International Workshop on Future Linear Colliders (LCWS14)
Belgrade, Serbia, October 2014

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INSTITUTO TECNOLÓGICO DE ARAGÓN

# FTD-ILD sub-detector power distribution system prototype based on Supercapacitors

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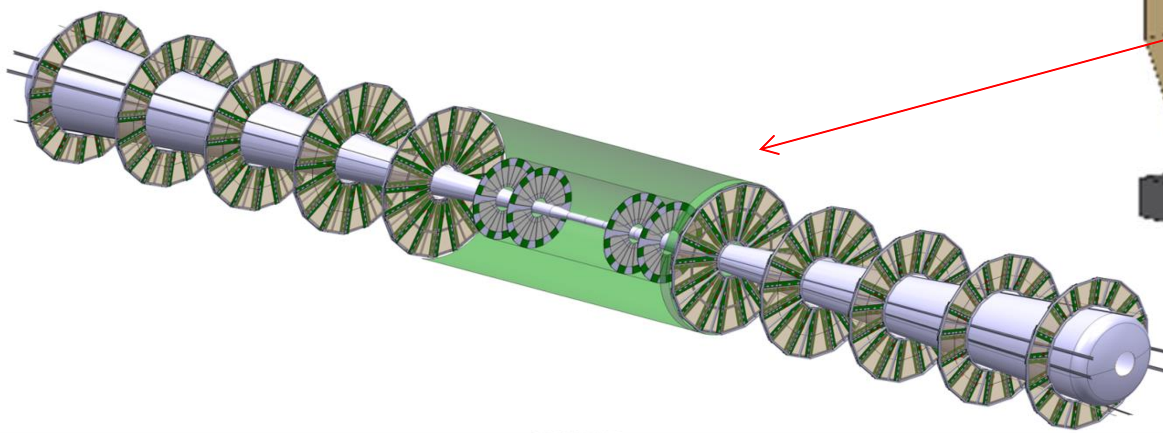
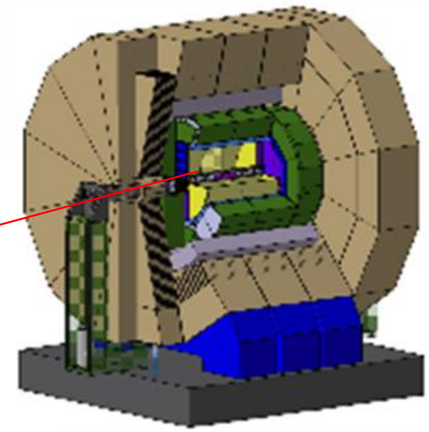
# OUTLINE

- 1. Introduction
- 2.Supercapacitors
- 3. Supercapacitors based power distribution.
- 4. FTD-ILD power group prototype
  - Power dissipation test results
- 5.Conclusions

# 1. Introduction

- The mstrip-FTD-ILD system is a silicon strip tracker located in the innermost part of the tracker region of the ILD.
  - It consists of 10 disks.
  - Each disk has 16 petals





- The FTD electronics will operate synchronously (or coordinated) with ILC accelerator....
  - 1 ms bunch train every 200ms ( Duty cycle of 0.5%)

# 1. Introduction

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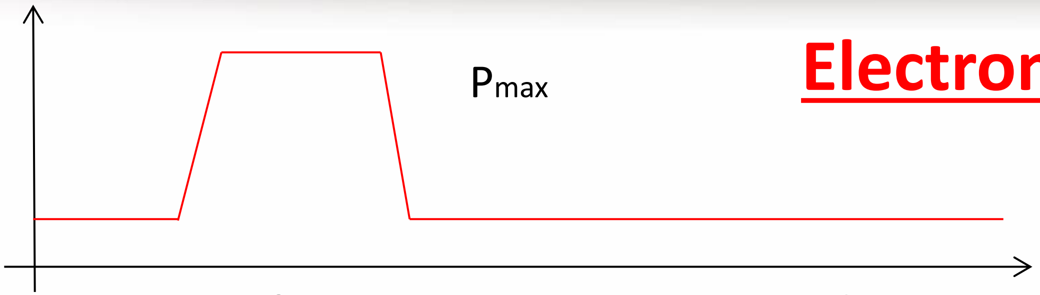


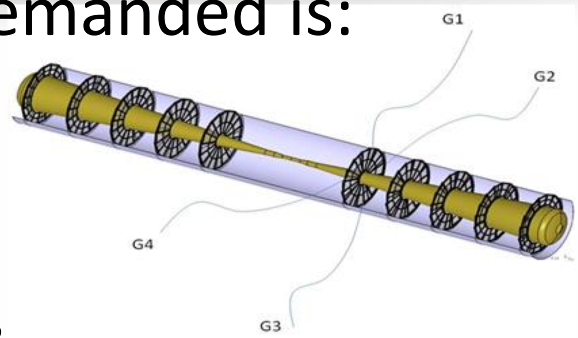

## Electronics duty cycle /power ?

$P_{standby} = 20\% \, P_{max}$

- Several conservative considerations have been assumed in the electronics operation:
  - Electronics duty cycle operation (2.5% - 5ms / 200ms).
    - 1 ms power up / down
    - 3 ms operation state to stabilize power and operate.
    - It minimizes transients
  - Power consumption during the standby (20% Pmax). !!!
    - It is a critical parameter (100W / 20W): 22 W/cycle
      - 2.5W/cycle - FEE ON ( 11%)
      - 19.5W/cycle – STAND BY (89 %)
    - If standby power 10W : Ptotal = 12.25 W/cycle
    - If FEE operation time 2.5ms: : Ptotal=21W/cycle

# 1. Introduction

- The total Strip-FTD current / power demanded is:
  - Bunch crossing state 458 A (≈ 860 W)
  - Stand-by state 91.6A (≈ 171W)
- System – Granularity: 1/4 Petal
  - Based on reliability and system design issues




| | MIDDLE PITCH | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| FTD | FTD3 | | FTD4 | | FTD5 | | FTD6 | | FTD7 | |
| | INN | OUT | INN | OUT | INN | OUT | INN | OUT | INN | OUT |
| Nº Readout | 33920 | 61504 | 41600 | 64224 | 45472 | 65504 | 51232 | 67424 | 63424 | |
| Chips per petal (256 ch) | 24 | | 26 | | 28 | | 29 | | 16 | |
| Optical links per petal | 1/2 | | 1/2 | | 1/2 | | 1/2 | | 1/2 | |
| I1.5 (A) per Petal | 1.75/0.35 | | 1.9/0.38 | | 2.05/0.41 | | 2.12/ 0.42 | | 1.16/0.23 | |
| I2.5 (A) per Petal | 1.05/0.21 | | 1.13/0.23 | | 1.22/0.24 | | 1.27/0.25 | | 0.7/0.14 | |
| I per petal | 2.79/0.56 | | 3.03/0.61 | | 3.26/0.65 | | 3.39/0.68 | | 1.86/0.37 | |
| I per disk | 44.6/8.9 | | 48.5/9.71 | | 52.08/10.42 | | 54.19/10.84 | | 29.76/5.95 | |
| TOTAL Mstrip-FTD Current (both sides) | | | 458 A / 91.6 A | | | | | | | |

( CMS upgrade TK elec.)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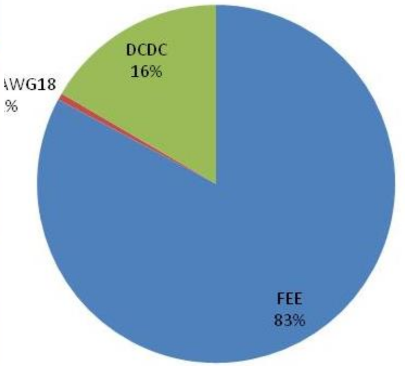
# 1. Introduction

