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The Monitoring System of the End Cap Calorimeter in the Belle II experiment

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Belle II

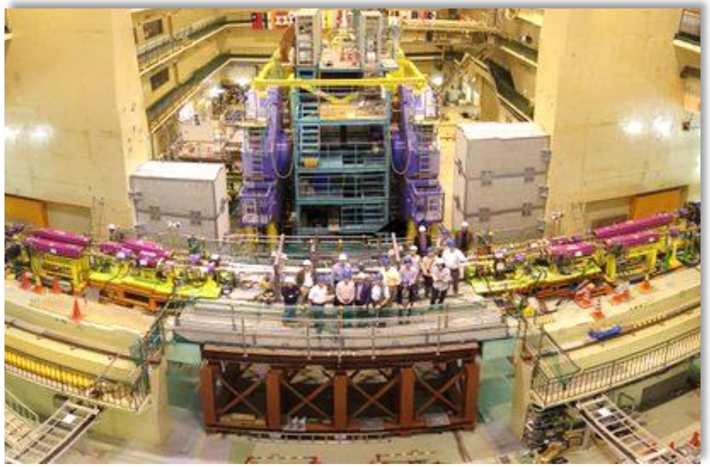
INFN Istituto Nazionale di Fisica Nucleare

Summary

- The Belle II experiment at KEK
- The end cap calorimeters
- The monitoring system
- Testing the hardware
- Noise issues
- Software architecture (just a bit, we will be late !)
- ... *and one for aficionados of One Piece Saga*

    (ワンピース Wan Pīsu) !

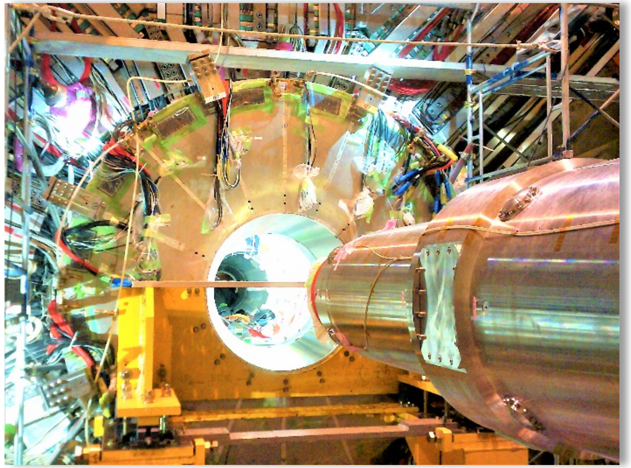
The Belle II Experiment @ KEK



The Belle2 detector, KEK (Tsukuba, JP)

- The Belle II experiment is presently in phase 2 operation with colliding beams at the SuperKEKB electron-positron accelerator, KEK (Tsukuba, JP).
- The detector is a major upgrade of the Belle experiment at the former KEKB collider and it is optimized for the study of rare B decays.
- The new design makes it also sensitive to signals of New Physics beyond the Standard Model, including studies of the dark sector.

The ECL Endcap Calorimeter

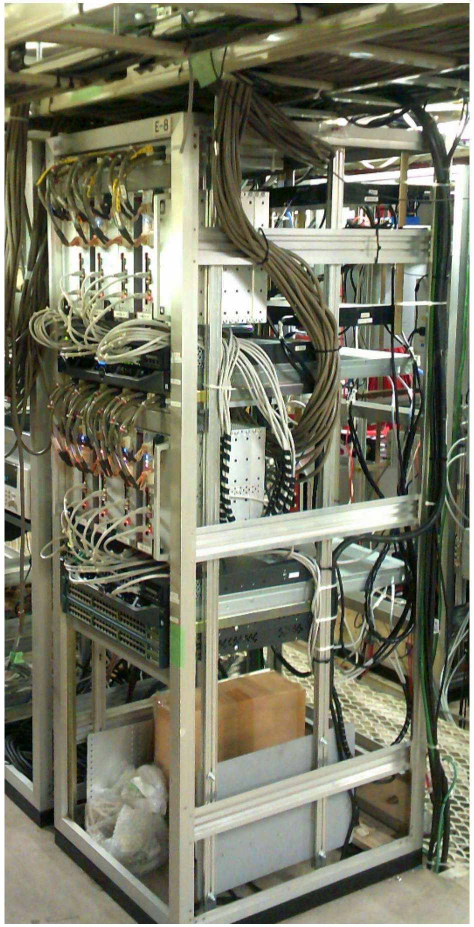


The ECL forward endcap during installation

Detail of an endcap sector cable harness

- The Belle II Electromagnetic Calorimeter (ECL) is based on CsI(Tl) scintillation crystals.
- It splits in a barrel and two annular end cap regions, Forward and Backward, named according to the asymmetric design of the collider.
- 2112 CsI(Tl) crystals are arranged in total in the two end caps, each composed by 16 sectors.

The Endcap Monitoring System



The endcap monitoring rack in the Electronic Hut

40m cable

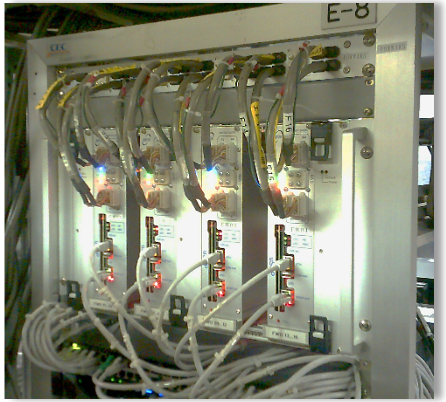
low-level, analog signals only, to avoid injecting noise in the detector

Each sector is equipped with 3 thermistors and 1 relative humidity active probe

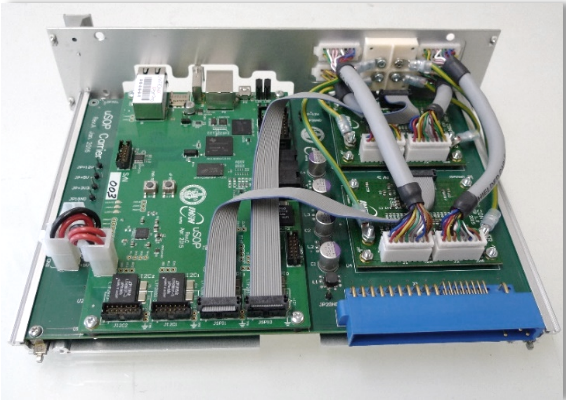
endcap sector

- CsI(Tl) crystals deliver a high light output at an affordable cost, however their yield changes with temperature and can be permanently damaged by humidity, due to the strong chemical affinity for moisture.
- While sensors and cabling have been inherited from the former Belle experiment, the ECL monitoring system (both barrel and end cap) has been fully redesigned.

