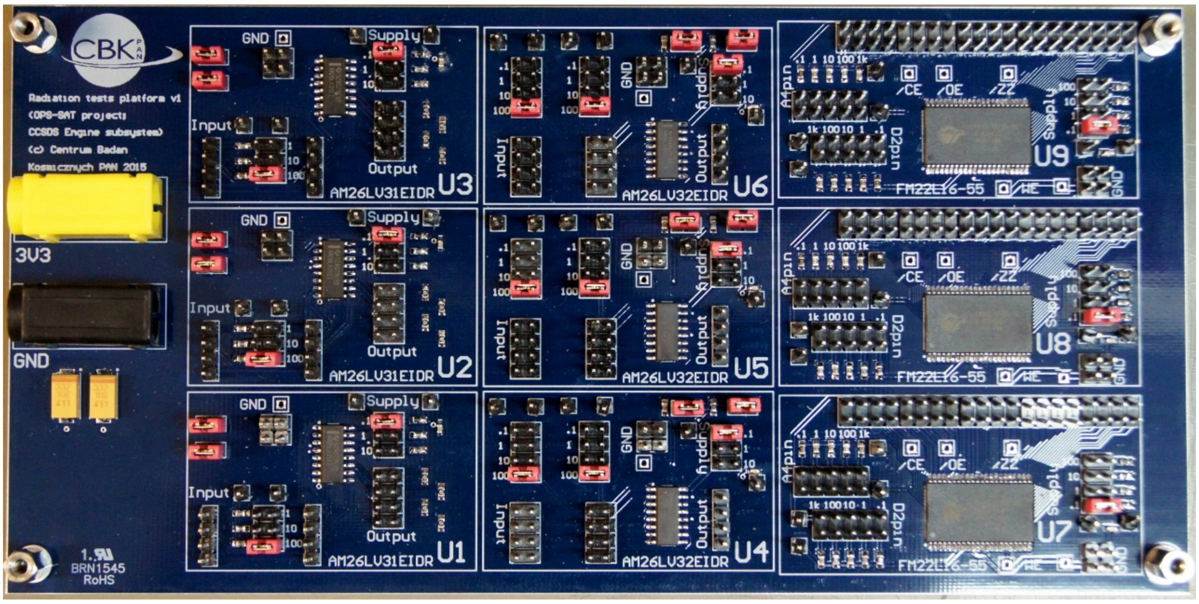

Figure 3.1: Printed circuit board housing all DUTs

The Cobalt-60 source is kept in a shielding made of Lead, for exposure it is moved to window in the shielding and creates radiation field with the shape of a cone. DUTs are installed few meters from the source (distance depends on required dose rate). PCB is shielded with glass cover to achieve uniform radiation field on DUTs. Irradiation setup is presented on Figure 3.2.

