

# Improvements of the LLRF system at FLASH

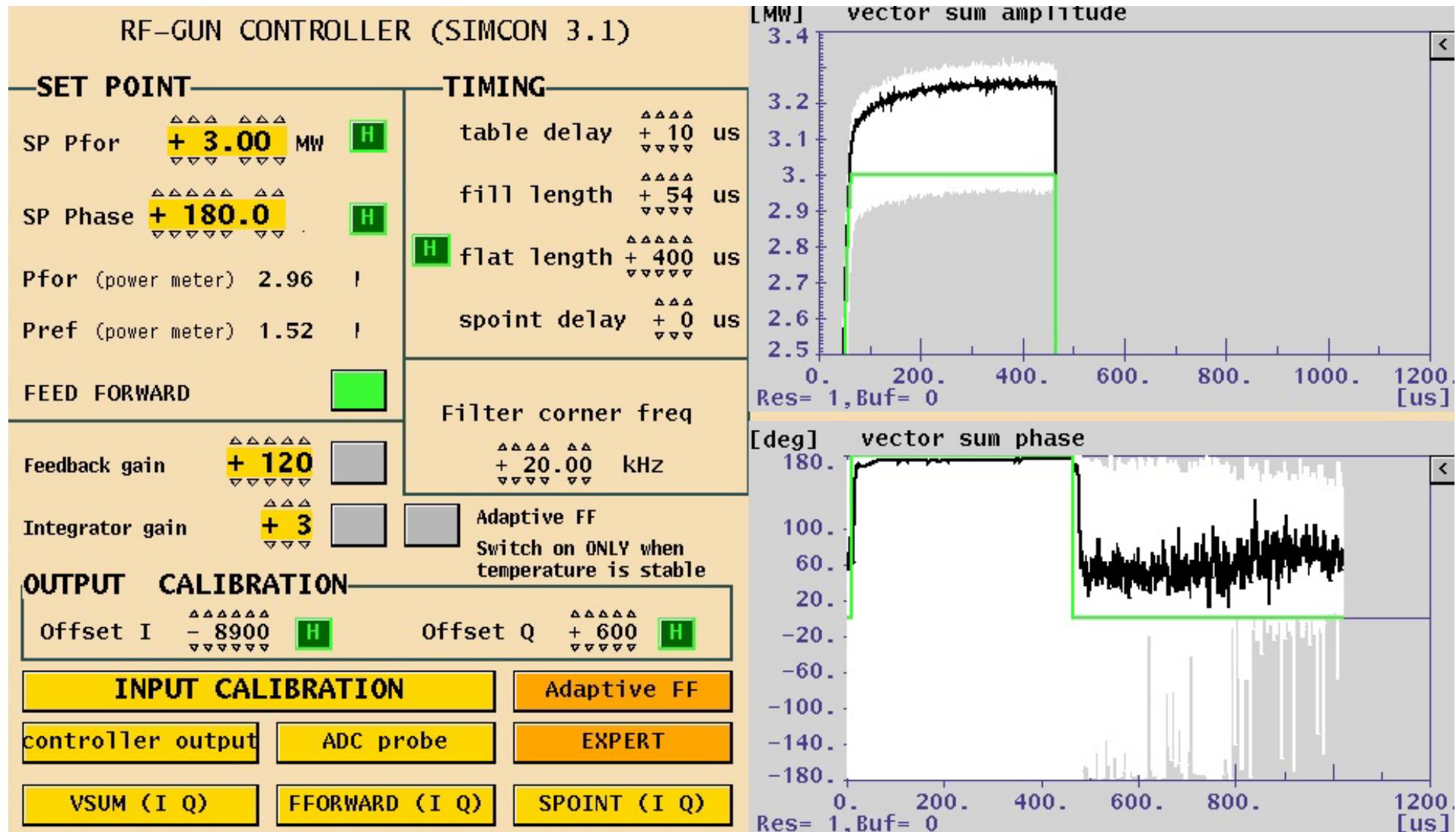
Mariusz Grecki, Waldemar Koprek  
and LLRF team

# Agenda

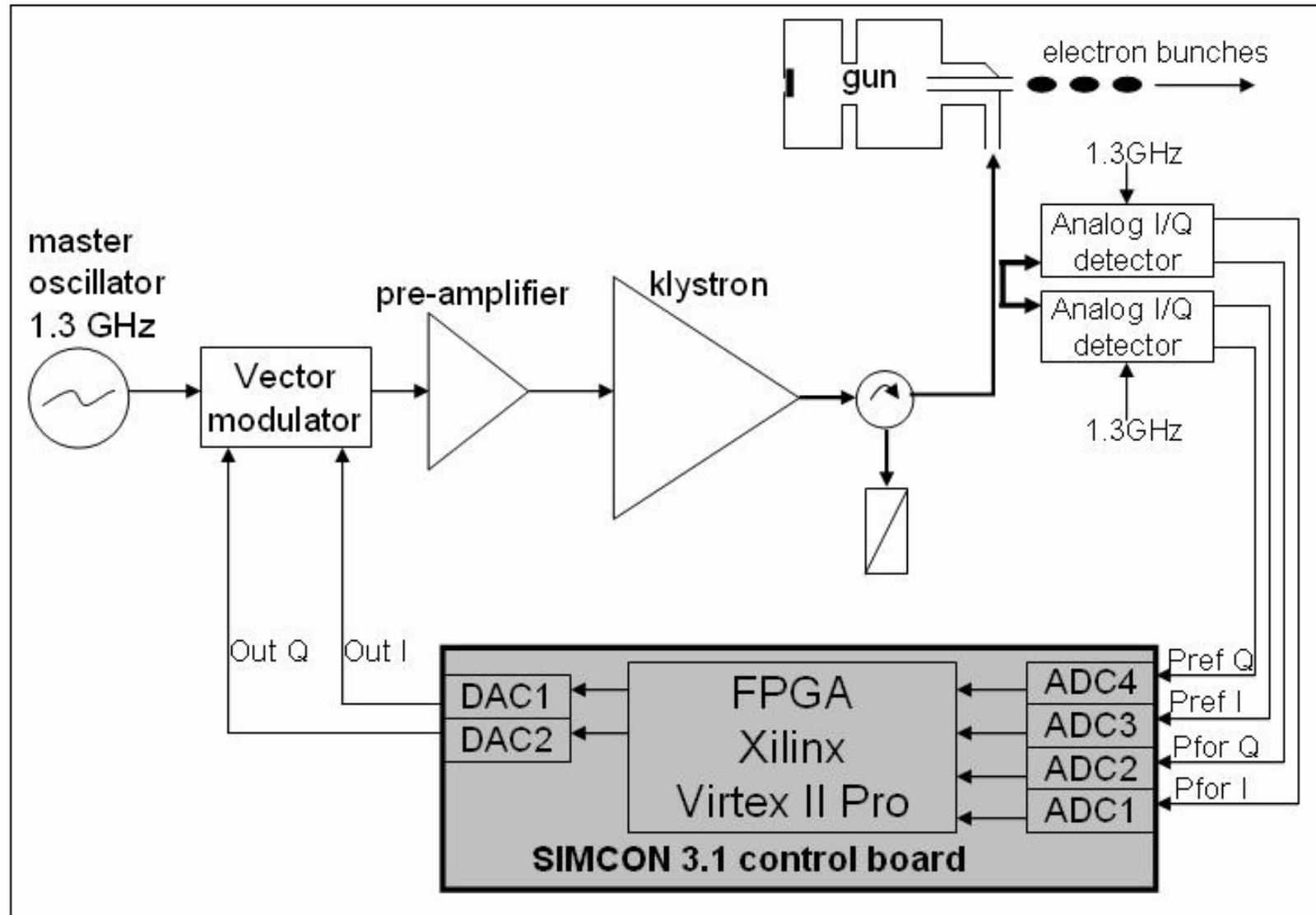
- GUN linearization
- Adaptive feed-forward at ACC1
- Beam load compensation at ACC1
- Klystron nonlinearity compensation
- Detuning measurement and Piezo control

