Intra-pulse RF feedbacks for normal conducting cavities with femto-second precision.

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for the LLRF team
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HELMHOLTZ ASSOCIATION

DESY

Overview.

- Concept of single cavity LLRF control
  - Hardware
  - Firmware
- Results from operation at REGAE
  - Latency budget
  - Feedback operation
- Outlook
  - Firmware improvements
  - Further facilities

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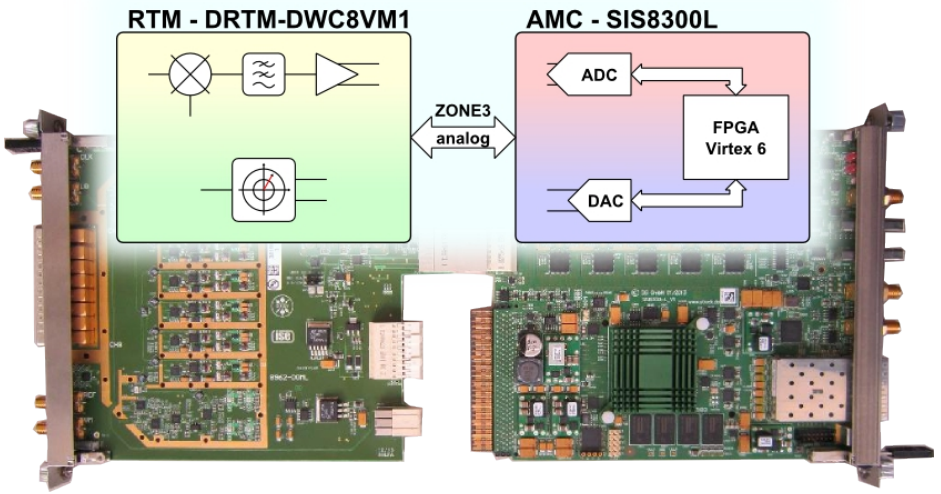
Basic Conditions.

- Multi cavity LLRF:
  - 8/16 (FLASH) or 32 (XFEL) cavities per klystron/RF station
  - 24/48/96 signals to detect for RF control (Probe, Forw., Refl.)
  - Super conductive
  - Low bandwidth (200Hz)
  - Long pulse length (800us)
  - Moderate operation speed (9MHz)
- Single cavity LLRF:
  - 1 – 2 cavities per klystron/RF station
  - Up to 6 signals to detect for RF control (Probe, Forw., Refl.)
  - Normal conductive
  - Higher dynamic/bandwidth (60-400kHz)
  - Short pulse length (3-10us)
  - High operation speed (125MHz)
- Exception:
  - CW machine with single superconductive cavity (e.g. ELBE)

Concept of Single Cavity LLRF Control.

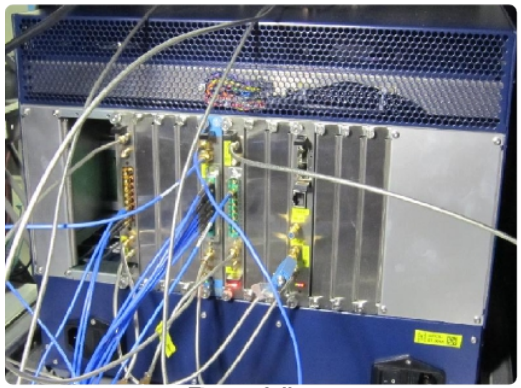
- Cost and performance optimized:
  - Combined hardware DRTM-DWC8VM1 (down converter and vector modulator)
  - More processing power on digitizer board SIS8300L (Xilinx Virtex 6)
  - Less hardware and less latency (no digital communication links, ~400ns less latency)



XFEL RF Gun
LLRF System

2HE 6 Slot MTCA Crate (Schroff)

