

Towards Attosecond RF Controls.

2nd ARD ST3 Workshop: ps and fs Electron and Photon Beams

Matthias Hoffmann
2nd ARD-ST3 workshop
HZDR , 26.- 27.02.2014

Overview.

- State of the art LLRF controls
- Limitations of todays field detectors
- New detector scheme for attosecond LLRF controls
- Simulation on attosecond LLRF controls
- Interferometer for LLRF
- Attosecond LLRF subcomponent requirements

State of the Art LLRF Controls.

> Single detector performance:

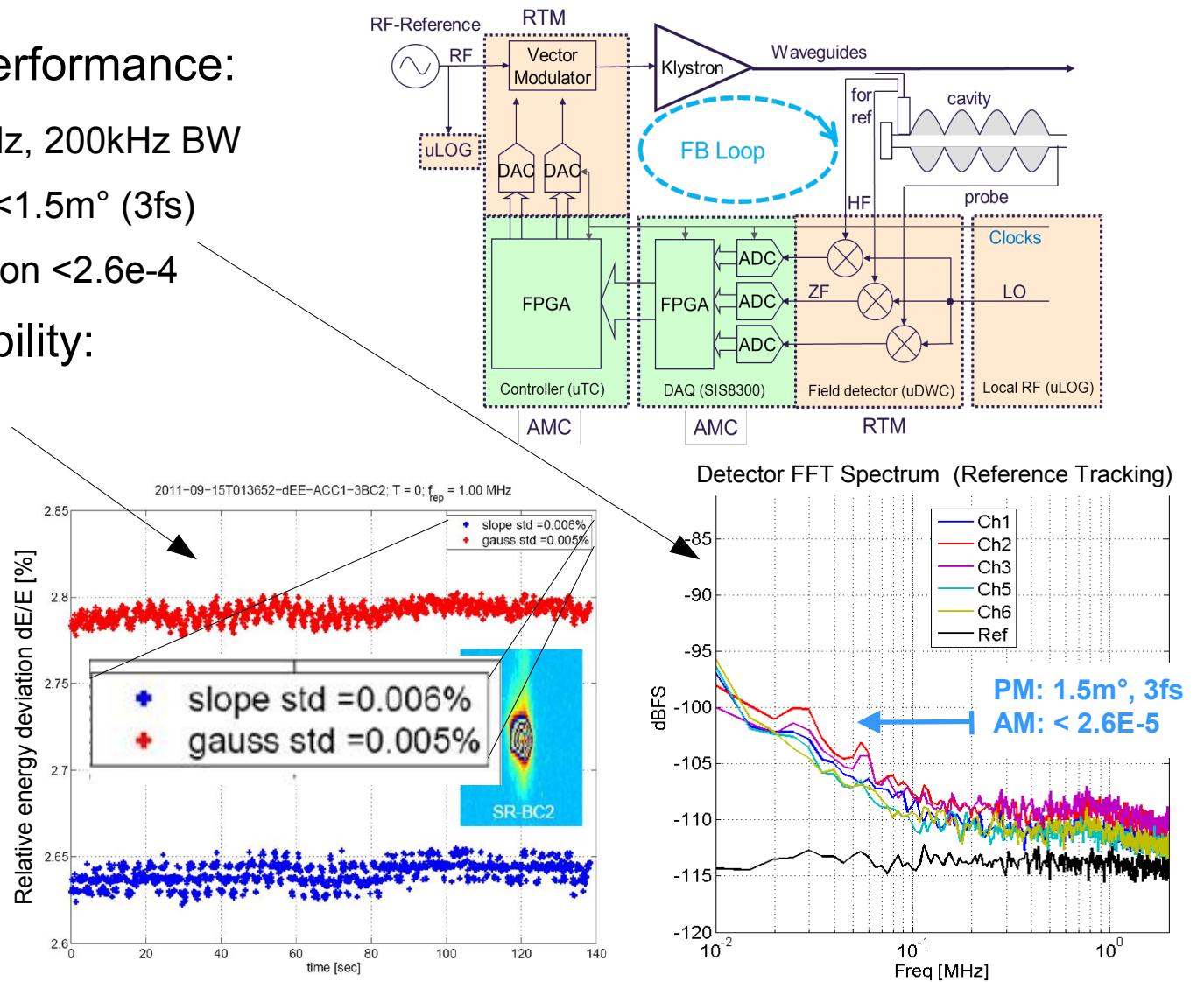
- Short term, 1.3GHz, 200kHz BW
- Phase resolution $<1.5\text{m}^\circ$ (3fs)
- Amplitude resolution $<2.6\text{e-}4$

