Precision regulation for SRF cavities using MTCA.4

Igor Rutkowski, R. Rybaniec[1]
Ł. Butkowski, C. Schmidt, M. Hoffmann[2]
M. Kuntzsch, H. Büttig, R. Schurig[3]

[1]Warsaw University of Technology
Institute of Electronic Systems
[2]Deutsches Elektronen-Synchrotron
[3]Helmholtz-Zentrum Dresden-Rossendorf

11.12.2014

Outline

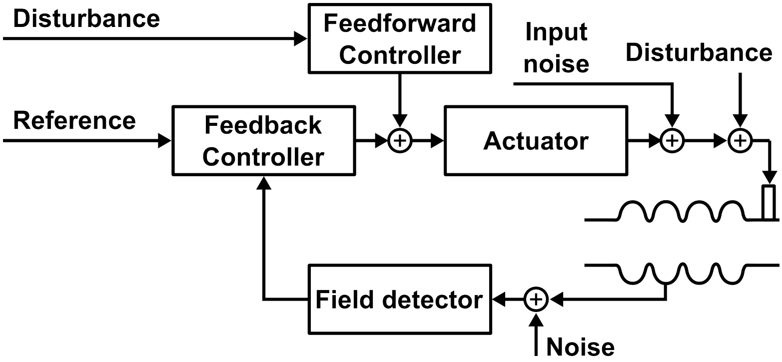
Sources of distrubances

- Cavity dynamics (filling/decay)
- Change of resonance frequency
  - Microphonics
  - Lorentz force detuning
  - Thermal effects (power dependent)
- Beam loading
  - Pulsed beam transient
  - Beam current fluctuation
- Quality of drive signal
  - Master Oscillator signal's fidelity
  - High power amplfiers' noise and distortions
  - Feedback system response
- Other
  - Drifts (cabling, electronics, power amplifiers)

Sources of distrubances in CW

- ~~Cavity dynamics (filling/decay)~~
- Change of resonance frequency
  - Microphonics
  - ~~Lorentz force detuning~~
  - ~~Thermal effects (power dependent)~~
- Beam loading
  - Pulsed beam transient
  - Beam current fluctuation
- Quality of drive signal
  - Master Oscillator signal's fidelity
  - High power amplfiers' noise and distortions
  - Feedback system response
- Other
  - Drifts (cabling, electronics, power amplifiers)

Control loop block diagram



Loop simulations

Cavity model

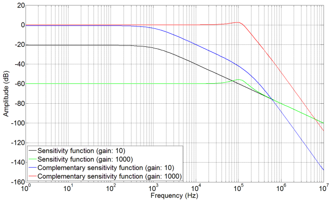
The transfer function of the cavity for π-mode is equal to

$$H_{cav}(s) = \frac{\omega_{1/2}}{\Delta\omega^2 + (s + \omega_{1/2})^2} \begin{pmatrix} s + \omega_{1/2} & -\Delta\omega \\ \Delta\omega & s + \omega_{1/2} \end{pmatrix}$$

where $\omega_{1/2} = \frac{w_0}{2 * Q_l}$, $\Delta\omega = \omega_0 - \omega$ is the detuning

Transfer Function

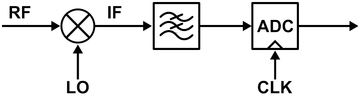
Sensitivty TF: from disturbance input to system output
Complementary sensitivity TF: reference signal/resiudal detector noise to the system's output



Proportional controller

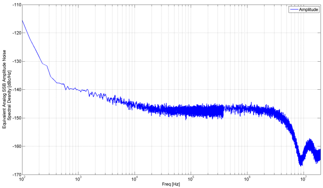
Field detection

- Possibilities: direct sampling, amplitude and phase detection, direct demodulation, heterodyne receiver, and others
- Considerations: noise, price, long term stability

