Low Level RF & Feedback

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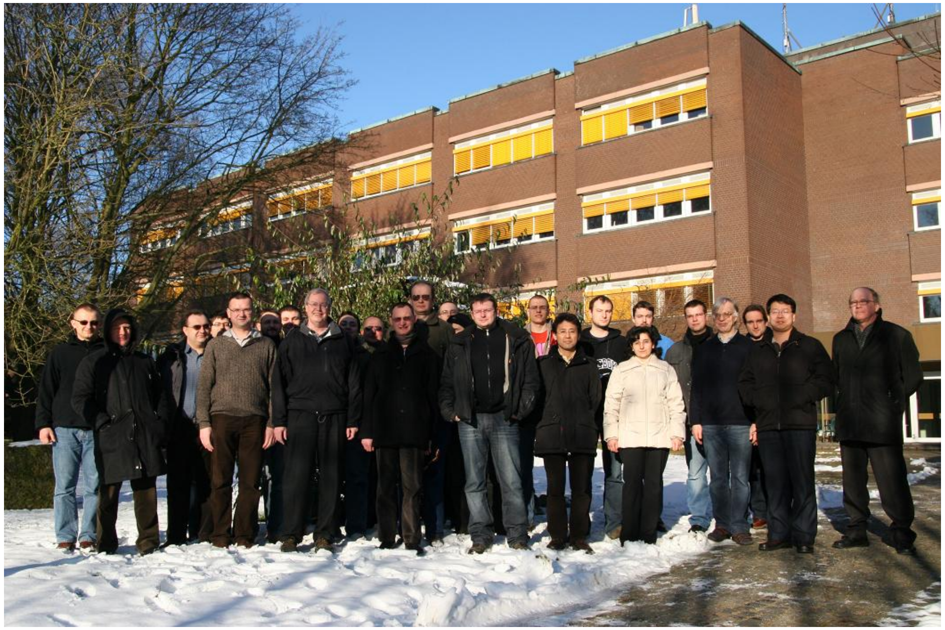
for LLRF team



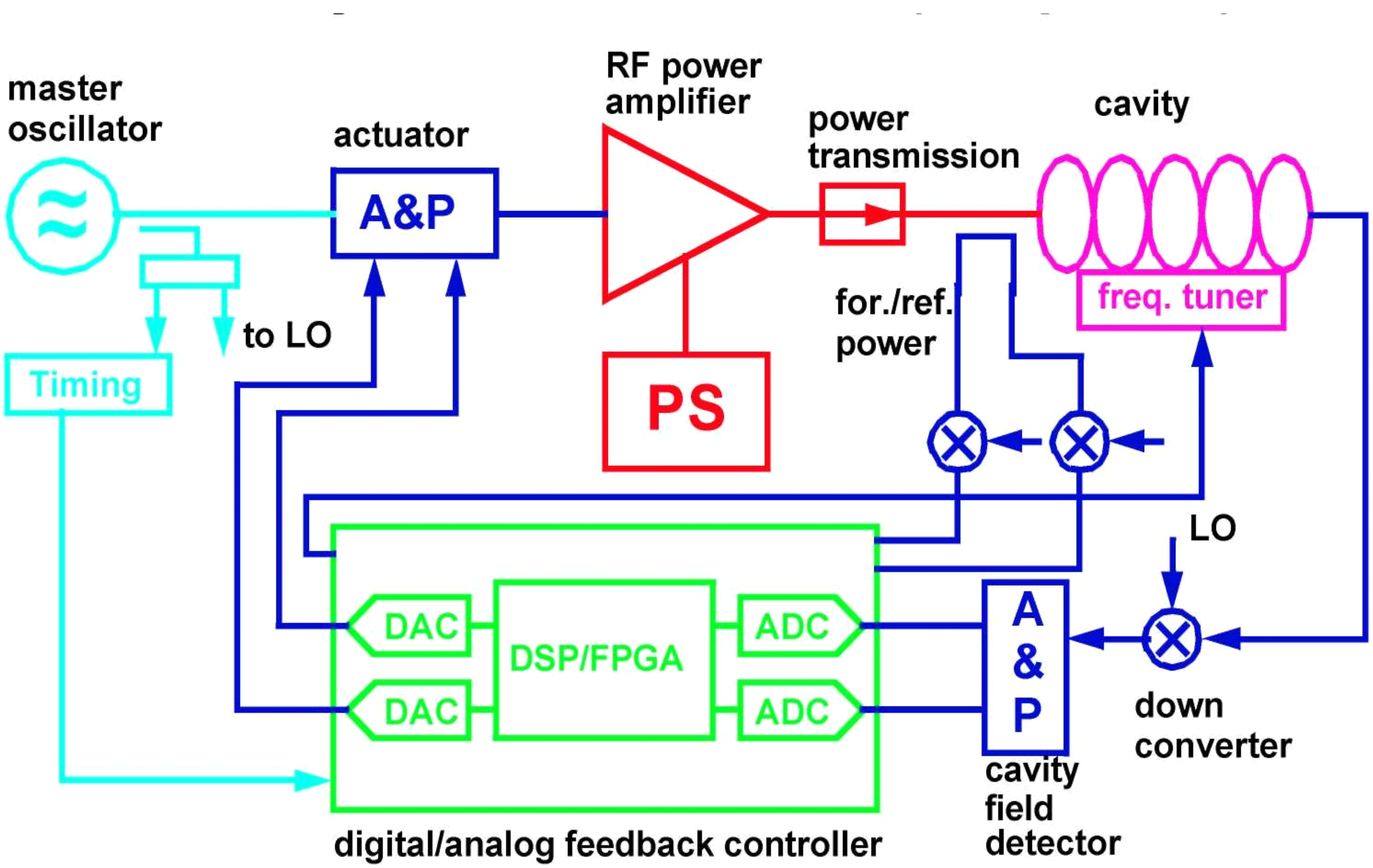
Agenda

- LLRF requirements
- Principle of RF Control
- Options for LLRF control
- Sources of Field Perturbations
- Noise sources in LLRF Systems
- Achieved amplitude and phase stability
- Detuning control
- Operation issues
- Software

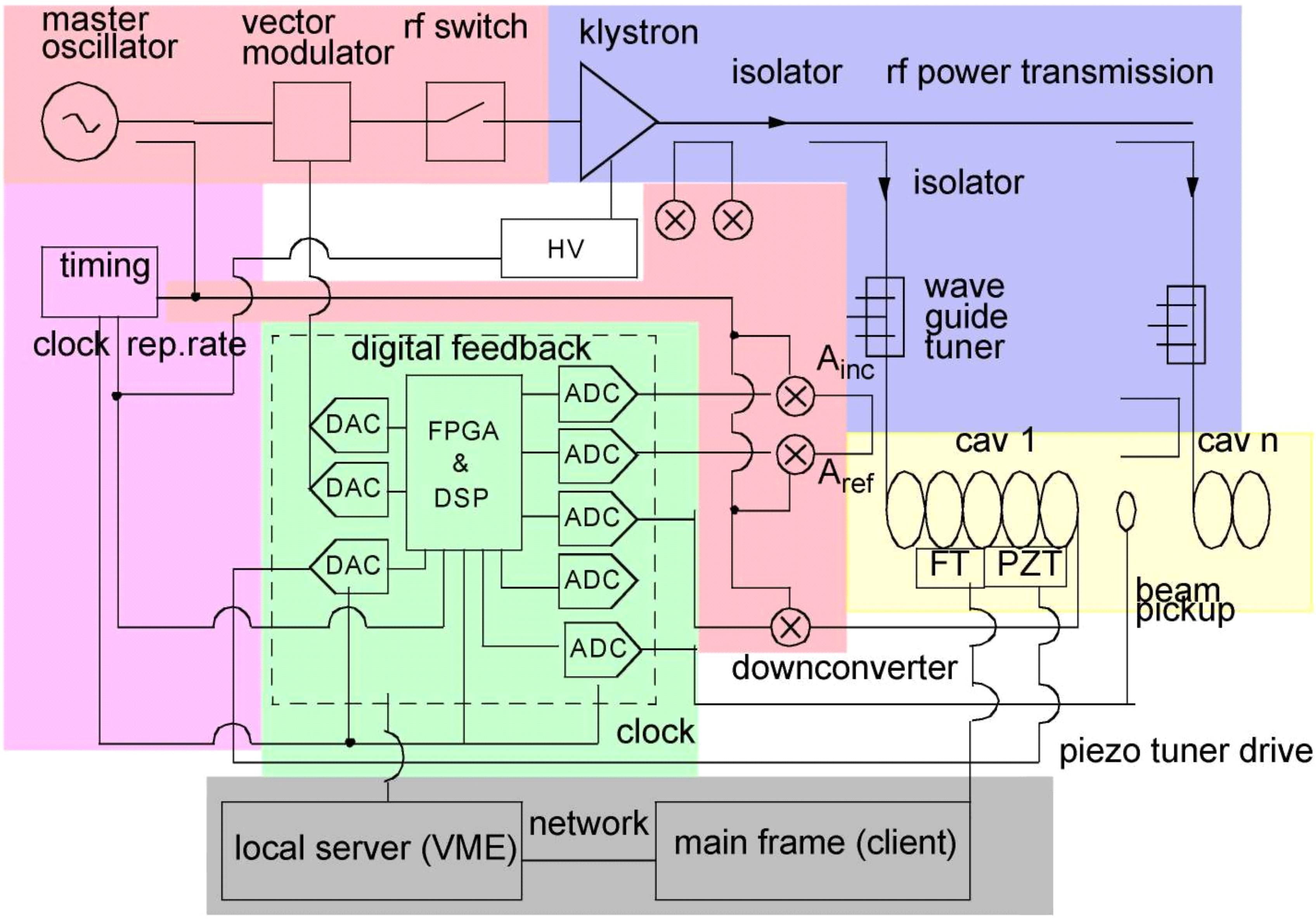
RF Control Requirements

- Maintain Phase and Amplitude of the accelerating field within given tolerances to accelerate a charged particle beam (e.g. XFEL: 0.01% for amplitude and 0.01 deg. for phase)
- Minimimize Power needed for control
- RF system must be reproducible, reliable, operable, and well understood
- Other performance goals
  - build-in diagnostics for calibration of gradient and phase, cavity detuning, etc.
  - provide exception handling capabilities
  - meet performance goals over wide range of operating parameters

