Load Sensors Acquisition System (LSAS) – CNRAD irradiation test (21.09.2012 – 3.12.2012)

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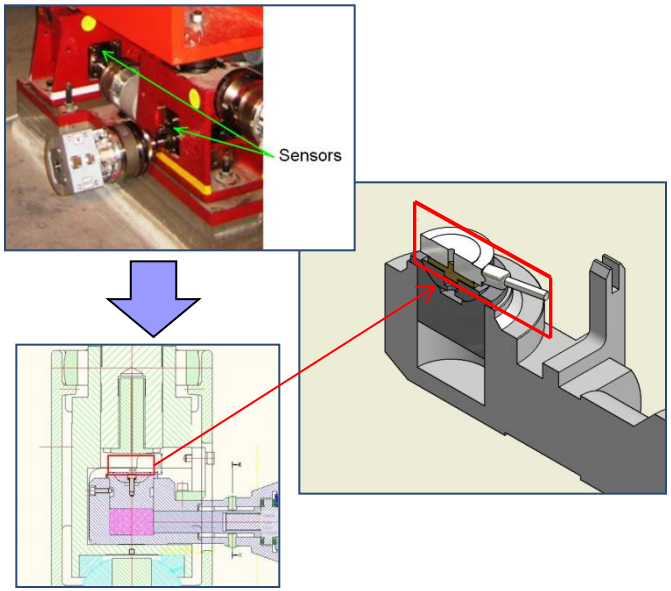
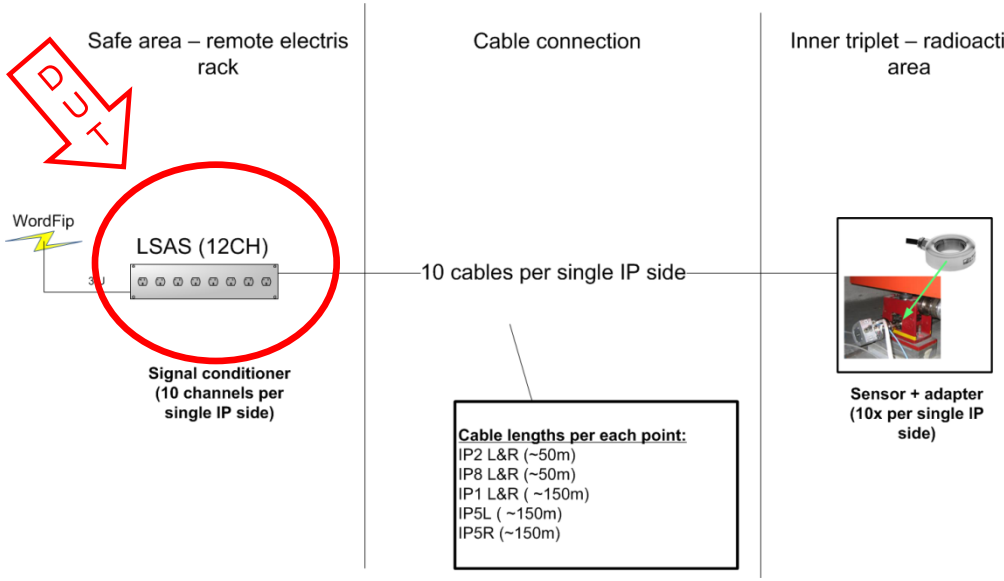
- Load sensors under Low-Beta quadrupoles – short introduction
- Load Sensors Acquisition System (LSAS) – DUT description
- Radiation levels at LSAS equipment locations
- CNRAD tests

Load sensors under Low-Beta quadrupoles

- **Main application**
  - ✓ Monitoring of LowBeta jack load when adjusting (according to risk of lontact lost). System is not critical for the LHC operation
  - ✓ Strain gauge (Wheatstone bridge) load sensor (HBM MPZ1108010, sensor constant ~1.3mV/V, Uexc = 5V, 20T range, typical bridge Uout → ~ -1 .. 6.5mV)
  - ✓ **DUT is an acquisition electronics crate, conditioning the load sensors signals and sending the measurement data via WordFIP**