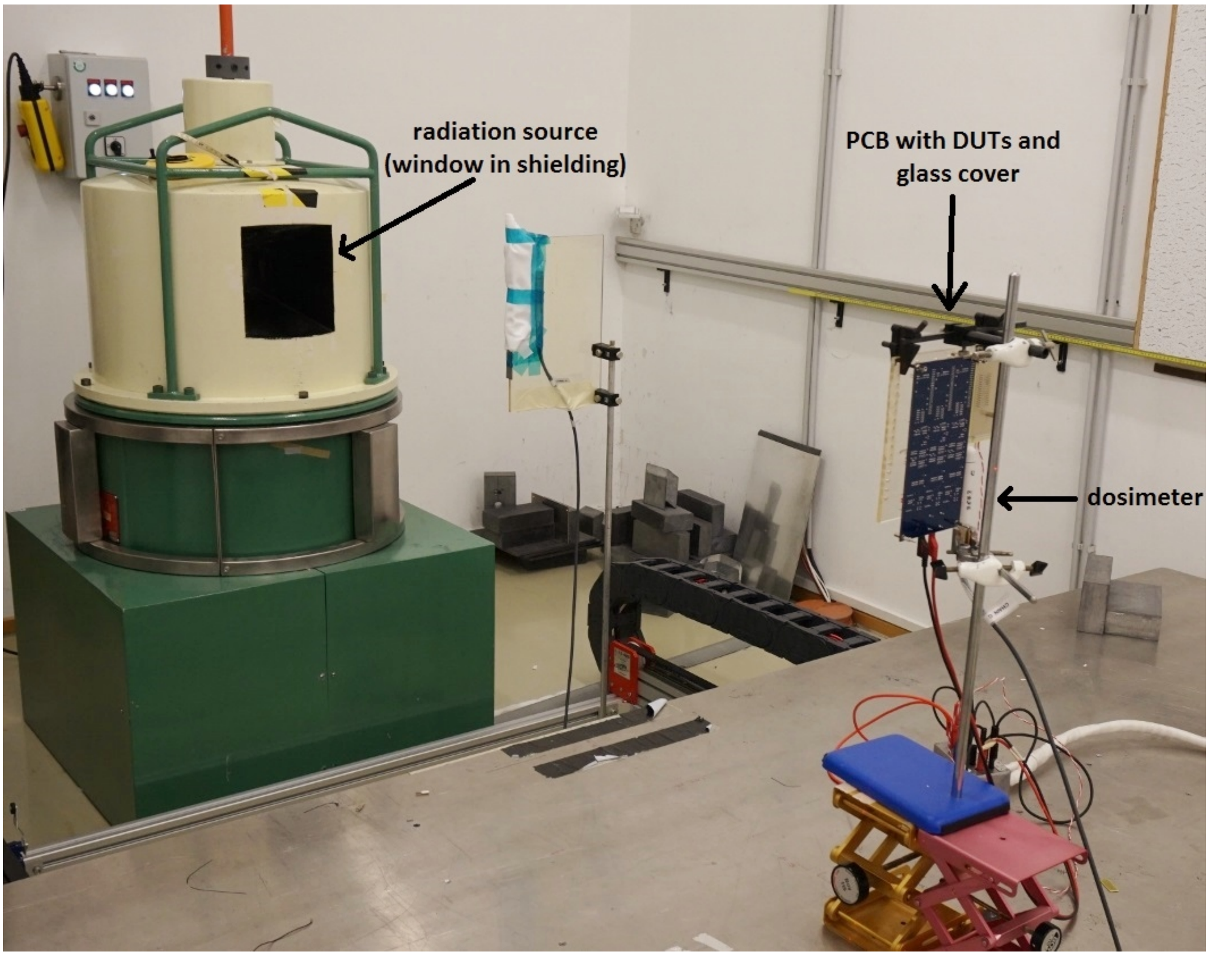

Figure 3.2: Irradiation setup

3.2 DUTs properties and biasing conditions

List of tested devices is presented in Table 3.1

Device type	Manufacturer	Number of devices	Enumeration
AM26LV31EIDR	Texas Instruments	3	U1, U2, U3
AM26LV32EIDR	Texas Instruments	3	U4, U5, U6
FM22L16-55-TG	Cypress Semiconductor	3	U7, U8, U9

Table 3.1: List of tested devices

AM26LV31EIDR is a quadruple differential line driver, during irradiation its inputs were left floating and its differential outputs had 120R differential loads as it is presented in Figure 3.3.