> Beam energy stability:

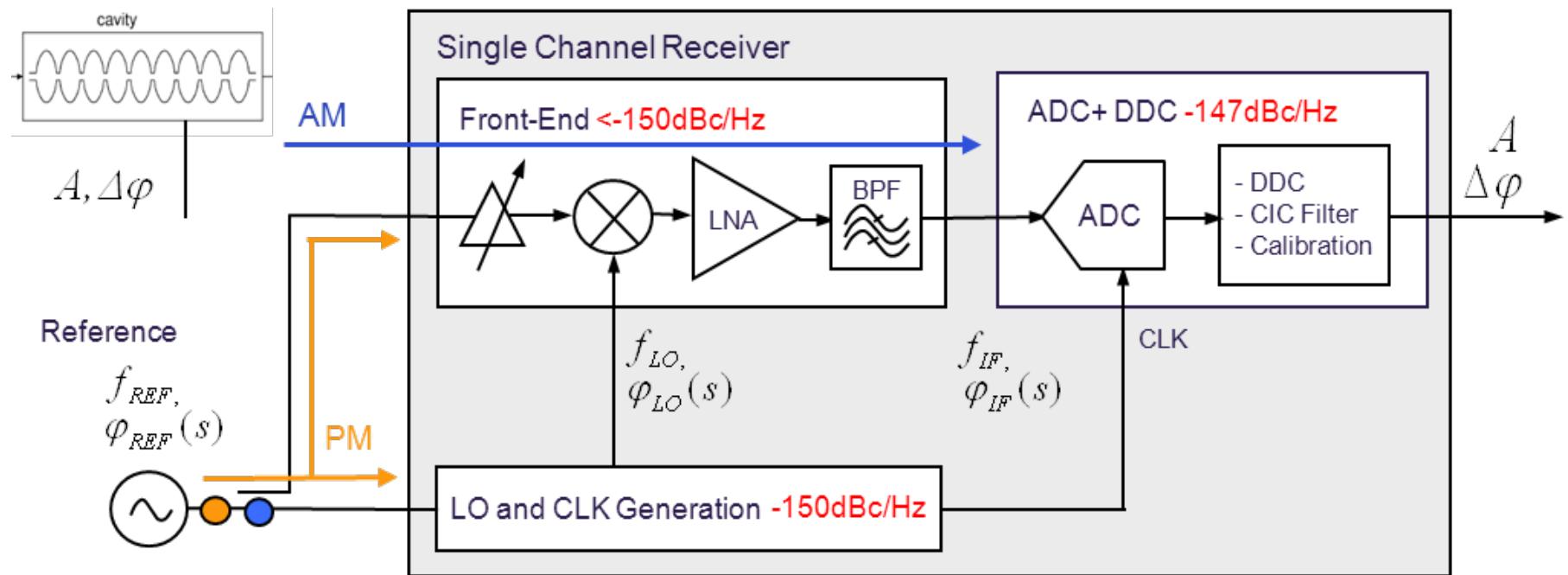
- $5\text{e-}5$ shot-to-shot

> Arrical time jitter:

- $<30\text{fs}$ intra bunch



Limitations of todays Field Detectors.