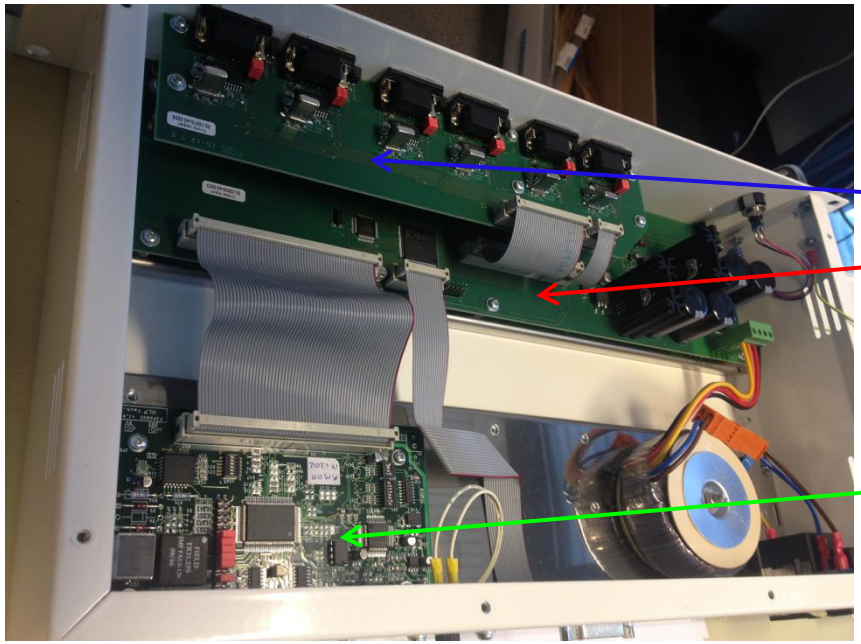


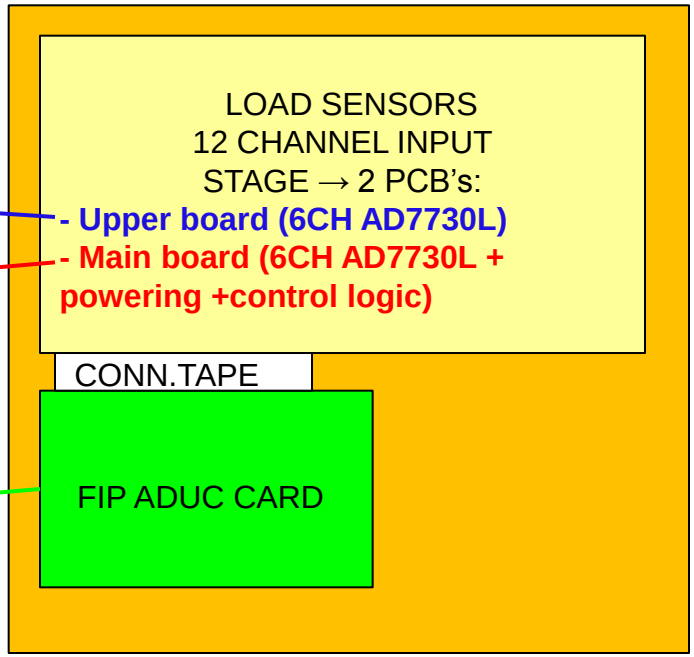
Single IP side (L or R) installation layout

- **Device Under Test**
  - ✓ 12 input channels;
  - ✓ Each channel input range ±10mV (scaled to ±15V @ data output)
  - ✓ AC excitation of sensors

DUT: Load Sensors Acquisition System (LSAS)

- **LSAS crate (load sensors signal conditioning by Analog Devices AD7730L)**
  - ✓ Based on existing „Survey Acquisition System (SAS)" used by BE-ABP-SU for alignment sensors measurements
  - ✓ FipADUC card for FIP communication and local connection by RS232 link
  - ✓ Self-diagnostic implemented