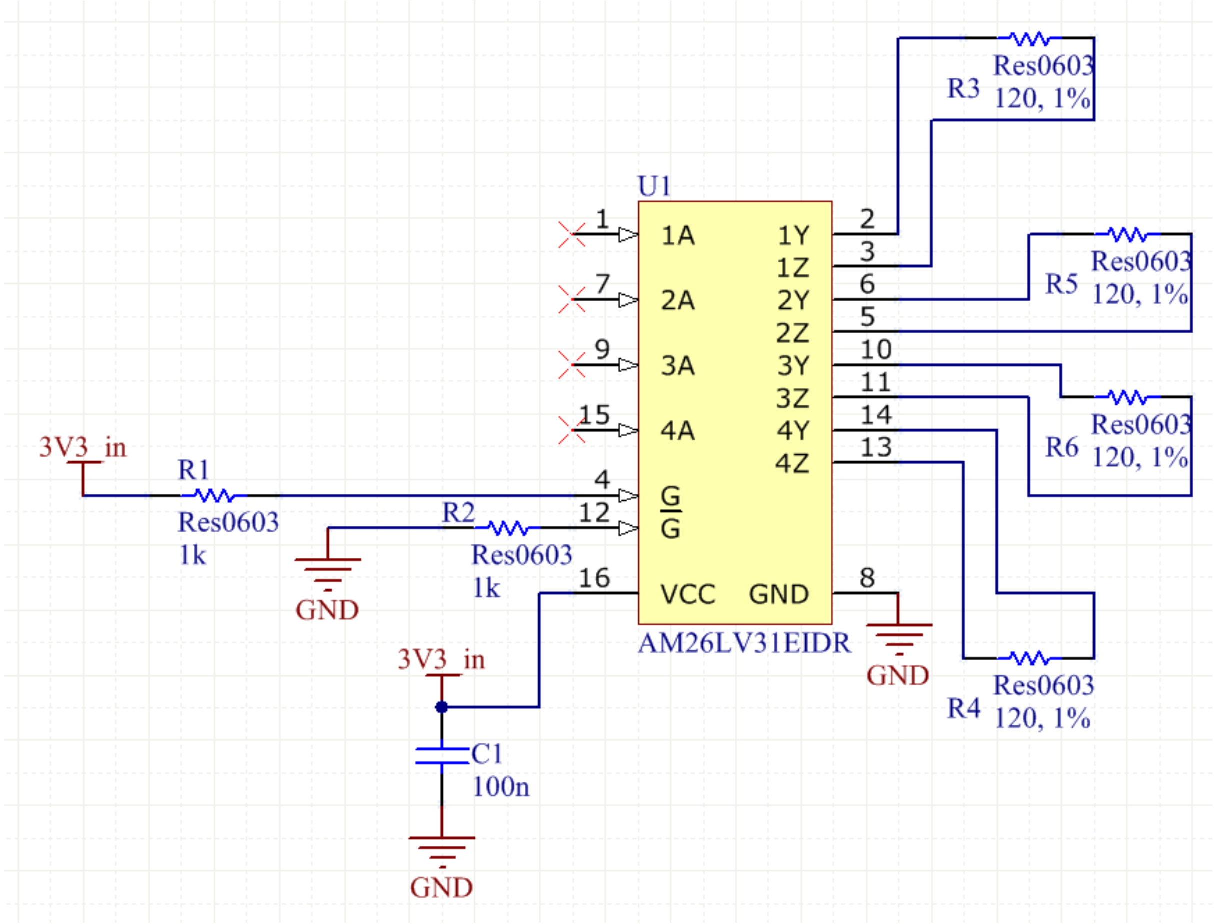

Figure 3.3: Biasing circuit for AM26LV31EIDR

AM26LV32EIDR is a quadruple differential line receiver, during irradiation its inputs had 120R resistors in parallel of each differential line and its outputs had 100kR loads as it is presented in Figure 3.4.