# Gun linearization

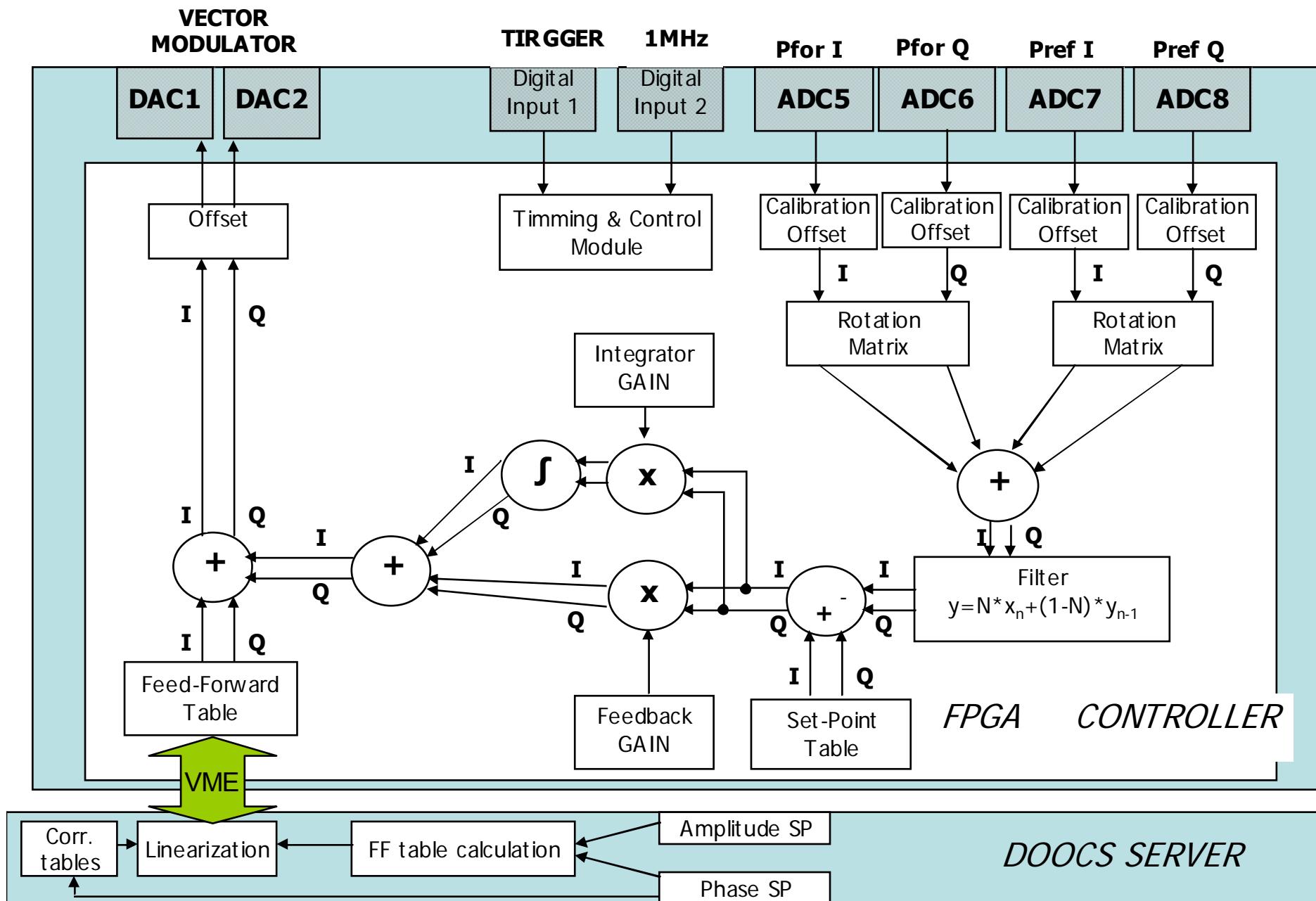
# Where is the problem?