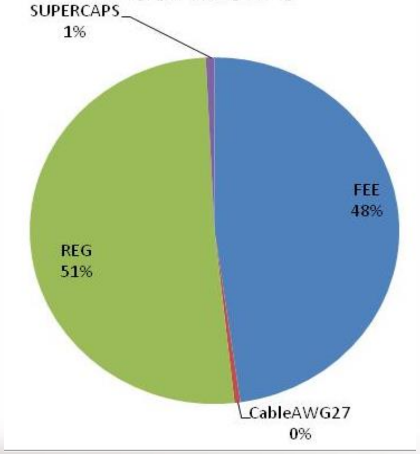
- There are several topologies that may be used for FTD.
  - DC-DC-based power distribution
  - Super-capacitor based power distribution
- Each of them has advantages and disadvantages.
  - A detailed study was presented in LCWS 2012 – Arlington (Texas)

| | DC-DC | Super-caps |
|---|---|---|
| Power dissipation | 228 W | 395 W |
| EMI phenomena | Yes | No* |
| RAD tolerant | Yes | ? |
| Material budget | (240 DC-DC) ? | (80 SC) ? |
| Reliability | ? | ? |
| Power pulse applications | Not frequent | Yes |
| Installed power | 1.4 kW | 0.48 kW |
| Primary PS | ≈ 36 W | ≈ 12 W |
| Mains protection (UPS effect) | No | Yes |



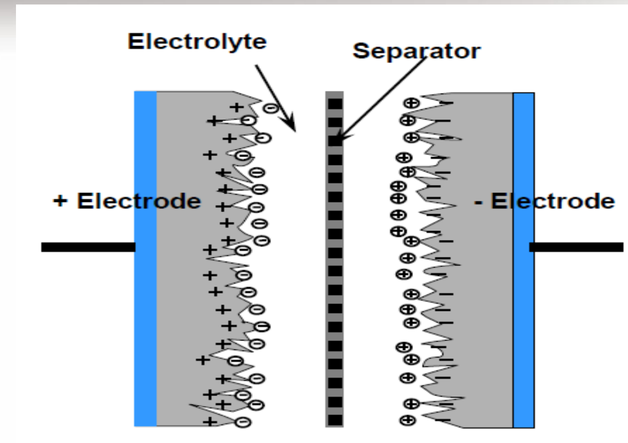

**DC-DC**

**SUPERCAPS**

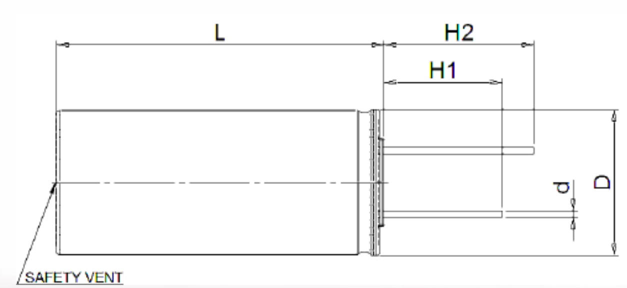


# 2. Supercapacitors

- The most important element in SC-LV regulation option is the super-capacitor.
  - It is new for HEP but not for industrial applications
- Super-capacitors are electrochemical capacitors with very high capacitance
- The most common super-capacitor is the double layer capacitor.
- Double layer capacitor structure
  - Electrodes: Activated Carbon
  - Separator: Cellulose
  - Electrolyte: Quaternary salt & acetonitrile.
  - Other: Aluminum
- Very light – few g / size 1-3 cm




| Size | Rated Voltage (V,DC) | Rated Capacitance (F) | MAX ESR(mΩ) | Dimension(mm) | | | | Volume (ml) | Weight (g) |
|---|---|---|---|---|---|---|---|---|---|
| | | | DC | D | L | W | T | | |
| Small | 2.7 | 3 | 55 | 8 | 20 | | | 1.0 | 1.5 |
| | 2.7 | 5 | 35 | 10 | 20 | | | 1.6 | 2.3 |
| | 2.7 | 6 | 33 | 8 | 30 | | | 1.5 | 2.3 |
| | 2.7 | 10 | 30 | 10 | 30 | | | 2.4 | 3.2 |
| | 2.7 | 25 | 25 | 16 | 25 | | | 5.0 | 6.5 |
| | 2.7 | 50 | 16 | 18 | 42 | | | 10.2 | 11.3 |



# 2. Supercapacitors

- There are four elements that have to be analyzed in detail for HEP applications
  - Material Budget.
  - Magnetic field issues
  - Cycling issues
  - Radiation issues

  (Material Budget and Magnetic field issues:) It seems OK but a detailed evaluation is required

- <u>Cycling issues (Reliability).</u>
  - Super-capacitor should be able to operate more that 10 million of cycles per year (DC-DC too)
    - After 1e6 of full duty cycles a SC may decrease the 20% of capacitance
- <u>Radiation issues</u>
  - Type of radiation: gammas & electrons
  - Total dose: 1 or 2 Mrad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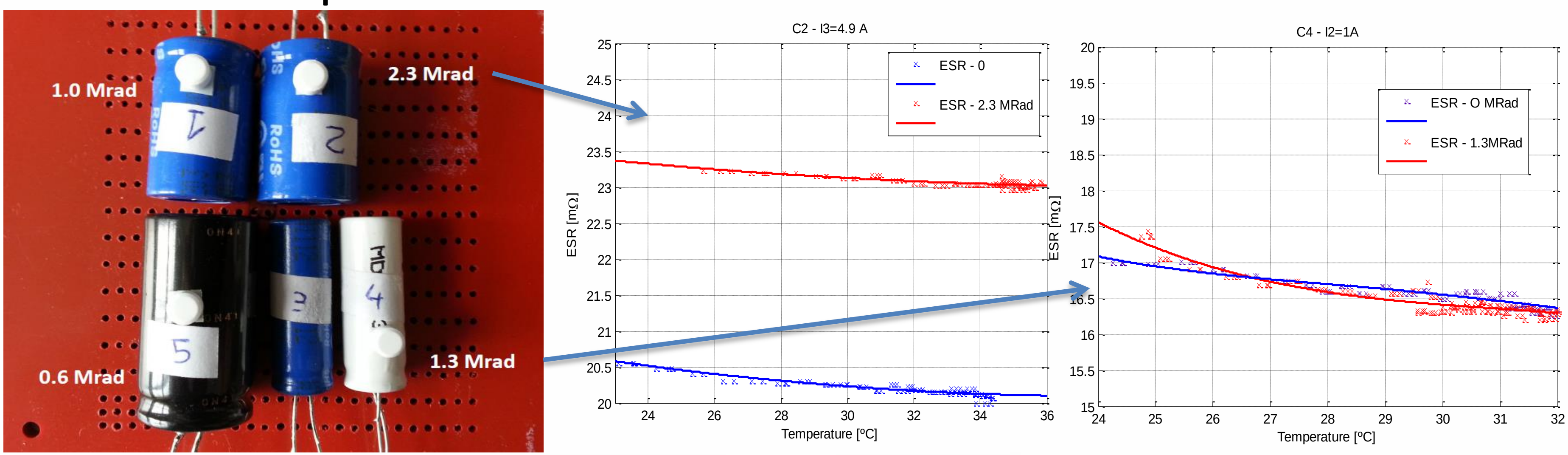
# 2. Supercapacitors

- A radiation test has been carried out in order to start the super-capacitor validation for FTD-ILD (*ECFA 2013*)
  - Electrons at 20 MEV (ELBA facility – University of Bonn)
- 5 super-capacitors have been tested – ESR(T) & C(T)
  - Different rates 3 x 10 F & 2 x 25 F
  - Different  companies (Maxwell, Nesscap & Panassonic)
- First results are very promising but it is still necessary a long validation process