REGAE LLRF System



Rear View

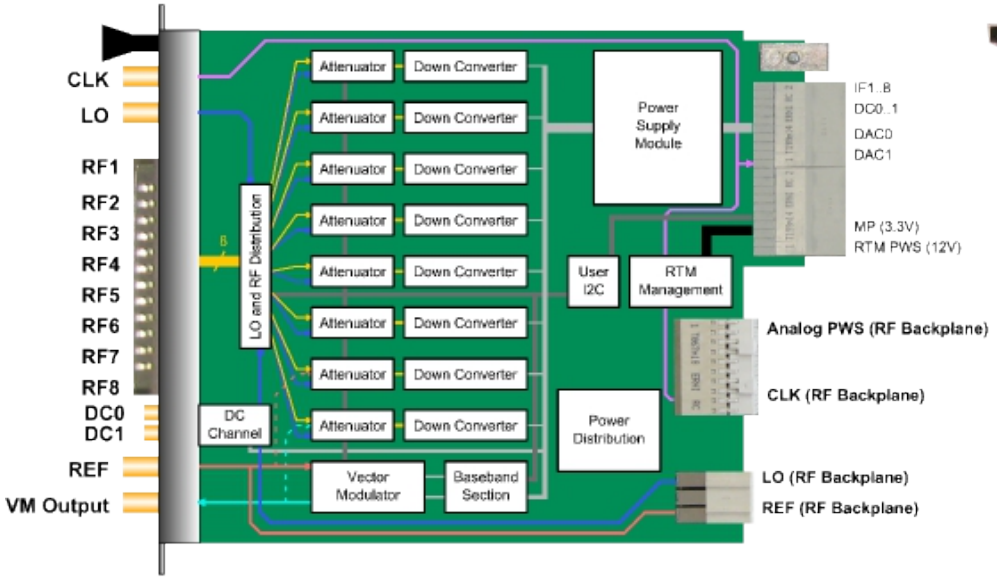
Front View

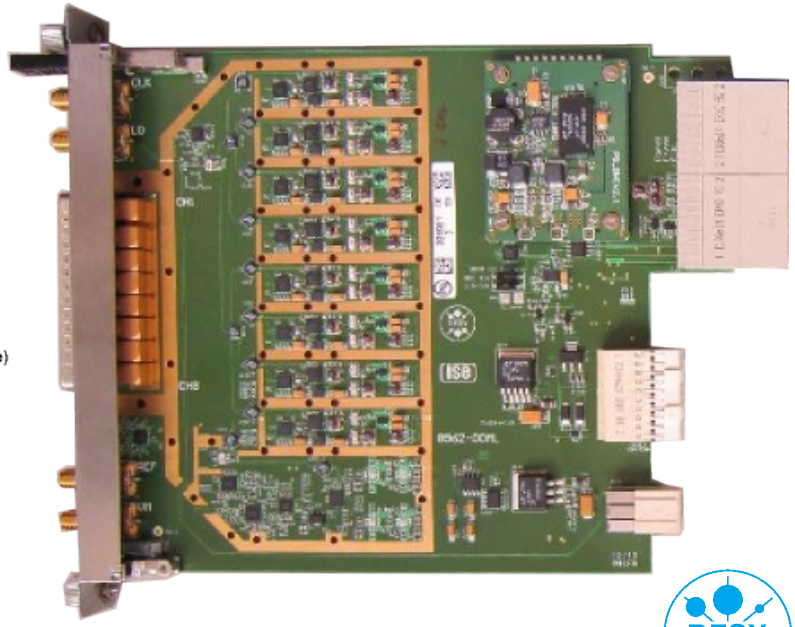
8HE 12Slot MTCA Crate (ELMA)

Single Cavity Control Hardware.

> RTM-DWC8VM1

- 8 Down converter channels (0.7..4GHz) (upgrade: 0.5..6GHz)
- 1 Vector modulator channel (0.05..6GHz)
- 2 DC channels (DC..400MHz)
- Digital adjustable attenuators (input and output)
- LO, ADC clock and reference from front panel or RF backplane
- On-board power level monitors and I2C support