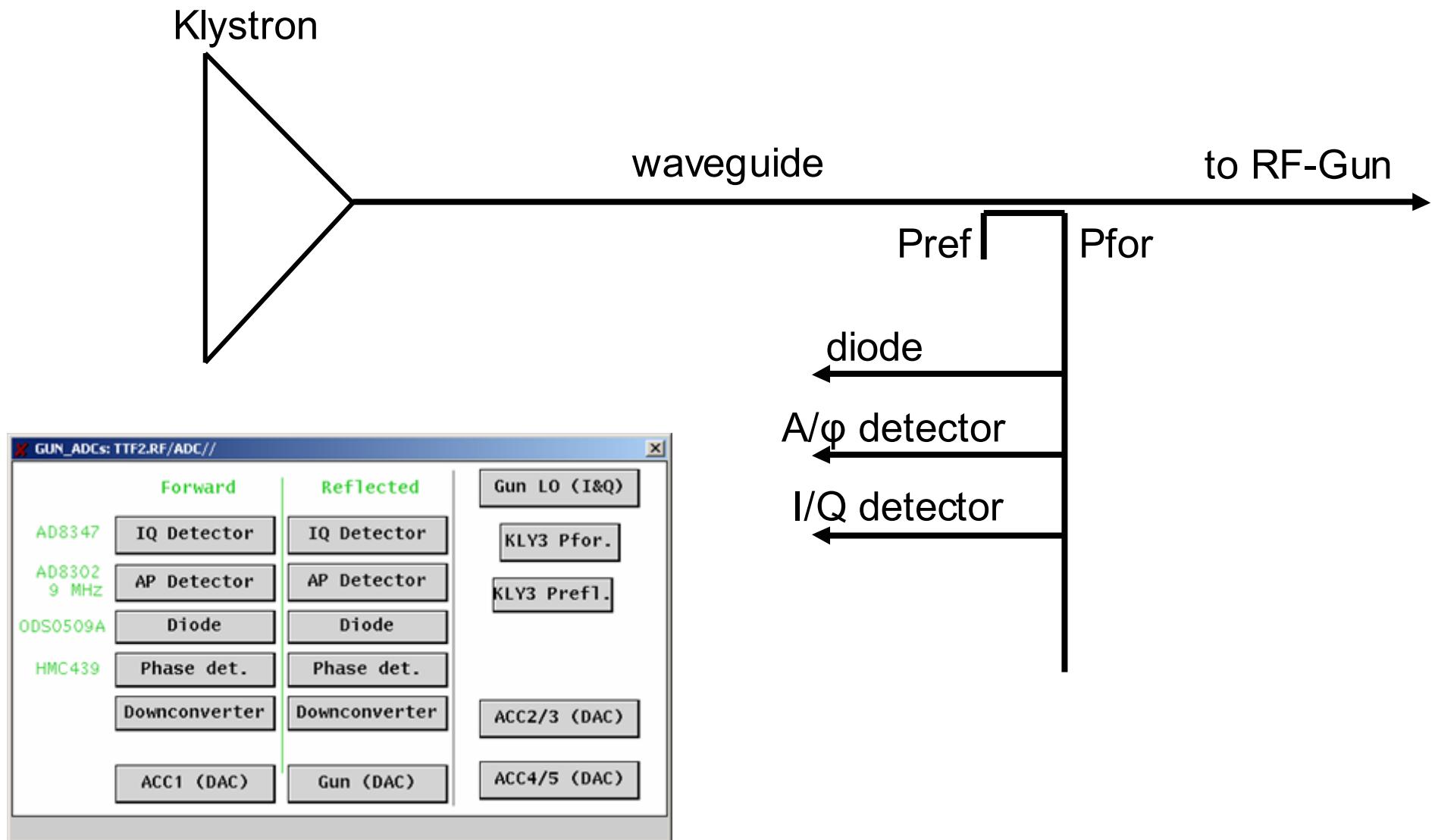
# RF-Gun setup



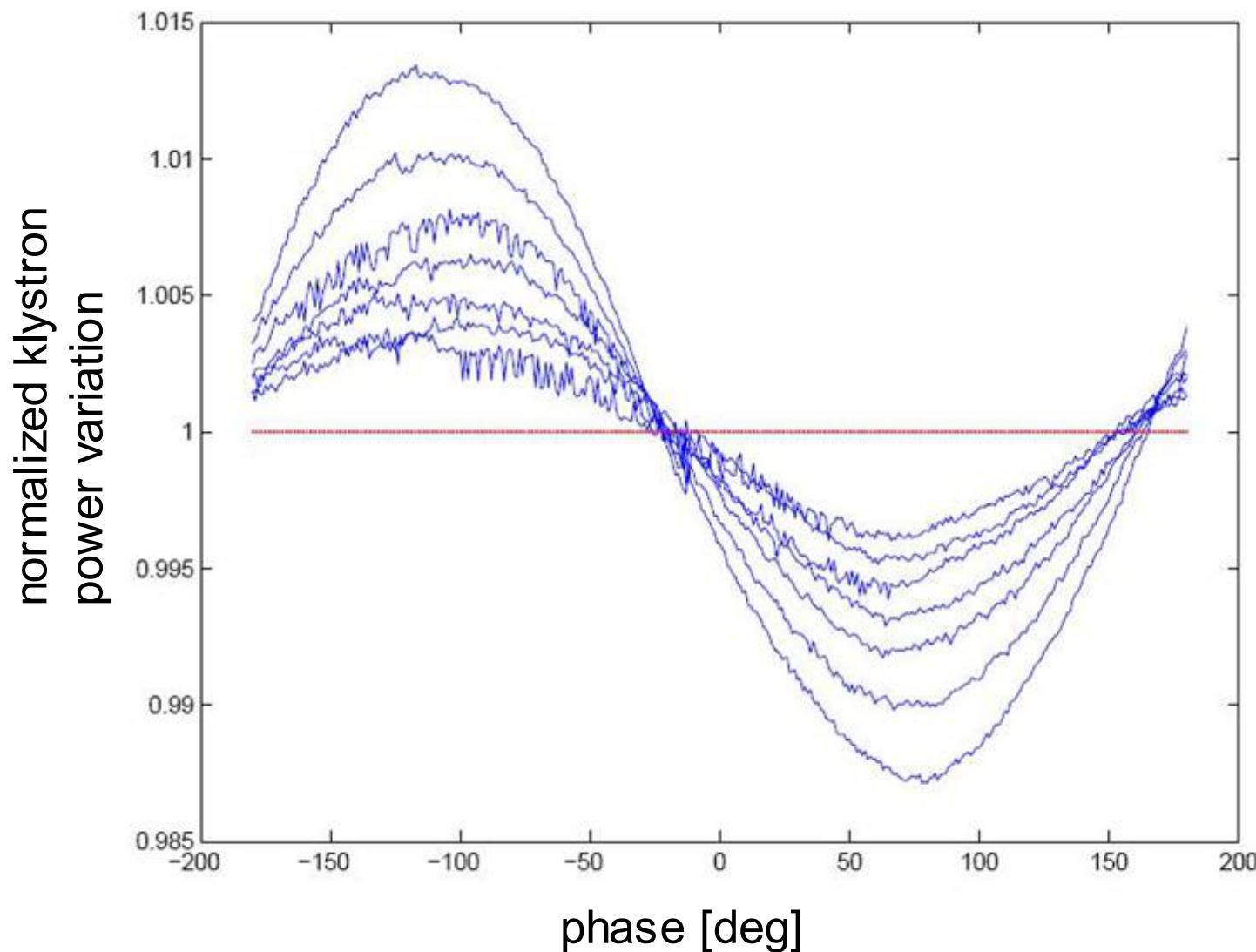
# High power chain linearization



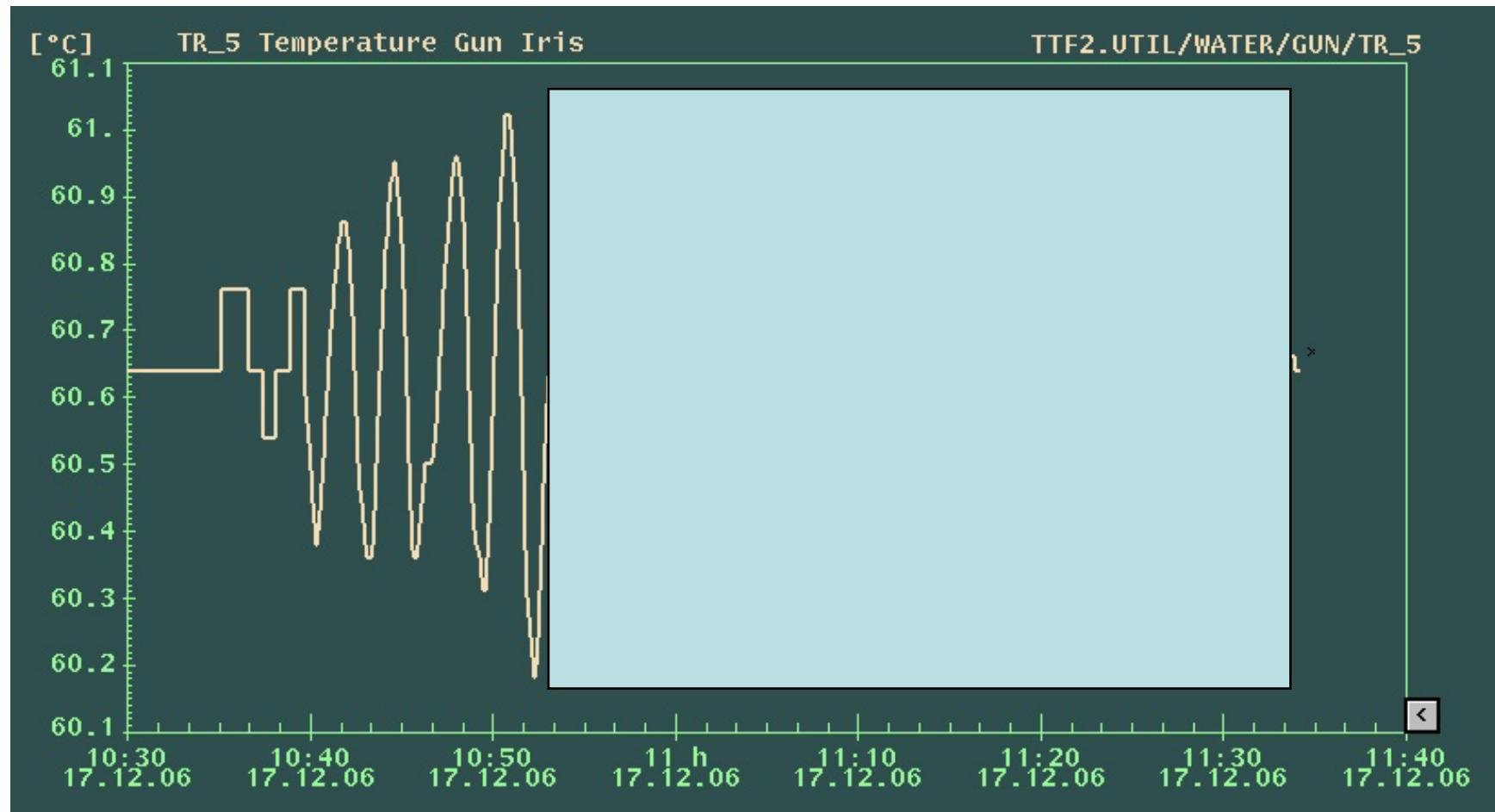
# Measurement devices of GUN forward power



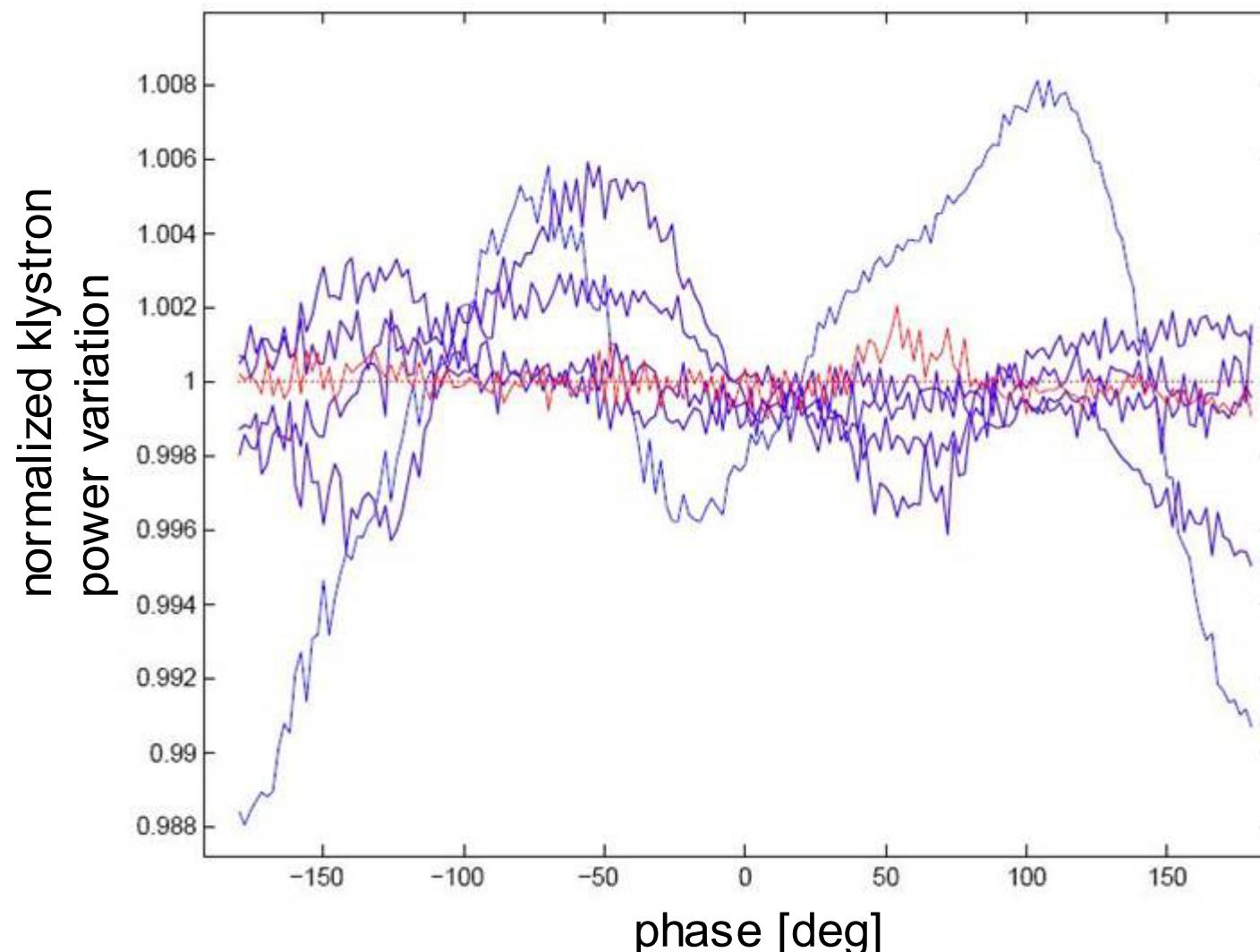
# High power chain linearization based on amplitude detector measurement