RF System Architecture



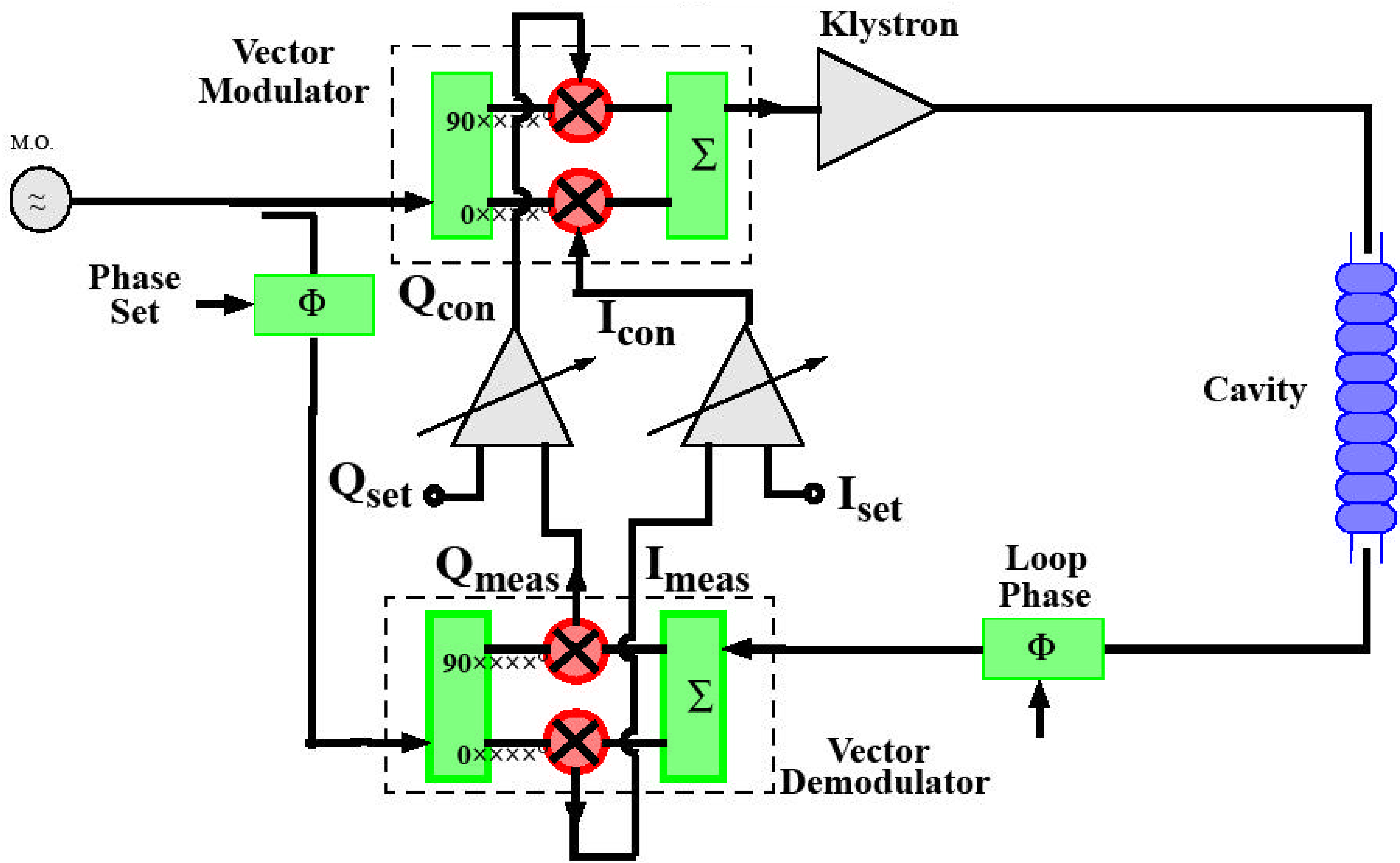
System Architecture Details



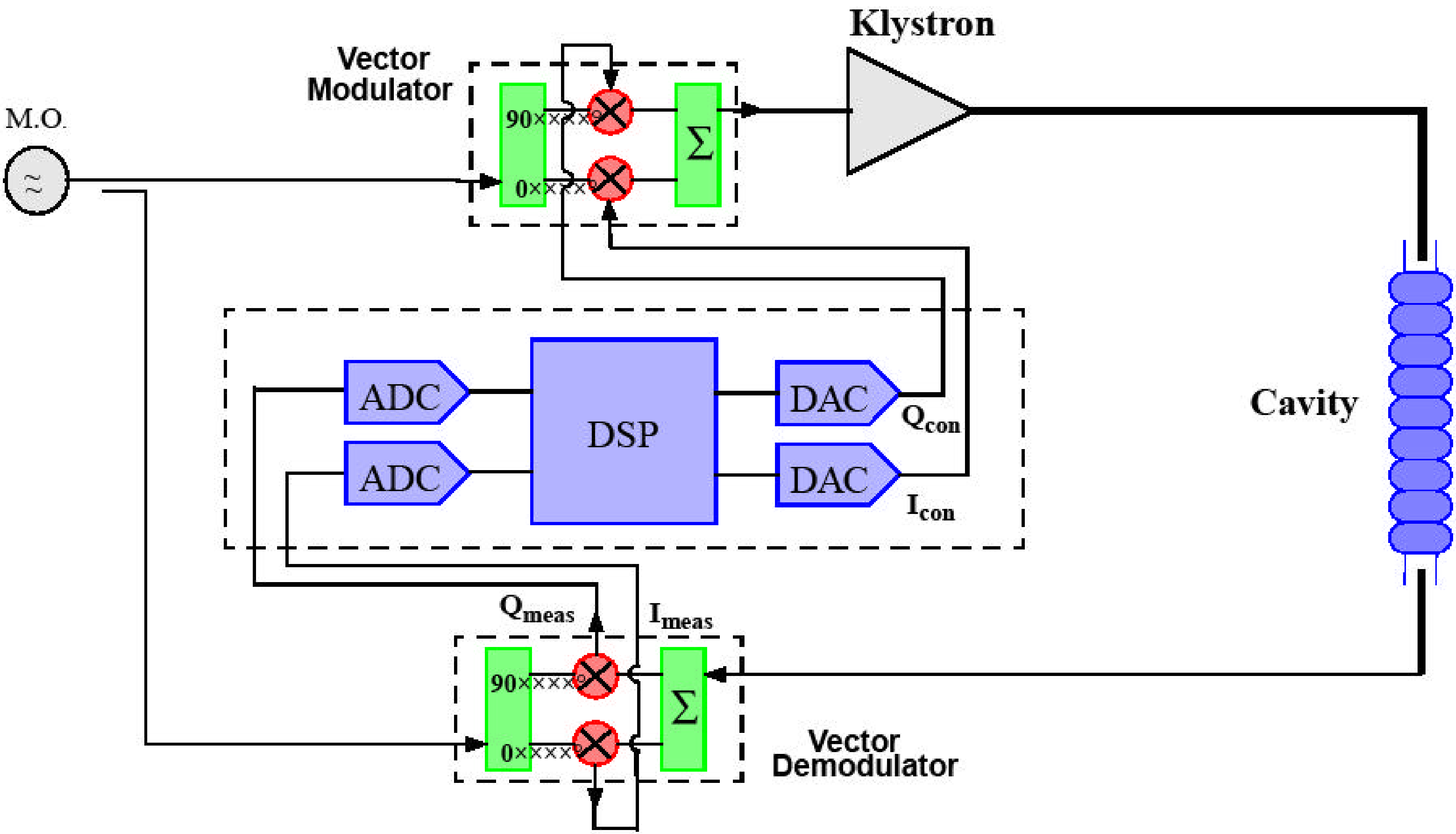
Control Choices

- Self-excited Loop (SEL) vs Generator Driven System (GDR)
- Vector-sum (VS) vs individual cavity control
- Analog vs Digital Control Design
- Amplitude and Phase (A&P) vs In-phase and Quadrature (I/Q) detector and controller

