
CERN

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Power Converters for Particle Accelerators
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CERN's standardised control electronics for the efficient integration of power converters in particles accelerators

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Control features & performances

FGC3-driven power converter types @ CERN

Making FGC3 control platform available to other labs

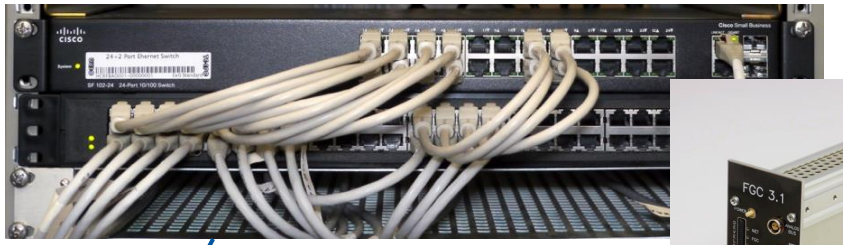
Conclusion

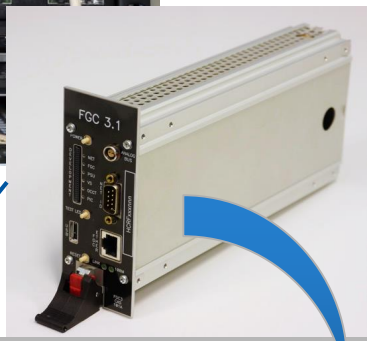
Brief Background

- **Objective**
  - Improve operation (time, HR & €) & new developments (time, HR & €)
- **Adopted solutions consider:**
  - Standard HD & SW
    - FGC interface (Function Generator Controller) / V3 profiting from previous versions made for the LHC development & operation over 2 decades
    - Std. Boards by functionality (interlocks, measurements, regulation, etc.)
    - Std. & maintainable software's
  - Flexibility
    - Control of any kind of converter (off-the-shelf or custom designed)
  - Upgradable
    - Design philosophy for easy upgrades
- **Today's status**
  - >2000 standard FGC3 controllers manufactured & hundreds in operation
  - All new converters equipped with FGC3
  - Until 2025, major cons. with FGC3 to eradicate obsolete controls