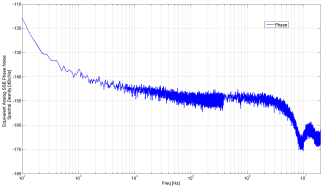


Heterodyne receiver

+Low noise, good linearity



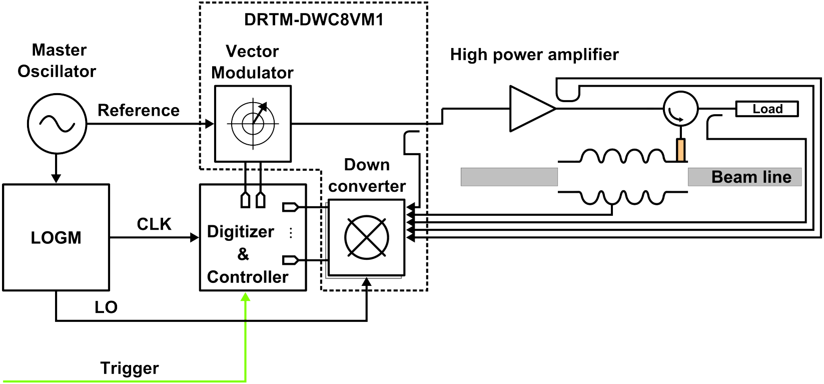
Amplitude noise - bandwidth [100 Hz- 1MHz]. Integrated: 5E-6



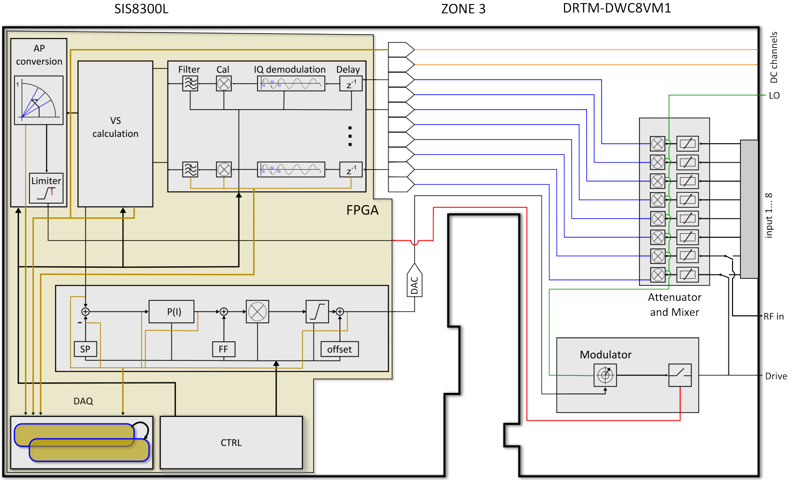
Phase noise - bandwidth [100 Hz- 1MHz]. Integrated: 7 fs.

U. Mavric, et al., "Multi-Channel Down-Conversion for MicroTCA.4 Based Control Systems," in *Proc. of the 2014 Real-Time Conf.*

Schematic block diagram of LLRF system (one cavity)

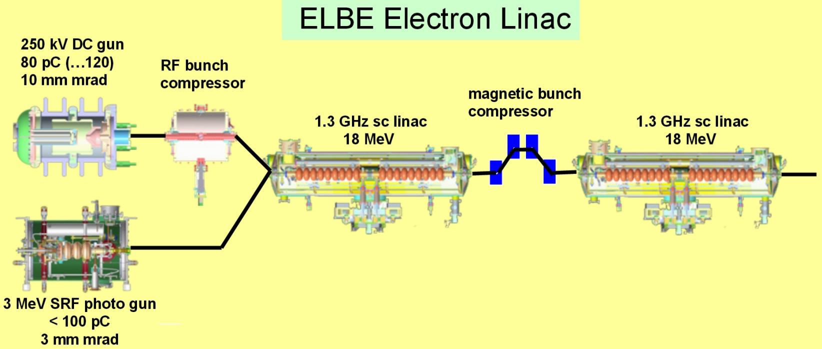


FW/HW Block diagram



Courtesy of Christian Schmidt, with later modifications.

Layout of ELBE



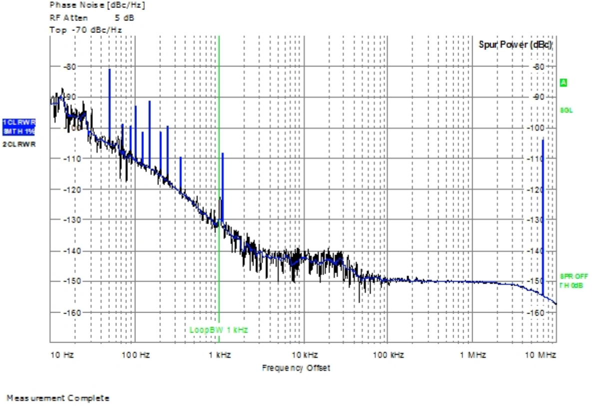
Source: Peter Michel "ELBE Upgrade", ARD Workshop February 2013