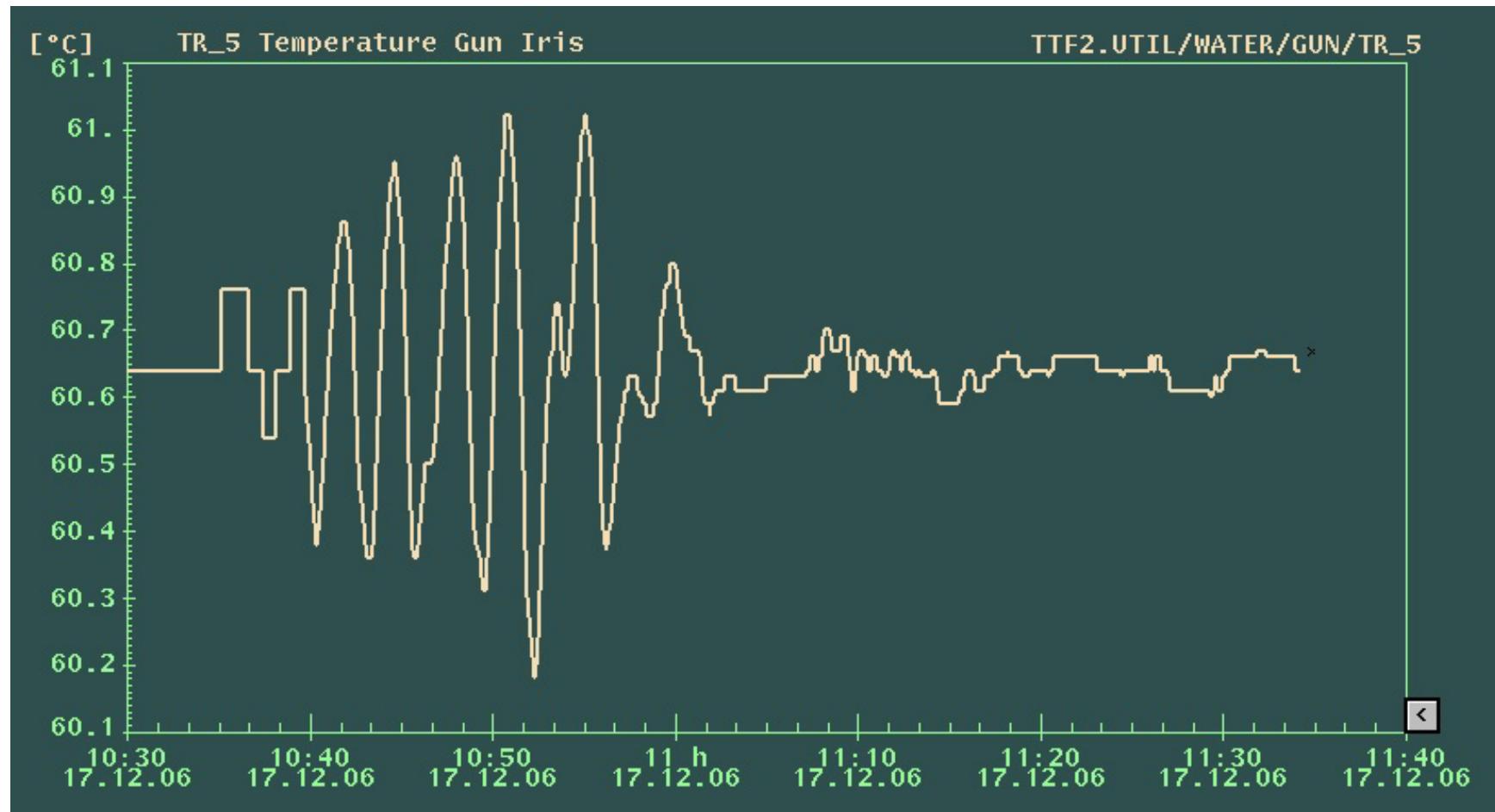
# Temperature behaviour during linearization



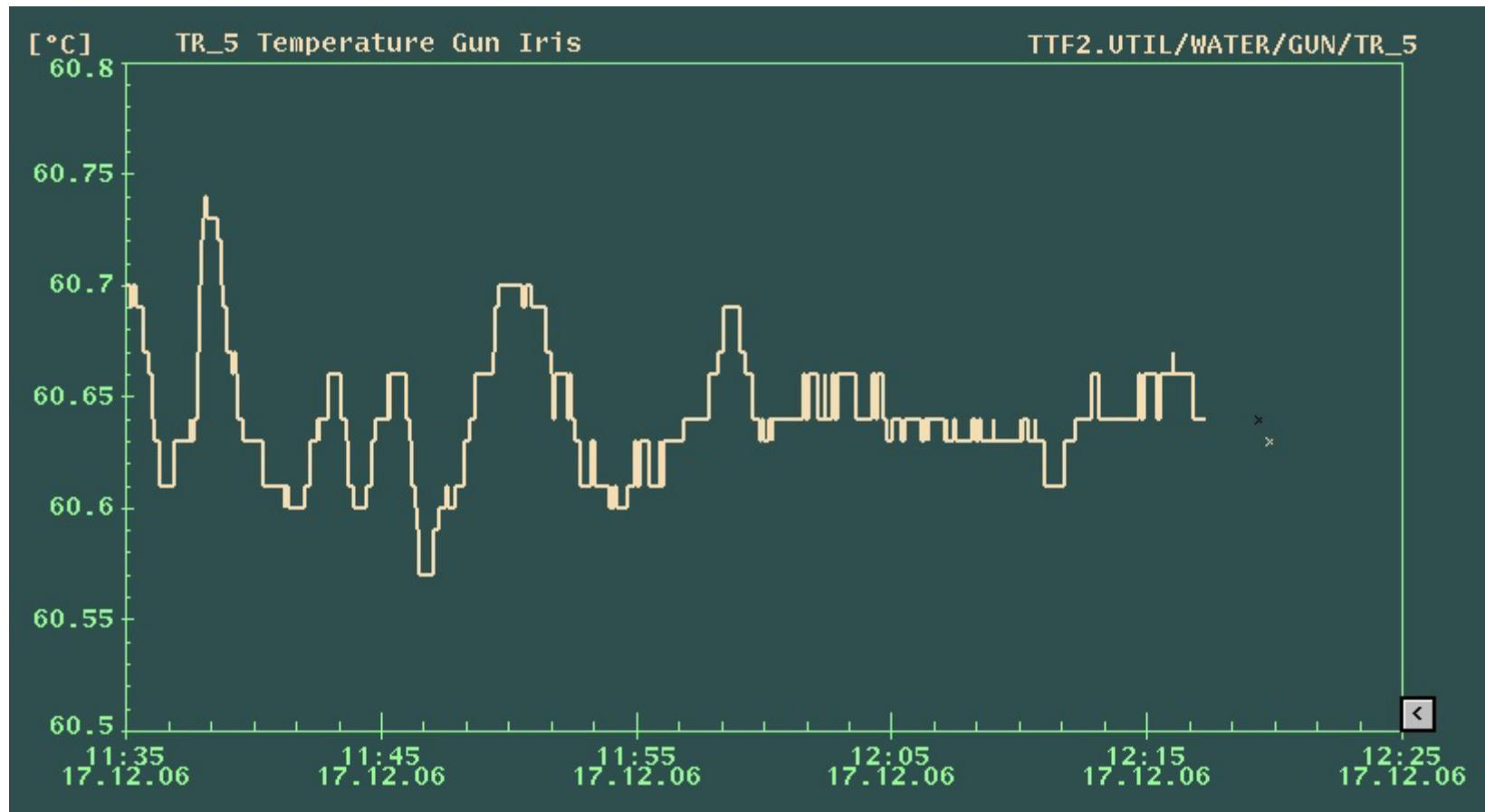
# High power chain linearization based on diode measurement



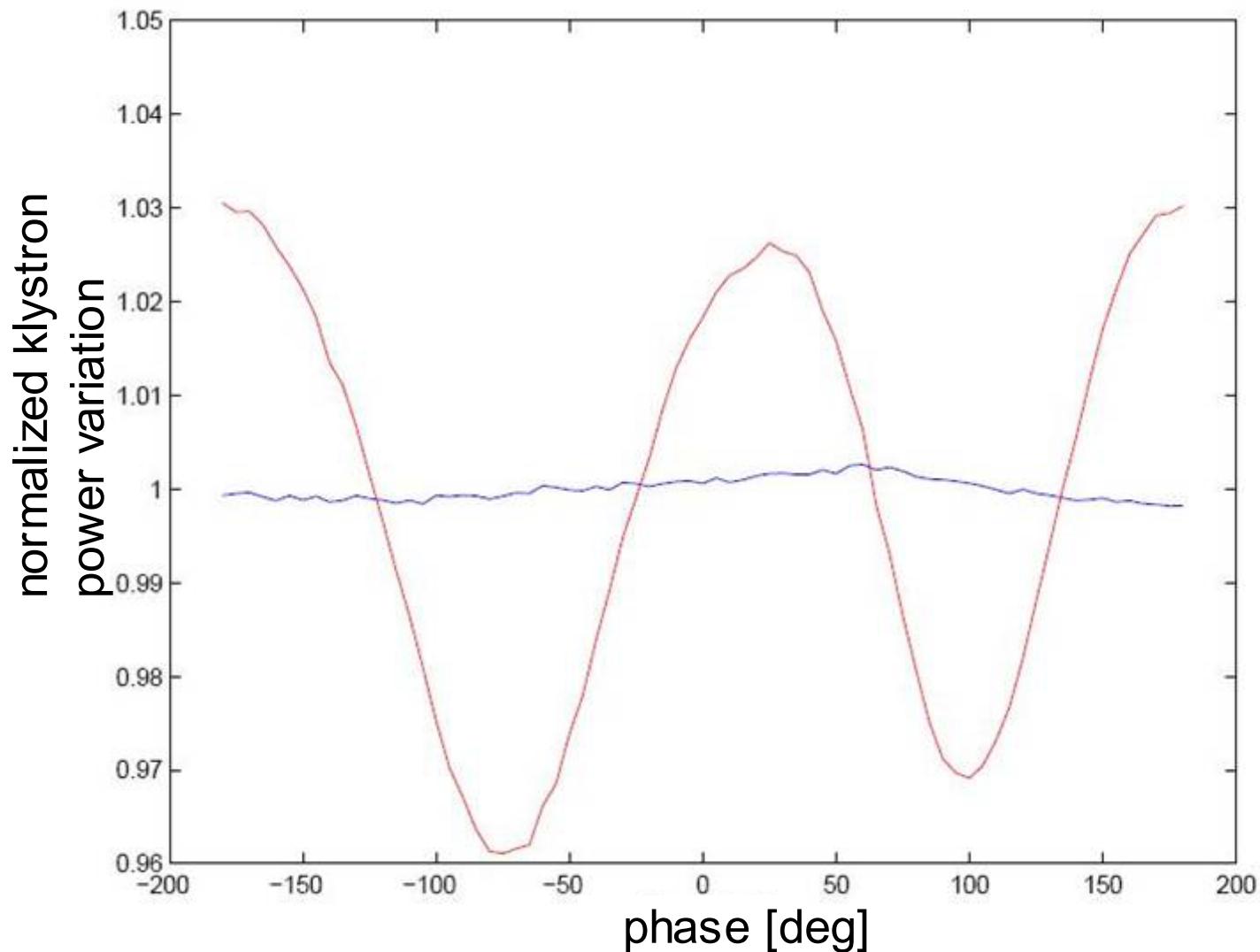
# Temperature behaviour during linearization