# 3. Supercapacitor based PS

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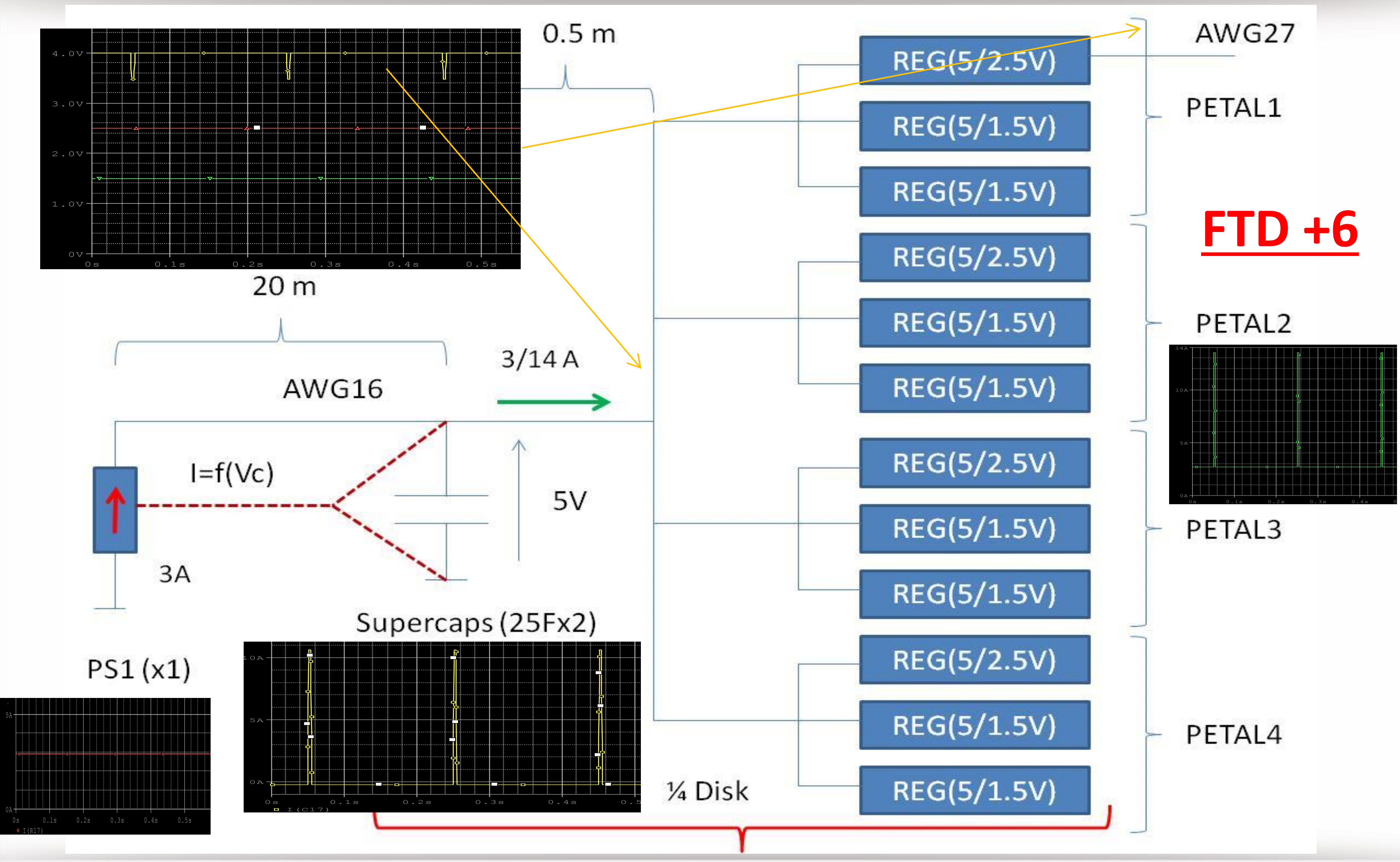
- The main elements of this topology are:
  - Supercapacitors:
    - Pulse power – Transients locally
  - LV regulators:
    - Stabilize FEE voltage
  - Current source :
    - Controls super-capacitor voltage

# 3. Supercapacitor based PS



# 3. Supercapacitor based PS

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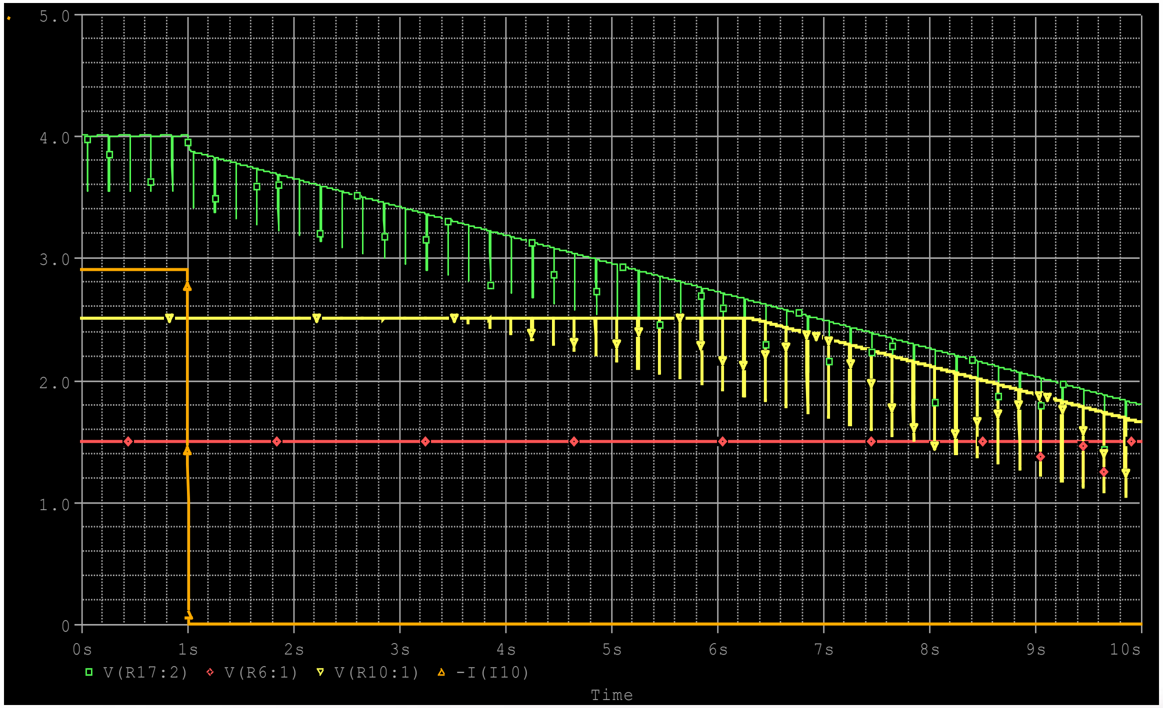
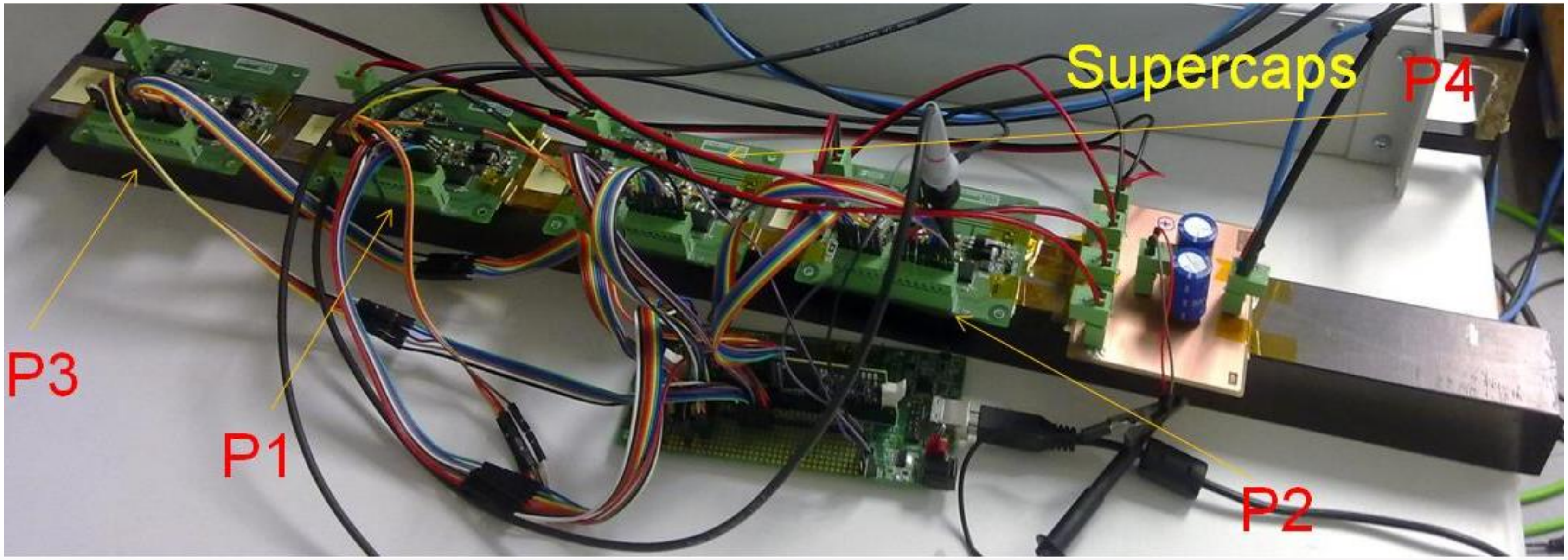
- The high capacitance has two advantages:
  - It will protects the system in case mains failure – Similar to UPS
    - It helps shutdown the system in a controlled way.
  - The dynamic response of primary power unit may be very slow
    - Remote regulation of the supercap voltage will be easy