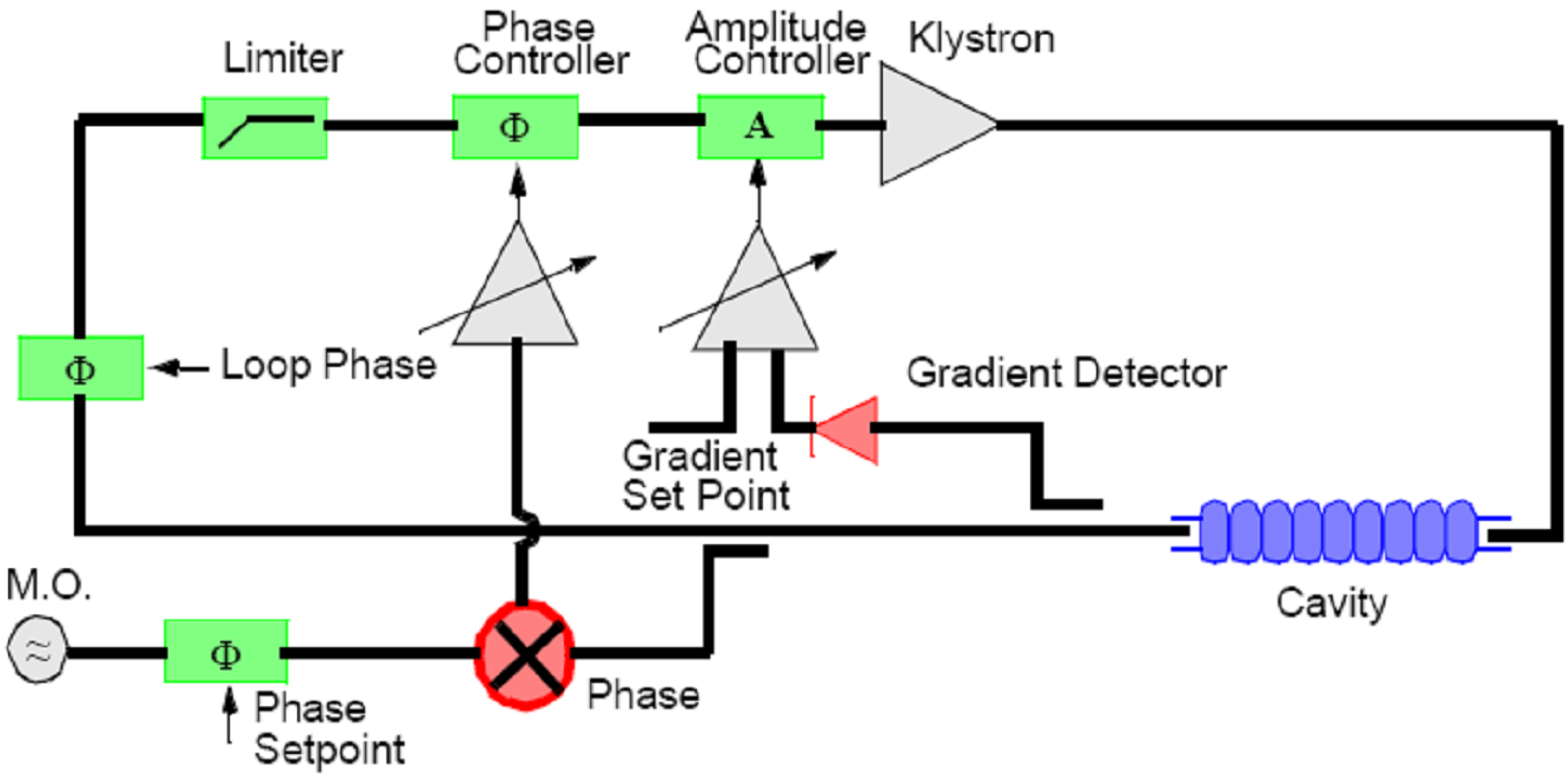
Analog LLRF system



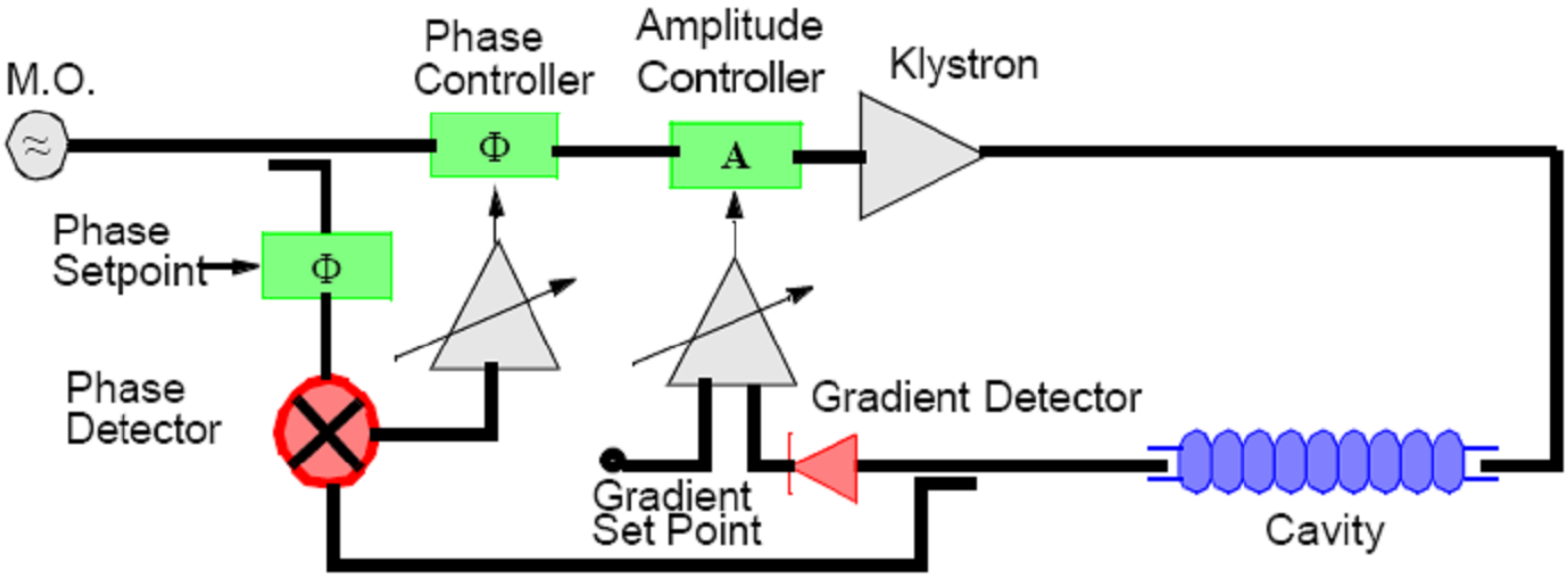
Digital IO control



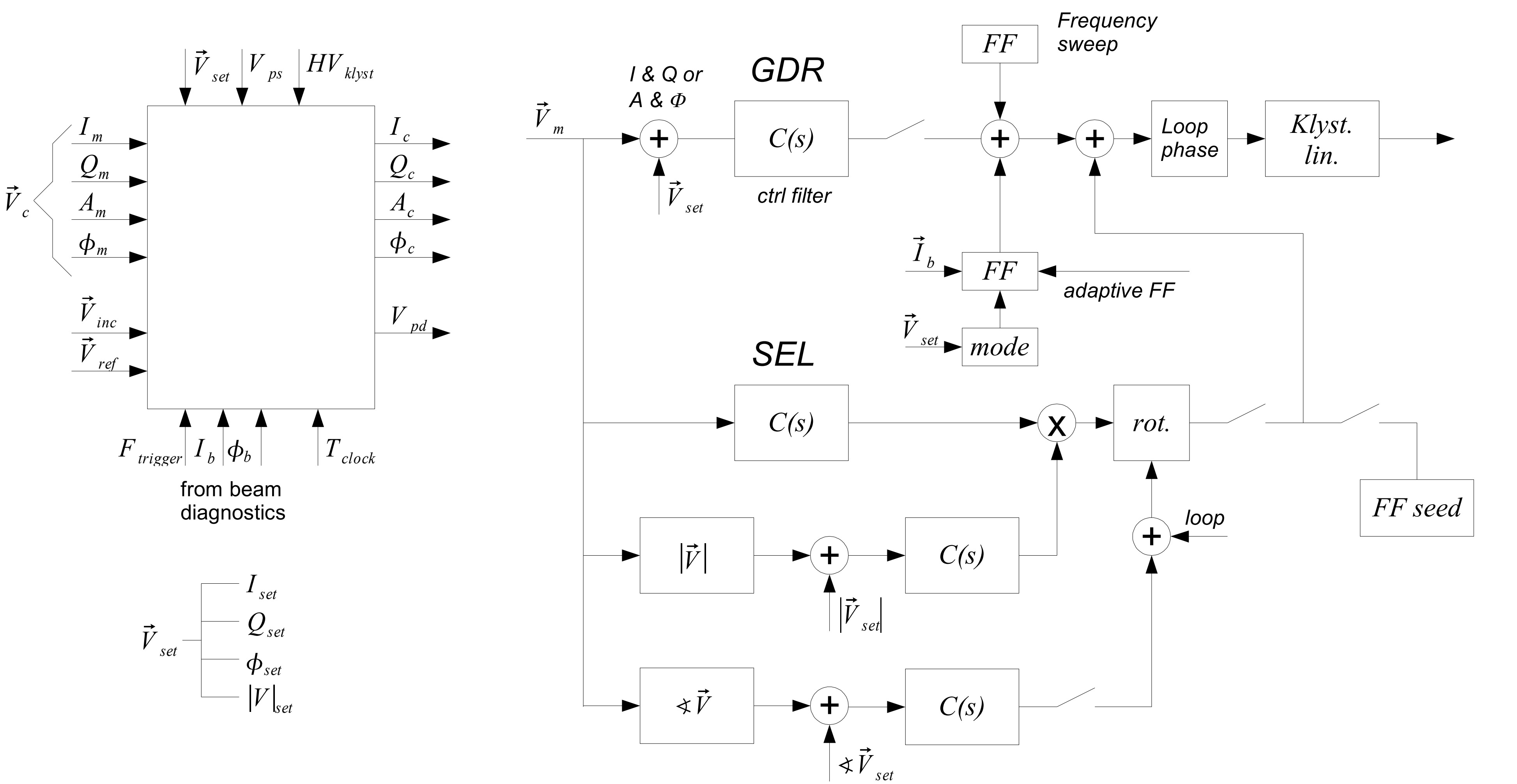
Self Excited Loop



Generator Driven Resonator



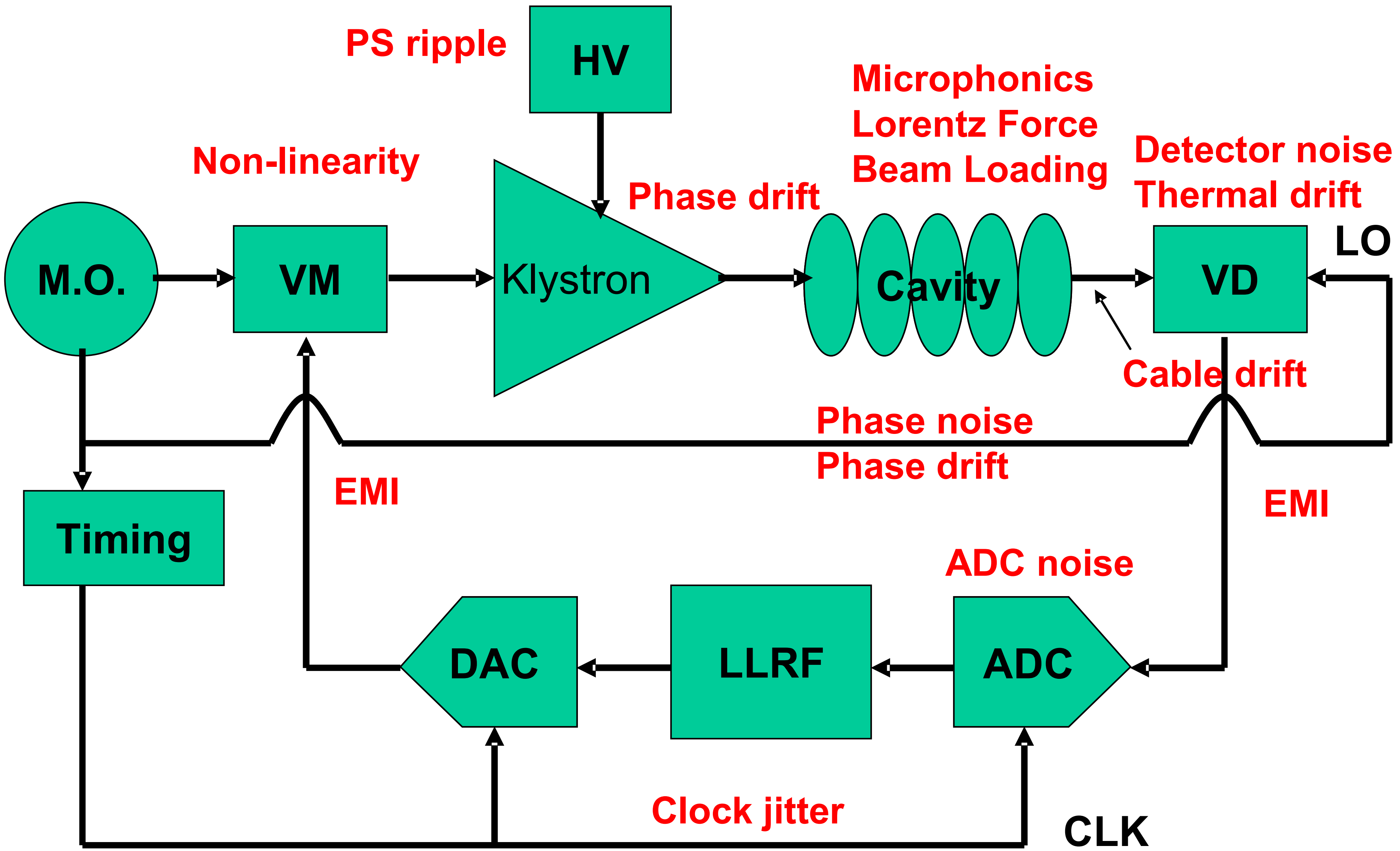
Block diagram of Universal Controller



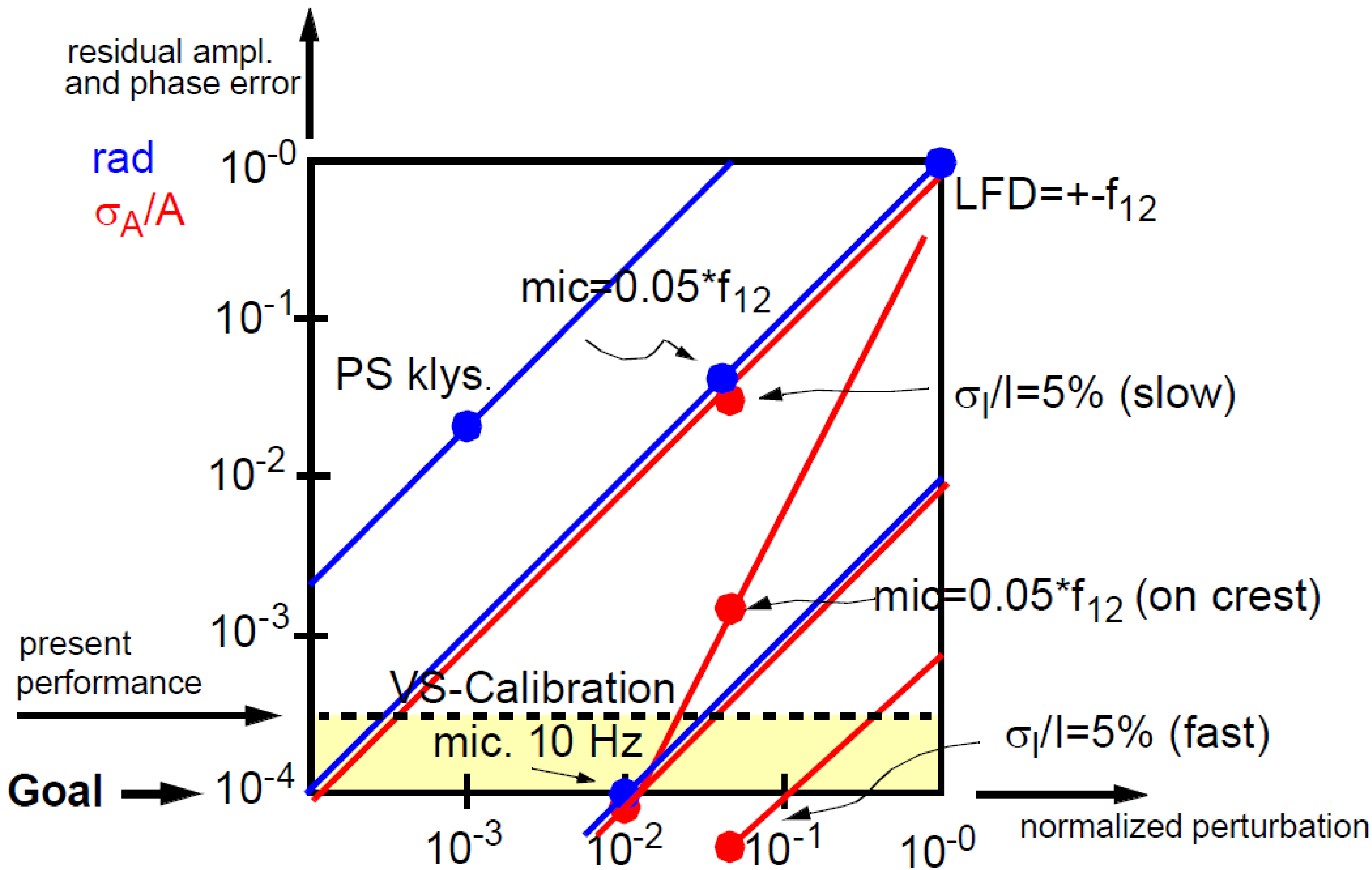
Sources of Field Perturbations

- Beam loading
  - –Beam current fluctuations
  - –Pulsed beam transients
  - –Multipacting and field emission
  - –Excitation of HOMs
  - –Excitation of other passband modes
  - –Wake fields
- Cavity drive signal
  - –HV- Pulse flatness
  - –HV PS ripple
  - –Phase noise from master oscillator
  - –Timing signal jitter
  - –Mismatch in power distribution
- Cavity dynamics
  - –cavity filling
  - –settling time of field
- Cavity resonance frequency change
  - –thermal effects (power dependent)
  - –microphonics
  - –Lorentz force detuning
- Other
  - –Noise in electronics (mixer, ADC)
  - –Thermal drifts (electronics, cables
  - –Interlock trips
  - –Response of feedback system