Linear
Technology
(2007)
LTC220x,
10nV/ $\sqrt{\text{Hz}}$



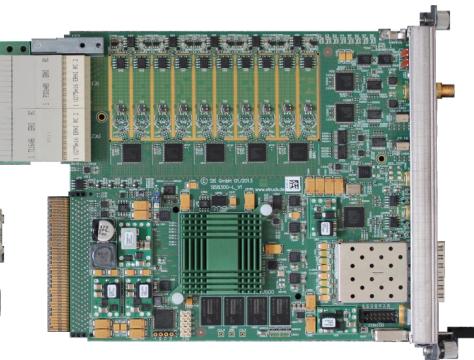
Analog
Devices
(2009)
AD9268-
125,
9nV/ $\sqrt{\text{Hz}}$



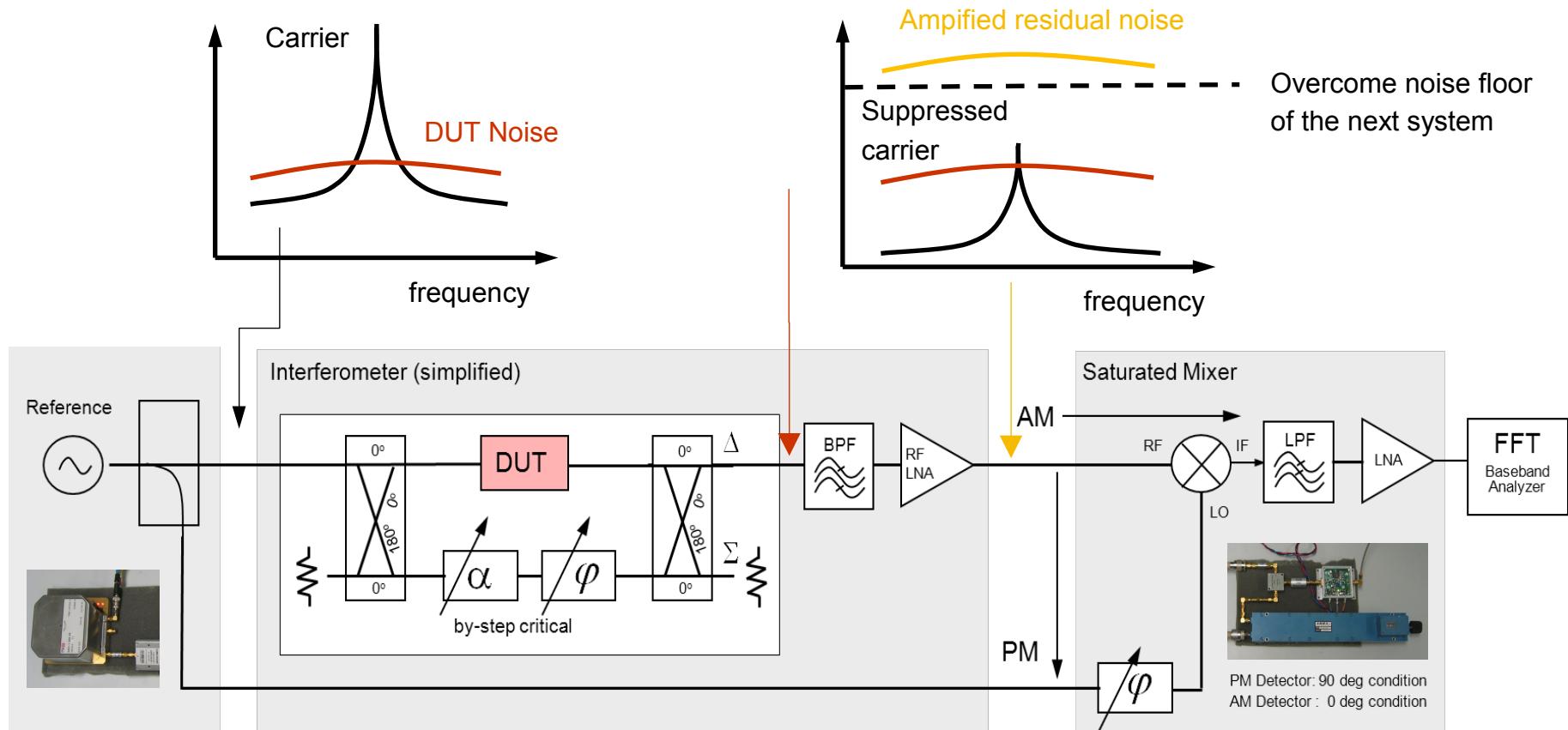
Texas
Instruments
, (2012)
ADS42LB6
9,
14nV/ $\sqrt{\text{Hz}}$



Texas
Instruments,
(2012)
ADC12D800
RF, 9nV/ $\sqrt{\text{Hz}}$



New Detector Scheme for Attosecond LLRF controls.