Reference and LO

New MO

R&S FSUP 26 Signal Source Analyzer — LOCKED

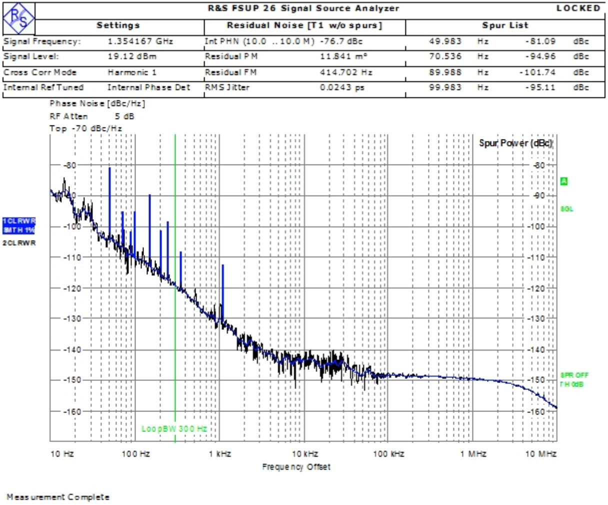
Settings		Residual Noise [T1 w/o spurs]		Spur List			
Signal Frequency:	1.300000 GHz	Int PHN (10.0 .. 10.0 M)	-78.2 dBc	100.025	Hz	-95.97	dBc
Signal Level:	14.88 dBm	Residual PM	9.930 m°	70.594	Hz	-98.80	dBc
Cross Corr Mode	Harmonic 1	Residual FM	472.338 Hz	89.989	Hz	-99.54	dBc
Internal Ref Tuned	Internal Phase Det	RMS Jitter	0.0212 ps	100.009	Hz	-92.69	dBc



1/2 Link locked, 3/4 Link unlocked

Reference and LO

Mixer based LOGM

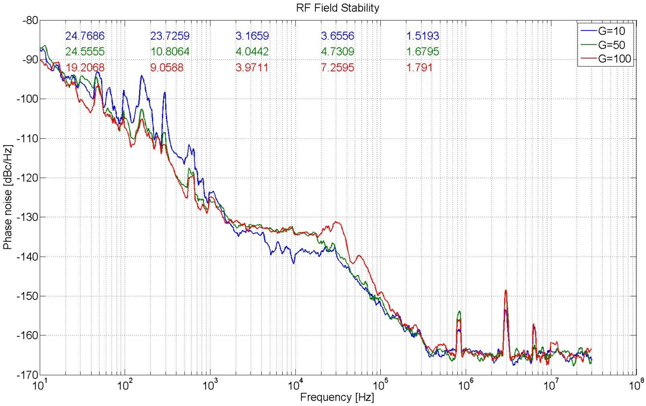


R&S FSUP 26 Signal Source Analyzer							LOCKED
Settings		Residual Noise [T1 w/o spurs]		Spur List			
Signal Frequency:	1.354167 GHz	Int PHN (10.0 .. 10.0 M)	-76.7 dBc	49.983	Hz	-81.09	dBc
Signal Level:	19.12 dBm	Residual PM	11.841 m°	70.536	Hz	-94.96	dBc
Cross Corr Mode	Harmonic 1	Residual FM	414.702 Hz	89.988	Hz	-101.74	dBc
Internal Ref Tuned	Internal Phase Det	RMS Jitter	0.0243 ps	99.983	Hz	-95.11	dBc

1/2 Link locked, 3/4 Link unlocked

Cavity 1

Gradient 10.5 MV/m and 800 uA beam.



Gain	10	50	100
Jitter (fs)	34.67	27.59	22.86

- Automated in-loop gradient ramp up
- Long-term tests
- Control system integration (MTCA4U)
- Real-time beam loading compensation

Acknowledgments

- HZDR team, esp. Michael Kuntzsch, Hartmut Büttig, Ulf Lehnert, Rico Schurig
- Maciej Grzegrzółka - setting up the system
- Radek Rybaniec, Łukasz Butkowski - Firmware
- Christian Schmidt, Matthias Hoffmann, Sven Pfeiffer, Wojtek Cichalewski - control theory, cavity operation, beam-based FB, IQ detection, experience as operators

Questions

Thank You for attention!