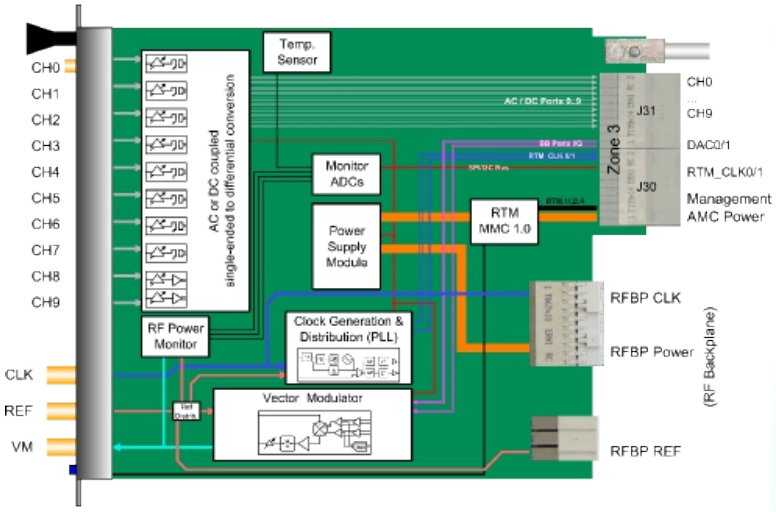


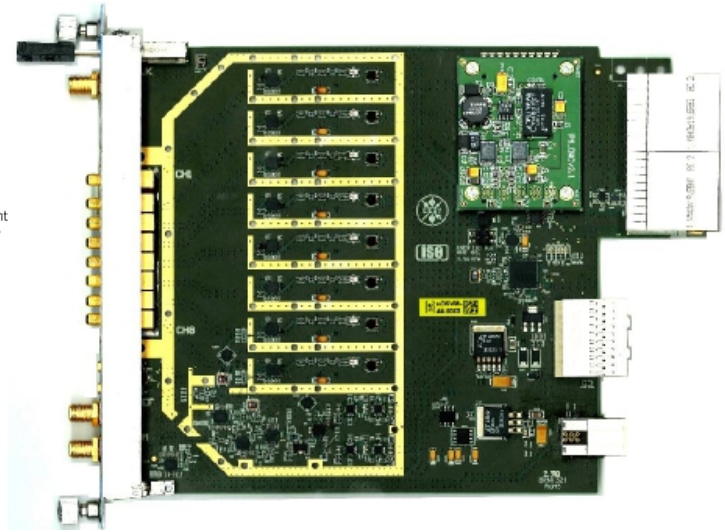


Single Cavity Control Hardware.