- > Apply substantial new detector concepts for 1/f-noise reduction
- > Overcome ADC noise limitation by RF amplification before IQ-detection using carrier suppression techniques

New Detector Scheme for Attosecond LLRF controls.

> Saturated mixer:

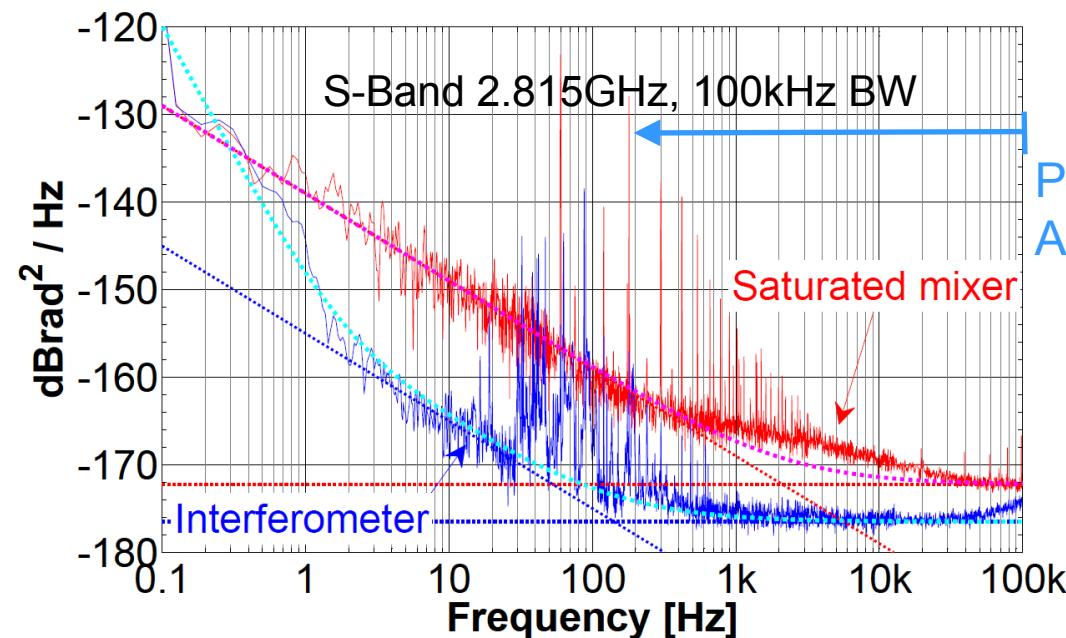
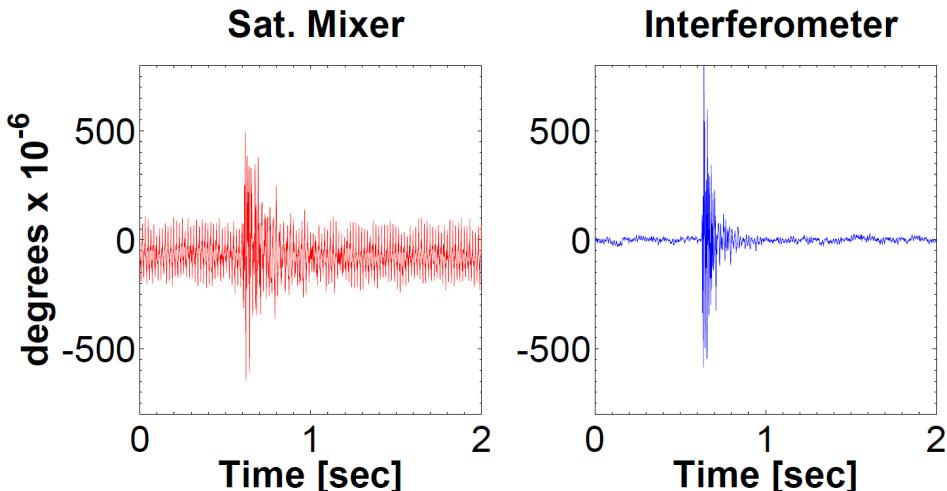
- 165dBc/Hz, <0.5fs resolution, 0.5V/rad

> Interferometer:

- 176dBc/Hz, <50as resolution, 15V/rad

> Carrier suppression

- Reduce 1/f-noise of the RF amplifier



Simulations on Attosecond LLRF Controls.