The monitoring crate layout



One crate with 4 boards per each endcap



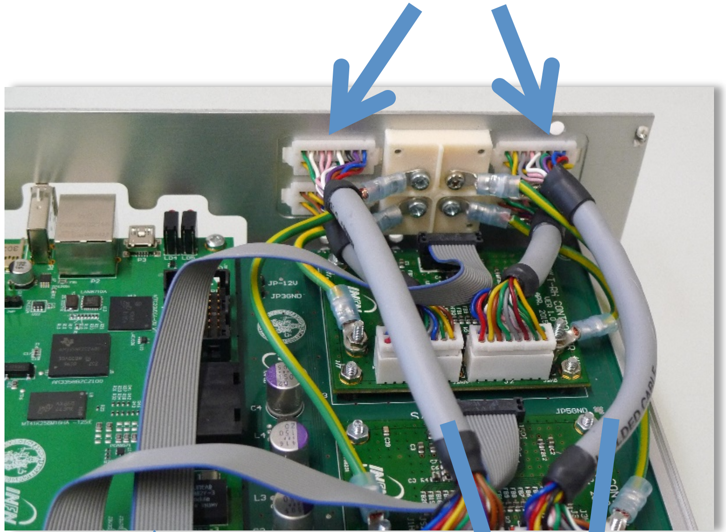
each board reads 4 sectors

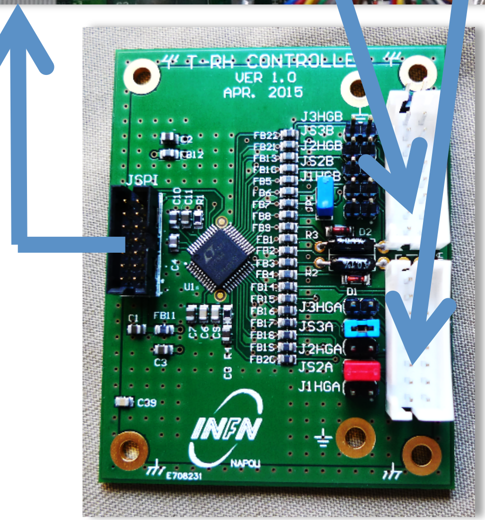
a single-board-computer per board

- Each endcap is read-out by 4 boards, based on a single-board-computer developed *ad hoc* for embedded applications: uSOP
- Each uSOP is interfaced with 2 high-performance controllers, capable to power and digitize the remote thermistors and humidity probes installed in 4 sectors
- Acquired and processed data are then sent to an Archiver via Ethernet LAN on a specific backbone assigned to monitoring and controls
- Each board runs the same software and it works independently from the others, such to avoid single-point-of-failures

Reading the sensors

From two sectors (40m cables)

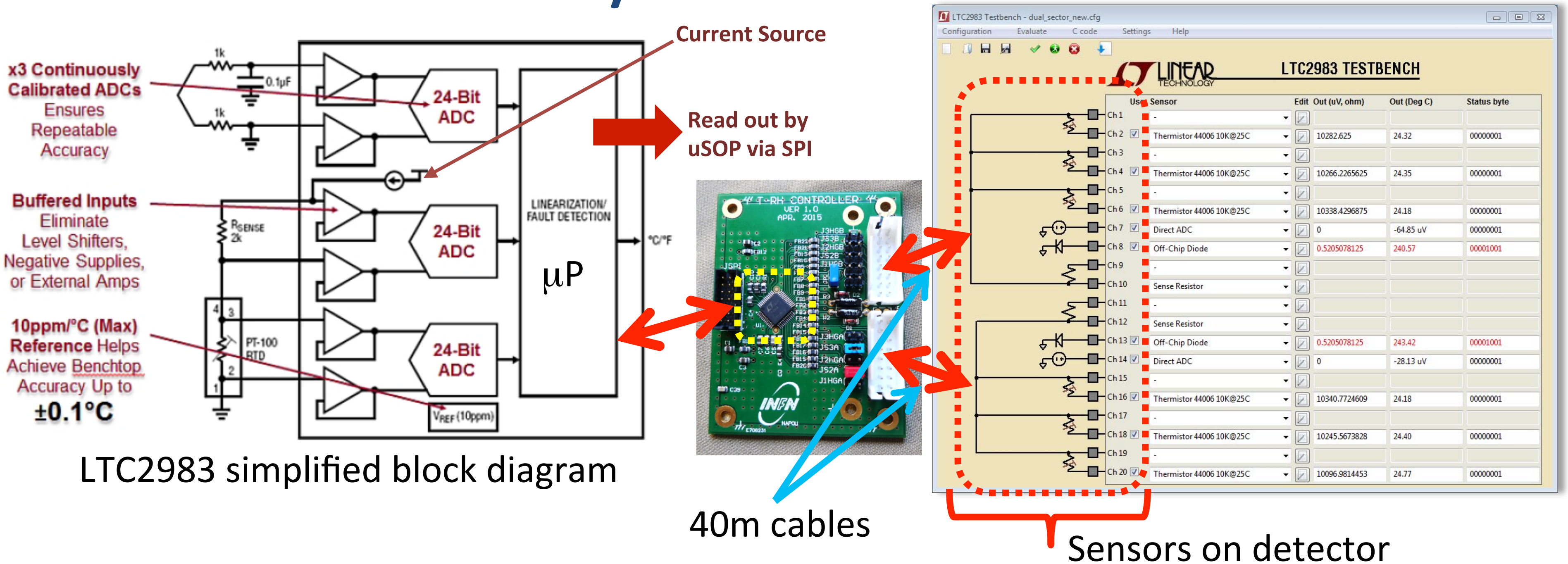




to uSOP (via SPI)

- On-detector sensors are read out by a controller which takes in input the analog thermistor and humidity signals from 2 sectors
- The controller powers, excitates, digitizes and linearizes the sensors
- uSOP supplies clean, galvanically isolated power to the controllers
- Read-out is handled via an isolated SPI serial bus