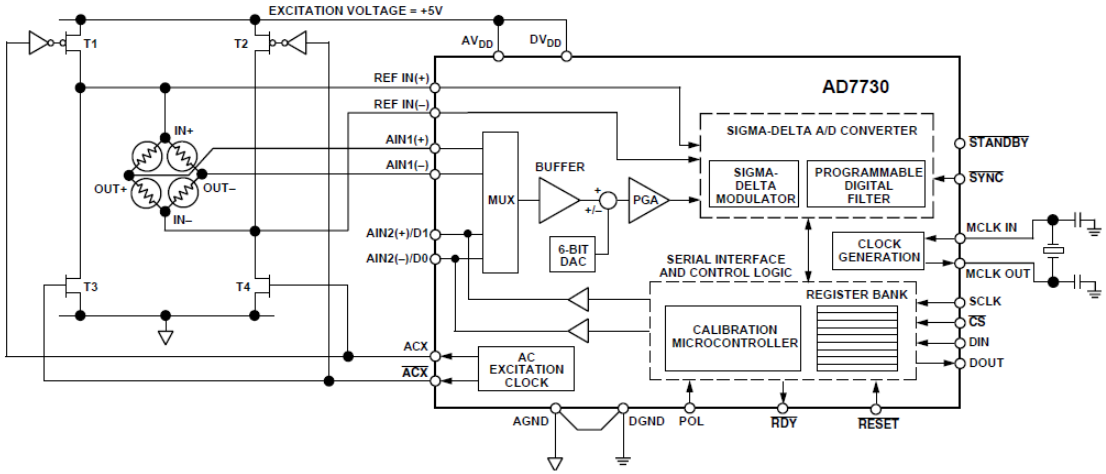




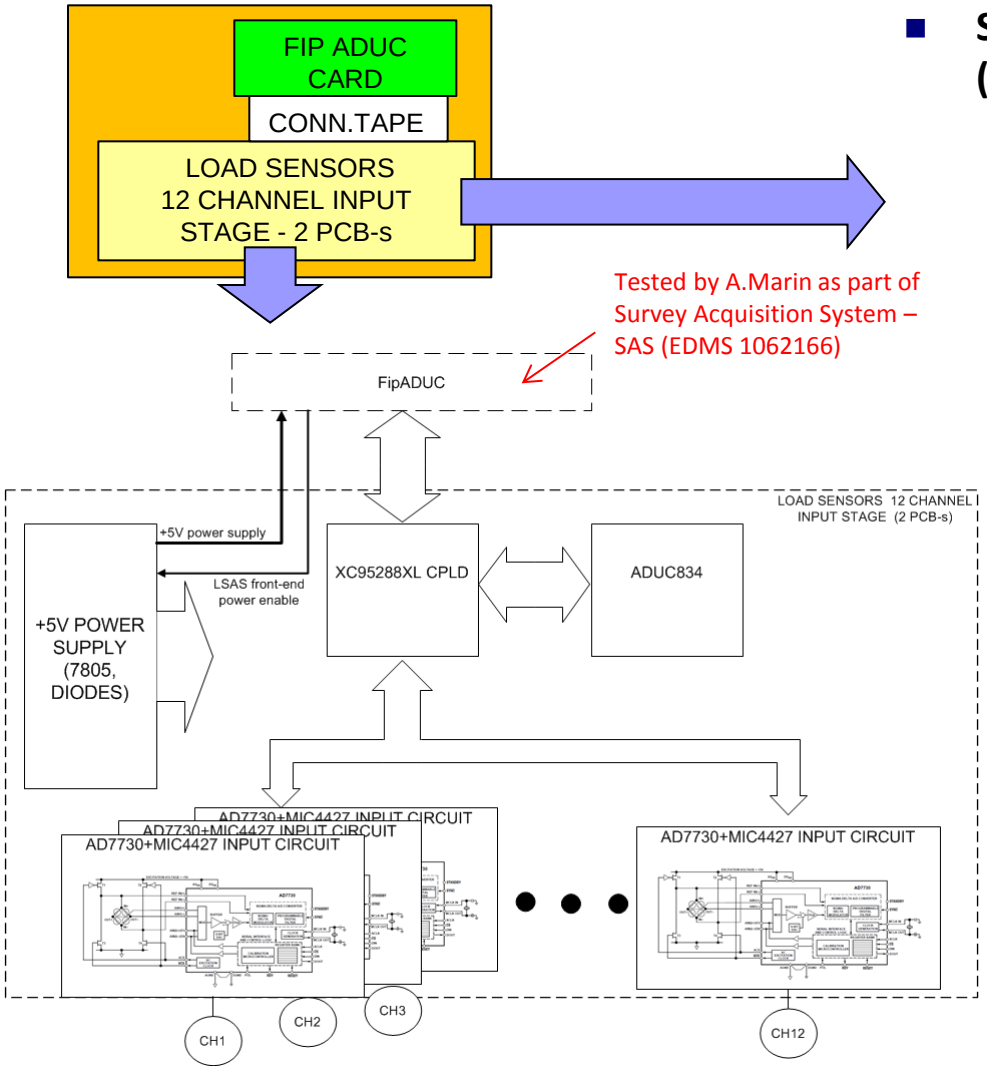
DUT: Load Sensors Acquisition System (LSAS)

AD7730L signal conditioner

- ✓ Analog Devices, CMOS, 24-Bit Sigma-Delta, Bridge Transducer ADC for Load Cell Applications. Equipped in digital filters, internal calibration microcontroller. Contain ~24B of RAM.
- ✓ Basic DSP abilities included (filters)
- ✓ The AD7730 retains its ratiometric operation with reference voltage varying in sympathy with the analog input voltage ($ADC_{OUT} = (V_{IN}/V_{REF})$ x Full-Scale x Scaling-Factor). Eliminate impact of excitation voltage change (cables resistances)
- ✓ AC excitation of the bridge addresses many of the concerns with thermocouple, offset and drift effects encountered in dc-excited applications



DUT: Load Sensors Acquisition System (LSAS)

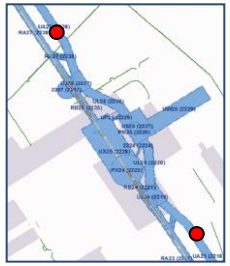


- **Semiconductors used for 12-channel input stage (2 PCB-s) of LSAS:**
  - ✓ **12 x AD7730L** –Bridge Transducer for Load Cell Applications.
  - ✓ **12xMIC4427** – Micrel, MOSFET driver – sensor supply polarization change in AC measurement mode (not tested)
  - ✓ **1xCPLD XC95288XL** – Xilinx CPLD, 288 macrocells – contains all board logic: AD7730L→ADUC834 signal multiplexer, FipADUC to ADUC834 bus interface, LED driver (not tested)
  - ✓ **1xADUC834** – Analog Devices, '51 based MCU – board diagnostics, AD7730L initializing & data reading, sensor measurements conversion & averaging, FipADUC communication (tested)
  - ✓ **12xLED HLMP-1700 or HLMP-1790** (tested)

POWER SUPPLY:

- ✓ **4x rectifying diodes 50WQ03FN** (tested)
- ✓ **2x IRF6215S** MOSFET transistor (tested)
- ✓ **1x LM7805** – Linear voltage stabilizer (tested)
- ✓ **1x LE33** (not tested)

Load Sensors Acquisition System (LSAS) – radiation levels at equipment location



- **Equipment locations:**
  - ✓ IP1: US15
  - ✓ IP2: UA23, UA27
  - ✓ IP8: UA83, UA87
  - ✓ IP5: UJ56 -> after LS1 UL55

- **Equipment quantity:**
  - ✓ Each IP -> 2 LSAS crates
  - ✓ LHC: 8 crates in total