FGC3 controls overview

Control structure/layers overview with FGC3





Accelerator Controls network

Accelerator timing

FGC Gateway

CTRI

Star-point 1

Ethernet Switch

Pulse injector

1 Gbps Ethernet

50 Hz sync

Star-point 3

Ethernet Switch

Pulse injector

100 Mbps Ethernet + 50 Hz sync

FGC3 1 | FGC3 2 | FGC3 3 | FGC3 4 | ... | FGC3 61 | FGC3 62 | FGC3 63 | FGC3 64

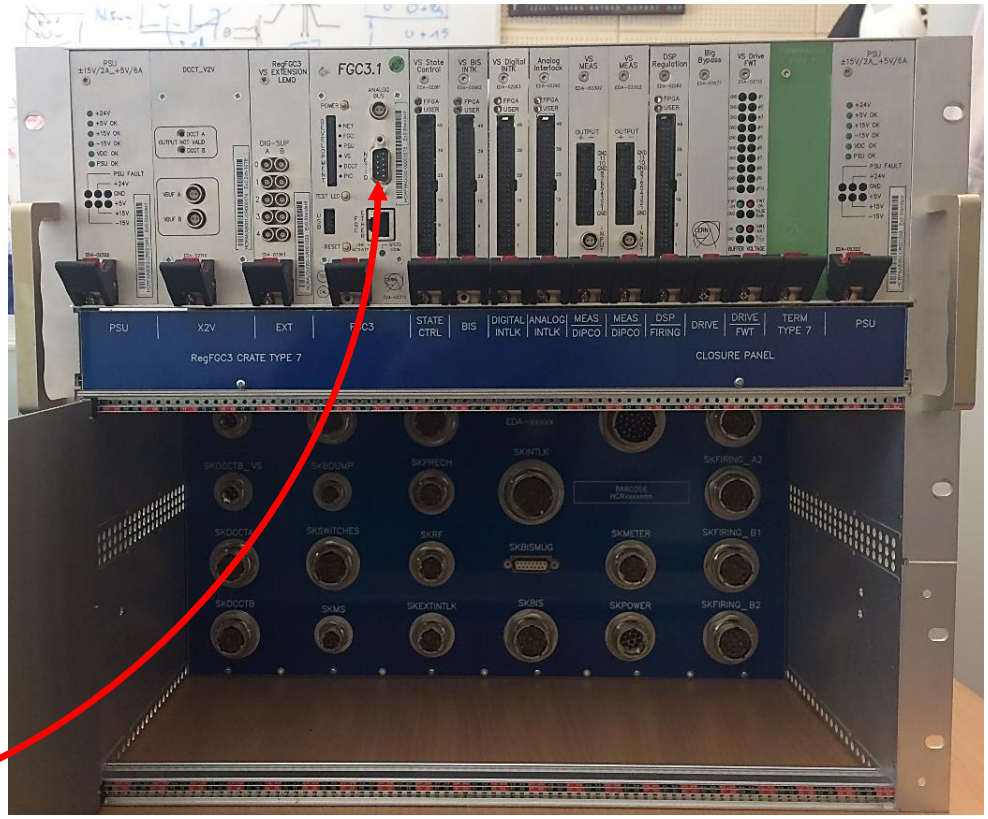
PC | PC | PC | PC | PC | PC | PC | PC

FGC3 controls overview

Regulation electronics platform based on FGC3” (RegFGC3)

- Several low-level controls standard boards with dedicated functions such as:
  - Measurement (e.g. DCCT, I to V)
  - Analogue or digital voltage regulation
  - Analogue or digital interlocks
  - State machine board
  - Etc.
- Connections between RegFGC3 boards, Connectors panel and FGC3 provided by back panel crate:
  Back panel crate = converter type
- Fieldbus address dongle for circuit / power converter identification

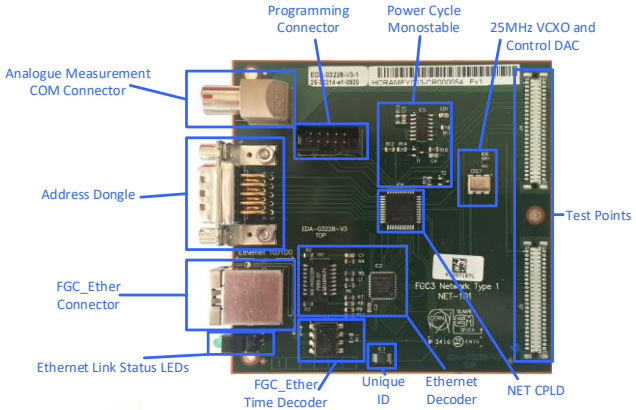
RegFGC3 chassis for Thyristor Power converters

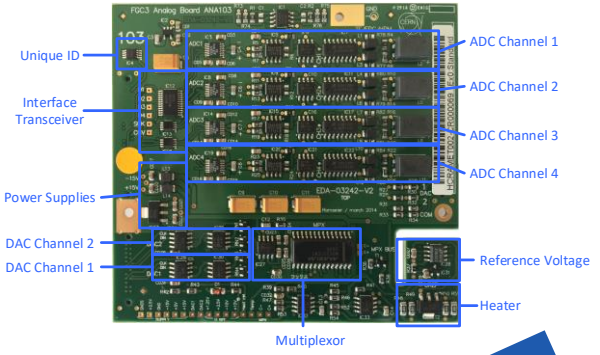


FGC3 controls overview

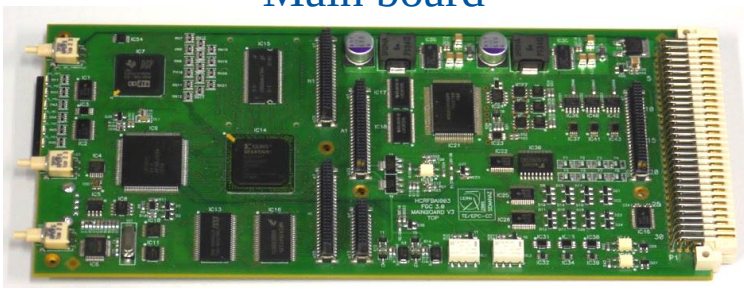
The FGC3 itself – How it's made?

Network and analog interface daughterboard
RJ45 connector -100 Mbps LAN controller
Analogue interface: four 500 ksps ADCs and two DACs