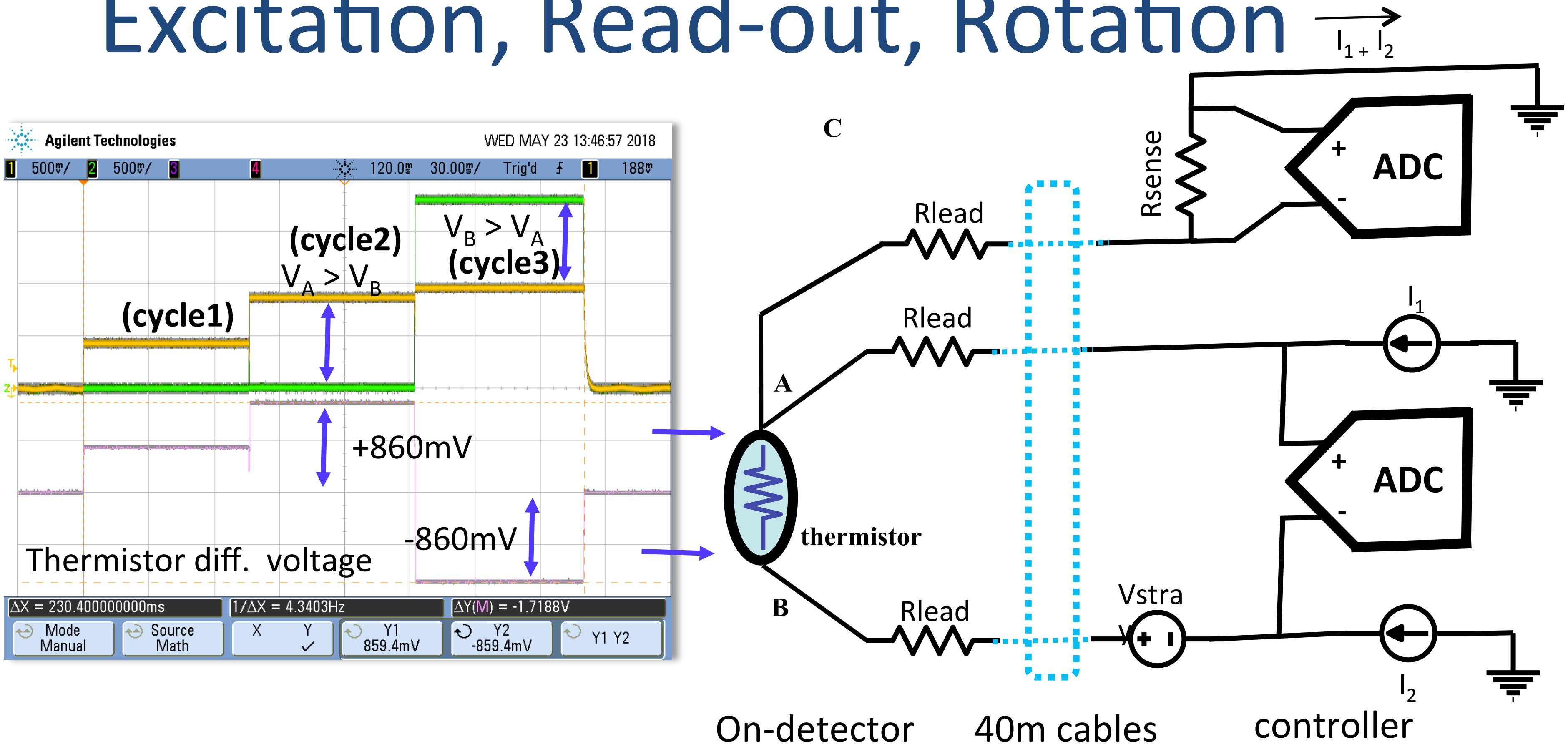
The T/Rh Controller



LTC2983 simplified block diagram

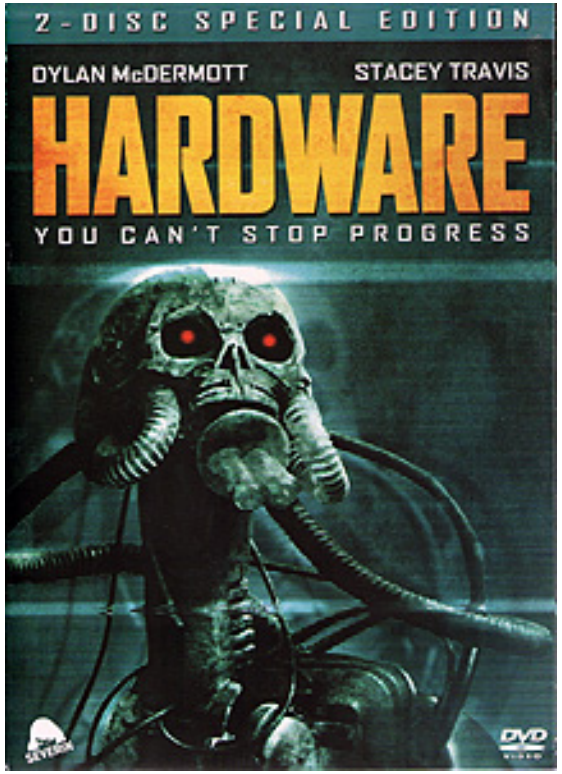
- Designed around the **LTC2983** System-on-Chip
- Full-feature platform, includes 3 ΣΔ 24-bit ADCs, Analog Front-End, current sources for excitation, uP for sensor linearization and direct output in °C
- Programmable to handle thermistors, thermocouples, RTD, generic sensors
- Supports 2,3 and 4-wire measurements, with stray thermocouple effects removal

Excitation, Read-out, Rotation

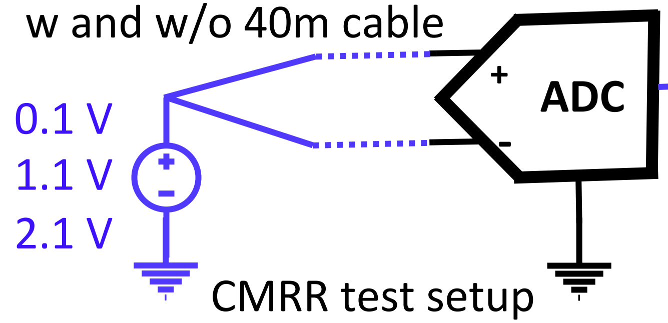


- 3-wire scheme (directly supported by LTC2983, compatible with the former cabling inherited by the Belle experiment) cancels out cable resistance
- Thermistor is first excitated with a trial current (**cycle1**), actual resistance is calculated in a ratiometric way, then generators establish a voltage of about 1V across the thermistor (**cycle2**), and a first sample is taken.
- Eventually, a new sample is taken after inverting the current (**cycle3**). By averaging the two measurements, stray thermocouple effects are removed.