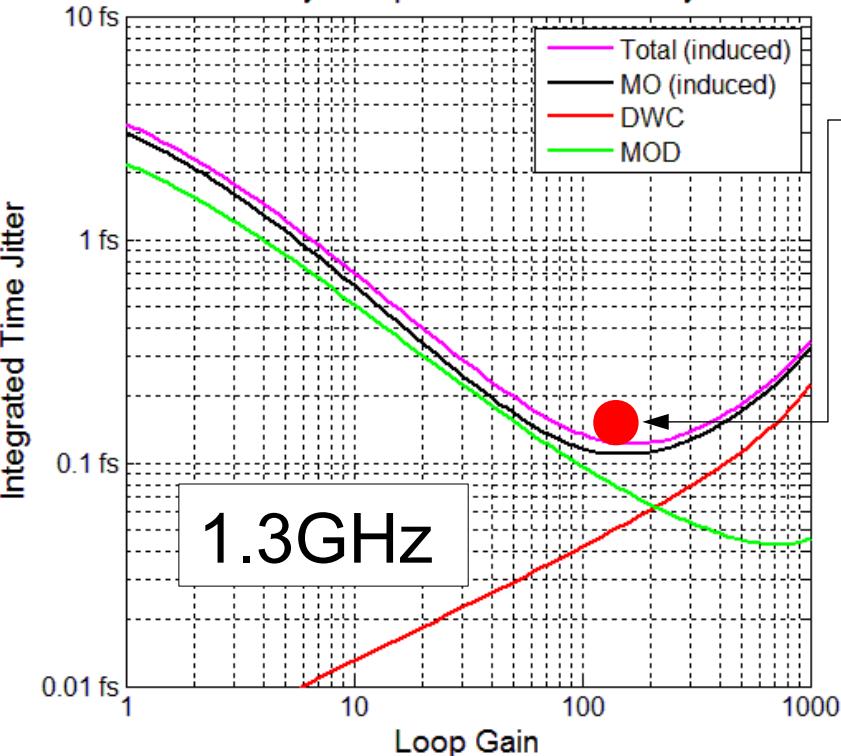
$$S_{\varphi, \text{RES}}(f_m) = \left| \frac{s}{s + \omega'_{12}} \right|^2 S_{\varphi, \text{MO}}(f_m) + \left| \frac{\omega'_{12}}{s + \omega'_{12}} \right|^2 \left[S_{\varphi, \text{DWC}}(f_m) + \frac{1}{g_0^2} S_{\varphi, \text{MOD}}(f_m) \right]$$