Main board

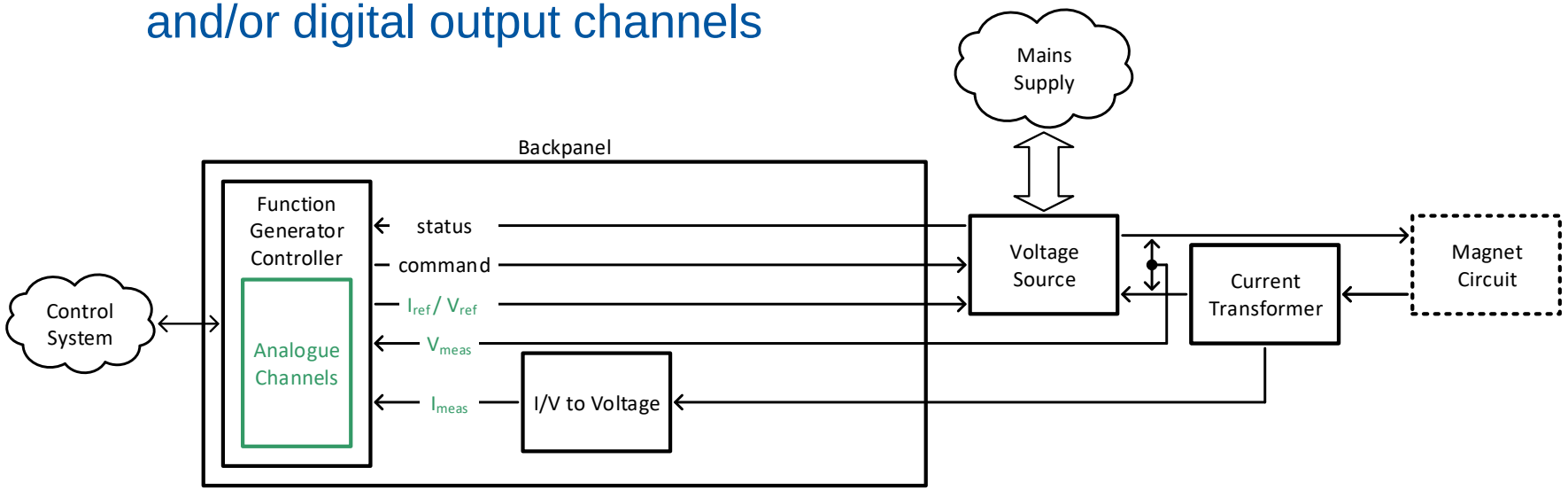


The FGC3 can be a standalone controller

FGC3 controls overview

2 main control implementations with FGC3

- Direct interface with FGC3
  - Can receive measured values from analogue and/or digital sources
  - Can apply the calculated reference output values to analogue and/or digital output channels