TESTING THE

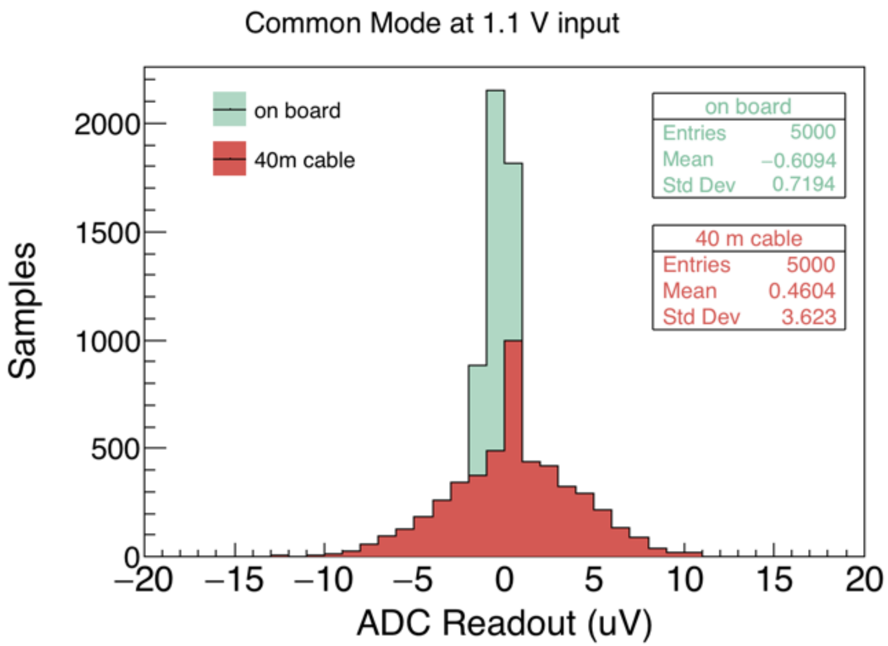

2-DISC SPECIAL EDITION
DYLAN McDERMOTT
STACEY TRAVIS
HARDWARE
YOU CAN'T STOP PROGRESS

Testing the Common Mode Rejection Ratio

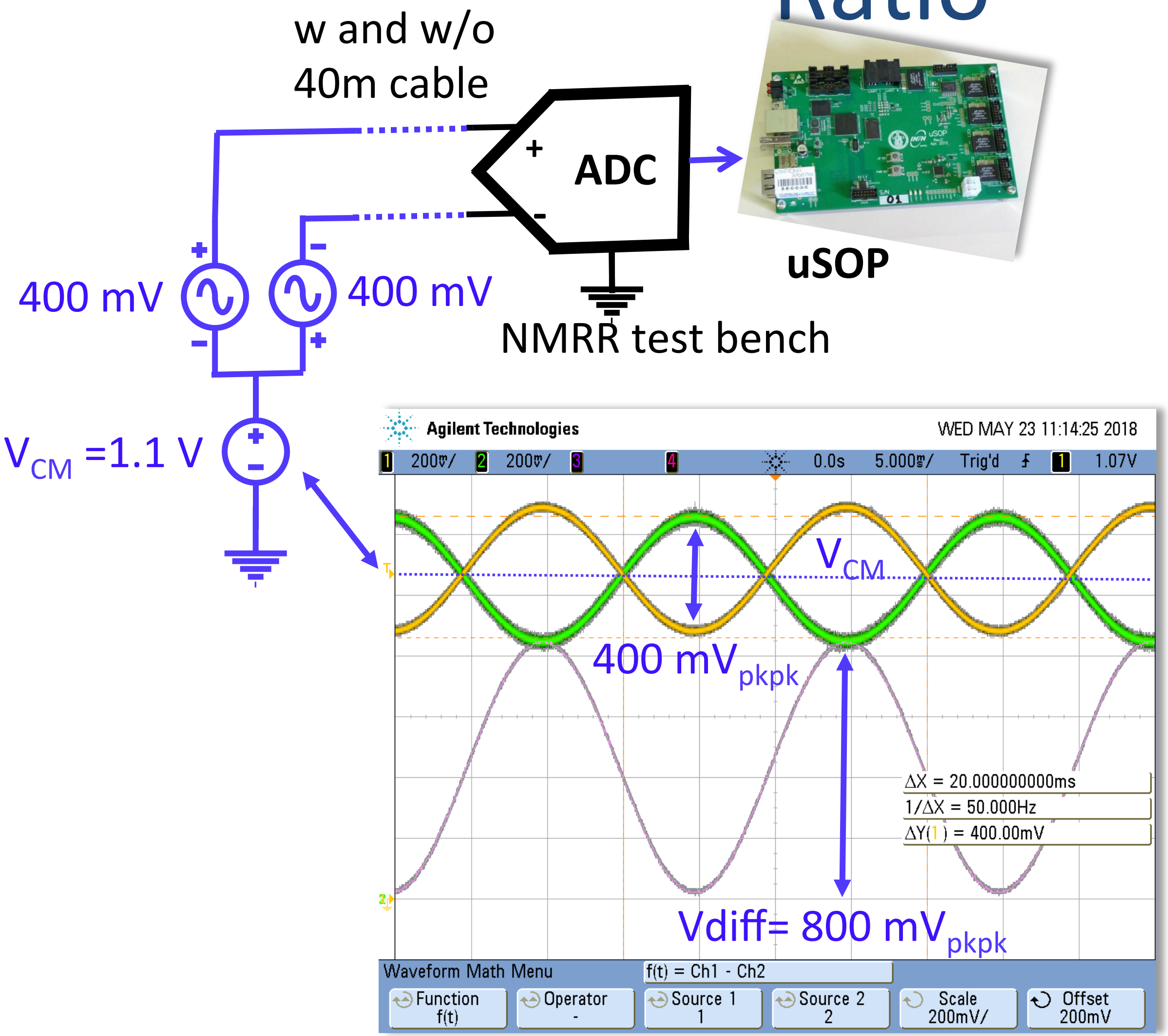


In a very noisy environment and in presence of long cables, a good figure of merit to determine system performance is the common-mode rejection ratio.

- CMRR has been measured at different input DC voltages, both with and without cables
- System level measurements (controller interfaced with uSOP, typical lab environment), give a CMRR of -135db, even better than the datasheet value
- The σ of the noise floor distribution (shorted inputs) increases by a few μV when a 40m cable is connected