Noise Sources in LLRF Systems

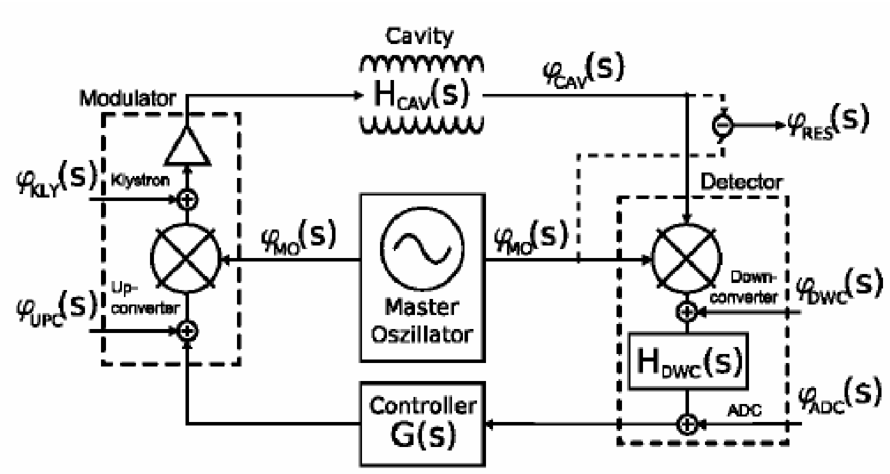


Error map



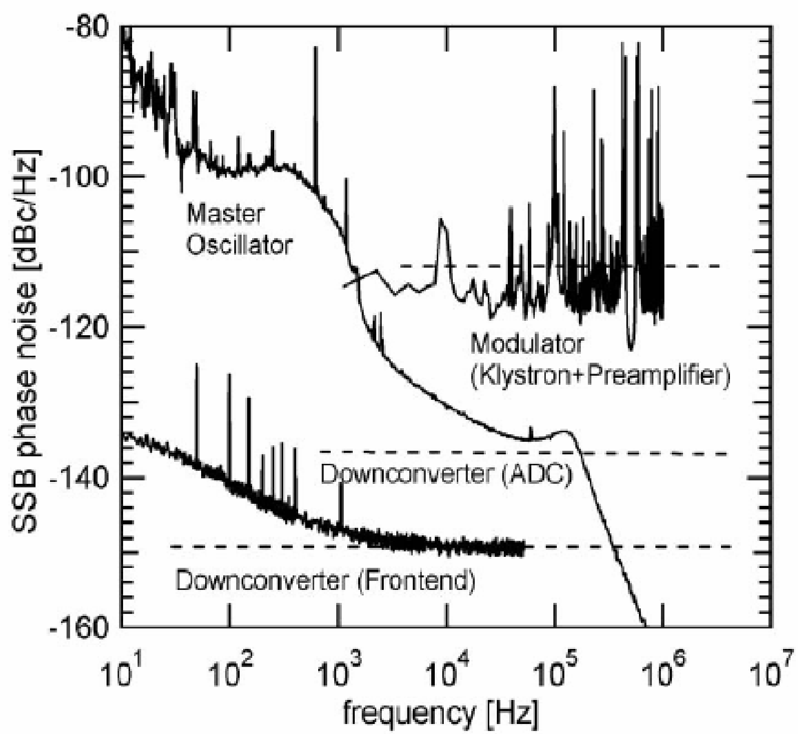
residual ampl.
and phase error
rad
σ_A/A
10^{-0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
LFD=+-f_{12}
mic=0.05*f_{12}
PS klys.
σ_I/I=5% (slow)
mic=0.05*f_{12} (on crest)
present
performance
VS-Calibration
mic. 10 Hz
σ_I/I=5% (fast)
Goal
10^{-3}
10^{-2}
10^{-1}
10^{-0}
normalized perturbation

Phase noise budget at FLASH

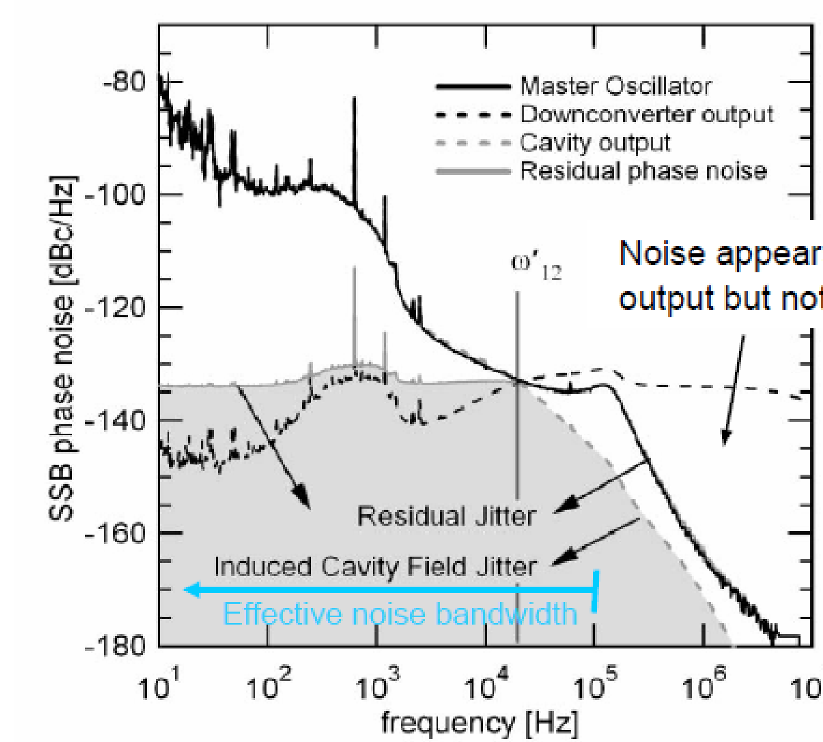


Subsystem	Phase noise [dBc/Hz]	Residual jitter [fs]	Induced jitter [fs]
MO	see Fig.3	14.1	5.5
DWC (Frontend)	−147	1.8	1.8
DWC (ADC)	−135	5.8	5.8
MOD	−110	1.2	1.2

- Phase noise measurements :



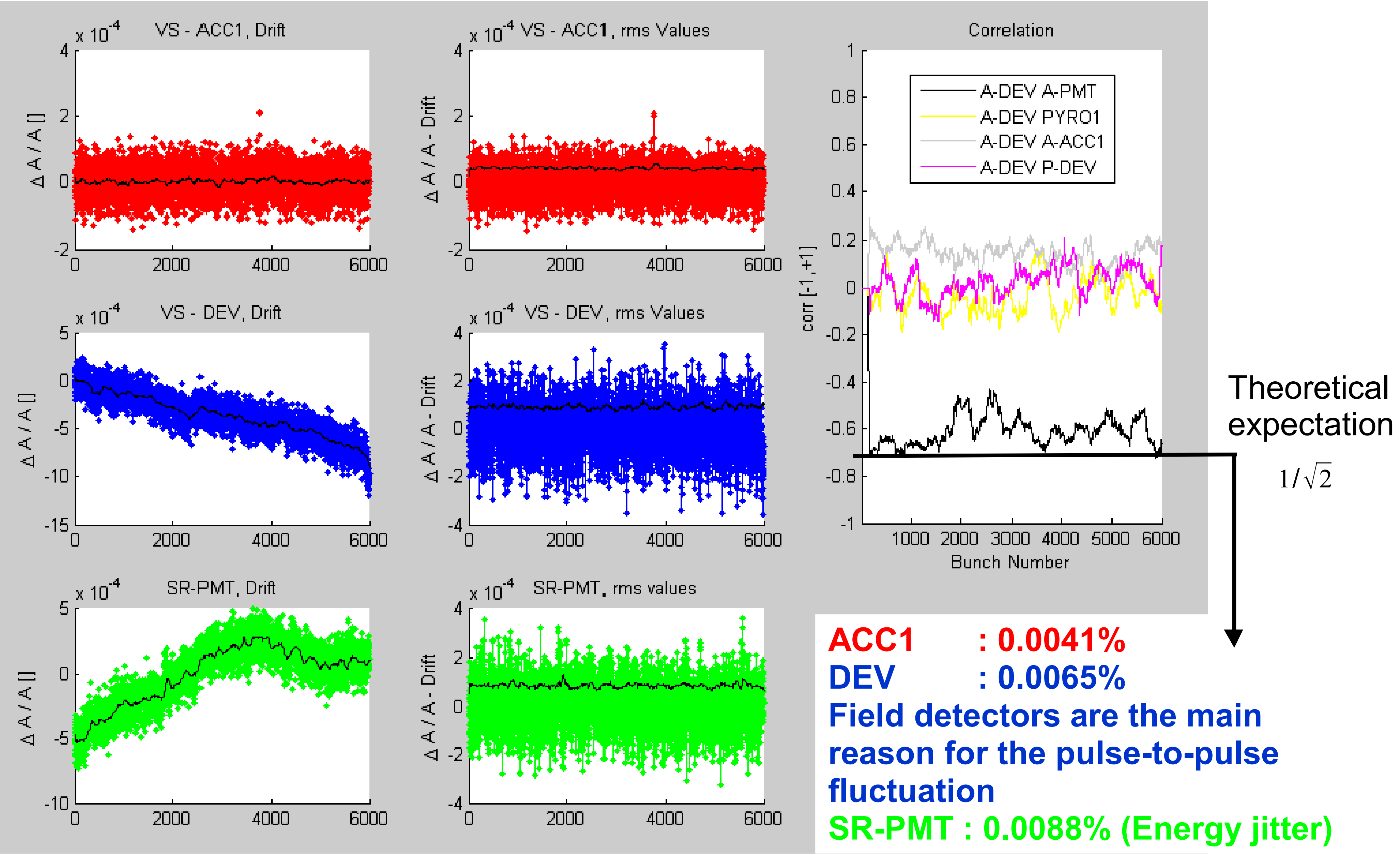
- Contributions to cavity field jitter :



Noise appears at the DWC output but not on the cavity field!