# Temperature behaviour during linearization

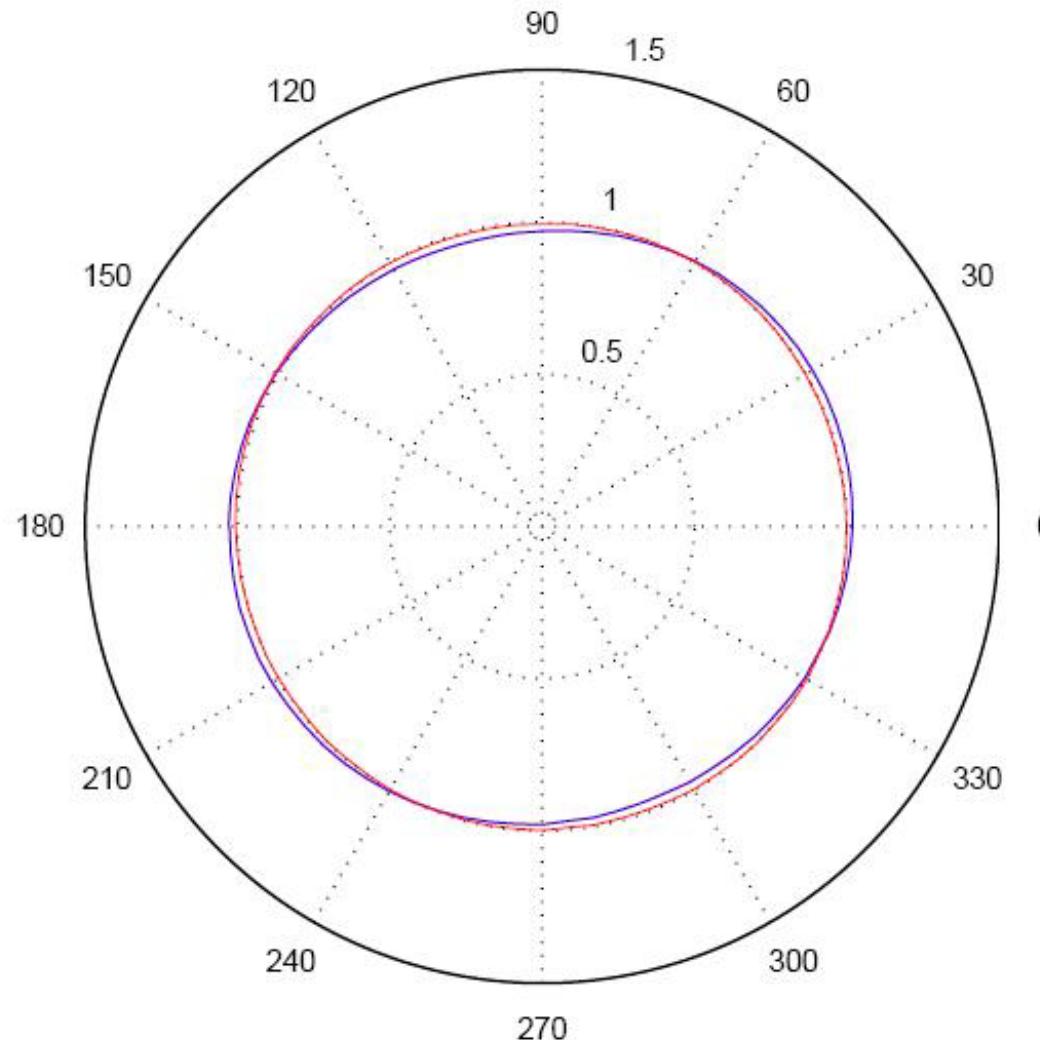


# Phase of diode vs forward power measured in SIMCON



# Phase scan of forward power

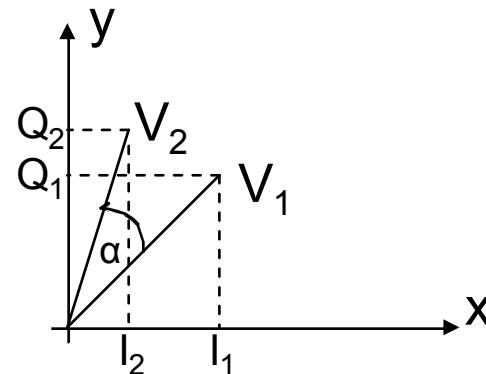
Input Power Forward calibration – /home/ttflinac/user/wkoprek/gunphase/FPGAGunPforCal.m



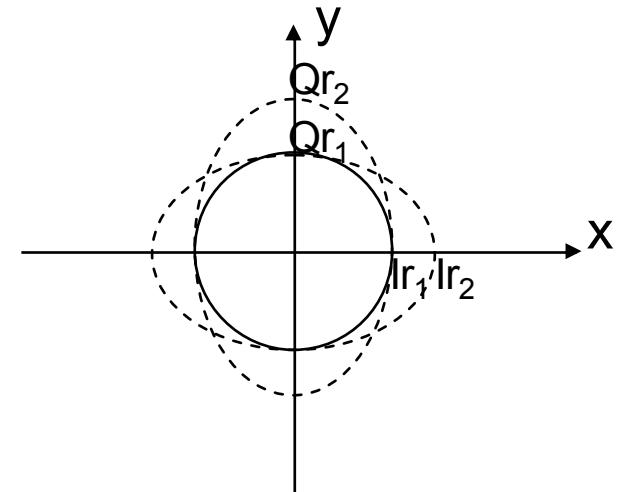
blue – before calibration, red – after calibration

# Rotation matrix

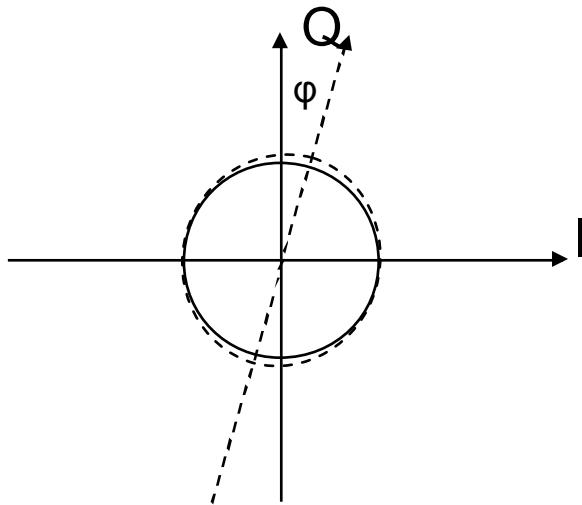
$$\begin{bmatrix} I_2 \\ Q_2 \end{bmatrix} = \begin{bmatrix} \cos(\alpha) & -\sin(\alpha) \\ \sin(\alpha) & \cos(\alpha) \end{bmatrix} \times \begin{bmatrix} I_1 \\ Q_1 \end{bmatrix}$$



$$\begin{bmatrix} I_2 \\ Q_2 \end{bmatrix} = \begin{bmatrix} A_{11} * \cos(\alpha) & -A_{12} * \sin(\alpha) \\ A_{21} * \sin(\alpha) & A_{22} * \cos(\alpha) \end{bmatrix} \times \begin{bmatrix} I_{in} \\ Q_{in} \end{bmatrix}$$



# Non-orthogonal I & Q



$$I_{\text{out}} = I_{\text{in}} + Q_{\text{in}} * \sin(\varphi)$$

$$Q_{\text{out}} = -Q_{\text{in}} * \cos(\varphi)$$

# New DOOCS control panels

$$\begin{bmatrix} I_{\text{rot}} \\ Q_{\text{rot}} \end{bmatrix} = \begin{bmatrix} A_{11} * \cos(\alpha) & -A_{12} * \sin(\alpha) \\ A_{21} * \sin(\alpha) & A_{22} * \cos(\alpha) \end{bmatrix} \times \begin{bmatrix} I_{\text{in}} \\ Q_{\text{in}} \end{bmatrix}$$

$$I_{\text{out}} = I_{\text{in}} + Q_{\text{in}} * \sin(\varphi)$$

$$Q_{\text{out}} = Q_{\text{in}} * \cos(\varphi)$$

	POW FOR I	POW FOR Q	POW REF I	POW REF Q
OFFSET	+ 900 ▼▼▼▼	+ 1690 ▼▼▼▼	+ 1440 ▼▼▼▼	+ 1050 ▼▼▼▼
GAIN	+ 1.00 ▼▼▼▼	+ 1.04 ▼▼▼▼	+ 1.26 ▼▼▼▼	+ 1.26 ▼▼▼▼
Cal MW HV		+ 4.30 ▼▼▼▼		
PHASE	+ 0.00 deg ▼▼▼▼		- 89.0 deg ▼▼▼▼	
LOOP PHASE		- 40.0 deg ▼▼▼▼		
	Expert settings			