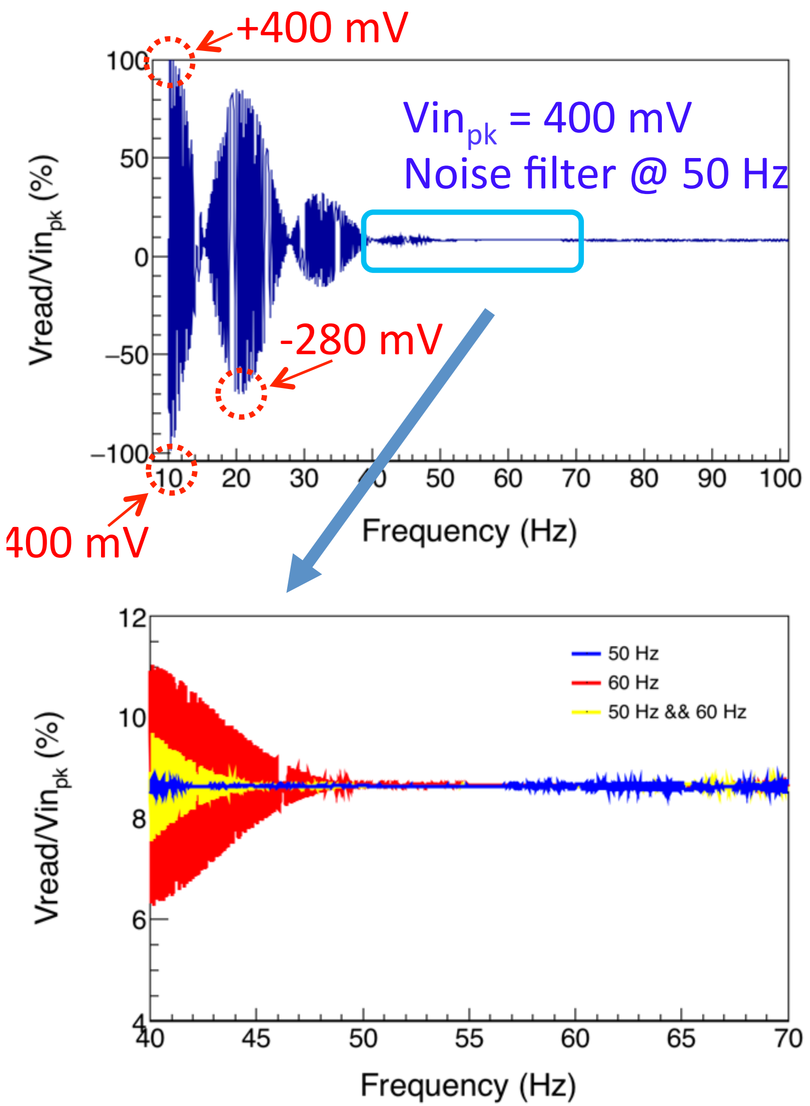


Testing the Normal Mode Rejection Ratio

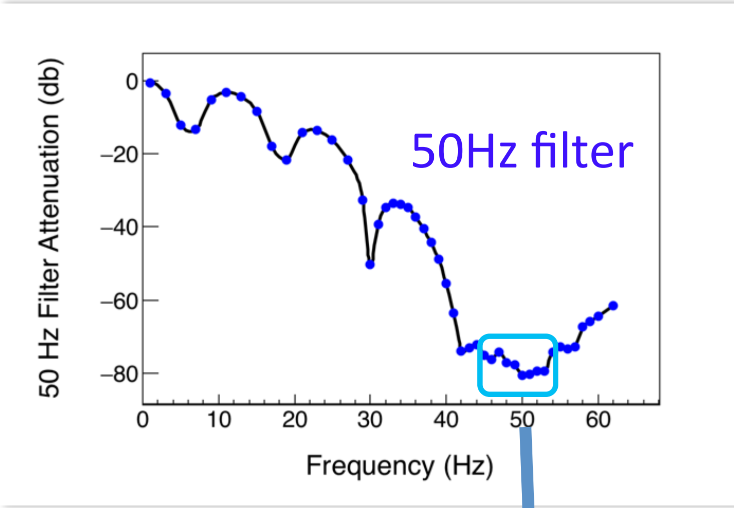


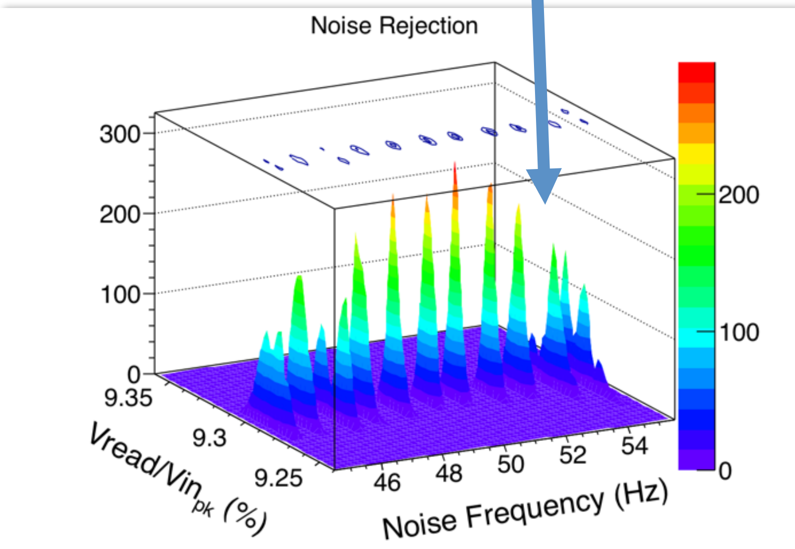
- Low frequency noise sneaks in the ADC and it can seriously degradates the sensor read-out
- NMRR has been measured in the range 10 – 100 Hz, comparing the 3 different filtering option offered by the LTC2983
- In this setup, $V_{diff} = V_+ + (-V_-)$ = 800mV and V_{CM} = 1.1 V

Sweeping the noise



- The on-chip LTC2983 notch filters are programmable on the power grid frequencies of 50 Hz, 60 Hz and 50-60 Hz
- Filters are effectives starting from 40Hz and shows *excellent* rejection of power noise
- In the plots, percentage of the noise amplitude seen by the ADC is plotted vs. noise frequency

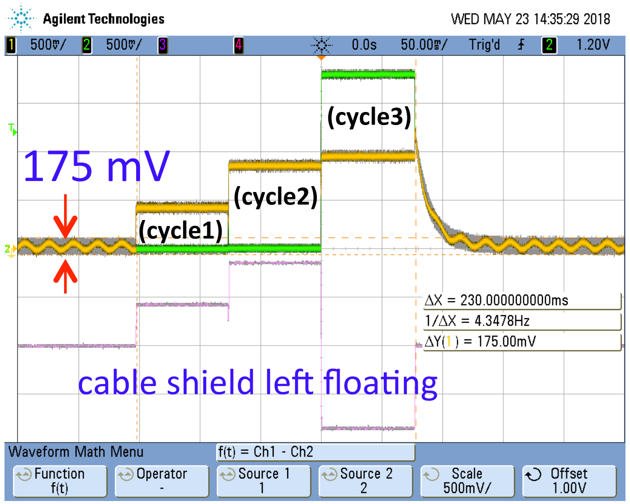


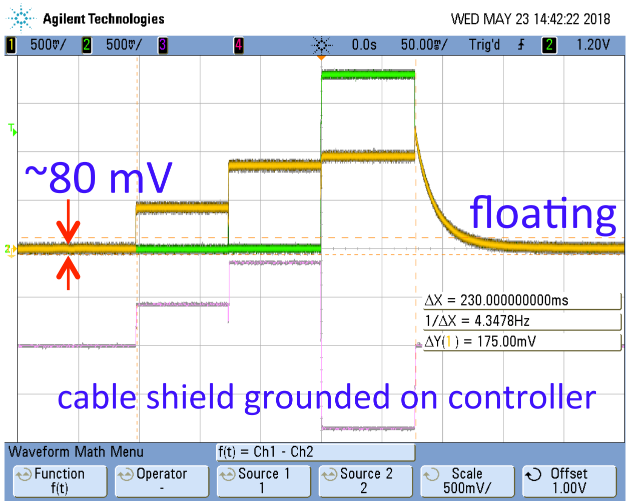


Filtering 50Hz noise

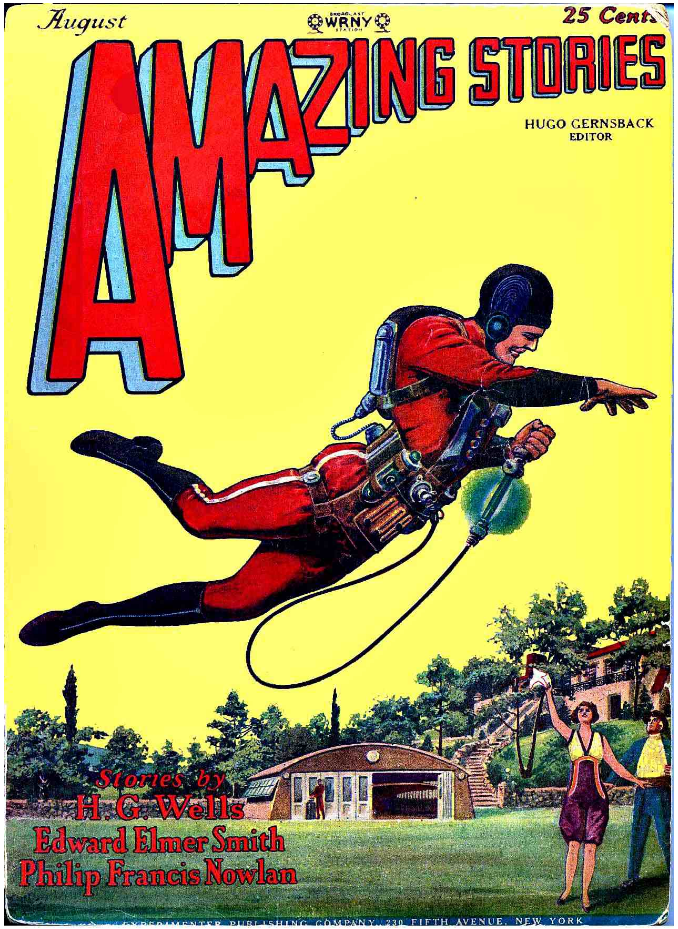
- For the 50Hz filter, the LTC2983 datasheet claims an attenuation of 120db *"… Guaranteed by design, not subject to test…"*
- A system test in the lab shows an attenuation of 80db, nearly flat from 45 to 55 Hz (not that bad !). Mains hum is virtually suppressed.
- 50/60Hz and 60 Hz filters have a similar attenuation, even if datasheet only quotes 75db