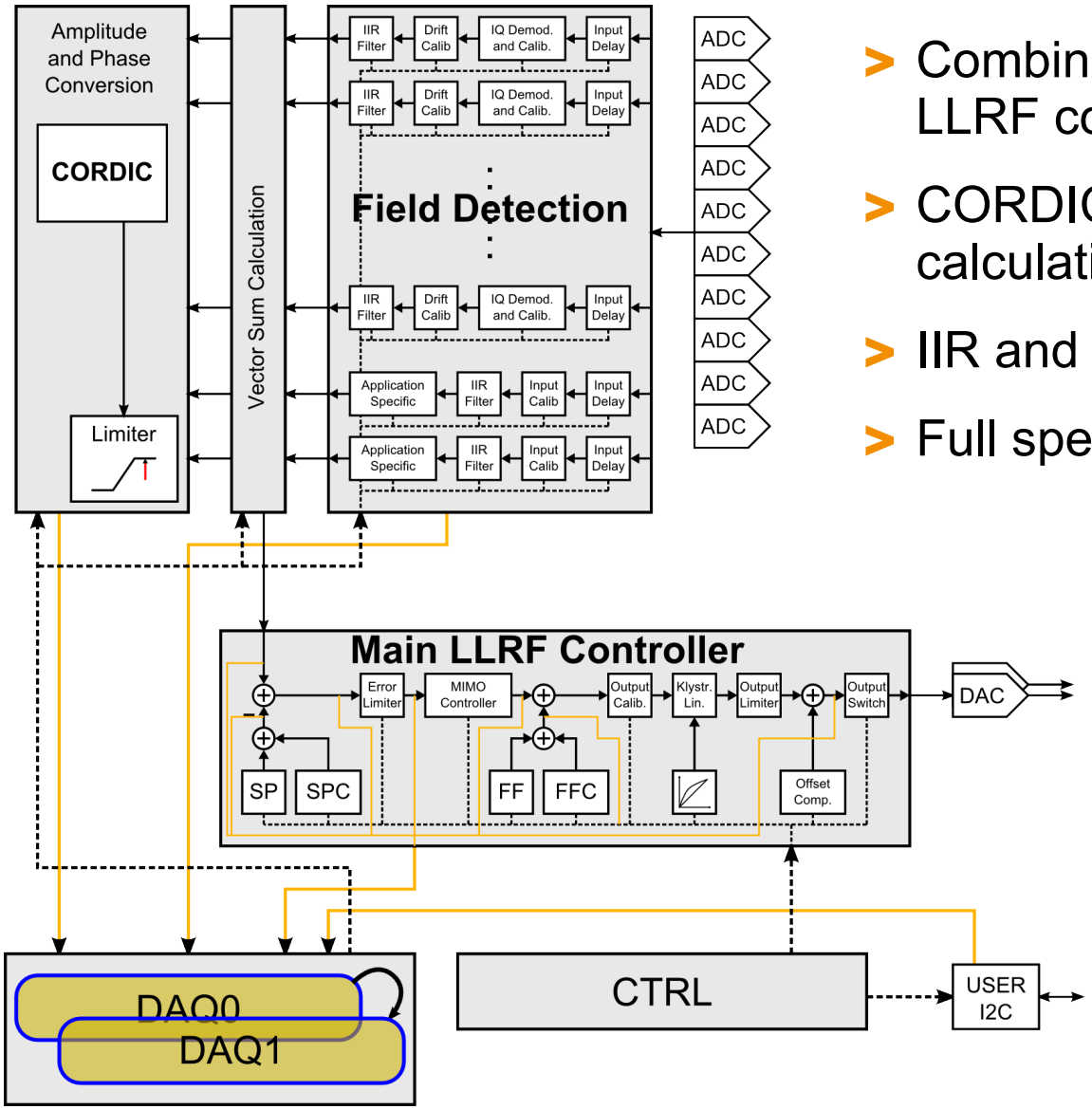
> DRTM-DS8VM1

- 8 Analog input channels (5..400MHz)
- 1 Vector modualtor channel (0.05..6GHz)
- 2 DC channels (DC..400MHz)
- Digital adjustable attenuators (input and output)
- ADC clock and reference from front panel or RF backplane
- On-board power level monitors and I2C support
- On-board low jitter PLL chip for clock generation and distribution





Single Cavity Controller Firmware.



- Combined field detection and main LLRF controller
- CORDIC for amplitude and phase calculation
- IIR and MIMO controller
- Full speed DAQ

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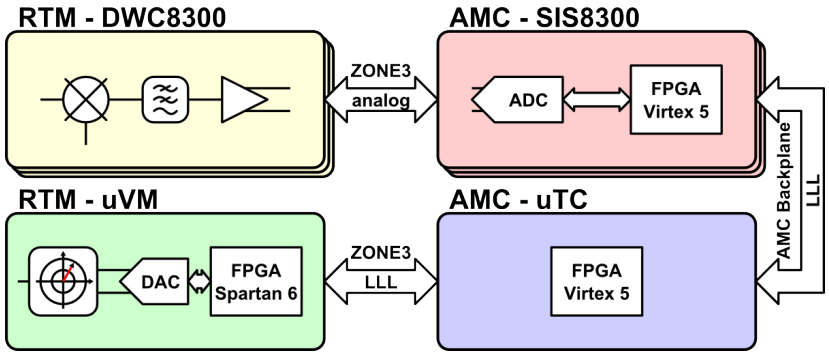
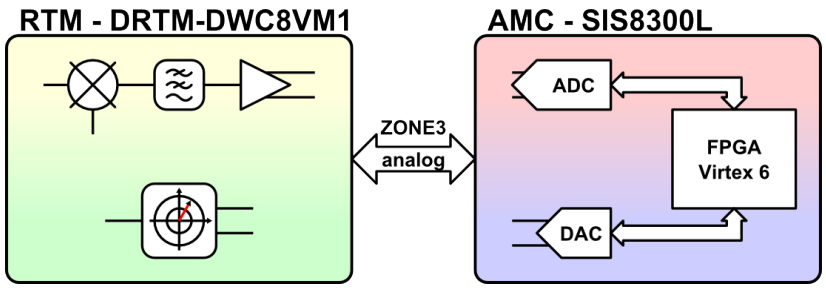
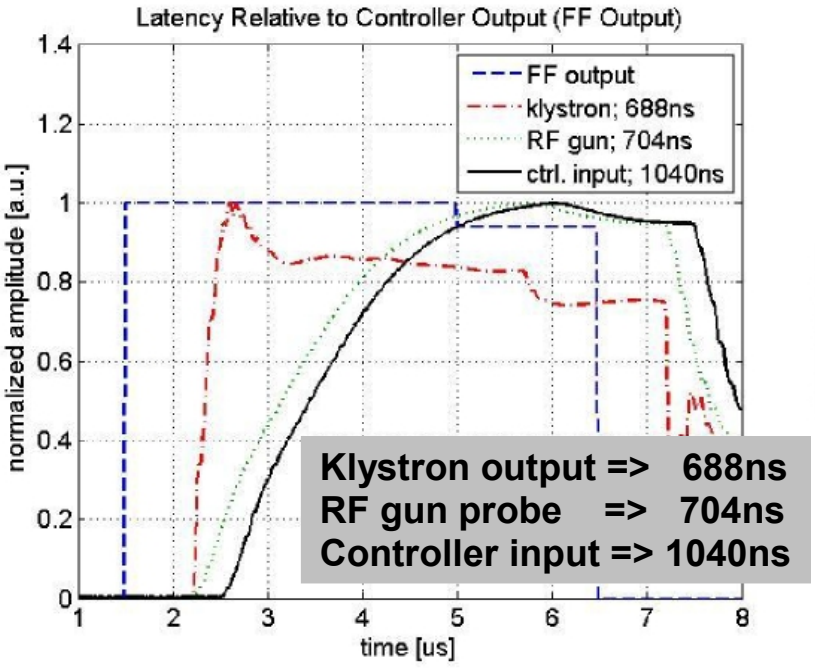
Results from REGAE – Latency Budget.