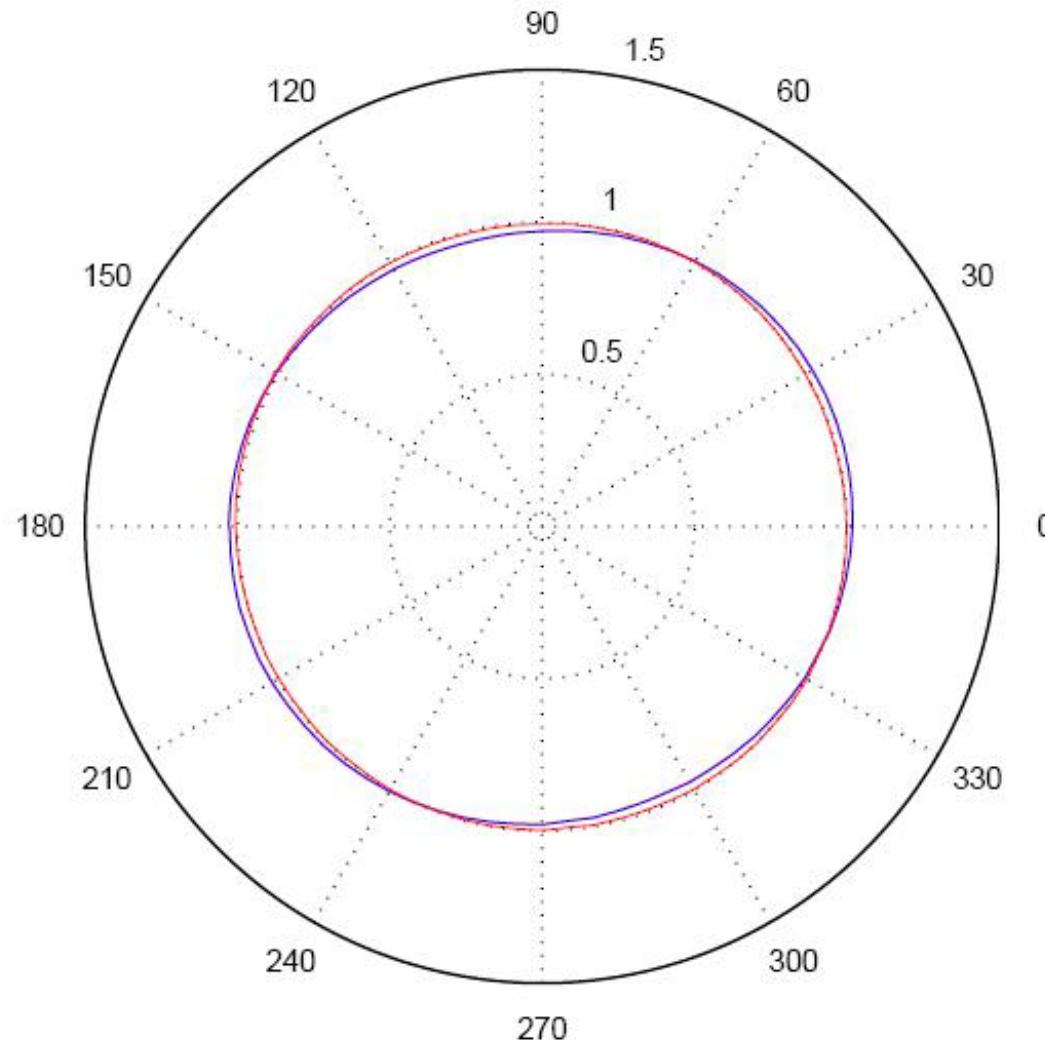
Input calibration panel

power forward	power reflected
phi - 1.00 ▼▼▼▼	phi - 2.00 ▼▼▼▼
A11 + 0.900 ▼▼▼▼	A12 + 0.900 ▼▼▼▼
A21 + 0.930 ▼▼▼▼	A22 + 0.930 ▼▼▼▼

Advanced input calibration panel

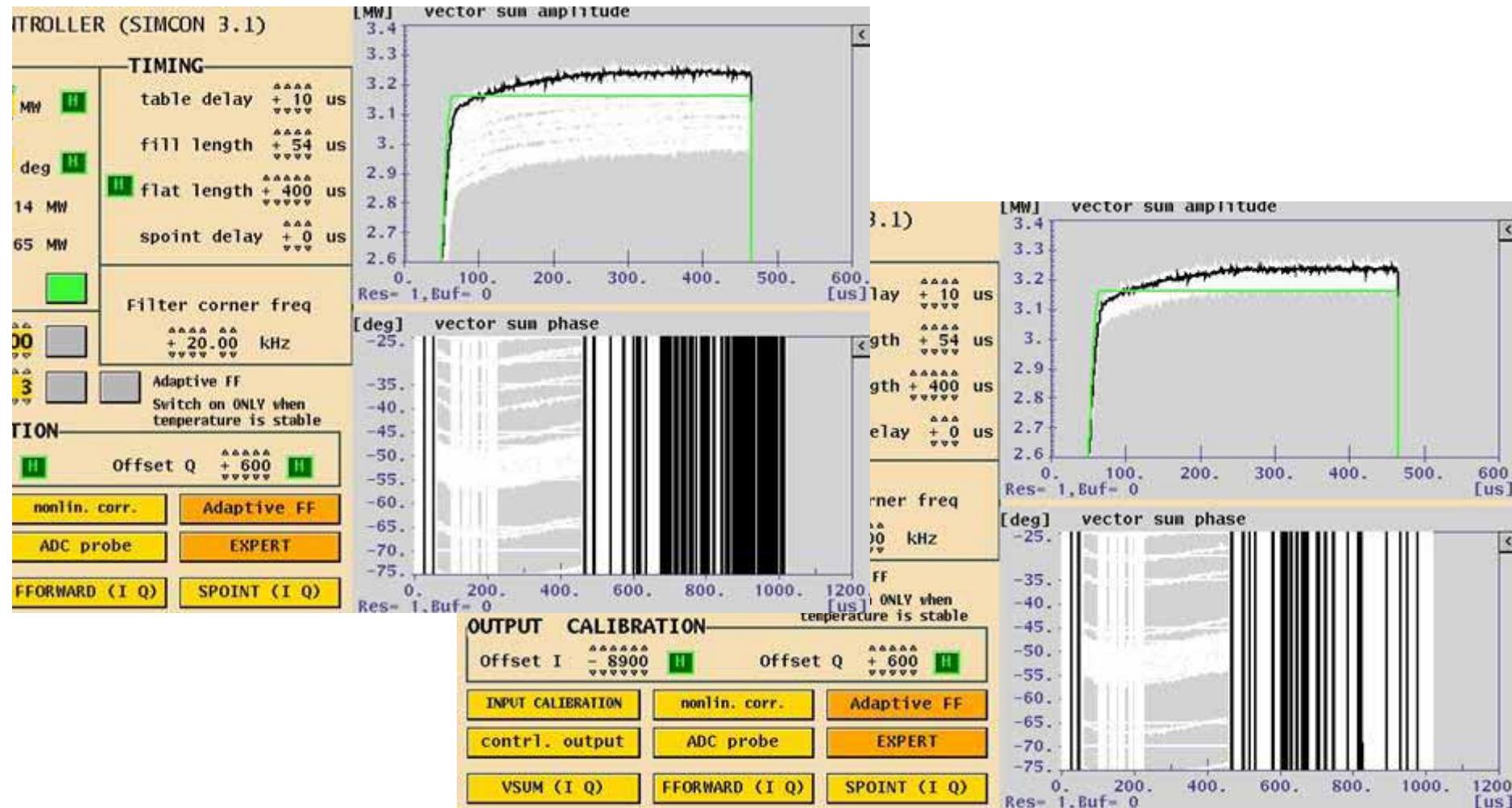
# Phase scan of forward power

Input Power Forward calibration – /home/ttflinac/user/wkoprek/gunphase/FPGAGunPforCal.m



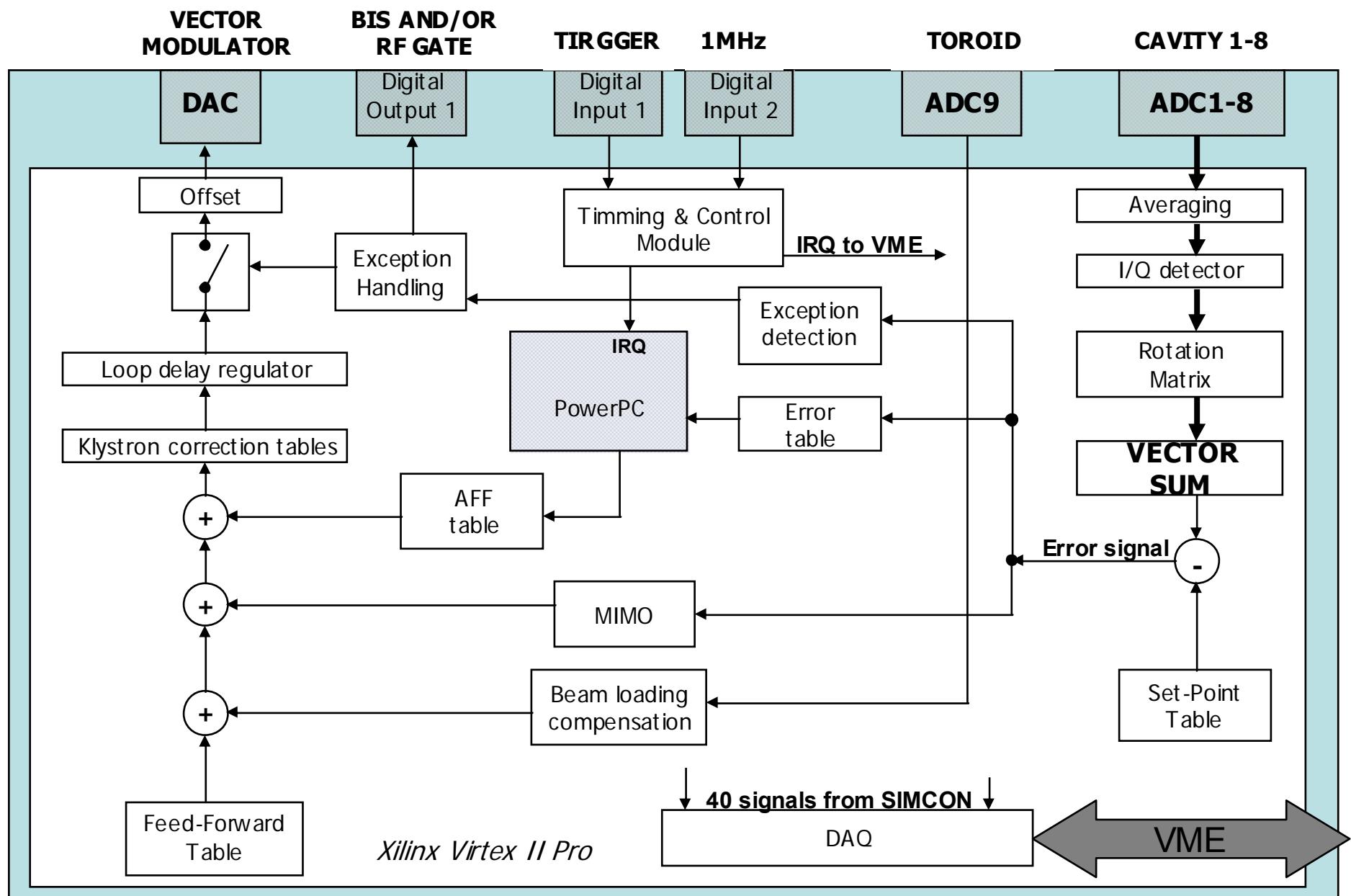
blue – before calibration, red – after calibration