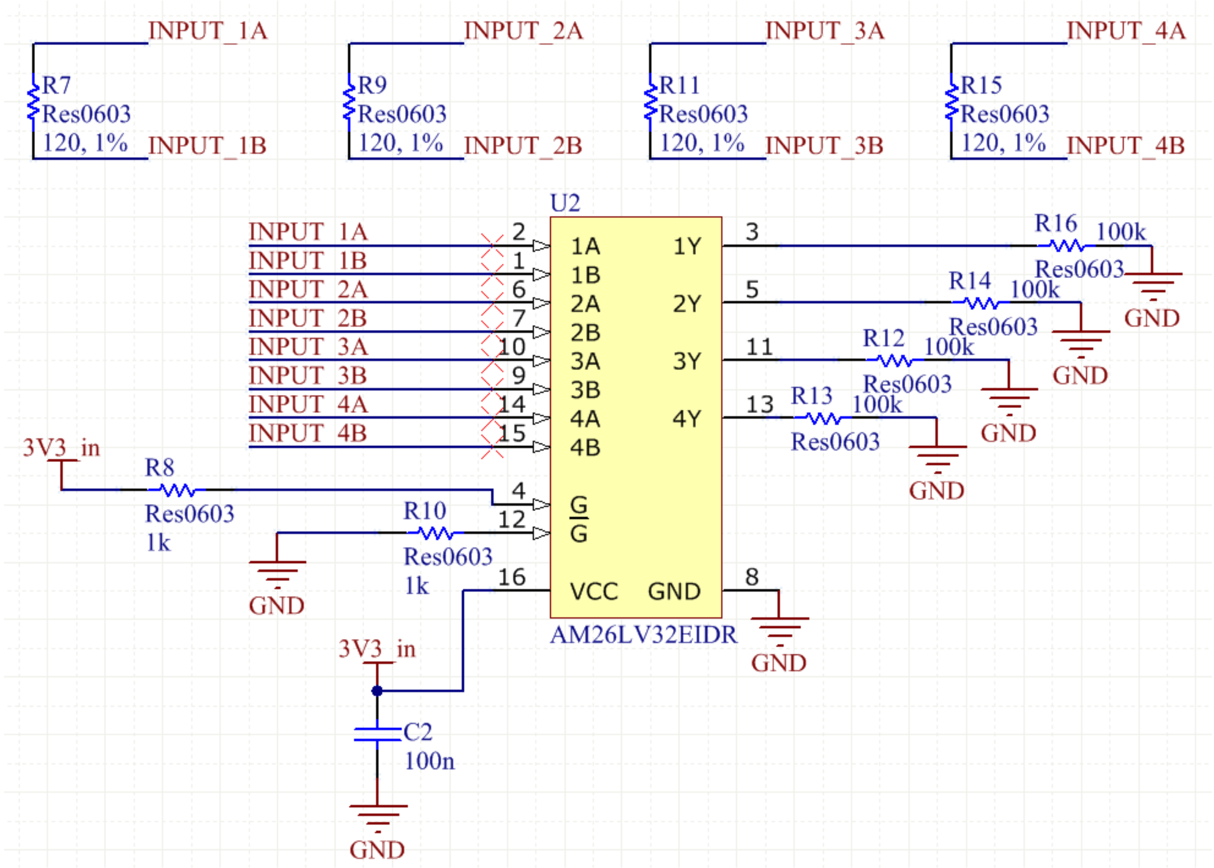

Figure 3.4: Biasing circuit for AM26LV32EIDR

FM22L16-55-TG is a ferroelectric random access memory with parallel interface, all of its digital inputs and outputs were left floating during irradiation.

3.3 Irradiation environmental conditions and dose rates

Data in this section is based on [AD1].

Environmental conditions during irradiation are presented in Table 3.2.

	Units	Min.	Max.	Time-weighted average
Temperature	°C	20	20.2	20.1
Pressure	mbar	1015.4	1023.8	1019.55
Relative Humidity	%	49.6	55.1	52.53

Table 3.2: Environmental conditions during irradiation

Irradiation was performed in three runs, time, dose levels and dose rates for each run are listed in Table 3.3.

Irr. Run	Start Date & Time (CET)	End Date & Time (CET)	Total Ionising Dose (water)	Total dose (water)
1	11/11/2015 16:23	12/11/2015 09:18	56.26 Gy	3.327 Gy/h
2	12/11/2015 11:48	12/11/2015 17:40	56.50 Gy	9.639 Gy/h
3	12/11/2015 19:10	13/11/2015 09:10	55.88 Gy	3.992 Gy/h
		Total	168.6 Gy	

Table 3.3: Irradiation time, dose levels and dose rates

Total absorbed dose was 168.6 Gy which is 16.86 krad.

There was no long-term annealing after irradiation.

4 Component characterization results

Characterization of devices is done after each irradiation run. This chapter describes measured parameters of devices and measurement results.

4.1 Parameters measured

Measured parameters are listed below (names in brackets indicate for each device given parameter is measured).