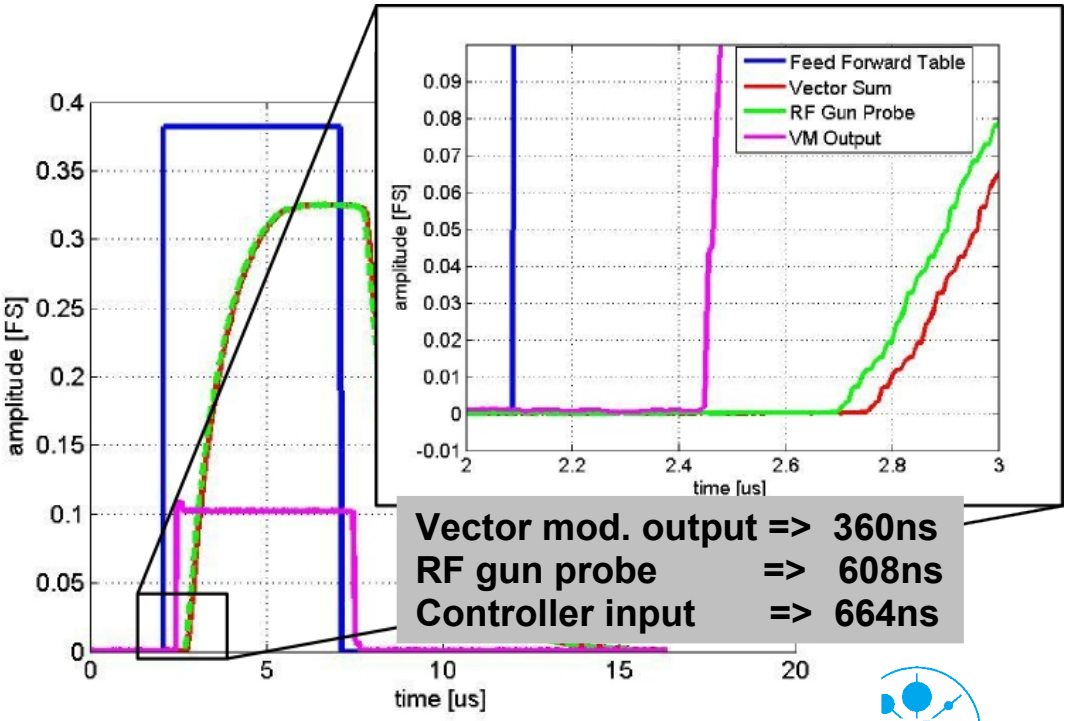


> Delay budget (old system):



Klystron output => 688ns
RF gun probe => 704ns
Controller input => 1040ns

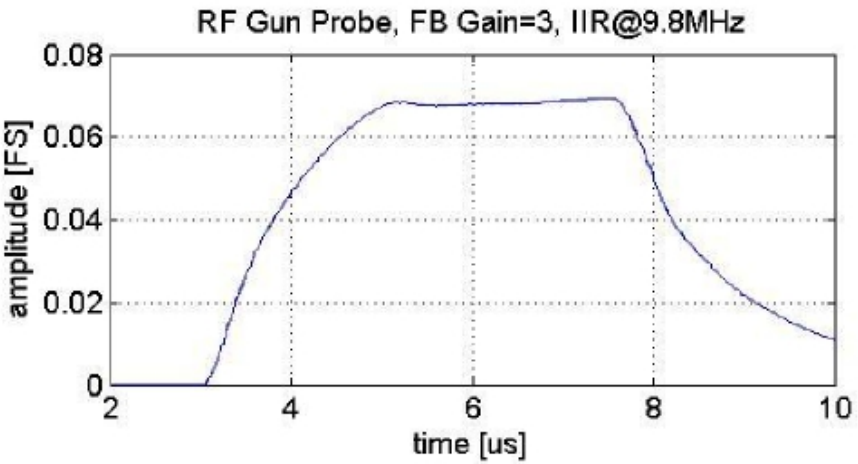
> Delay budget (new system):