# Before and after input linearization



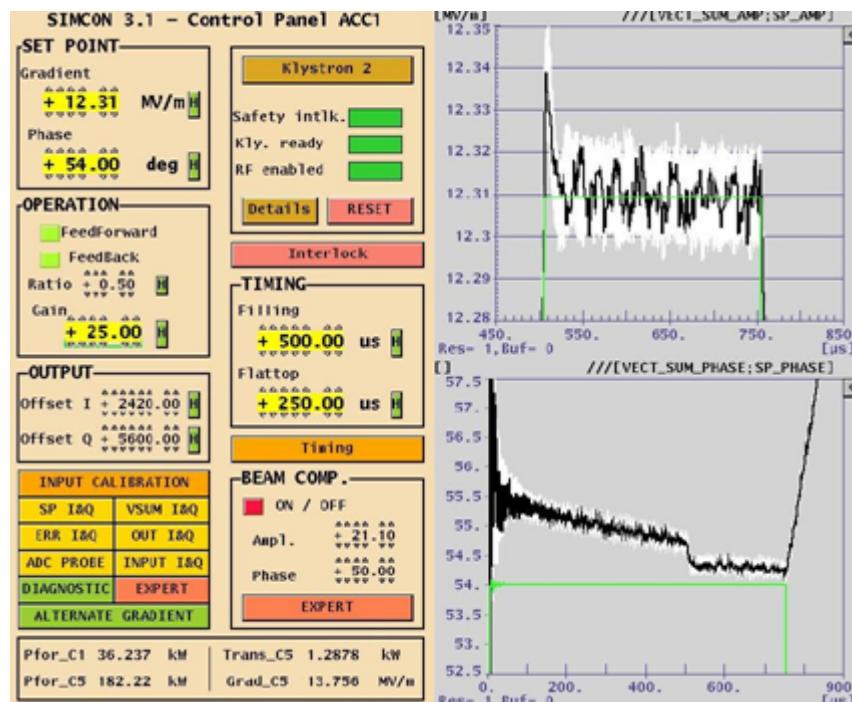
# Adaptive FF at ACC1

# SIMCON 3.1 BOARD – FIRMWARE

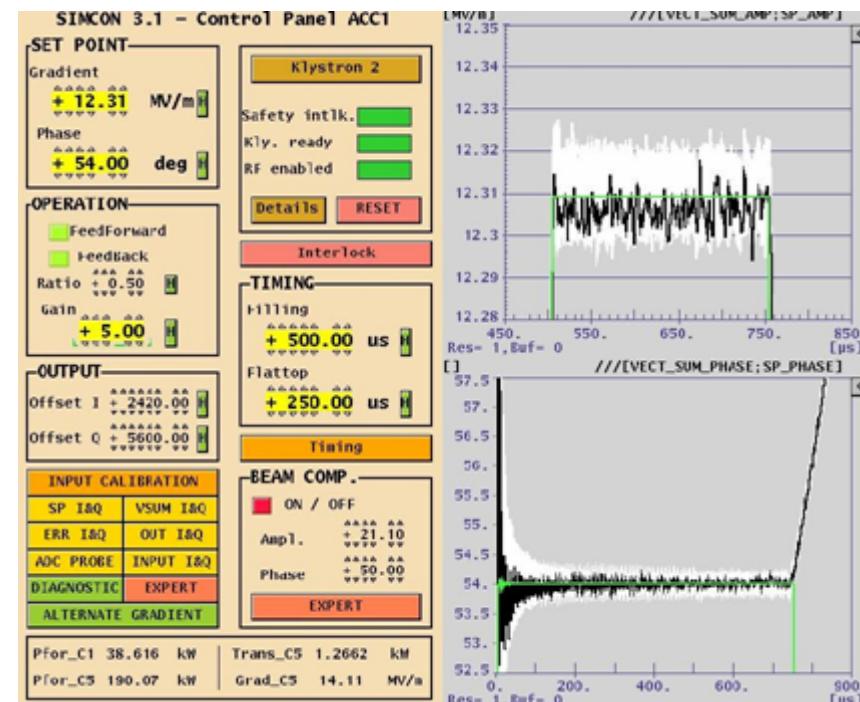


# AFF vs FB

**FB, Gain=25, AFF OFF**

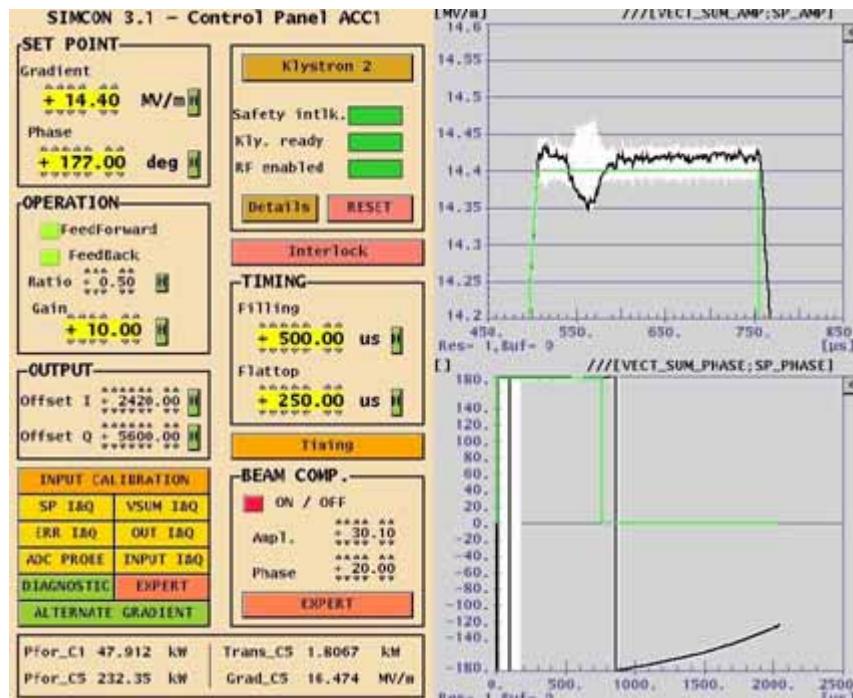


**FB, Gain=5, AFF ON**

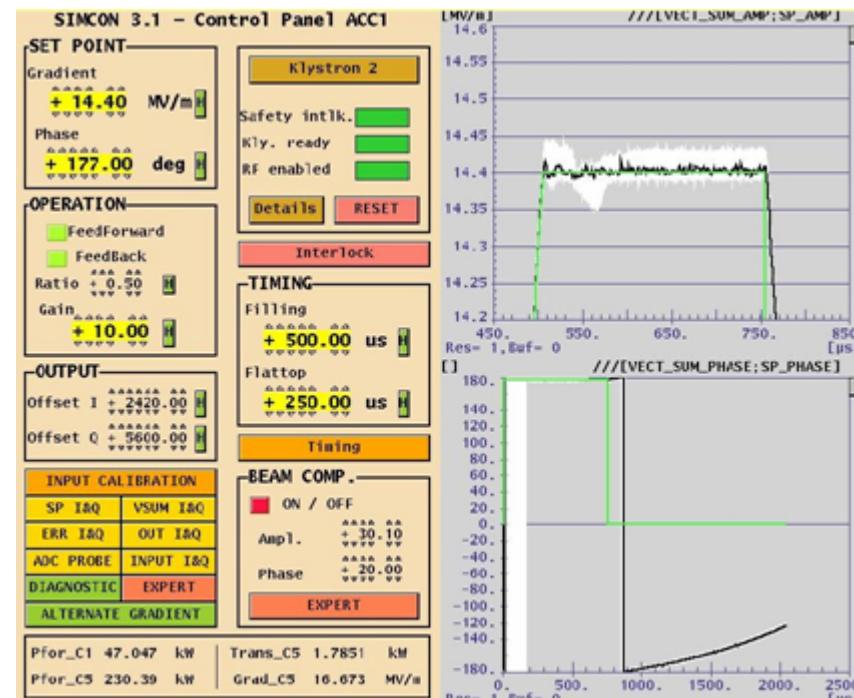


# AFF used for beam load compensation

**AFF OFF**



**AFF ON**

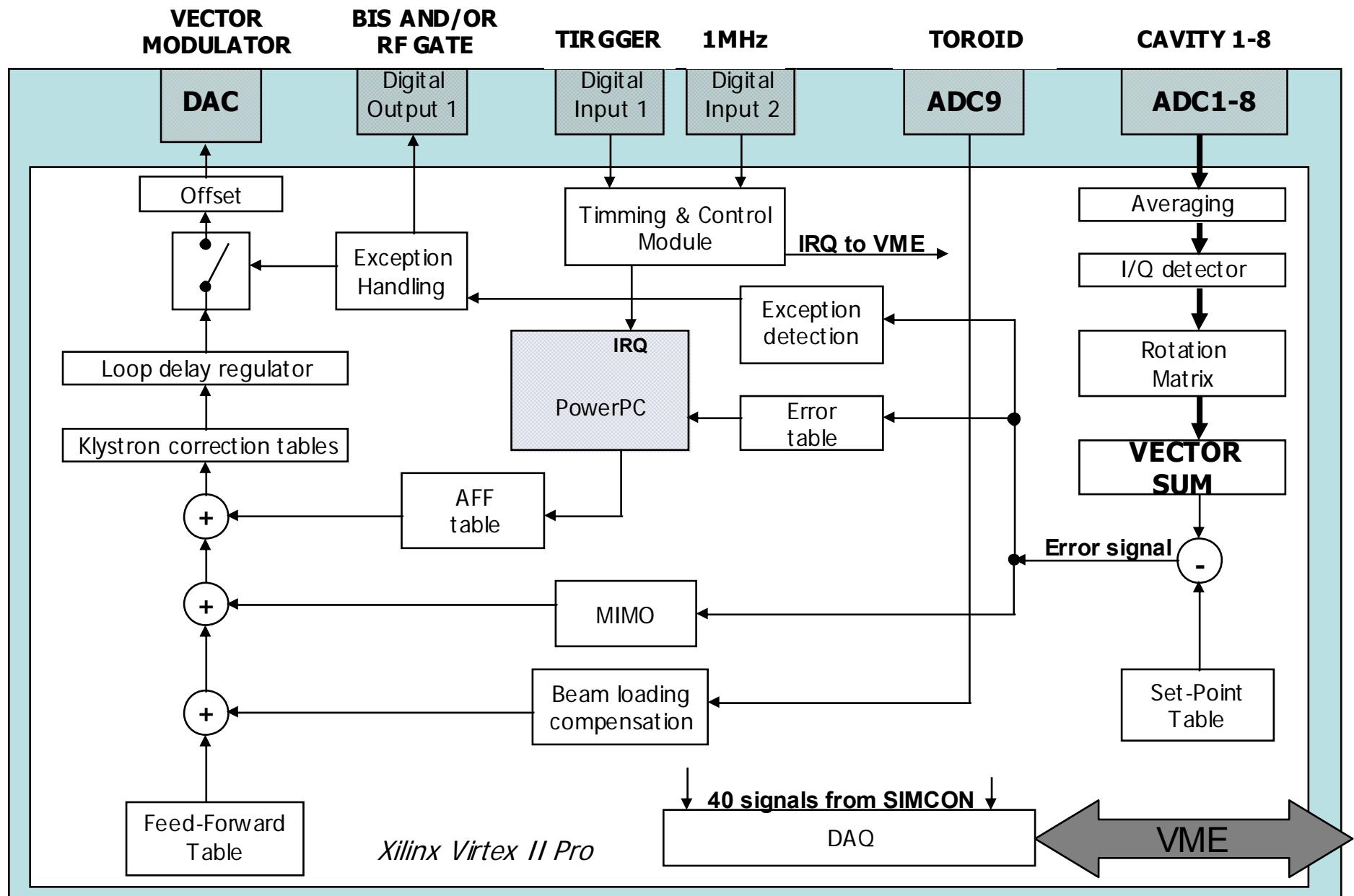