- The duration of the shut-down capability will depends on :
  - Capacitance
  - Voltage

# 4. FTD-ILD power group prototype

- A real prototype of 1 Group of FTD sub-detector (FTD +6) has been developed
  - 4 load boards - It simulates the FEE (hybrid) per petal
  - 2 Super-capacitors (several distance to Dummy loads – 50cm /10cm)
  - 1CF structure – It has been developed by FERMILAB–CMS Tracker II
  - Ip=13.5A – Isb =2.7A (Per petal – Ip=3.4A / Isb=0.7A)
  - Vsc = 4.2 V / Vinp=4V



# 4. FTD-ILD power group prototype

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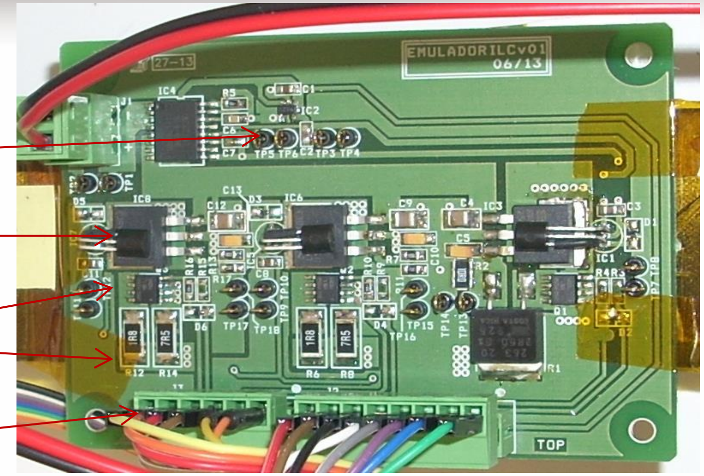
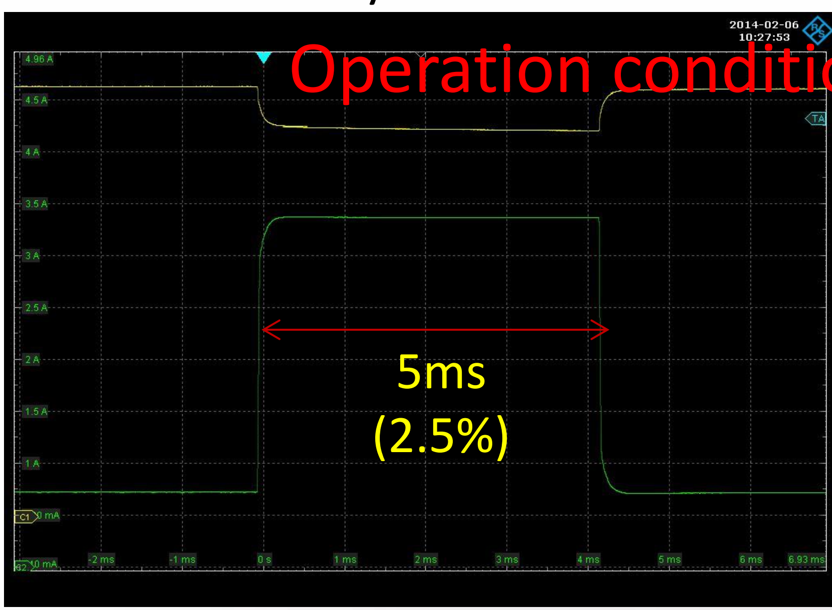
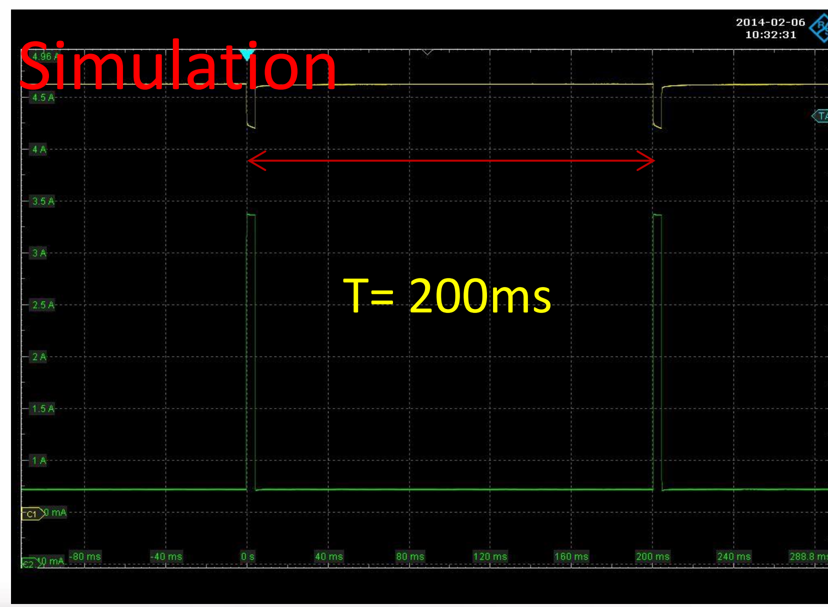
- An ILC-FEE emulator has been designed
  - Testing points
  - 3 LV regulators
    - 2x1.5V / 1x2.5V
  - Pulse load: 3 x (2 resistors)
  - 3 x MOSFET
  - Driven by Texas Instruments CB