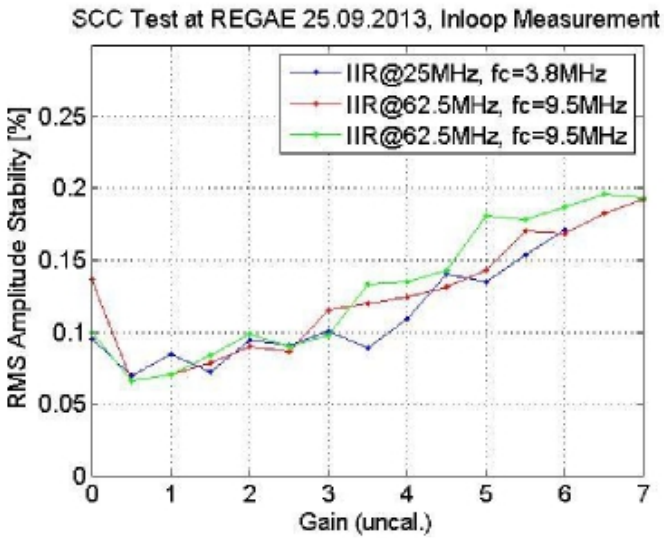


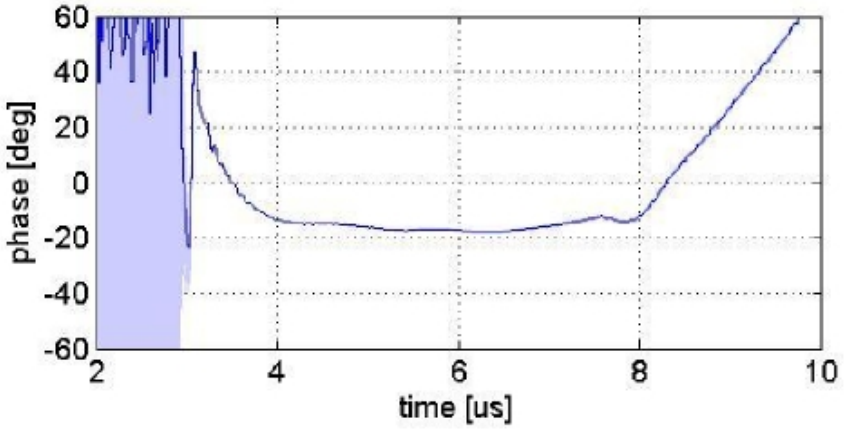
Vector mod. output => 360ns
RF gun probe => 608ns
Controller input => 664ns

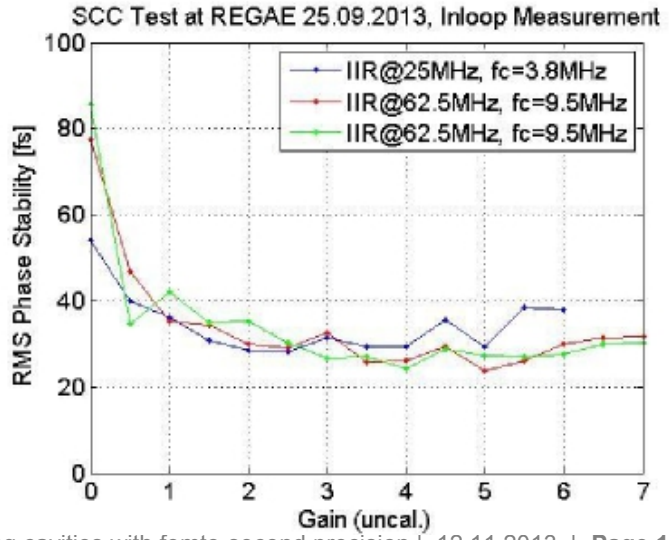
Results from REGAE – Feedback Operation.

Feedback Gain Scan with new LLRF Hardware









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Firmware Improvements.

- DAC operation at 250MHz (dual DAC)
- Controller operation at 125MHz
  - IIR filter in field detection
  - IIR in MIMO controller
- Full speed operation of external memory (larger DAQ)
- Klystron linearization
- VM linearization
  - Full rotation matrix
- Latency optimization
  - Different clocking zones
  - Parallel data processing
  - Usage of full FPGA resources