high-pass filtered
low-pass filtered

$$\omega'_{12} = g_0 \omega_{12}$$

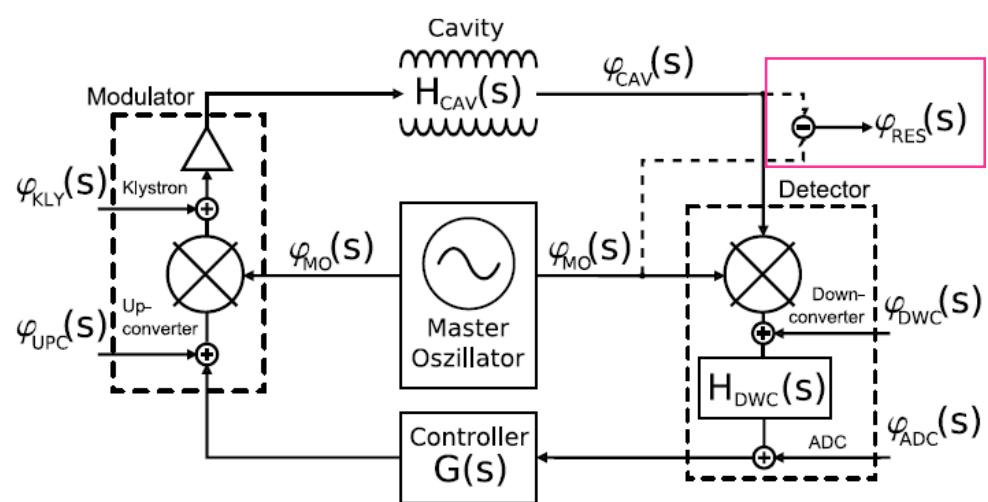
$$G(s) = g_0$$

Cavity field phase noise instability

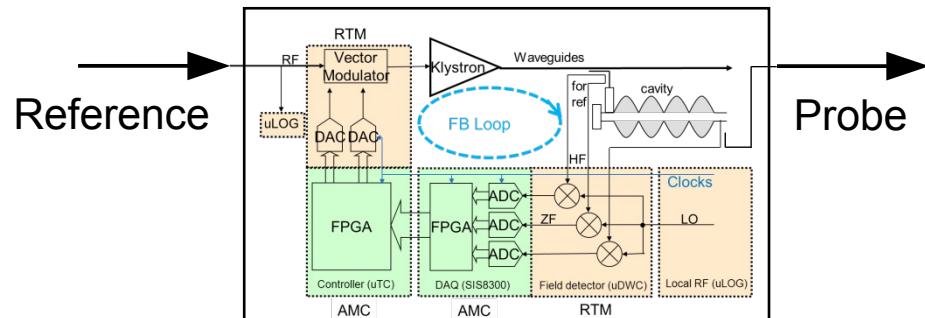


Field jitter:
<200as (rms)

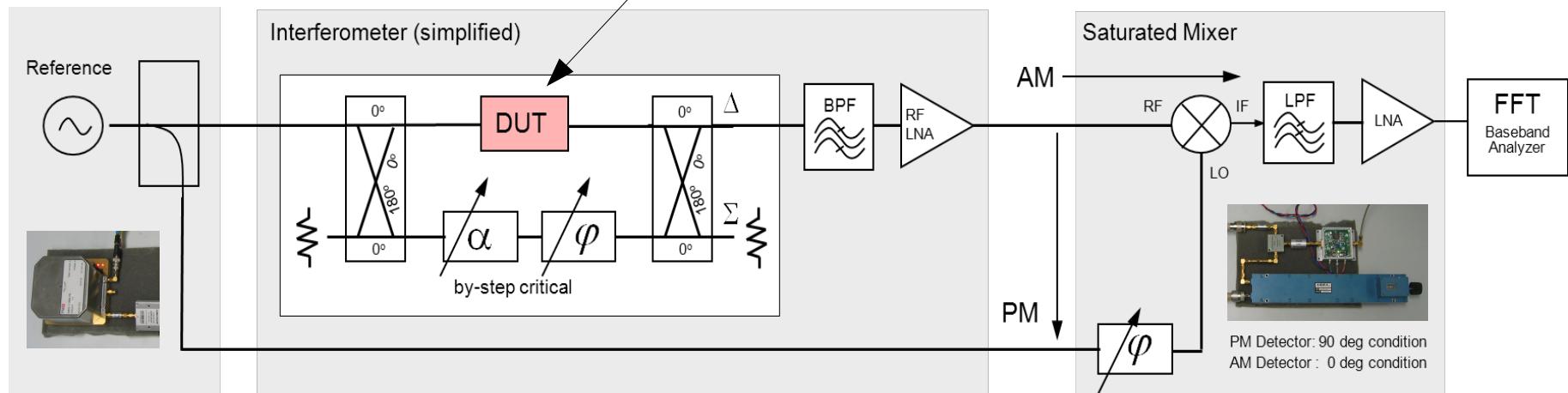
F.Ludwig et. al. 'Phase Stability of the Next Generation RF Field Control for VUV- and X-ray Free Electron Laser', EPAC 2006, Edinburgh, UK.