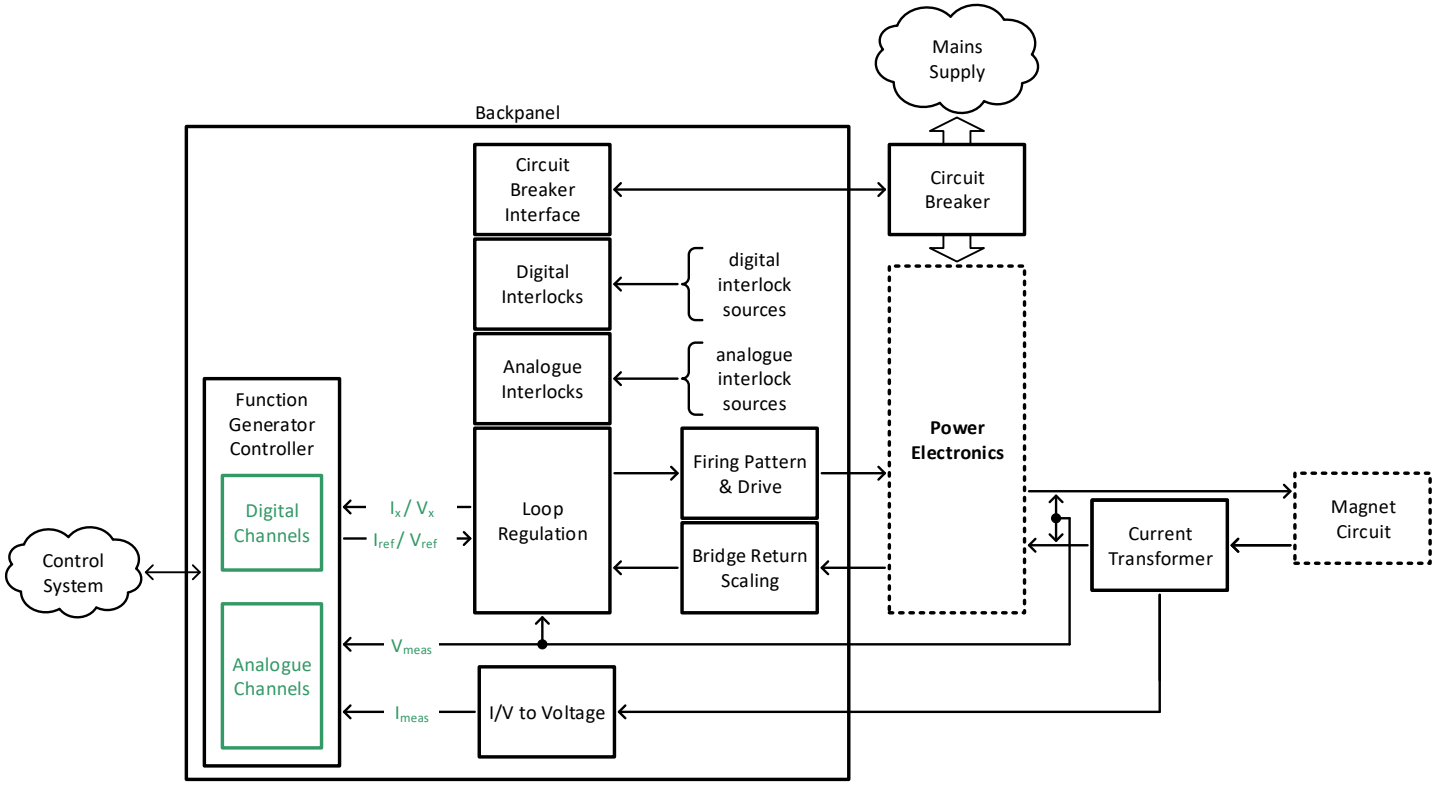


Example of FGC3 Analogue Regulation Voltage Sources

FGC3 controls overview

3 main control implementations with FGC3

- Interfacing FGC3 via low-level RegFGC3 controls



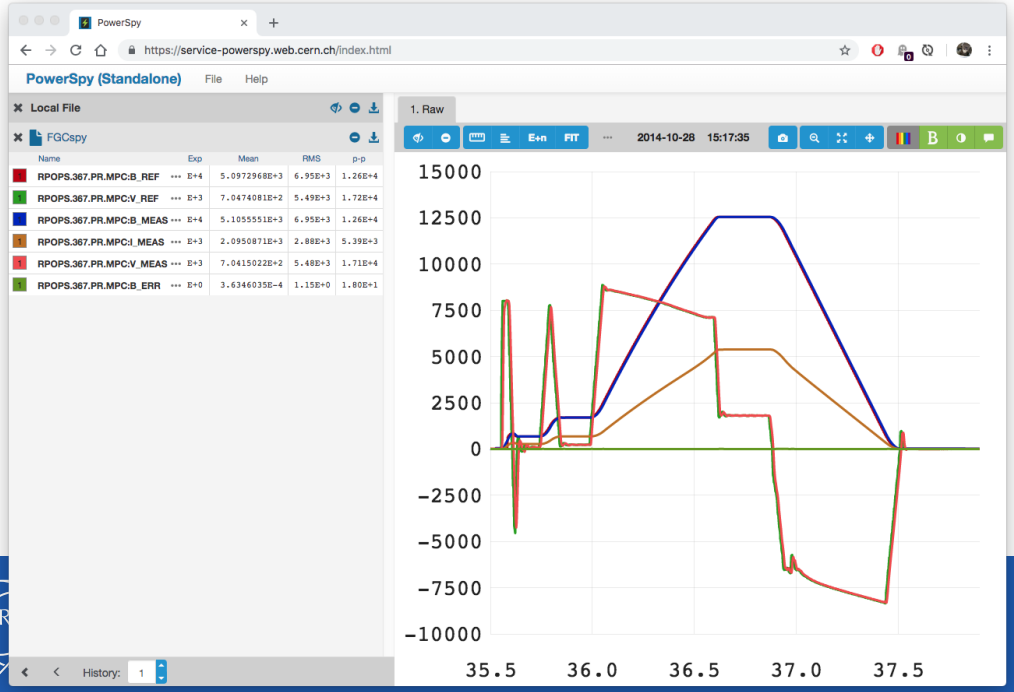
Example of direct control of power components

Control features & performances

- Main features
  - FGC3 can regulate magnet field or current and converter voltage
  - Advanced online/offline measurements analysis & Post mortem (through PowerSpy)
  - Remote firmware updates
  - Auto calibration
- Main performances
  - Regulation bandwidth up to 1 kHz
  - Data sampling at 10 kHz

(a note on PowerSpy)

- PowerSpy is a graphing tool developed by our group
  - A standalone version is freely available at https://cern.ch/service-powerspy
  - Reads simple CSV files - no need for an FGC3!
  - There are example data files and video tutorials (YouTube) under the Help menu