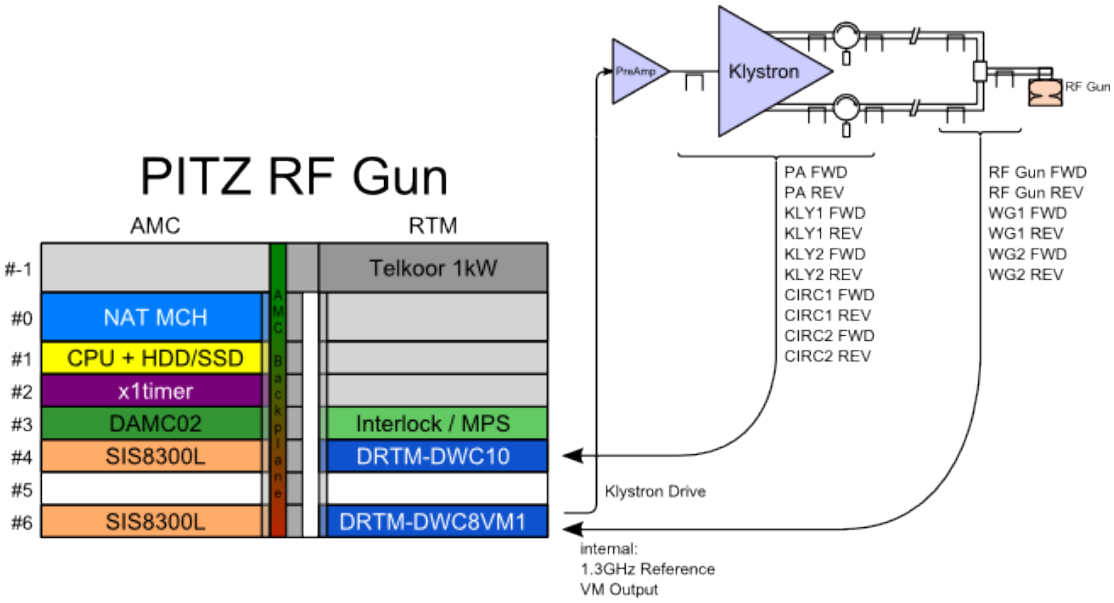
Further Facilities @ DESY.

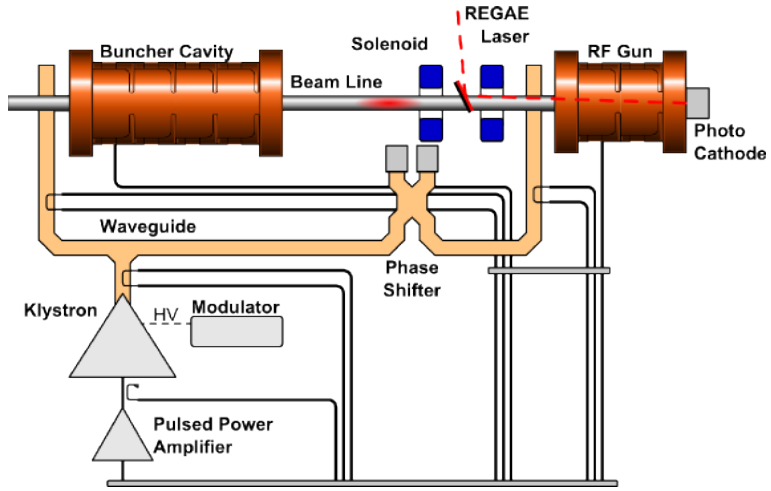
> XFEL/FLASH/PITZ RF gun

- 1.5-cell normal conductive RF gun
- 1.3GHz L-band structure
- 1.5ms pulse length at 10Hz repetition rate
- DESY - PITZ Booster (8-cell structure)

> REGAE RF gun and buncher

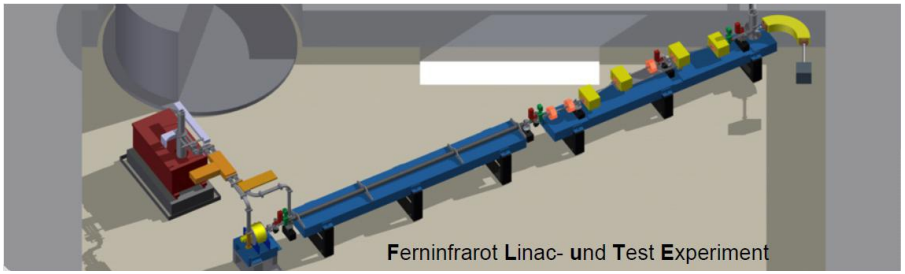
- Normal conductive RF gun (1.5-cell) and buncher cavity (4-cell)
- 3.0GHz S-band structures
- 6us pulse length at 50Hz repetition rate