- Isup - supply current of the chip, measured indirectly as voltage drop on serial sense resistor (AM26LV31EIDR, AM26LV32EIDR, FM22L16-55-TG)
- VOH - high-level output voltage (AM26LV31EIDR, AM26LV32EIDR)
- VOL - low-level output voltage (AM26LV31EIDR, AM26LV32EIDR)
- tPHL - propagation delay time, high- to low-level output (AM26LV31EIDR, AM26LV32EIDR)
- tPLH - propagation delay time, low- to high-level output (AM26LV31EIDR, AM26LV32EIDR)

Most of parameters are measured using Agilent Infinium 1GHz, 4GSa/s oscilloscope, Isup is measured indirectly using oscilloscope or Fluke digital multimeter.

For AM26LV31EIDR, VOH, VOL, tPHL and tPLH are measured for 2MHz input square signal generated by HP 8116A Programmable Pulse/Function Generator.

For AM26LV32EIDR, VOH, VOL, tPHL and tPLH are measured for 2MHz input differential signal generated by AM26LV31EIDR device (signal on input of AM26LV31EIDR is from HP 8116A).

For AM26LV31EIDR and AM26LV32EIDR chips, two channels (lines) were measured:

- 1A -> 1Y, 1Z; 2A -> 2Y, 2Z for AM26LV31EIDR
- 1A, 1B -> 1Y; 2A, 2B -> 2Y for AM26LV32EIDR

4.2 Measurement results

4.2.1 Results for AM26LV31EIDR chip

4.2.1.1 Isup [mA]

	Initial	5.626 krad	11.276 krad *)	16.864 krad *)
Isup (U1)	69	70	68.4	68.3
Isup (U2)	69	70	68.5	68.6

Isup (U3)	69	70	68.3	68.5
mean Isup	69	70	68.4	68.5

*) measurement tool changed from oscilloscope to DMM for last two columns (measurements for 11.276 krad and 16.864 krad)

4.2.1.2 **VOH [V]**

Channel 1, output A, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U1)	*)	2.77	2.74	2.73
VOH (U2)	2.8	2.75	2.74	2.74
VOH (U3)	2.78	2.75	2.74	2.74
mean VOH	2.79 *)	2.757	2.74	2.737

*) during U1 initial measurement, chip was powered through 10R resistor due to mistake in setup and resulting supply voltage was below its nominal operating voltage, therefore results from these measurement should not be considered in overall analysis; mean value calculated for U2 and U3 results only

Channel 1, output A, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U1)		3.35	2.9	2.96
VOH (U2)	2.97	2.95	2.86	2.94
VOH (U3)	*)	2.94	2.85	2.91
mean VOH	2.97	3.08	2.87	2.937

*) measurement value not registered for U3 overshoot field

Channel 1, output B, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U1)		2.84	2.8	2.81
VOH (U2)	2.88	2.77	2.81	2.81
VOH (U3)	2.88	2.77	2.81	2.81
mean VOH	2.88	2.793	2.807	2.81

Channel 1, output B, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U1)		3.44	3.29	3.22
VOH (U2)	3.3	3.31	3.3	3.2
VOH (U3)		3.3	3.3	3.31
mean VOH	3.3	3.35	3.297	3.243

Channel 2, output A, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U1)		2.77	2.73	2.74
VOH (U2)	2.81	2.77	2.75	2.74
VOH (U3)	2.79	2.78	2.74	2.74
mean VOH	2.8	2.773	2.74	2.74

Channel 2, output A, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U1)		3.42	2.93	2.95
VOH (U2)	*)	3.43	2.93	2.96
VOH (U3)	3.08	3.46	2.97	2.95
mean VOH	3.08	3.437	2.943	2.953

*) measurement value not registered for U2 overshoot field

Channel 2, output B, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U1)		2.74	2.81	2.81
VOH (U2)	2.88	2.74	2.81	2.81
VOH (U3)	2.9	2.75	2.8	2.81
mean VOH	2.89	2.743	2.807	2.81

Channel 2, output B, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U1)		3.02	3.14	3.15
VOH (U2)		3.02	3.13	3.19
VOH (U3)	3.38	3.02	3.15	3.13
mean VOH	3.38	3.02	3.14	3.157