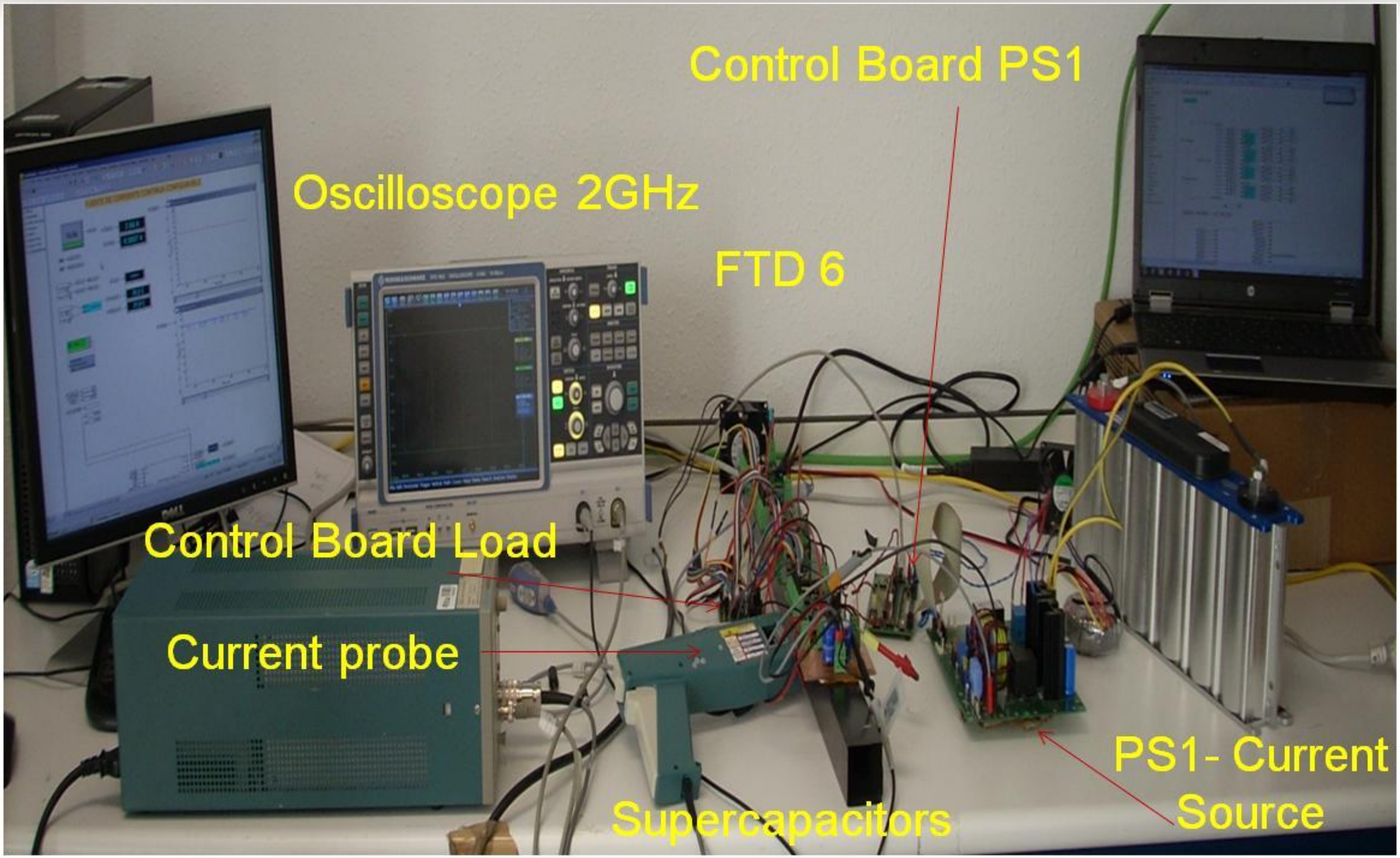



Operation condition = Simulation



# 4. FTD-ILD power group prototype



# 4. FTD-ILD power group prototype

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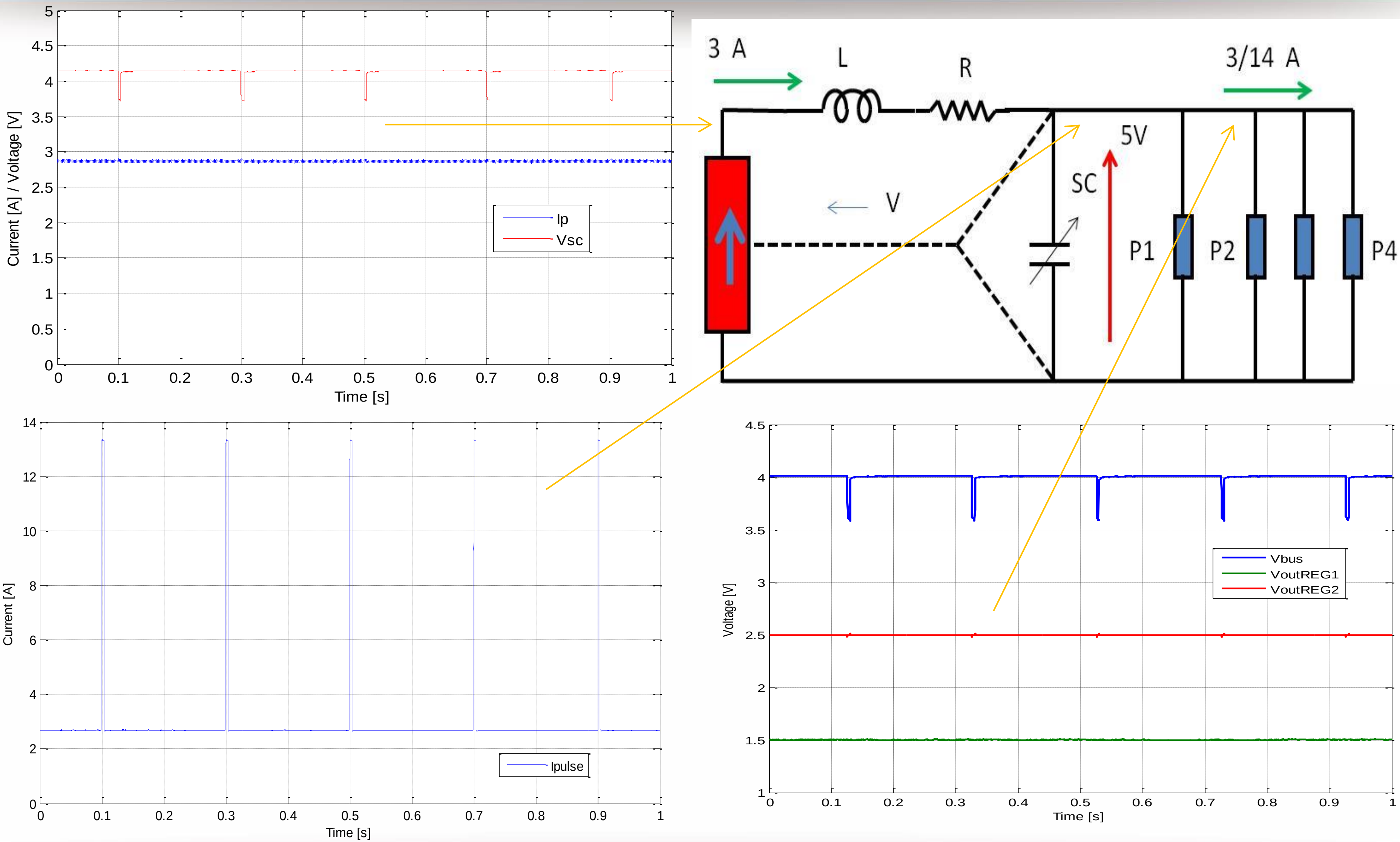