Beam-based monitors

Field stability studies (pulse-to-pulse)



ACC1 : 0.0041%

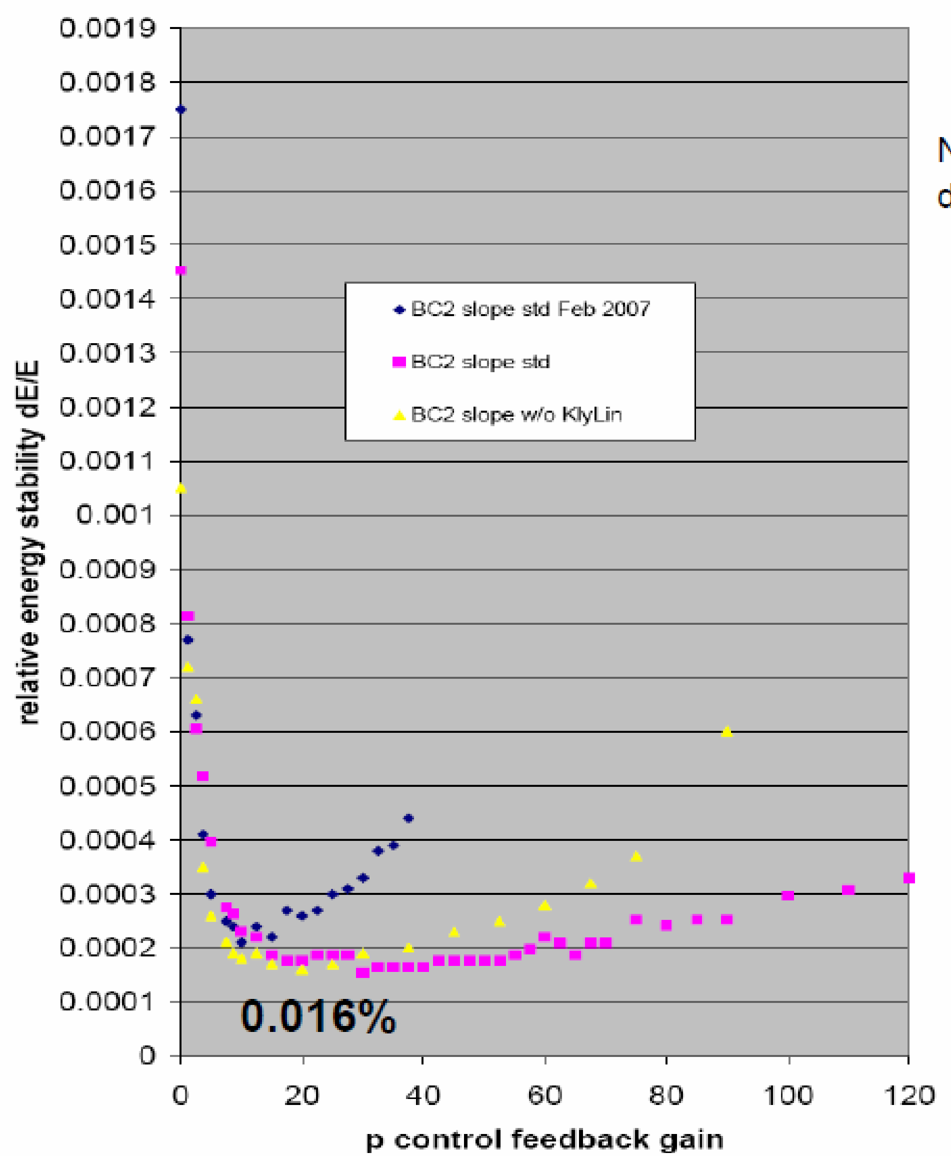
DEV : 0.0065%

Field detectors are the main reason for the pulse-to-pulse fluctuation

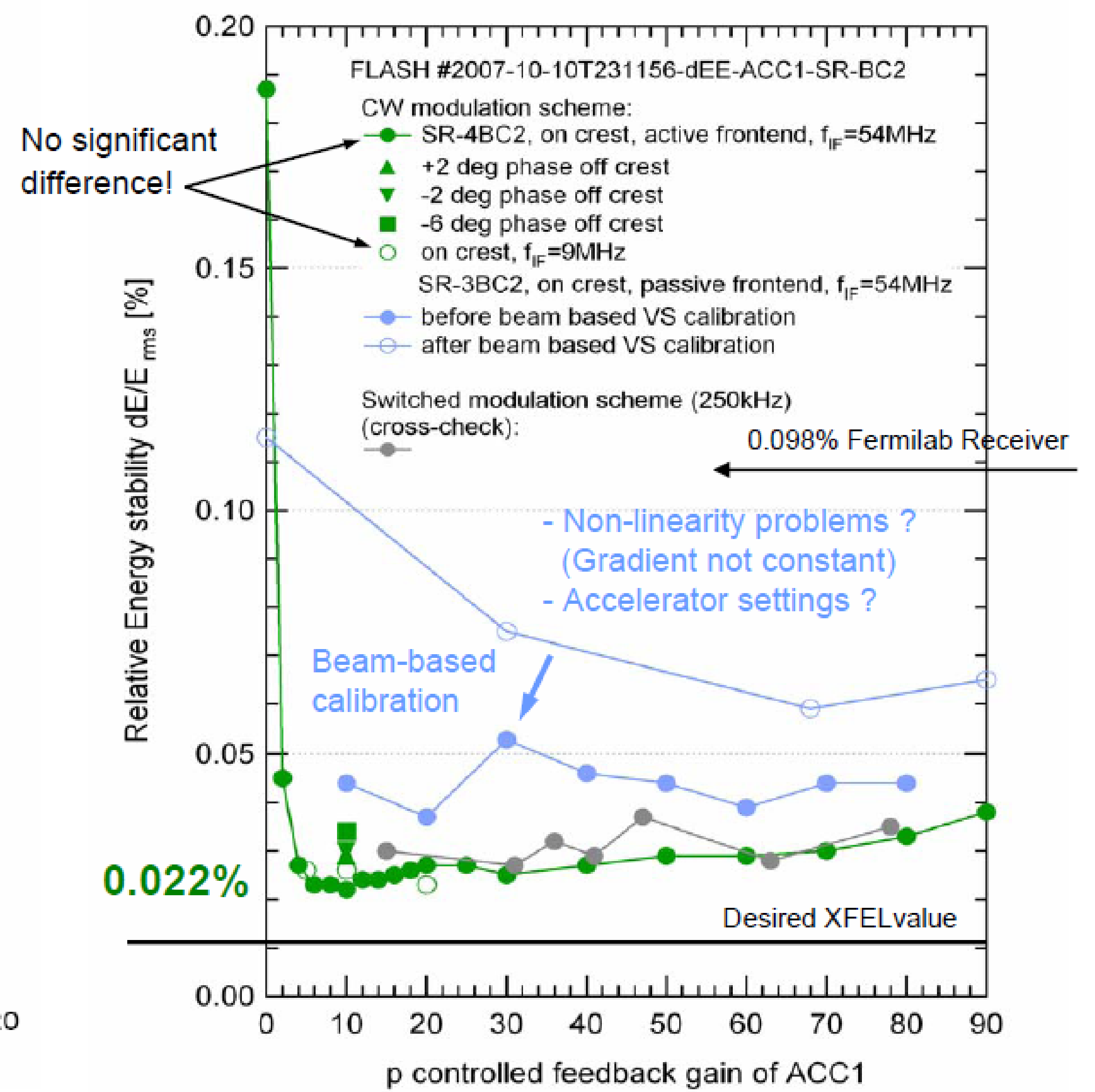
SR-PMT : 0.0088% (Energy jitter)

Beam stability at FLASH (ACC1)

- IQ sampling down-converter (250kHz):



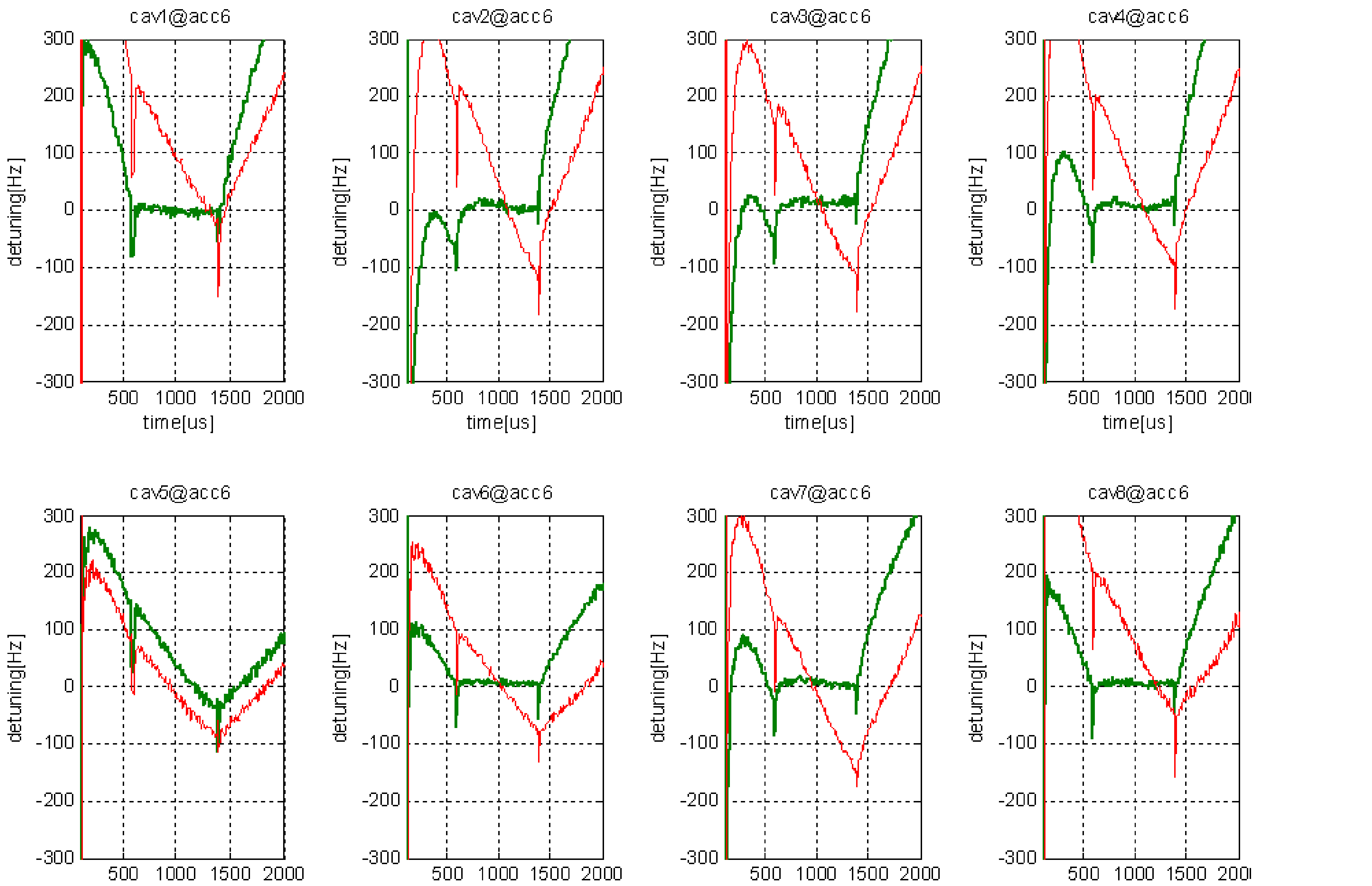
- IF sampling down-converters (9,54MHz):