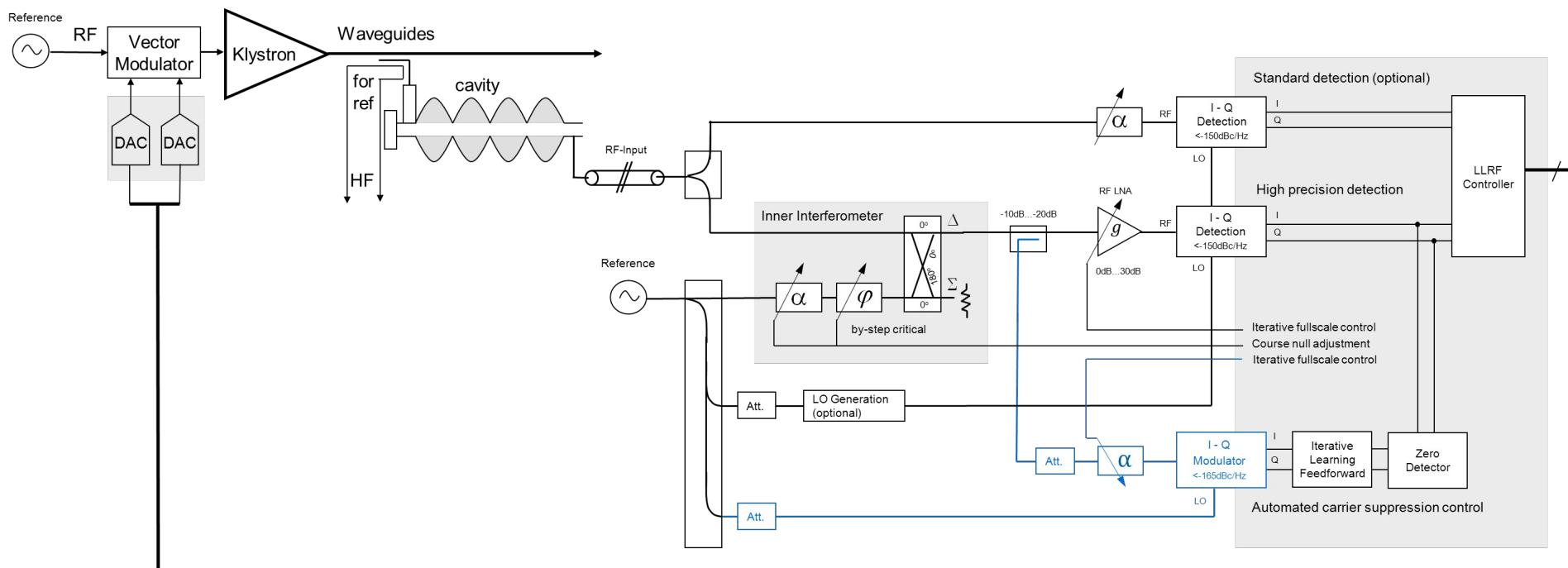
Interferometer for LLRF.