Radiation levels 2012 (according to: *Radiation Levels around the LHC; P. Mala, M. Brugger, M. Calviani, A. Nordt ; ATS /Note/2013/032.*
US15, UA23, UA27, UA83, UA87, UL55 are considered as non-critical)

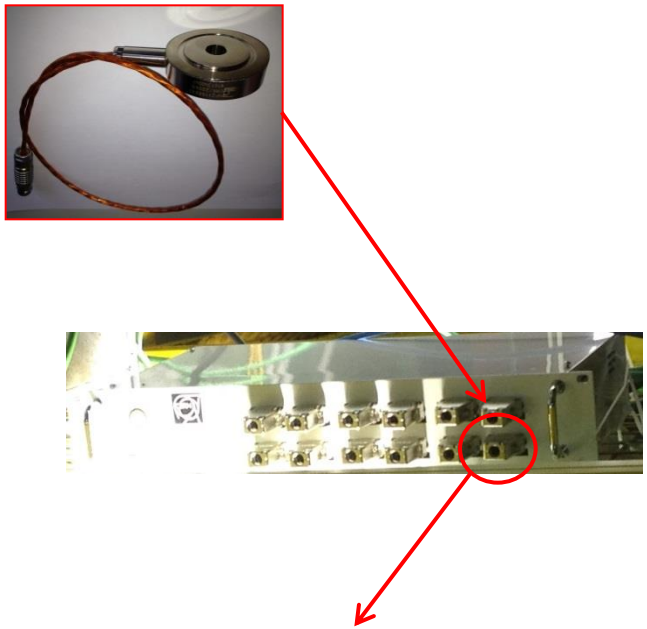
- ✓ Total Ioinizing Dose < 0.1 Gy/year
- ✓ High Energy Hadron fluence < $1x10^{7}cm^{-2}$

Radiation levels considered to tests → TID 100Gy

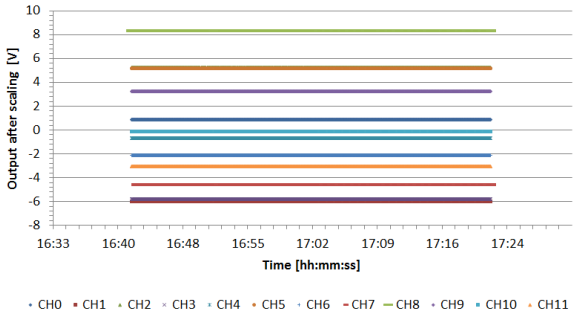
(according to: *IRRADIATION D'UN CHÂSSIS SAS 1ÈRE GÉNÉNATION; A. Marin, EDMS 1062166 → SAS falirue at TID 98Gy;*
1stR2E RADIATION SCHOOL & WORKSHOP Divonne, June 2nd/3rd2009; M.Brugger for the R2E Study Group)

- ✓ Total Ioinizing Dose UJ56: 1-10 Gy/year
- ✓ High Energy Hadron fluence UJ56: $1x10^{9}$ - $1x10^{10}$ cm^{-2}
- ✓ 1MeV neutron equivalent UJ56: $1x10^{10}$ - $1x10^{11}$