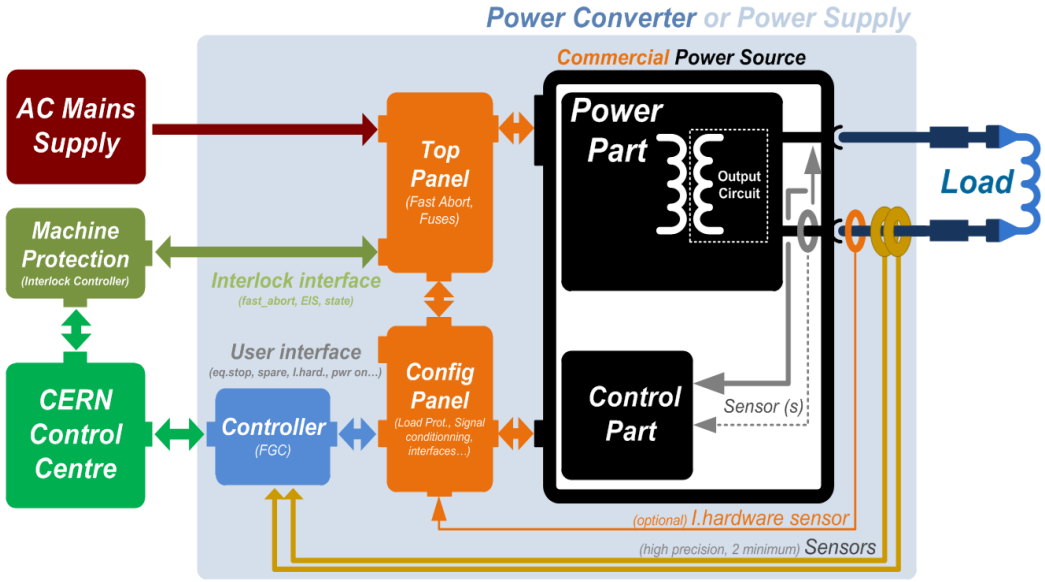


A version can be licensed to run on an Apache web server at your lab. Contact Nicholas.Ziogas@cern.ch

FGC3-driven power converter types @ CERN

- CERN's specifically designed power converters with FGC3
  - All sorts of switch-mode power converters (resonant, 4 quadrants, etc.)
  - Thyristors-based power converters
  - Capacitor discharge-based pulsed converters (ms-range)
  - High voltage DC & power modulators converters
- **Commercial / Off-the-shelf power converter:**

With simple addition of standard interfacing modules, off-the-shelf power converters can be efficiently integrated into the CERN control environment with same functionalities



FGC3-driven power converter types @ CERN

- An example of the LEGO concept with commercial power supplies

Electronic Crate (FGC3 & regFGC3)