Shielding and Grounding



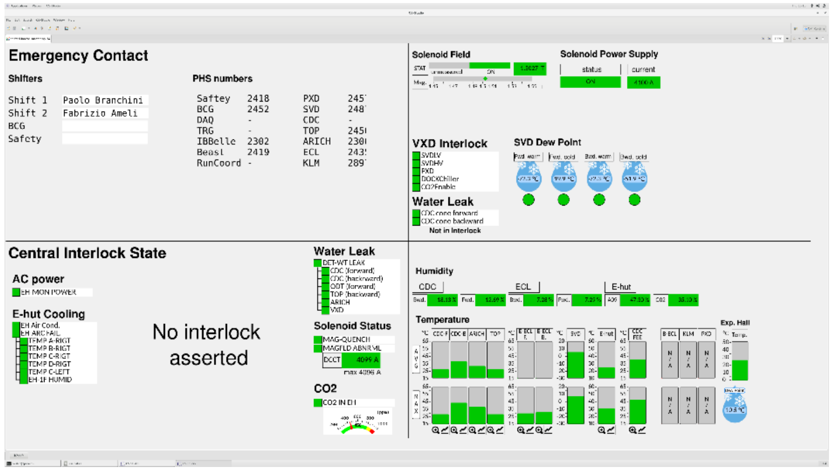


- To avoid self-heating, LTC2983 excitates the thermistors only during read-out
- Cables are left floating in between measurements and they can inject common noise into the detector
- Leaving the cable shield floating on both *near* (controller) and *far* (detector) ends gives the worst case scenario
- Grounding the shield on the controller end gives the lowest noise
- Galvanic isolation of the controller avoids ground loops by design



ABOUT SOFTWARE DEVELOPMENTS …

The Software Architecture



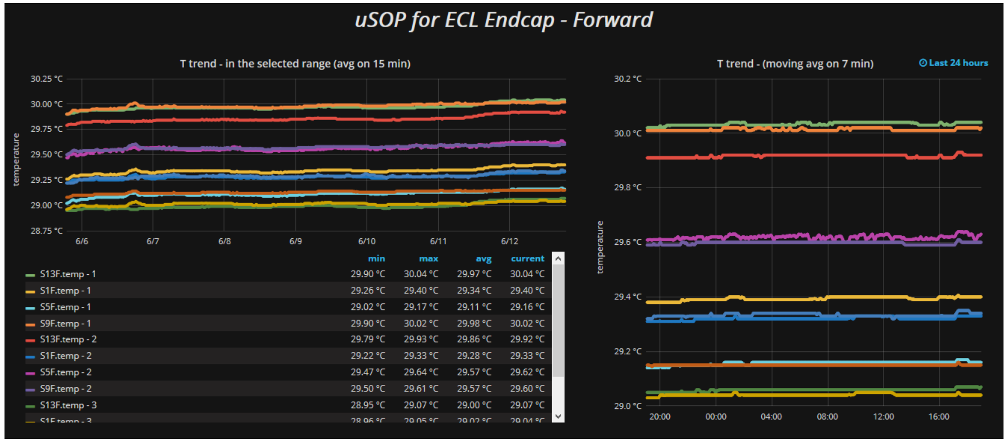
Top level monitoring panel in control room

- For more information, please, also see the poster n.550 of Seokhee Park, about “Environmental Monitoring for Belle II”

- The entire BELLE2 monitoring system speaks EPICS
- EPICS (http://www.aps.anl.gov/epics/) is a set of Open Source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific instruments such as a particle accelerators and large scientific experiments
- uSOP boards sends on a LAN infrastructure PVs with acquired data (T and Rh)
- PVs are consumed by Archivers and GUI based on CSS/Boy
- Experts and developers have access to a web based display showing full-feature information on time series