Load Sensors signal simulation – CNRAD measurements

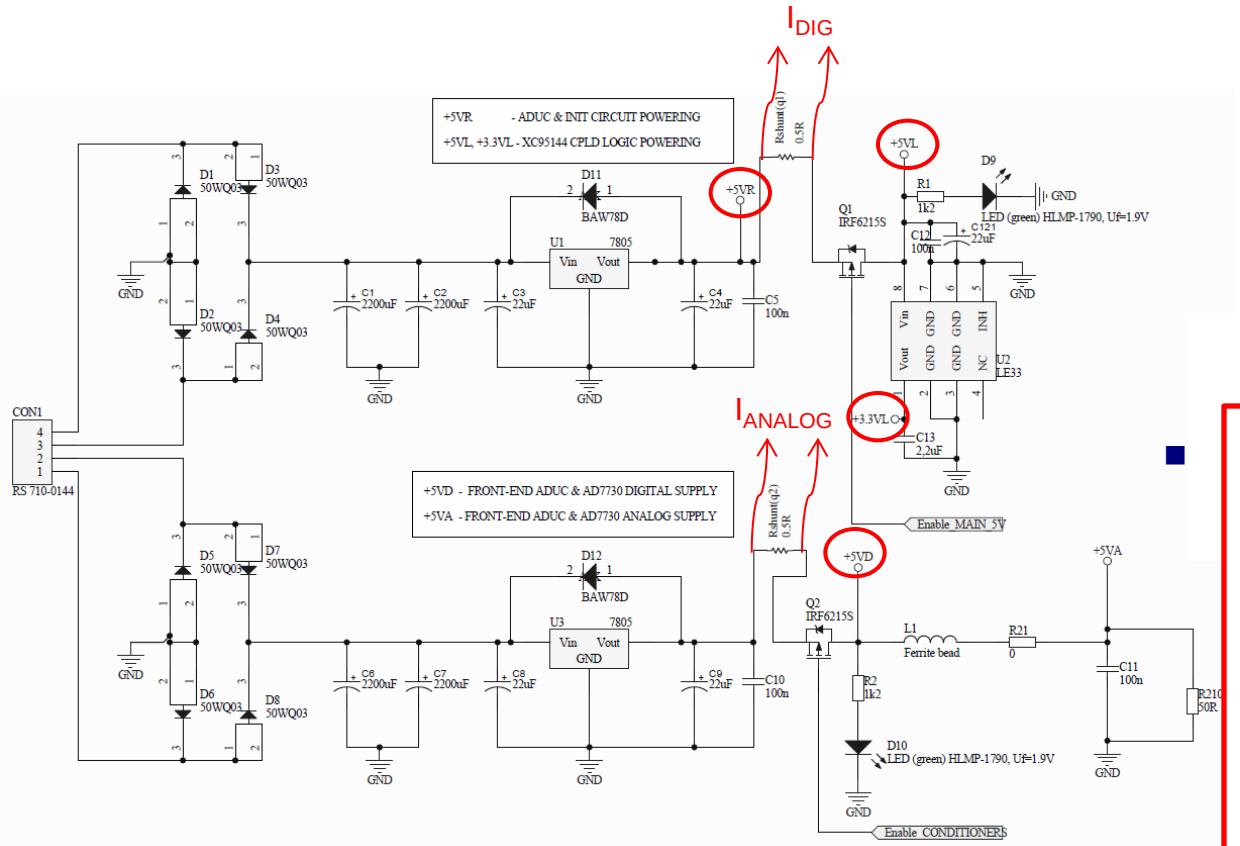


- To simulate real sensor connected to the input channel of LSAS crate – the special adapters enclosed in metal envelopes were prepared
- The single adapter contained metalized-resistors circuit - representing Wheatstone bridge of original HBM MPZ1108010 load sensor
- Resistor resistances were selected to have different input value on each channel (within entire range of conditioner input channels)



- Main purpose of the test was to check the stability of the sensors signal over the LSAS crate irradiation

Supply voltages and currents – CNRAD measurements



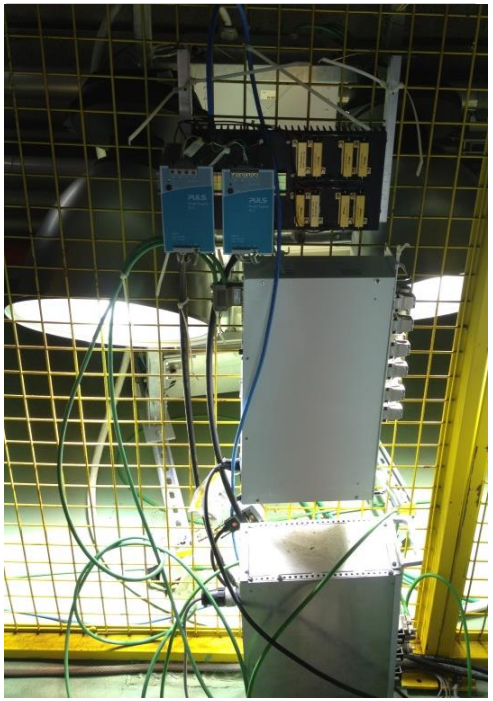
- **Supply voltages measurement before and after irradiation**
  - ✓ LSAS board logic powering, ADUC834: +5VL, XC95288 : +3.3VL
  - ✓ +5VR (FipADUC powering, main supply for LSAS board logic)
  - ✓ AD7730L signal conditioners powering – digital and analog supply: +5VD (DVdd), +5VA (AVdd)

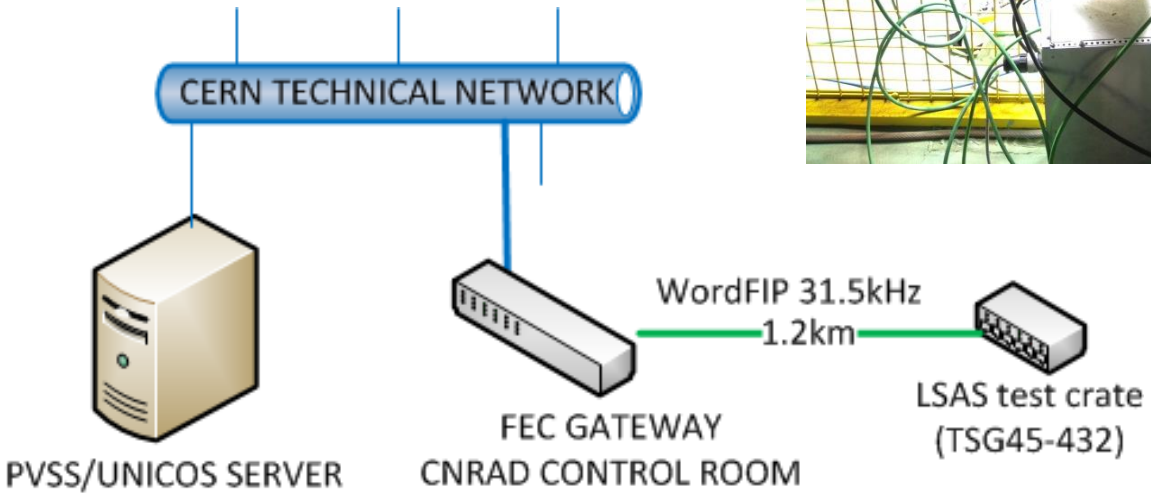
LOST PROBABLY BECAUSE OF FAULT DURING INSLATTATION IN CNRAD.
UNFORTUNATELY DETECTED AFTER IRRADIATION STARTED