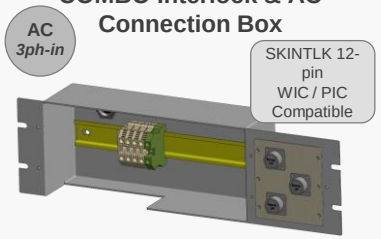
COMBO AC Distribution Box

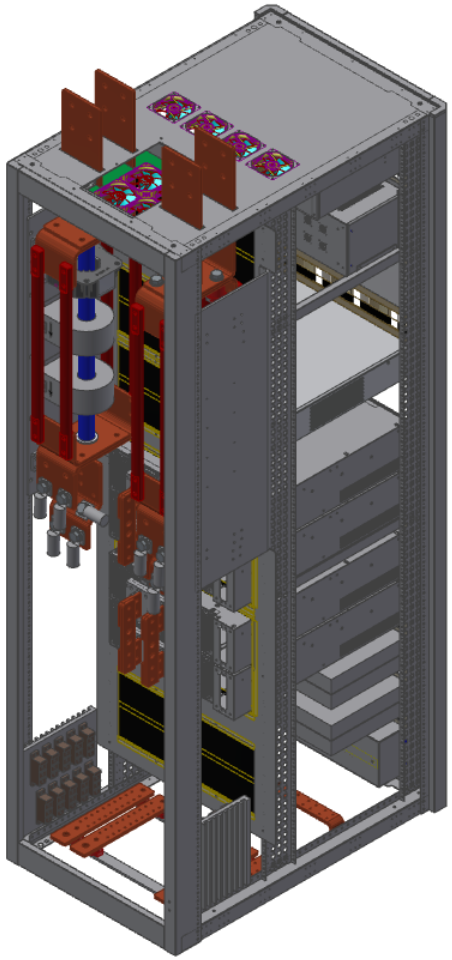
COMBO AC-DC Aux Pwr Box

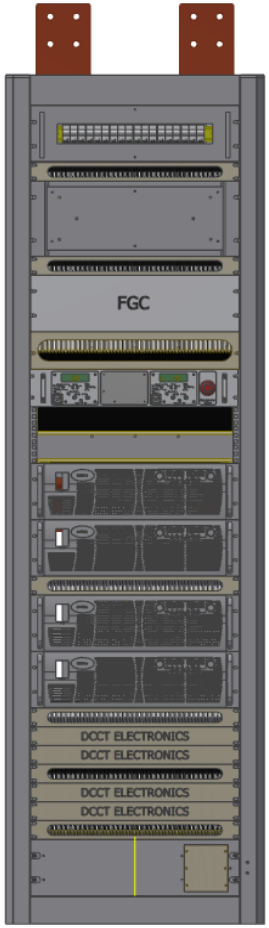
Commercial Power Sources

COMBO Config Panel

COMBO Interlock & AC Connection Box







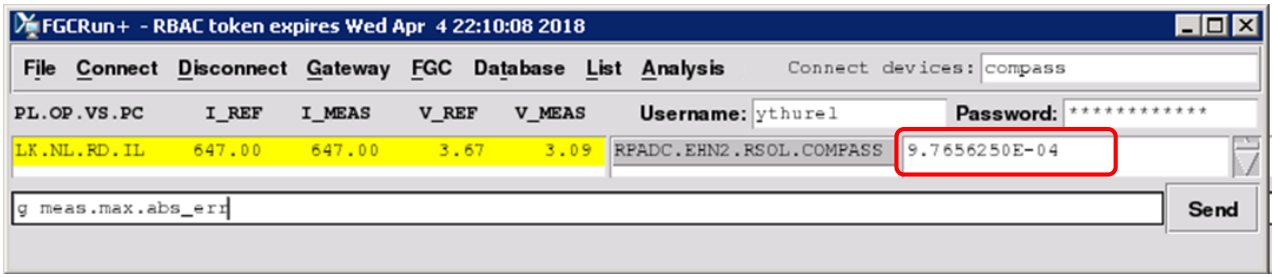
FGC3-driven power converter types @ CERN

- The look in reality…

FGC3-driven power converter types @ CERN

- Why adding external DCCTs? (even 2x!!)
  - See **now** a **COMBO** converter (FGC3 + 2x DCCTs, taking care of the control loop performances.

COMBO (FGC3 + 2x DCCTs)



Less than 1 mA of regulation error @ 647 A. (1 ppm of 800 A)

Stability in the range of < 10 ppm (5 ppm for 30 min)

Linearity in the range of < 5 ppm

Making FGC3 control platform available to other labs

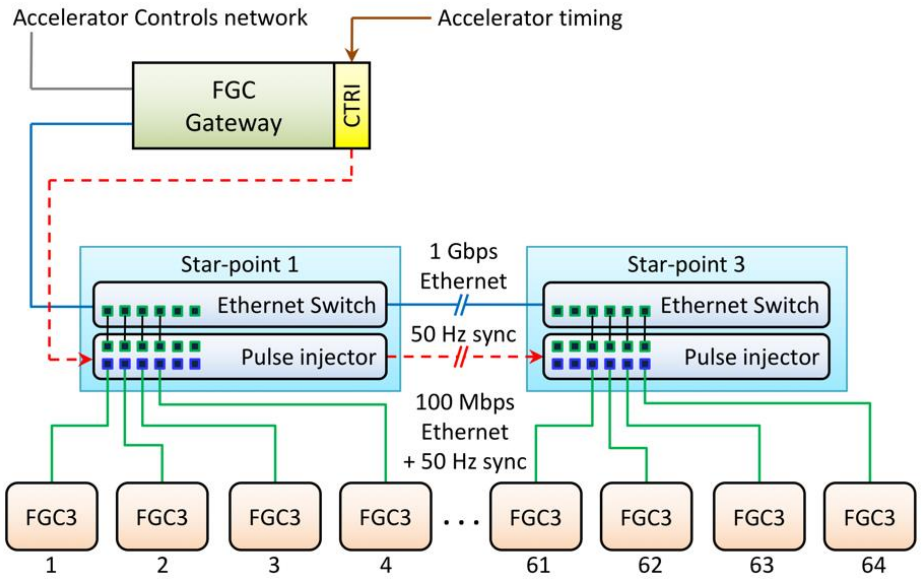
- In 2016, project started to make FGC3 usable outside CERN
  - Software development to integrate the FGC3 into the EPICS and TANGO frameworks
  - In 2018, first FGC3 deployed into operation using EPICS at TRIUMF lab, controlling the new 20 kA power converter for their main cyclotron magnet.
  - More FGC3s will be deployed in 2018-2019 under TANGO at ESRF in Grenoble (FR) and under EPICS at FREIA in Uppsala (SE)