Piezos installed at FLASH

Producent ratings	Noliac	PI ceramic
Model:	SCMAS/S1/A/10/10/30/200/42/6000	P-888.90
Cells:	8	8
Voltage:	< 200 V	< 120 V
Blocking force:	6 kN	3 kN
Size:	10 mm x10 mm x 30 mm	10 mm x10 mm x 35 mm
Capacitance:	6 μF	12 μF

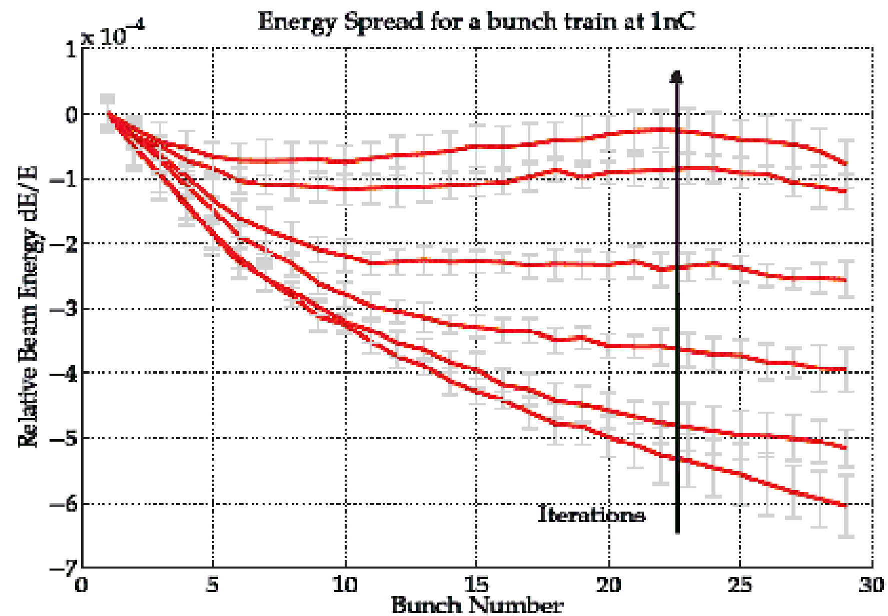
LFD by piezos in ACC6 at FLASH

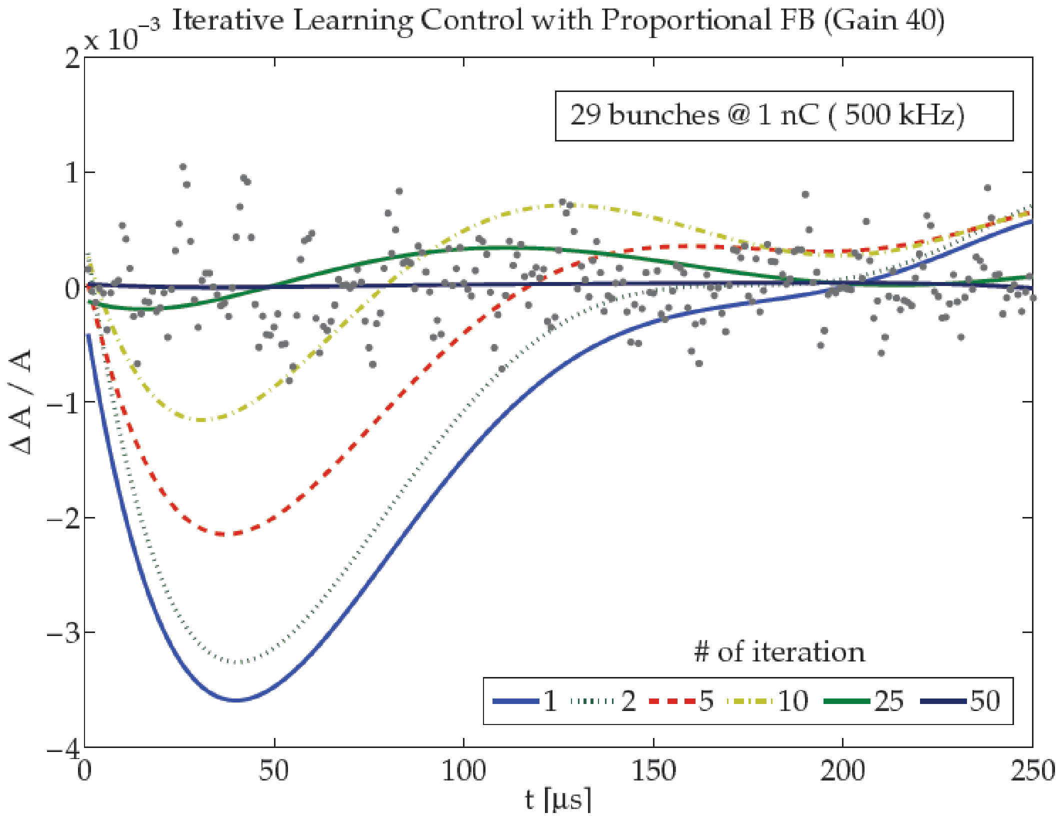


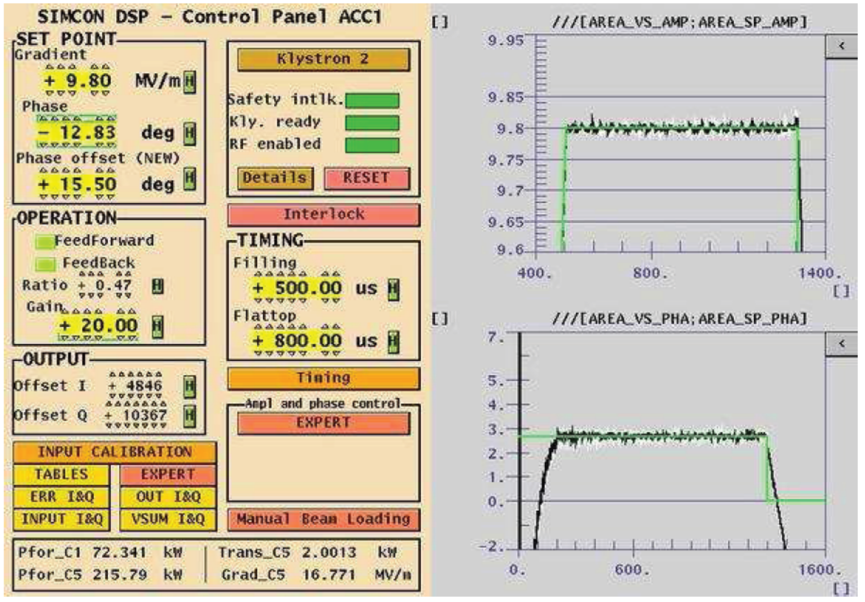
Iterative learning control

Adaptive learning of optimal feed forward signal

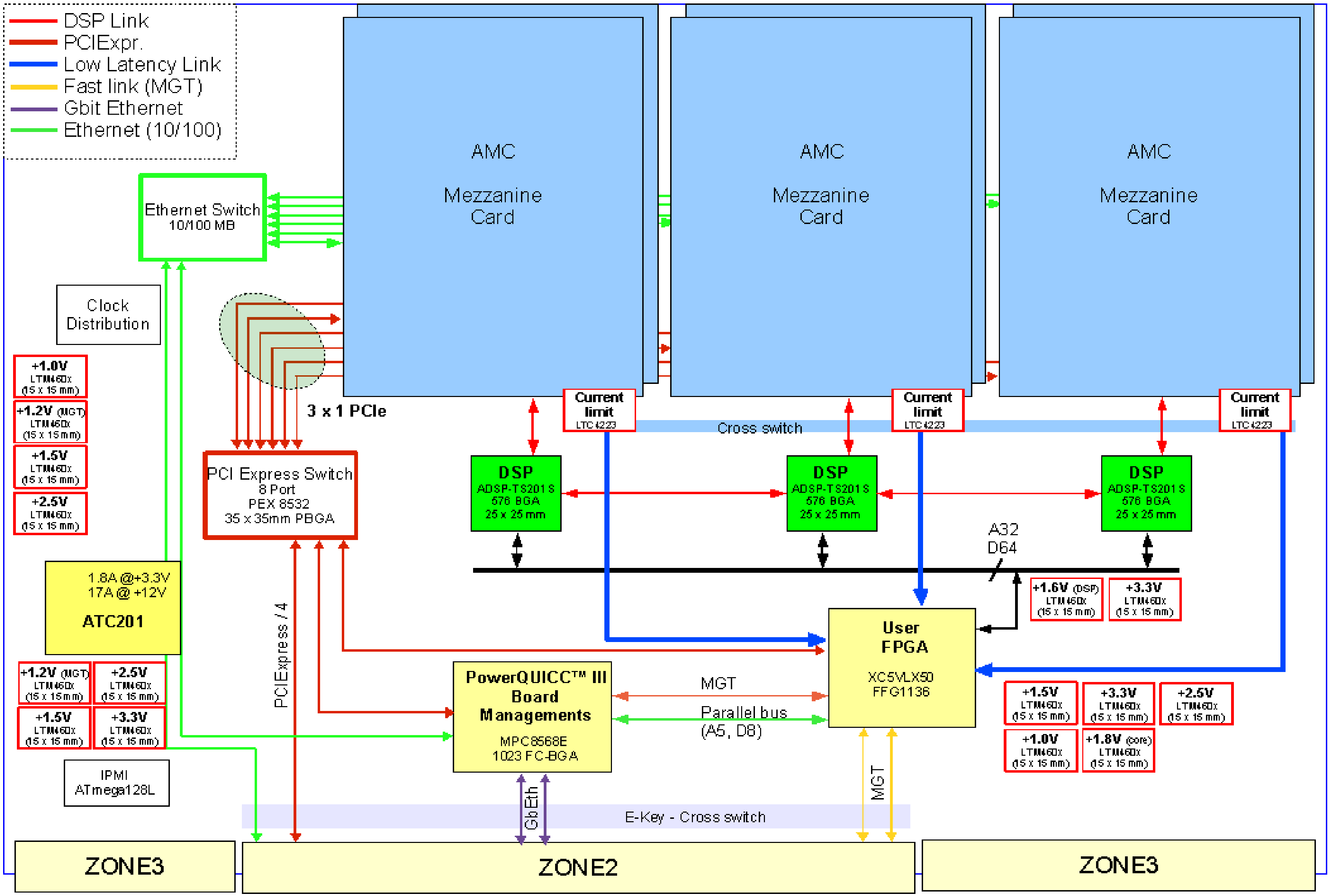
- Beam loading compensation
- Cover repetitive field deviations