4.2.1.3 **VOL [V]**

Channel 1, output A, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U1)		0.2	0.21	0.21
VOL (U2)	0.23	0.22	0.22	0.21
VOL (U3)	0.23	0.22	0.22	0.21
mean VOL	0.23	0.213	0.217	0.21

Channel 1, output A, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U1)		-0.52	0	0.01
VOL (U2)	0.08	0.09	0.03	0.02
VOL (U3)		0.1	0.05	0.02
mean VOL	0.08	-0.11	0.027	0.017

Channel 1, output B, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U1)		0.14	0.13	0.14
VOL (U2)	0.15	0.2	0.14	0.14
VOL (U3)	0.12	0.2	0.13	0.14
mean VOL	0.135	0.18	0.133	0.14

Channel 1, output B, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U1)		-0.46	-0.53	-0.47
VOL (U2)	-0.43	-0.4	-0.47	-0.43
VOL (U3)		-0.47	-0.5	-0.54
mean VOL	-0.43	-0.443	-0.5	-0.48

Channel 2, output A, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U1)		0.2	0.21	0.21
VOL (U2)	0.22	0.2	0.22	0.21
VOL (U3)	0.23	0.2	0.22	0.21
mean VOL	0.225	0.2	0.217	0.21

Channel 2, output A, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U1)		-0.32	0.12	0.03
VOL (U2)		-0.29	0.15	0.04
VOL (U3)	0.08	-0.36	0.15	0.06
mean VOL	0.08	-0.323	0.14	0.043

Channel 2, output B, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U1)		0.22	0.14	0.13

VOL (U2)	0.13	0.22	0.14	0.14
VOL (U3)	0.12	0.22	0.14	0.14
mean VOL	0.125	0.22	0.14	0.137

Channel 2, output B, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U1)		0.08	-0.3	-0.26
VOL (U2)		0.07	-0.32	-0.2
VOL (U3)	-0.18	0.08	-0.31	-0.28
mean VOL	-0.18	0.077	-0.31	-0.247

4.2.1.4 **tPLH [ns]**

Channel 1:

	Initial	5.626 krad	11.276 krad	16.864 krad
tPLH (U1)		7.16	7.53	7.52
tPLH (U2)	7.64	7.24	7.55	7.58
tPLH (U3)	7.53	7.2	7.6	7.47
mean tPLH	7.585	7.2	7.56	7.523

Channel 2:

	Initial	5.626 krad	11.276 krad	16.864 krad
tPLH (U1)		6.76	7.13	7
tPLH (U2)	7.02	6.58	7.16	7.09
tPLH (U3)	7.05	6.6	7.13	7
mean tPLH	7.035	6.647	7.14	7.03

4.2.1.5 **tPHL [ns]**

Channel 1:

	Initial	5.626 krad	11.276 krad	16.864 krad
tPHL (U1)		8.36	8.73	8.71
tPHL (U2)	8.51	8.4	8.65	8.73
tPHL (U3)	8.44	8.36	8.76	8.67
mean tPHL	8.475	8.373	8.713	8.703

Channel 2:

	Initial	5.626 krad	11.276 krad	16.864 krad

tPHL (U1)		7.45	7.93	7.75
tPHL (U2)	7.53	7.31	7.82	7.78
tPHL (U3)	7.49	7.33	7.87	7.72
mean tPHL	7.51	7.363	7.873	7.75

4.2.2 **Results for AM26LV32EIDR chip**

4.2.2.1 **Isup [mA]**

	Initial	5.626 krad	11.276 krad *)	16.864 krad *)
Isup (U4)	6	6	6.14	6.01
Isup (U5)	6	5.5	6.08	6.04
Isup (U6)	6	6	6.04	6.1
mean Isup	6	5.83	6.09	6.05

*) measurement tool changed from oscilloscope to DMM for last two columns (measurements for 11.276 krad and 16.864 krad)

4.2.2.2 **VOH [V]**

Channel 1, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U4)	3.18	3.3	3.3	3.23
VOH (U5)	3.3	3.29	3.3	3.23
VOH (U6)	3.3	3.29	3.3	3.23
mean VOH	3.26	3.293	3.3	3.23