LSAS installation – CNRAD measurements

- The LSAS test crate was installed in TSG45 – position 432 in order to reach TID of 100Gy

- LSAS crate data acquisition was realized by Front End Computer using 31.5kHz WordFIP connection. Input channels measurements and diagnostic events were logged on PVSS server created for the test purposes





- In case of DUT functional interrupt – remote reset possibility by power supply OFF and ON was provided

LSAS – CNRAD measurements

- Irradiation started 21.09.2012. Data logging started 24.09.2013.
- 30.10.2012 FIP communication with LSAS crate was lost after TID of 93Gy. No data were registered after this date, however DUT was powered and irradiated till 03.12.2012. Total dose taken by the device during whole test was 153Gy

INTEGRATED	Test start	FIP communication lost	End of irradiation	
	21.09.2012	30.10.2012	03.12.2012	Weekly (average)
1MeV neutron eq. [cm-2]	0	9.2E+11	1.52E+12	1.52E+11
Hadrons >~20MeV [cm-2]	0	7E+11 (6.6E+11 logged)	1.1E+12	1.1E+11
Dose [Gy]	0	93	153	15.3

- During period 21.09.2012 - 30.10.2012 observed 4 different types of failures
  - ✓ SEFI: AD7730L chip communication error (reading of data from conditioner chip impossible). Action: restart of INPUT ACQUISITION BOARDS
  - ✓ SEFI: FipADUC communication lost. Action: remote restart of LSAS crate by power OFF and ON.
  - ✓ SEU or SET: glitches in measured input signals. After one FIP communication cycle – the measured data back to proper values. Action: NONE
  - ✓ One SEE: FIP communication lost. Action: REMOTE RESTART ATTEMPT (IMPOSSIBLE) – DEVICE COMMUNICATION LOST
- There was no significant input signal drift for any channel over whole logged period (and after)

Signal stability of LSAS input channels – CNRAD measurements

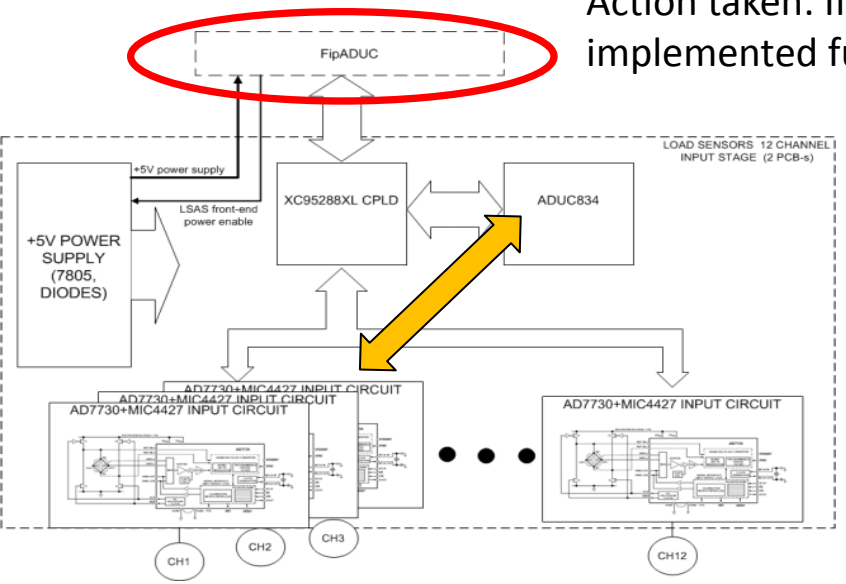
- There was no significant input signal drift for any channel over whole logged period (and after)
  - ✓ During data logging period (24.09.2012 - 30.10.2012) the input signals measured by all channels were stable. Only the CH7 showed small drift of ~0.1V which is negligible
  - ✓ After irradiation - the LSAS test crate was checked. Suprisingly, the crate worked normally in local mode (data transfer by RS232). It was impossible only to start the FIP connection, what may be linkled with microFIP chip damage on the FipADUC board
  - ✓ Data read by the RS232 link showed that after TID of 153Gy almost all input channels values was the same as before the test. Only CH2 had a drift of ~0.3V. Signal of CH7 with previousely observed drift of ~0.1V back to the initial value

SAMPLES OF INPUT SIGNAL OVER IRRADIATION TIME COMPARED WITH BEFORE IRRADIATION AND AFTER IRRADIATION:

Time	TID [Gy]	CH1 [V]	CH2 [V]	CH3 [V]	CH4 [V]	CH5 [V]	CH6 [V]	CH7 [V]	CH8 [V]	CH9 [V]	CH10 [V]	CH11 [V]	CH12 [V]
2012/09/14 17:00:00	0	0.8610	-5.9782	5.2219	-5.7922	-0.6603	5.1614	-2.1033	-4.5654	8.3708	3.2637	-0.1165	-3.0370
2012/09/27 16:46:21	14	0.8642	-6.0460	5.2063	-5.7898	-0.6531	5.1502	-2.0939	-4.5699	8.3506	3.2867	-0.1081	-3.0463
2012/09/30 14:17:17	22	0.8663	-5.9967	5.2391	-5.7836	-0.6430	5.1605	-1.9986	-4.5255	8.3343	3.2532	-0.0894	-2.9993
2012/10/01 07:54:22	25	0.8624	-6.0243	5.2387	-5.7715	-0.6991	5.1575	-1.9921	-4.5652	8.3425	3.2629	-0.1048	-3.0434
2012/10/04 15:56:09	33	0.8573	-6.0104	5.2330	-5.7854	-0.6620	5.1668	-2.0861	-4.5592	8.3459	3.2888	-0.1069	-3.0421
2012/10/06 22:41:07	39	0.8611	-6.0144	5.2057	-5.7815	-0.6518	5.1534	-2.0993	-4.5692	8.3437	3.2748	-0.1067	-3.0375
2012/10/10 00:53:36	47	0.8709	-5.9972	5.2078	-5.7899	-0.6544	5.1427	-2.0671	-4.5417	8.3527	3.2808	-0.1044	-3.0533
2012/10/14 11:15:38	57	0.8567	-5.9189	5.1906	-5.7855	-0.6538	5.2062	-2.0757	-4.5254	8.3250	3.2872	-0.1058	-2.9923
2012/10/16 03:04:14	61	0.8664	-5.9434	5.2336	-5.7813	-0.6602	5.1648	-2.0783	-4.5295	8.3385	3.2702	-0.1041	-3.0470
2012/10/20 04:31:13	68	0.8571	-5.9391	5.2310	-5.8024	-0.6491	5.1605	-2.1099	-4.5509	8.3443	3.2786	-0.1049	-3.0421
2012/09/23 13:40:19	76	0.8628	-5.9613	5.2208	-5.8061	-0.6995	5.1788	-1.9930	-4.5503	8.3638	3.2761	-0.1077	-3.0433
2012/10/26 11:06:05	82	0.8646	-5.9442	5.2117	-5.8056	-0.6549	5.1509	-1.9971	-4.5657	8.3676	3.2893	-0.0842	-3.0936
2012/10/29 07:29:37	89	0.8509	-5.9421	5.2235	-5.7701	-0.6407	5.1699	-1.9999	-4.5284	8.3438	3.2781	-0.0693	-3.0460
2013/02/11 14:00:00	153	0.84584	-6.3625	5.24509	-5.82695	-0.67827	5.154876	-2.10963	-4.5402	8.387013	3.26155	-0.11086	-3.0548

Single Event Functional Interrupt – CNRAD measurements

- AD7730L chip communication errors were observed. INPUT STAGE microcontroller couldn't read one of the 12 input channels circuits.



Action taken: INPUT STAGE restart using implemented functionality

CHANNEL	AD7730L COMM ERROR (number of events)
1	5
2	4
3	5
4	8
5	21
6	4
7	7
8	6
9	3
10	6
11	2
12	4
TOTAL:	**75**

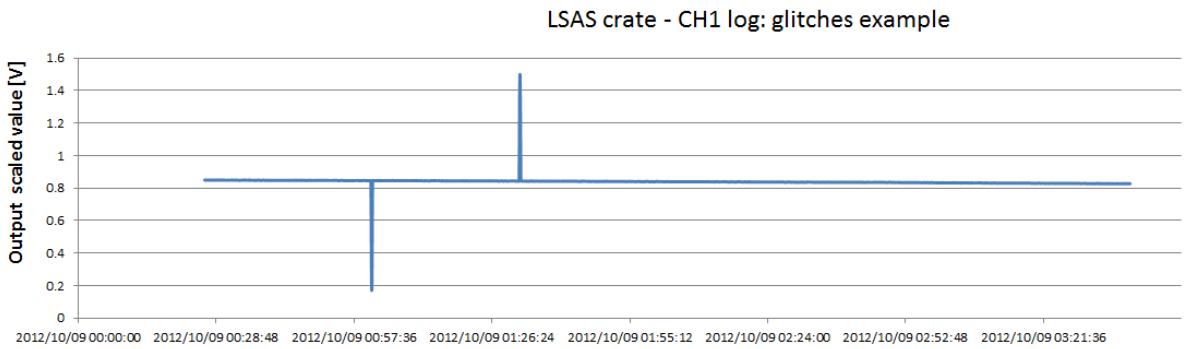
- Communication lost with FipADUC card: **9 events occured**

Action taken: remote restart of LSAS crate

- Cross section
  - ✓ HeH fluence **6.6E+11 cm^{-2}**
  - ✓ Errors (total) **84**
  - ✓ **Cross section = 84 / 6.6E+11 cm^{-2} =1.27E-10 cm^{2}**

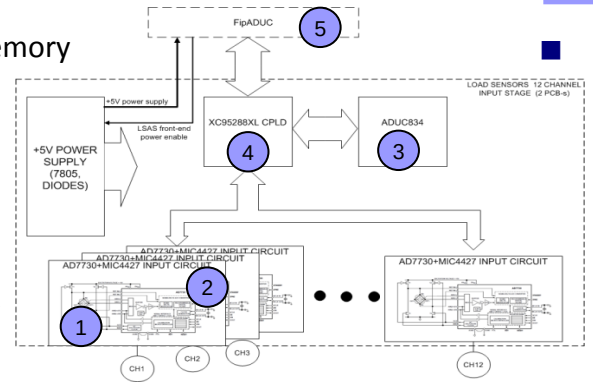
Single Event Transient or Single Event Upset – CNRAD measurements