# 4. FTD-ILD power group prototype

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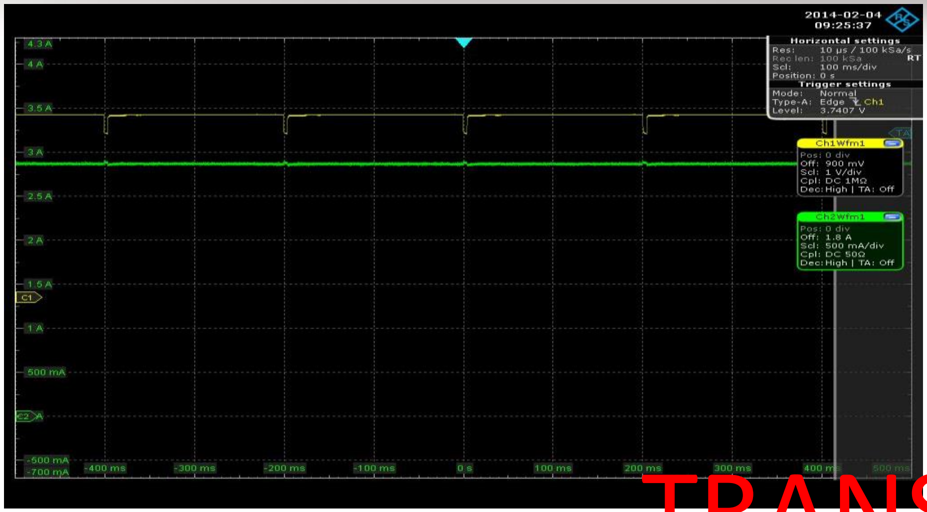
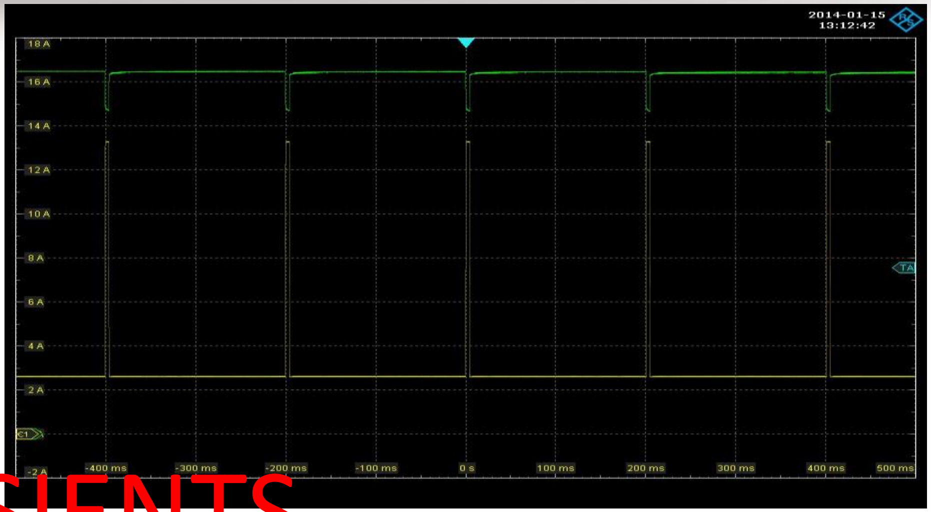
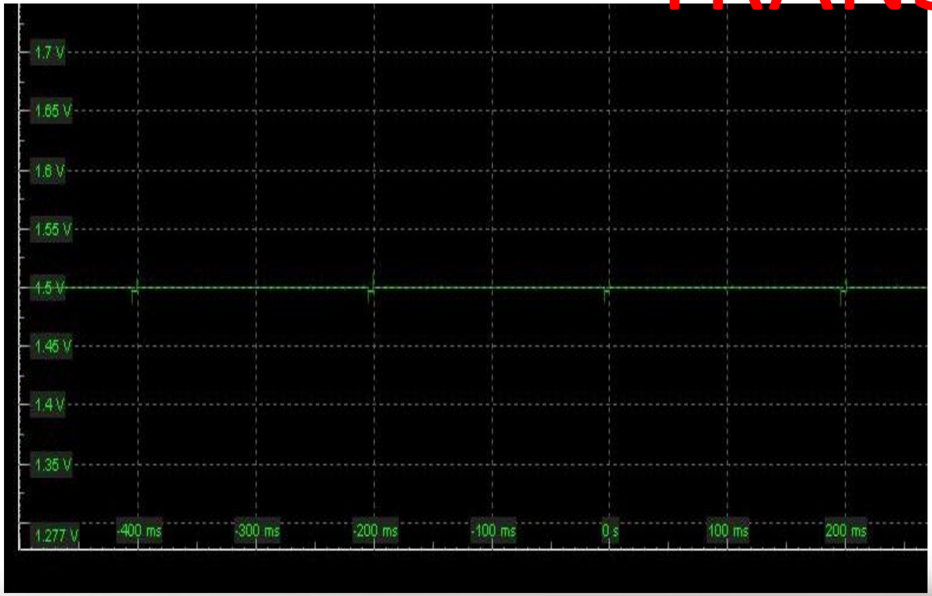
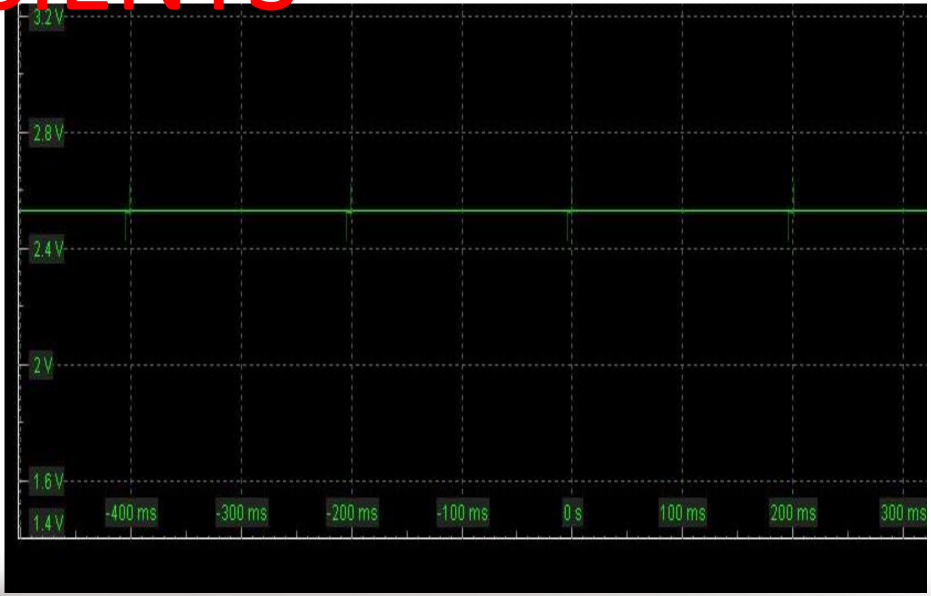