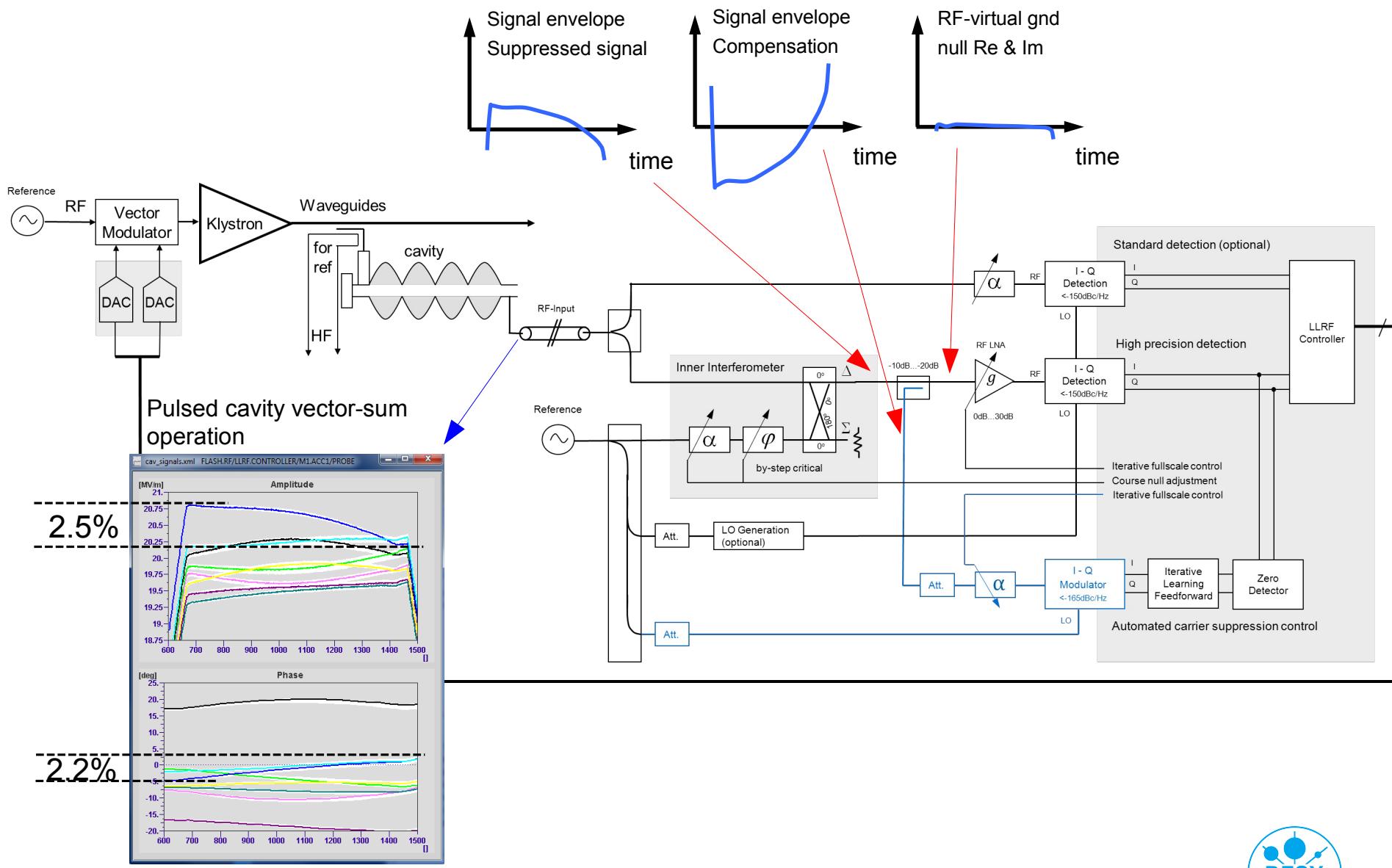
Simplified replacement: **DUT**



Interferometer for LLRF – more Details.



Interferometer for LLRF – even more Details.



Interferometer for LLRF – Summary.

- > Automated carrier suppression tracking (compensate drifts and slopes during flattop)
- > Combine interferometer and non-IQ detector
- > Iteratively or using complementary filters in the controller
- > Needs drift calibration
- > Efficient for continuous wave (CW) operation
- > **Single cavity:** Analog bypassed digital system (hybrids) using complementary filters
- > **Multi cavities:** $\sqrt{3}$ (passive receivers) $\times \sqrt{8}$ (VS-scaling) $\times \sqrt{8}$ (8 receivers per cavity)

Attosecond LLRF Subcomponent Requirements.

> Master reference:

- Machine jitter budget, locking bandwidth
- -15dB..-20dB above unity gain
- DRO, SCLO + passive filtering

> High power actuator chain:

- -10dB by removing spurious
- -10dB by IOTs, solid state amplifiers

> Field detectors:

- -15..-25dB
- Interferometer
- Superscaling
- Analog and digital hybrids

Thank You for Your Attention!

Special acknowledgments to:

Frank Ludwig, Uros Mavric, Holger Schlarb, Christian Schmidt,
Sven Pfeiffer, Tim Berenc