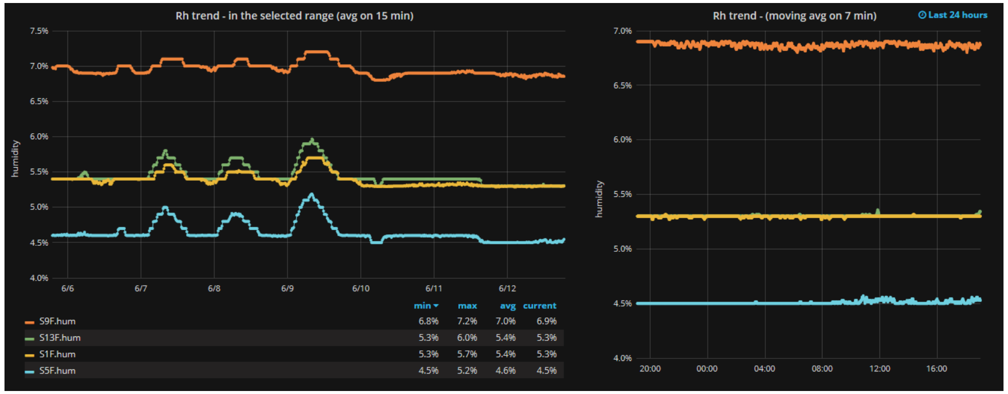
Time Series

Temperature display



weekly trend

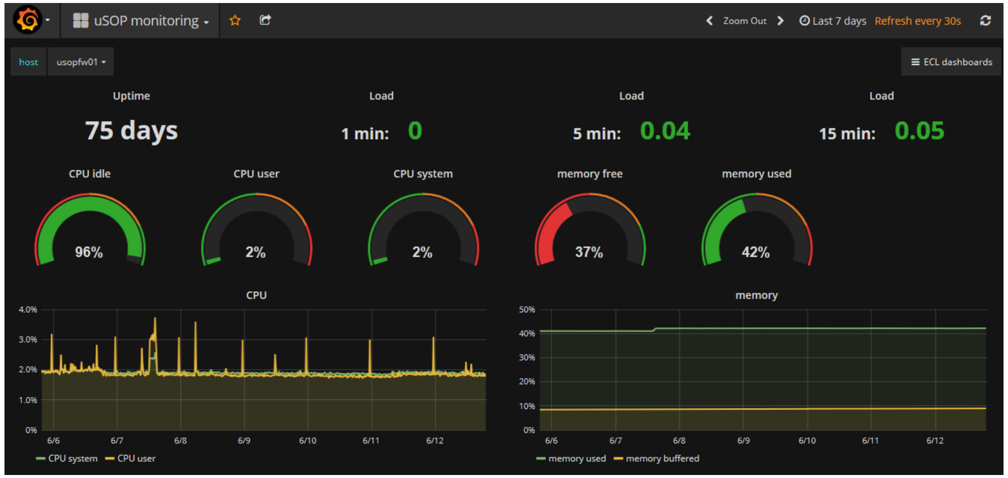
daily trend

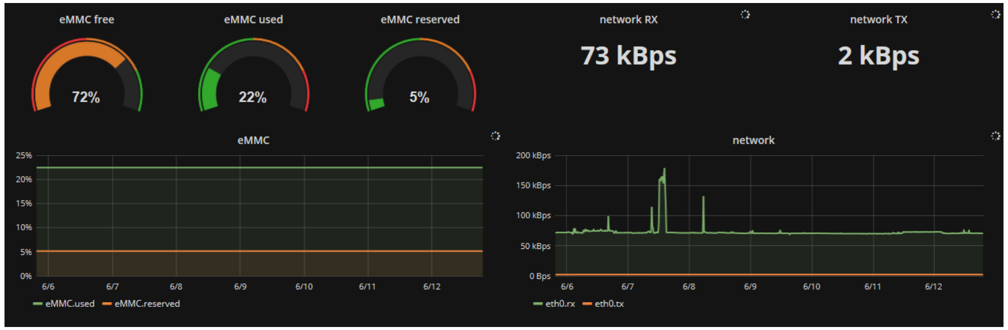


Relative Humidity display

- T and Rh vs. time can be browsed on a web page
- Endcap sectors can be added/removed interactively to/from the display
- A high resolution window shows the last 24 hours, an averaged window shows the weekly trend
- Accuracy limited by the sensors, not by the read-out

uSOP Metrics





- Beside environmental variables, the uSOP most relevant metrics are also monitored, like uptime, CPU load, Memory usage, network activity

Conclusions

- The monitoring system of the BELLE2 endcap calorimeter matches or exceeds the performance of a lab grade benchtop solution
- It is based on uSOP, an embedded LINUX platform developed *ad hoc*
- Sensor controller is based on LTC2983, a system-on-chip with *astonishing* specs and flexibility
- Greatest attention payed to noise issues, galvanic isolation, achievable read-out resolution, reliability
- Lab tests to validate the design
- Architecture fully integrated in the BELLE2 EPICS framework

- An afterpulse for the Manga lovers... Wait for the next slide !

An afterpulse... just for fun ...

- Usopp (ウソップ) is one of the *One Piece* characters by the manga writer Eiichiro Oda
- Usopp has a <u>bad</u> reputation in the Straw Hat Pirates crew !
  - "uso" (うそ) in his name means "lie" or "falsehood" (嘘).
  - he also has a track record of cowardice and spitefulness...
- Well, even if they both live and *perform* in Japan, uSOP is not Usopp !

ありがとう

Thank you

BACKUP

uSOP – uP and utilities

512 MB DDR3 RAM

4 GB Flash eMMC

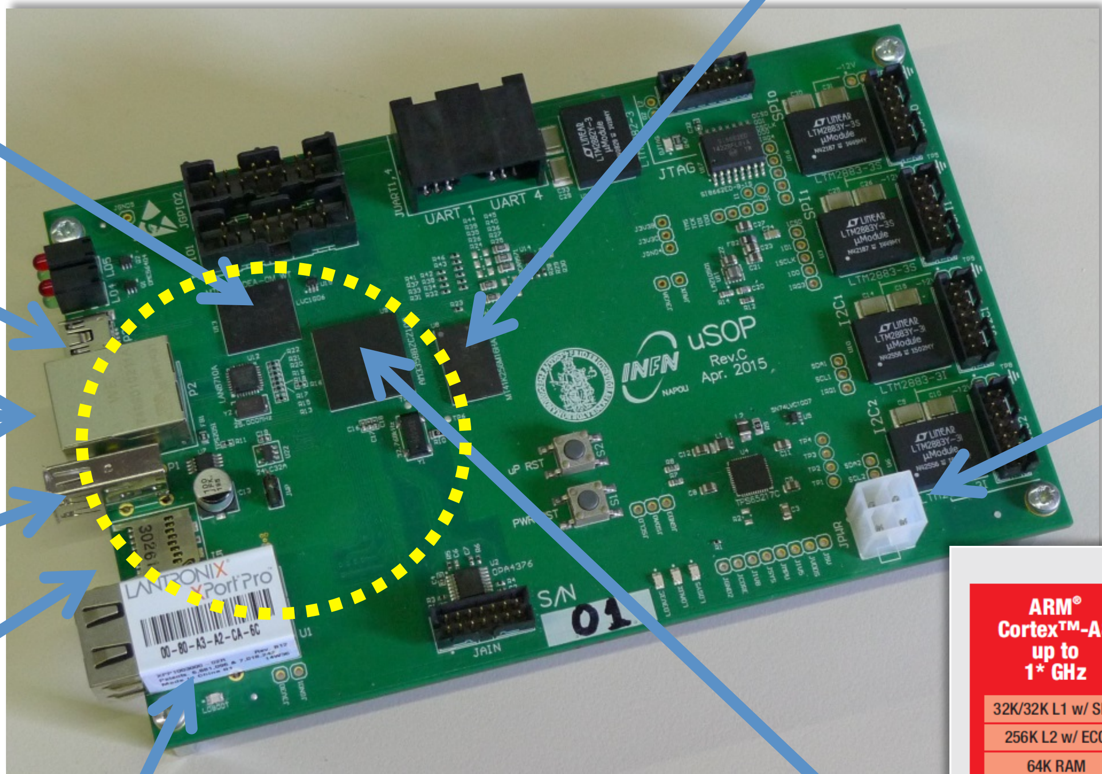
USB device

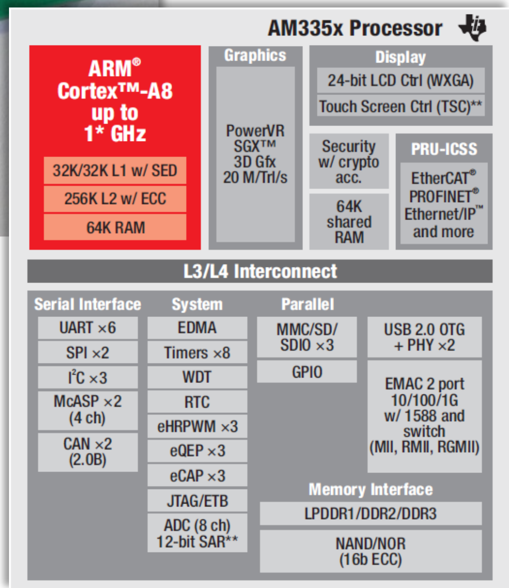
10/100 Ethernet

USB host

uSD

5V, 500mA (typ)