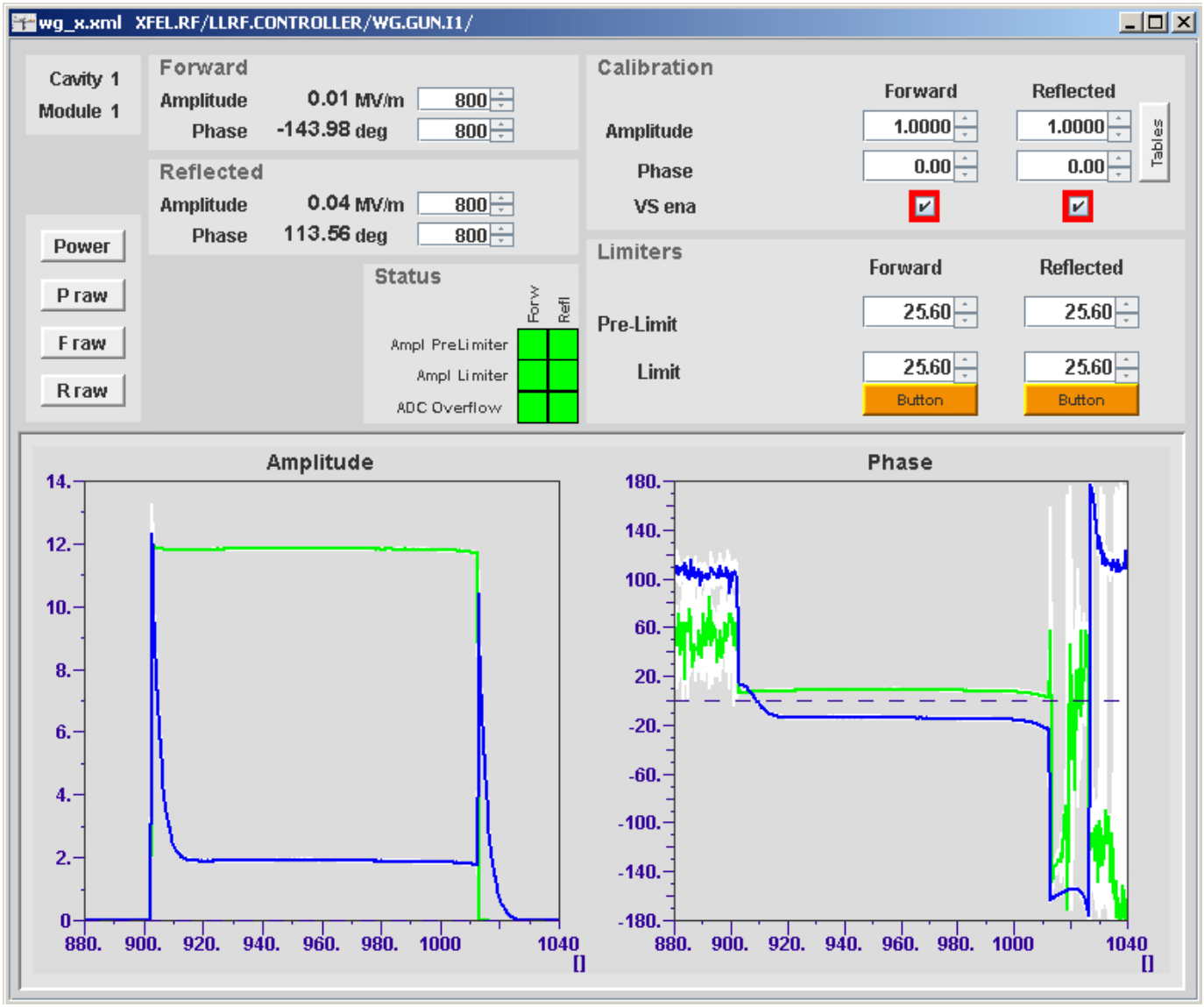
Further Facilities.

- DESY - PITZ/XFEL TDS
  - 14-cell normal conductive TDS
  - 3.0GHz S-band structure
  - 0.1 to 3.1us pulse length at 10Hz repetition rate
- KIT - FLUTE facility
  - Normal conductive RF gun (2.5-Cell) and linac
  - 3.0GHz S-band structures
  - 5us pulse length at 100Hz repetition rate
  - Upgrade with buncher cavity



- HZDR - ELBE facility
  - 4 TESLA type cavities
  - 1.3GHz super conductive
  - CW operation
- ESS facility
  - Proton linac, neutron source
  - 352MHz and 704MHz cavities
  - One klystron per cavity
  - Normal and super conductive cavities
  - 3.5ms pulse length at 14Hz repetion rate
  - LLRF and diagnostic (BPMs)
- CANDLE
- SINAD

First RF in XFEL RF Gun.



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