- Glitches were observed within the input channels measurement data. Glitches appeared only for single FIP cycle. At the next cycle signal returned to correct value



CHANNEL	Glitches observed (number of events)
1	32
2	30
3	30
4	59
5	67
6	32
7	71
8	105
9	23
10	33
11	34
12	51
TOTAL:	**567**

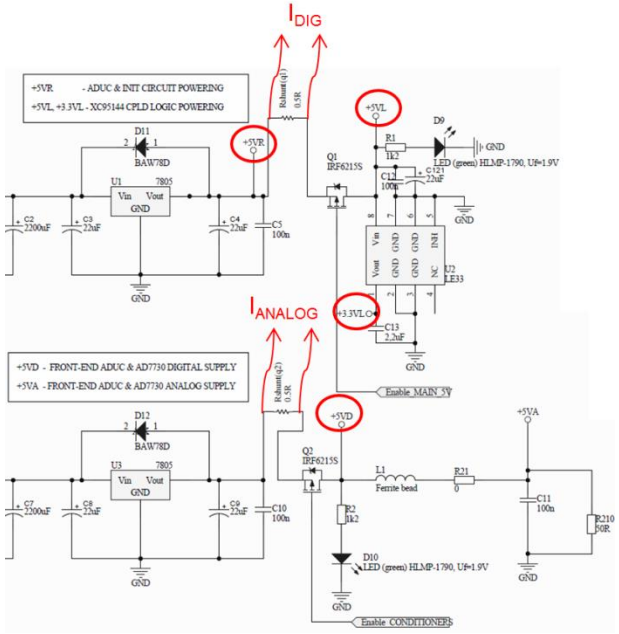
- Possible reasons
  - ✓ (1) Single Effect Transient (SET) in AD7730L internal analog cirquitry
  - ✓ (2) Single Effect Upset (SEU) (bit switch) in AD7730L internal RAM or communication register
  - ✓ (3) SEU in in INPUT STAGE microcontroller memory
  - ✓ (4) SEU in XC95288 output data register
  - ✓ (5) SEU in FipADUC card chips memories



- Action taken: NONE
- Non critical for the system functionality

- Cross section
  - ✓ HeH fluence **6.6E+11 cm^{-2}**
  - ✓ Errors (total) **567**
  - ✓ **Cross section = 567/ 6.6E+11 cm^{-2} =8.6E-10 cm^{2}**

Power supply (volatges and currents) – CNRAD measurements



	BEFORE IRRADIATION	AFTER IRRADIATION (153Gy)	DRIFT OBSERVED
DIGITAL SUPPLY (XC95288, ADUC834, LEDS)			
+VR5 [V]	5.02	5.01	-0.01
I_{DIG} [mA]	69	60	-9
+5VL [V]	4.98	4.81	-0.17
+3.3VL [V]	3.31	3.33	0.02
AD7730L SUPPLY			
I_{ANALOG} [mA]	261	240	-21
+5VD, +5VA [V]	4.97	4.37	-0.6
MOSFETs U_{DS} VOLTAGE DROP			
U_{DS} Q1 [V]	0.02	0.147	**0.127**
U_{DS} Q2 [V]	0.08	0.68	**0.6**

- Possible TID effect observed on power supply MOSFET keys
  - ✓ Voltage drop on MOSFETs Q1, Q2 increased, which may be linked with transistors characteristics change according to TID taken by MOSFETs. However, the drift has not visiblee impact to the operation of LSAS. Also any MOSFETs control problems were observed
  - ✓ Current consumption for „analog" and „digital" part of INPUT STAGE PCBs decreased, which looks linked with decrease of supply voltages (+5VL, +5VD, +5VA) generated by voltage drop on MOSFETs Q1, Q2

Summary – CNRAD measurements

- LSAS crate crossection
  - ✓ Assuming Total High Energy Hadron Fluence taken by the equipement during logged period **6.6E+11 cm^{-2}**
  - ✓ The total amount of non-destructive faults were 9 FipADUC stops + 75 AD7730L communication lost = **84**,
  - ✓ Equipement crossection: **84/6.6E+11 cm^{-2} = 1.27E-10cm^2**

- Probability of LSAS crate errors within 1 year of work
  - ✓ Assuming Total High Energy Hadron Fluence per year for locations US15, UA23, UA27, UA83, UA87, UL55: $1x10^7 cm^{-2}$
  - ✓ 8 LSAS crates installed in locations mentioned above
  - ✓ Probability of non-destructive fault of equipement will be: P= **8* 1.27E-10 cm^2 * 1E7cm^{-2} = 0.01 per year**
  - ✓ **Theoretical Mean Time Between Failures for all LSAS installed in LHC will be: MTBF = 100 years**

- Total Ionizing Dose resistance
  - ✓ Assuming Total Ionizing Dose per year for locations US15, UA23, UA27, UA83, UA87, UL55: 0.1Gy/year
  - ✓ **The theoretical LSAS crate lifetime will be 93Gy / (0.1 Gy/year) = 930 years**