TRANSIENTS



# 4. FTD-ILD power group prototype

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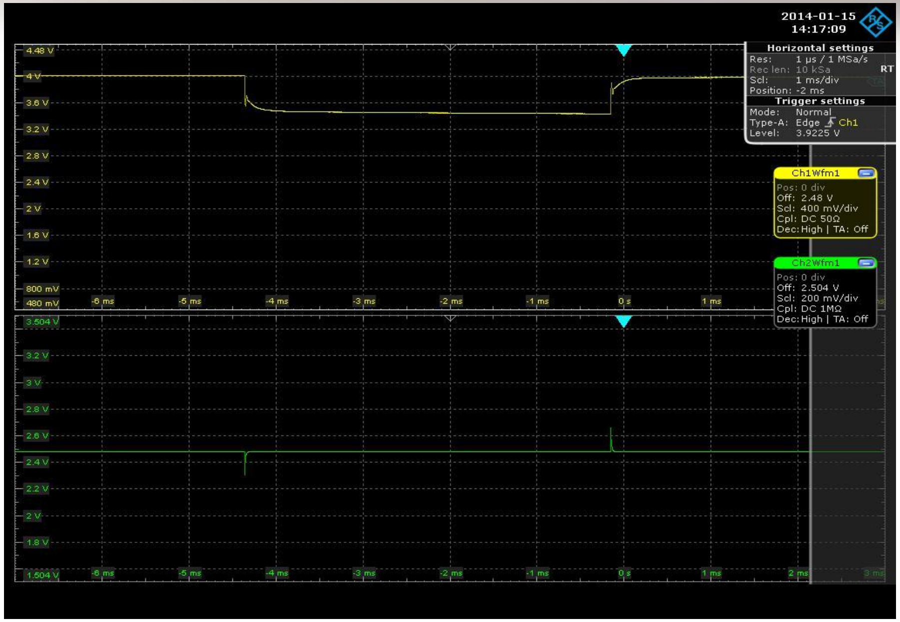
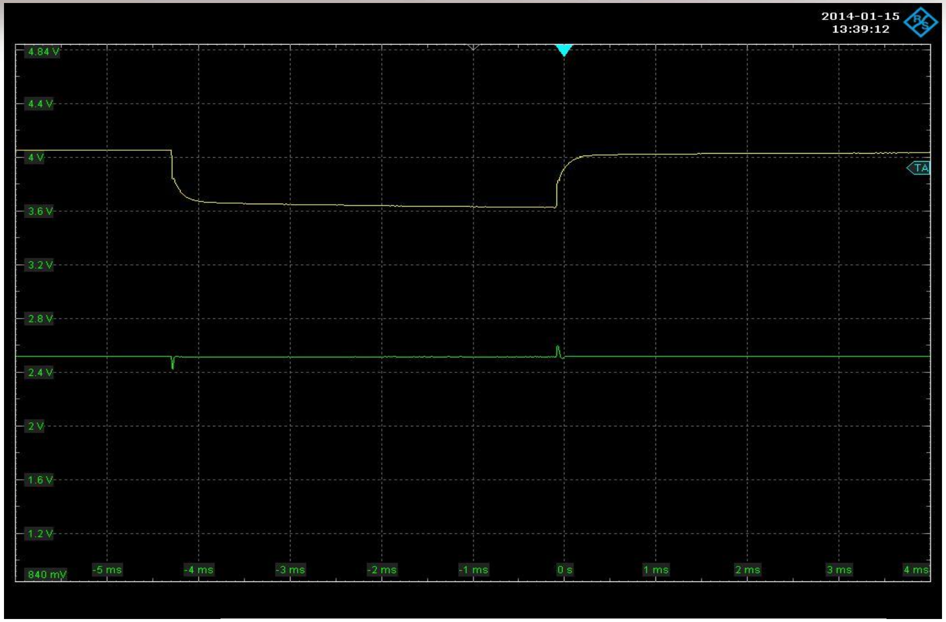
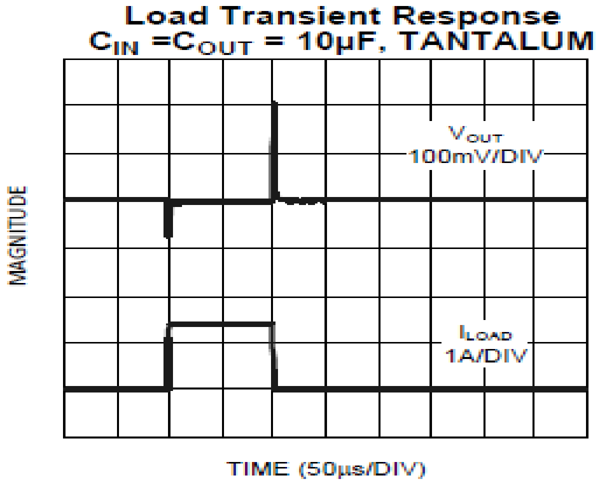