Making FGC3 control platform available to other labs

Synchronization: A slight integration difference outside CERN

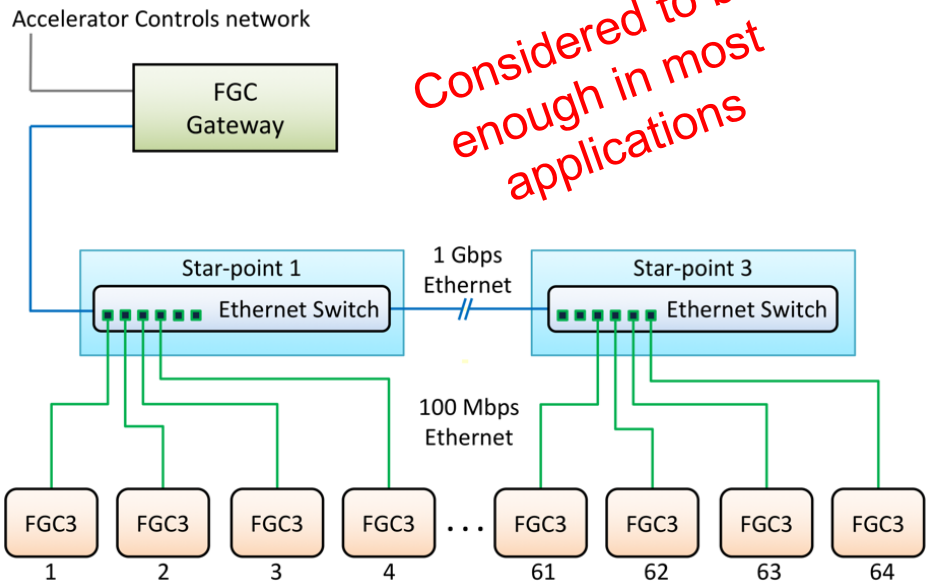
At CERN

50 Hz pulses from Acc. Timing interface through gateway - typical phase error less than 40 ns



Outside CERN

With time of arrival of “time packets” sent by the gateway over the Ethernet every 20 ms – typical phase error of 10-20 μs



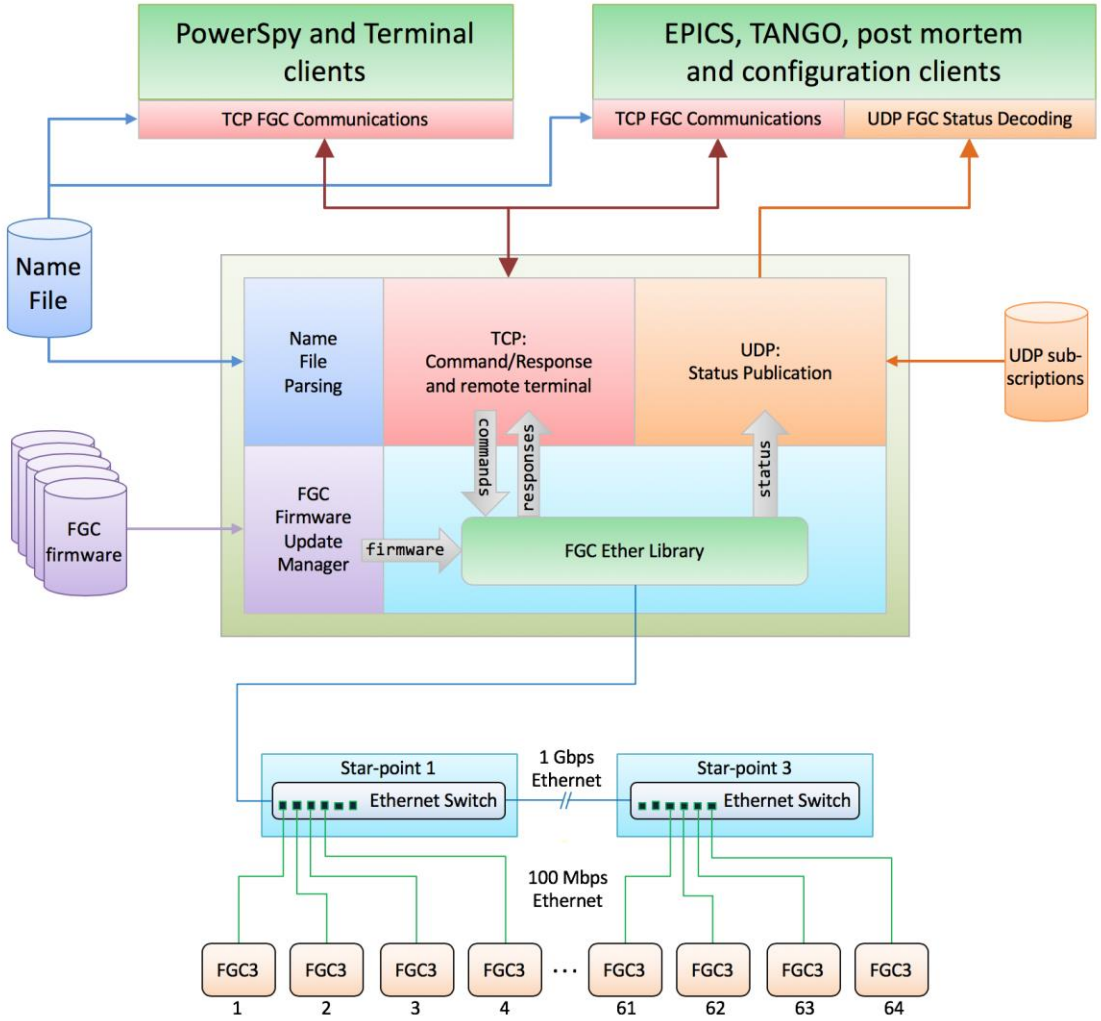
Conclusion on FGC3 Platform

- The new standard at CERN in the medium to long term (2035 at least)
- Can manage all sorts of power converters, including commercial off-the-shelf products
- Available to other laboratories through licensing
  - With complete software stack and long term software support
  - With the guarantee that at CERN it wont be obsolete in the next couple of decades!