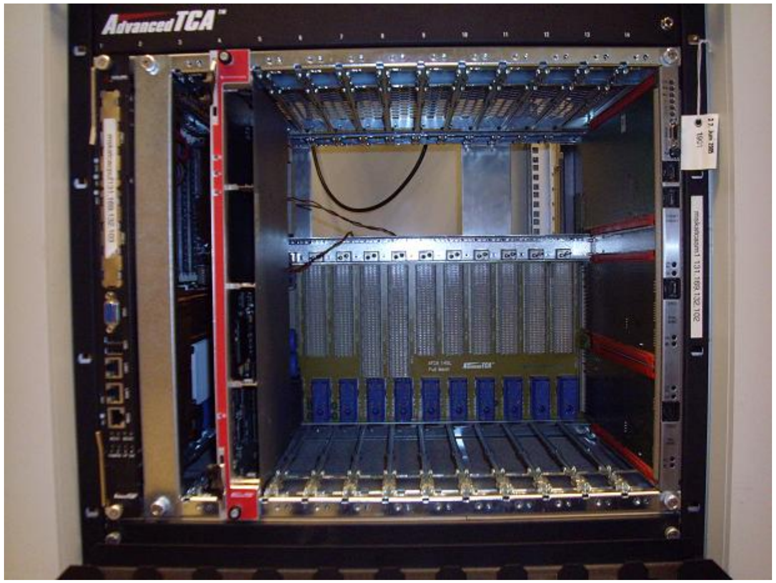


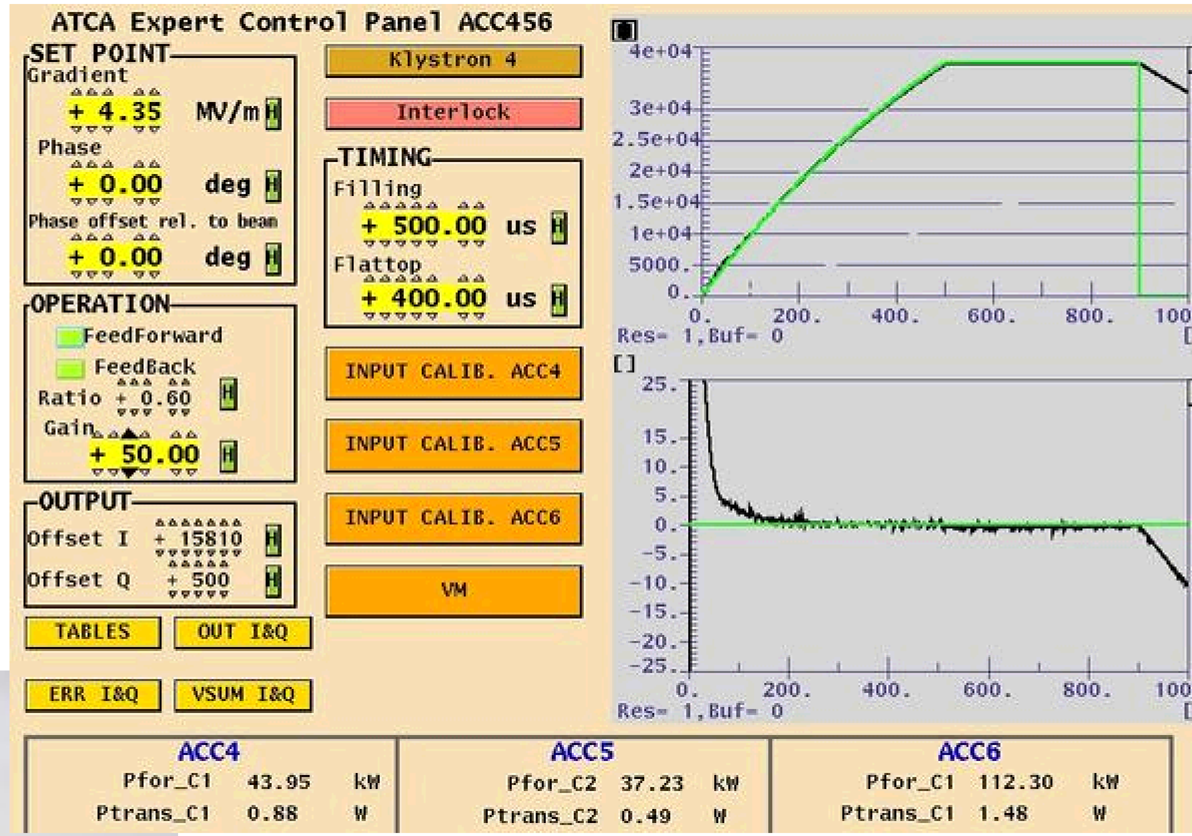


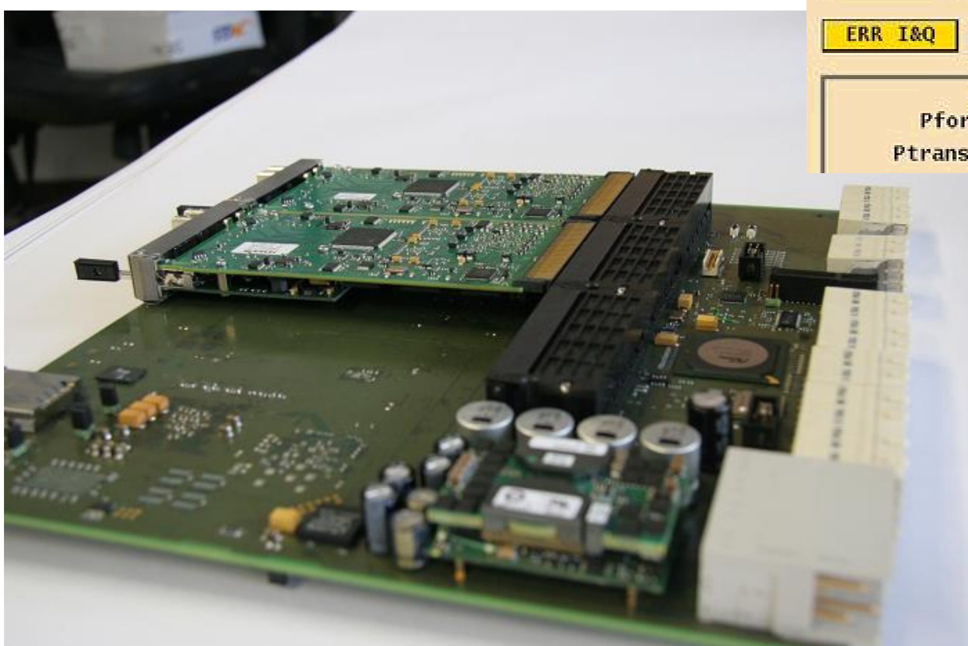
Block diagram of ATCA carrier board



ATCA based LLRF system at FLASH







Flash Logbook entry:

16.09.2009 07:35

Butkowski, Koprek, Piotrowski

ATCA-based LLRF system controls in FB mode 24 cavities in ACC456

xTCA for Physics CC Membership

Corporate Members	Corporation/Institution	Committee Members
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30	Pentair/Schroff	2
31	Performance Technologies	3
32	PICMG Japan	1
33	Pigeon Point Systems	1
34	Pinnacle Data Systems	2
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36	Rittal/Kaparel	2
37	SAIC	1
38	Scan Engineering Telecom	1
39	SLAC National Accelerator Lab	2
40	Triple Ring Technologies	1
41	Yamaichi	1
41	**Totals**	60

LLRF software

- Control Algorithms (Fdbck/ Feedforward)
- Meas. QL and detuning
- Cavity Frequency Control (Fast and Slow)
- Amplitude/Phase Calibration
- Vector-Sum Calibration
- Loop phase and loop gain
- Adaptive Feedforward
- Exception Handling
- Klystron Linearization
- Lorentz Force Compensation
- Automation of operation

Conclusion

- Requirements for Crab Cavities LLRF should be investigated and defined
- Current LLRF system at FLASH provides beam energy stability at the level of ~0,01%
- Cavity detuning can be reduced with fast tuners
- Availability, reliability and operability of the LLRF system is very important