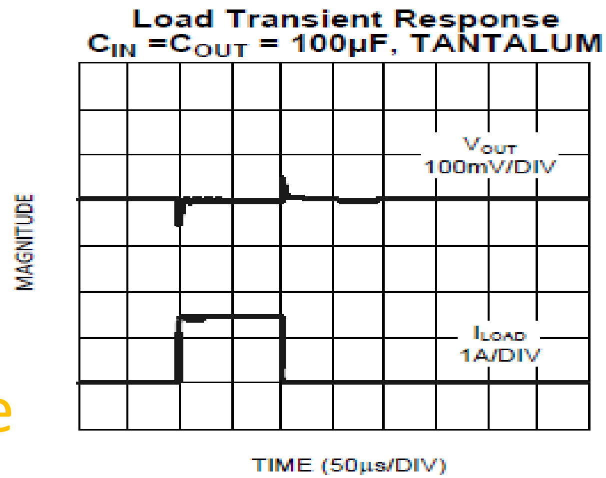




Regulator

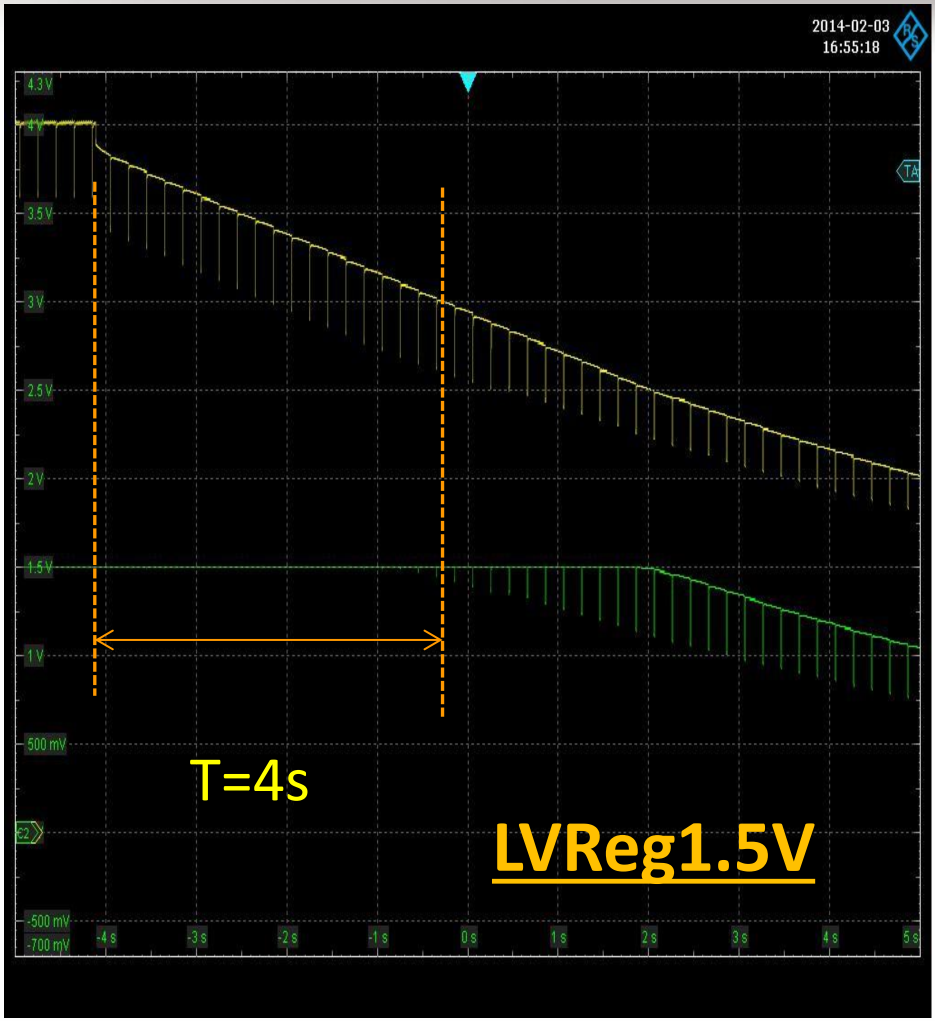
Transient

&

Cable inductance



# 4. FTD-ILD power group prototype

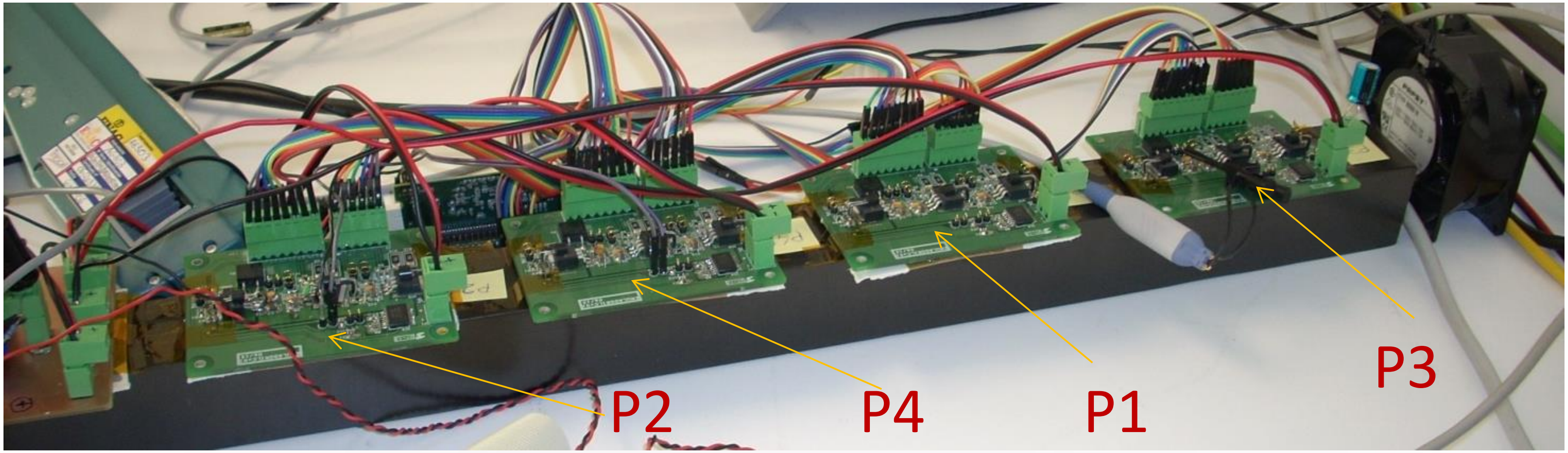




**Major Fault – UPS capability**

# 4.1 FTD-ILD power group prototype: Power dissipation test

- A very simple temperature test has been performed
- Temperature sensors were installed on each board:
  - One Termistor (PTC) per LV regulator
  - Temperature is processed by the control board
- A fan has been installed on one side of the CF structure
  - It has been switched on /off
- Systems were running more than 3 hours
- Baseline Temperature : 21ºC



# 4.1 FTD-ILD power group prototype: Power dissipation test

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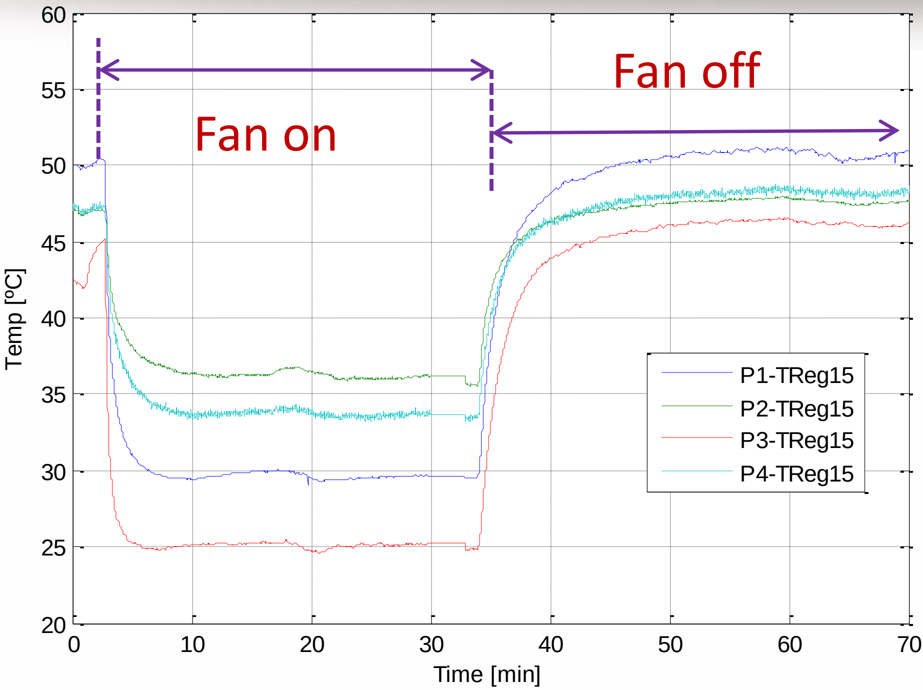


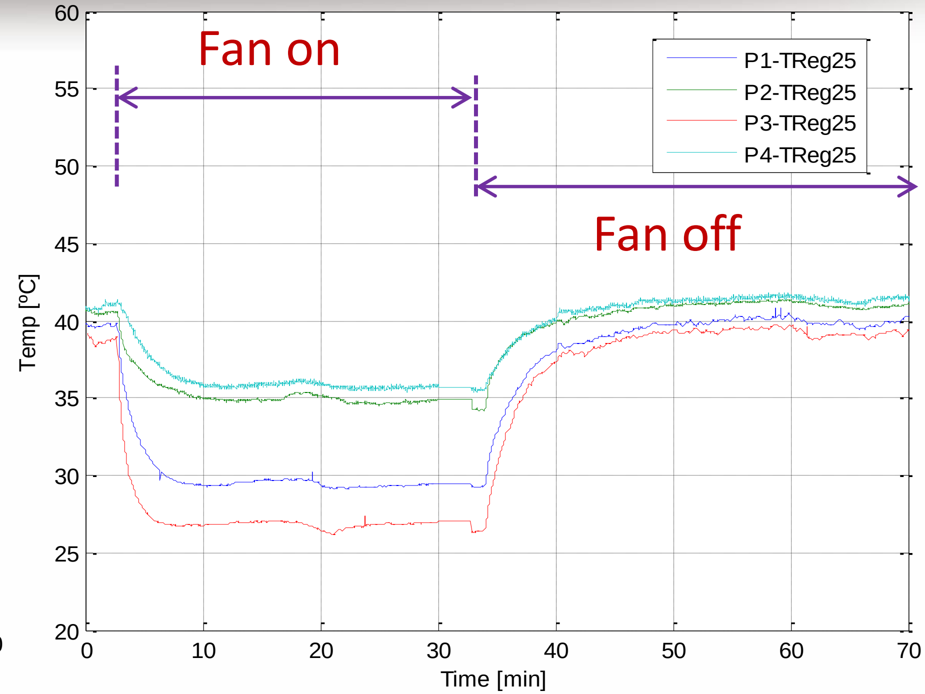


- LVReg (1.5V) dissipates more power than LV (2.5V)
- From the point of view of electronics, “this prototype” does not need to be cooled (resistances dissipate power too)
- Not Cooled: Tmax(P1)≈51ºC (ΔT ≈ 30ºC) / Tmin(P3)≈ 46ºC (ΔT ≈ 25ºC)
- Cooled: Tmax(P2)≈34ºC (ΔT ≈ 13ºC) / Tmin(P3)≈ 25ºC (ΔT ≈ 4ºC)
- Pulsing effect is very small from the point of view temperature

# 5. Conclusions

- A general overview of the supercapacitor based power supply distribution system for FTD-ILD has been presented
- Main characteristics and key elements have been shown
  - Operation condition ( regulation , pulsing , supercapacitors..)
- Supercapacitors fit quite well power pulsing requirements
  - Radiation hardness shows no stoppers
    - It still requires a detail analysis
- A real prototype of 1 group has been developed and tested
  - Very good agreement with simulations
- Power dissipation aspects :
  - From electronics point of view, this system does not need to be cooled
  - The pulsing effect seems not to have a big impact
- The results are very promising but a long study of the system is required in order to define final specification