Channel 1, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U4)	4	4.17	4.21	4.08
VOH (U5)	4.24	4.12	4.18	4.24
VOH (U6)	4.2	4.19	4.19	3.98
mean VOH	4.147	4.16	4.193	4.1

Channel 2, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U4)	3.28	3.29	3.3	3.23
VOH (U5)	3.29	3.3	3.3	3.23
VOH (U6)	3.31	3.3	3.3	3.23

mean VOH	3.293	3.297	3.3	3.23

Channel 2, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOH (U4)	4.17	3.96	3.92	4.08
VOH (U5)	4.29	4.04	3.84	4.1
VOH (U6)	4.12	4.02	3.78	4.03
mean VOH	4.193	4.007	3.847	4.07

4.2.2.3 **VOL [V]**

Channel 1, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U4)	0.07	-0.03	-0.3 *)	0.04
VOL (U5)	0.07	-0.03	-0.03	0.04
VOL (U6)	0.08	-0.03	-0.03	0.04
mean VOL	0.073	-0.03	-0.03 *)	0.04

*) value -0.3V is considered as a mistake in readout from oscilloscope for U4 chip at 10krad level – for other chips and second channel, after 5krad and 10 krad there is value -0.03V; therefore mean value is calculated only for U5 and U6

Channel 1, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U4)	-0.7	-0.72	-0.82	-0.84
VOL (U5)	-0.66	-0.7	-0.85	-0.99
VOL (U6)	-0.81	-0.76	-0.85	-0.86
mean VOL	-0.723	-0.727	-0.84	-0.897

Channel 2, steady state values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U4)	0.05	-0.03	-0.03	0.04
VOL (U5)	0.07	-0.03	-0.03	0.04
VOL (U6)	0.12	-0.03	-0.03	0.04
mean VOL	0.08	-0.03	-0.03	0.04

Channel 2, overshoot values:

	Initial	5.626 krad	11.276 krad	16.864 krad
VOL (U4)	-0.67	-0.51	-0.73	-0.65
VOL (U5)	-0.6	-0.68	-0.73	-0.8

VOL (U6)	-0.62	-0.7	-0.73	-0.835
mean VOL	-0.63	-0.63	-0.73	-0.762

4.2.2.4 **tPLH [ns]**

Channel 1:

	Initial	5.626 krad	11.276 krad	16.864 krad
tPLH (U4)	14.05	14.53	14.62	14.26
tPLH (U5)	14.09	14.75	14.65	14.37
tPLH (U6)	13.96	14.64	14.62	14.34
mean tPLH	14.03	14.64	14.63	14.323

Channel 2:

	Initial	5.626 krad	11.276 krad	16.864 krad
tPLH (U4)	13.07	13.25	13.35	12.77
tPLH (U5)	13	14.13	13.44	13.05
tPLH (U6)	13.07	13.91	13.34	13.08
mean tPLH	13.047	13.763	13.377	12.967

4.2.2.5 **tPHL [ns]**

Channel 1:

	Initial	5.626 krad	11.276 krad	16.864 krad
tPHL (U4)	13.49	13.08	13.27	13.22
tPHL (U5)	13.82	13.64	13.76	13.65
tPHL (U6)	13.65	13.67	13.87	13.69
mean tPHL	13.653	13.463	13.633	13.52

Channel 2:

	Initial	5.626 krad	11.276 krad	16.864 krad
tPHL (U4)	12.36	12.26	12.4	12.09
tPHL (U5)	12.27	12.65	12.55	12.33
tPHL (U6)	12.35	12.67	12.53	12.31
mean tPHL	12.327	12.527	12.493	12.243

4.2.3 **Results for FM22L16-55-TG chip**

4.2.3.1 **Isup [uA]**

	Initial	5.626 krad	11.276 krad	16.864 krad
Isup (U7)	2	2	2	2
Isup (U8)	2	2	2	2
Isup (U9)	2	2	2	2 / 3 *)
mean Isup	2	2	2	2 / 2.33

*) result changing from 2 to 3 uA, better accuracy was not available in this measurement