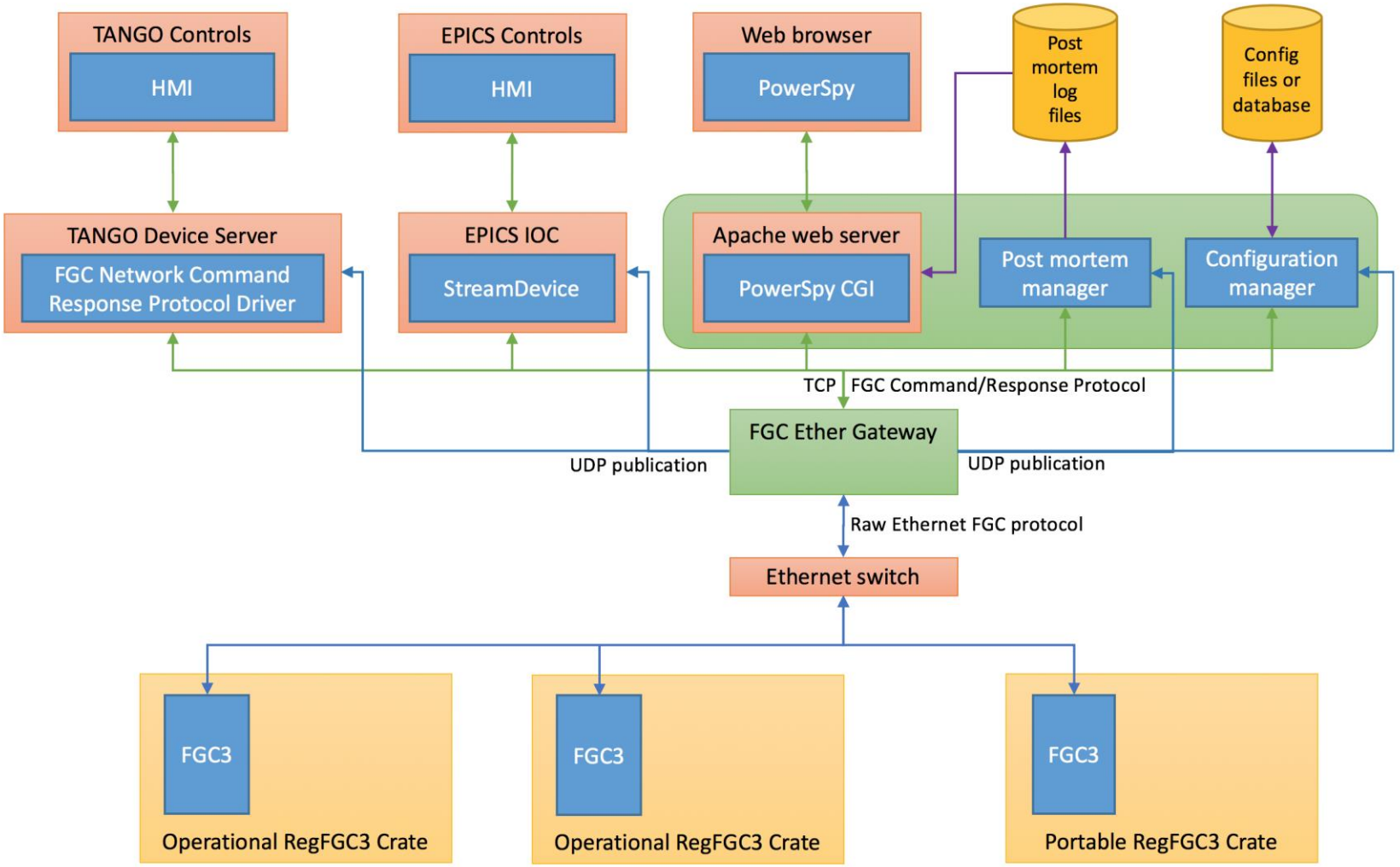
References

- For a deeper look on what presented:
  - Q. King, *Using CERN Power Converter Controls with EPICS and TANGO*, EDMS No. 2002516
  - B. Todd, *FUNCTION GENERATOR / CONTROLLER 3.1 (FGC 3.1)*, EDMS No. 1377659
- Contacts if interested in the FGC3 platform
  - Nick Ziogas (Knowledge Transfer Group) - Nicholas.Ziogas@cern.ch

Spare slides



Spare slides

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