10/100 Ethernet (controls and management only. **See next slide**)

uSOP – Peripherals/Intf

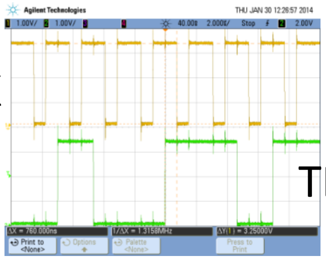
- Timers
- PWM
- Event Capture
- PRU

16 x GPIO

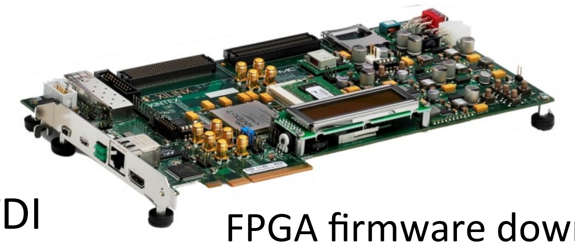
2 x RS232 (*)

JTAG (*)

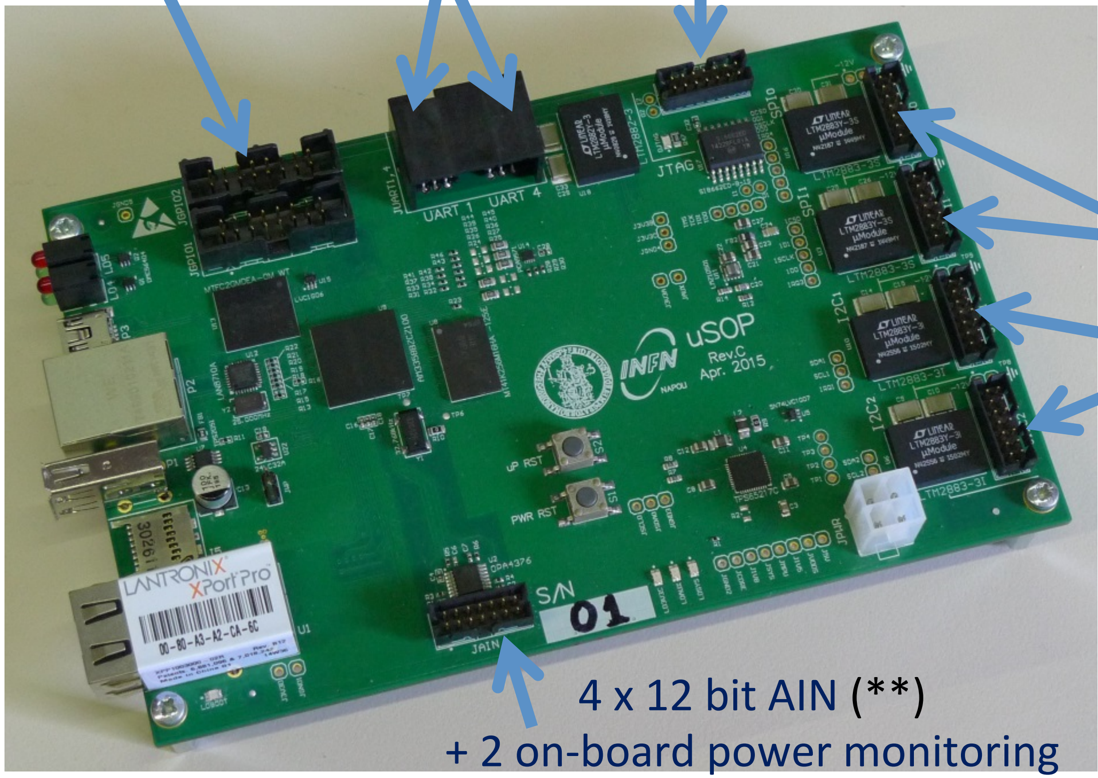
TCK

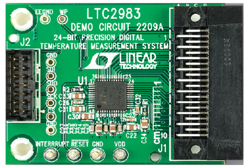


TDI



FPGA firmware download





2 x SPI (*)

2 x I2C (*)

* = fully isolated, 5V-12V supply

** = buffered

4 x 12 bit AIN (**)

+ 2 on-board power monitoring

Sensors For Belle II ECL

- **Thermistor: SEMITEC 103AT-2**

Resistance -Temperature

Temperature	Type							Temperature	Type						
(°C)	102AT	202AT	502AT	103AT	203AT	503AT	104AT	(°C)	102AT	202AT	502AT	103AT	203AT	503AT	104AT
−50	24.46	55.66	154.6	329.5	1253	3168	11473	35	0.7229	1.424	3.508	6.940	13.06	32.48	60.94
−45	18.68	42.17	116.5	247.7	890.5	2257	7781	40	0.6189	1.211	2.961	5.827	10.65	26.43	48.10
−40	14.43	32.34	88.91	188.5	642.0	1632	5366	45	0.5316	1.033	2.509	4.911	8.716	21.59	38.13
−35	11.23	24.96	68.19	144.1	465.8	1186	3728	50	0.4587	0.8854	2.137	4.160	7.181	17.75	30.44
−30	8.834	19.48	52.87	111.3	342.5	872.8	2629	55	0.3967	0.7620	1.826	3.536	5.941	14.64	24.42
−25	6.998	15.29	41.21	86.43	253.6	646.3	1864	60	0.3446	0.6587	1.567	3.020	4.943	12.15	19.72
−20	5.594	12.11	32.44	67.77	190.0	484.3	1340	65	0.3000	0.5713	1.350	2.588	4.127	10.13	15.99
−15	4.501	9.655	25.66	53.41	143.2	364.6	969.0	70	0.2622	0.4975	1.168	2.228	3.464	8.482	13.05
−10	3.651	7.763	20.48	42.47	109.1	277.5	709.5	75	0.2285	0.4343	1.014	1.924	2.916	7.129	10.68
−5	2.979	6.277	16.43	33.90	83.75	212.3	523.3	80	0.1999	0.3807	0.8835	1.668	2.468	6.022	8.796
0	2.449	5.114	13.29	27.28	64.88	164.0	390.3	85	0.1751	0.3346	0.7722	1.451	2.096	5.105	7.271
5	2.024	4.188	10.80	22.05	50.53	127.5	292.5	90	0.1536	0.2949	0.6771	1.266	1.788	4.345	6.041
10	1.684	3.454	8.840	17.96	39.71	99.99	221.5	95			0.5961	1.108	1.530	3.712	5.037
15	1.408	2.862	7.267	14.69	31.36	78.77	168.6	100			0.5265	0.9731	1.315	3.185	4.220
20	1.184	2.387	6.013	12.09	24.96	62.56	129.5	105			0.4654	0.8572	1.134	2.741	3.546
25	1.000	2.000	5.000	10.00	20.00	50.00	100.0	110			0.4128	0.7576	0.9807	2.369	2.994
30	0.8486	1.684	4.179	8.313	16.12	40.20	77.81								

Unit(kΩ)

- **Relative Humidity Probe:** unfortunately the used probe from Vaisala is no longer produced (Humicap180)
- A new model with similar performance, given as reference, is HMP110 (accuracy 1.5 %)