# AFF status

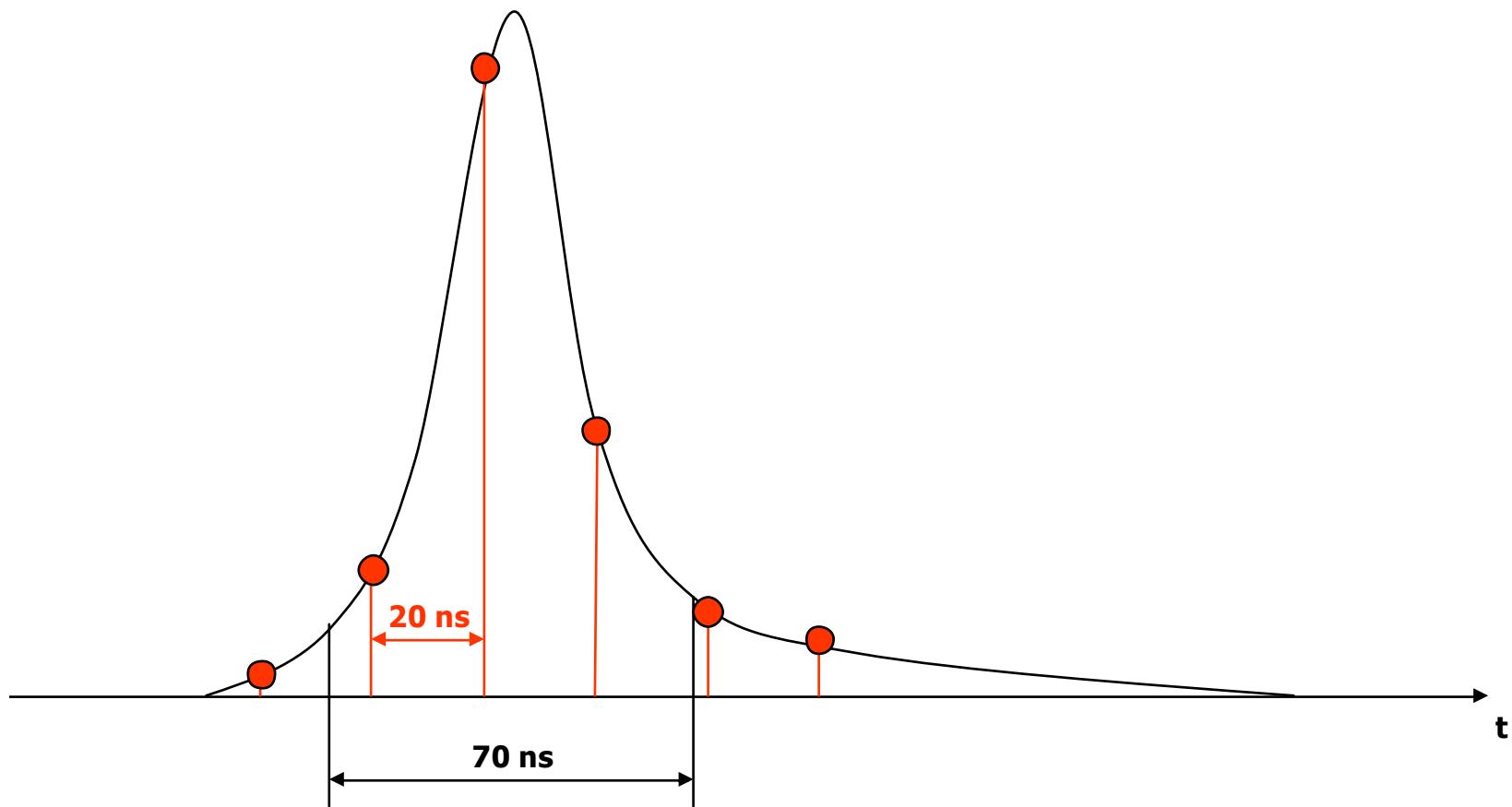
- implemented in FPGA and PowerPC
- two versions of AFF tested
- stable operation over minutes
- control through virtual RS-232 port
- DOOCS control panel not ready

Beam load compensation at ACC1

# SIMCON 3.1 BOARD – FIRMWARE

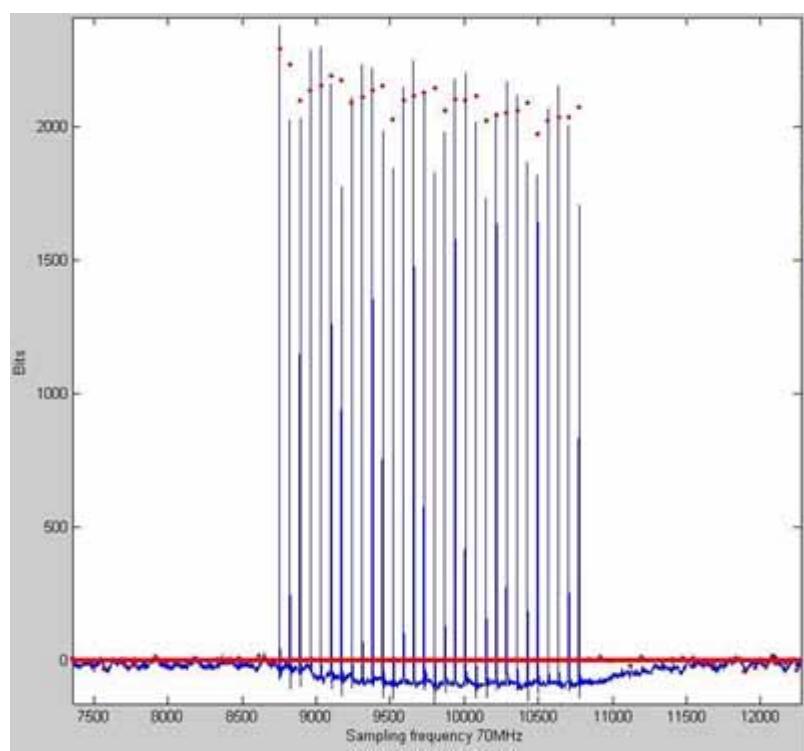


# Sampling of toroid signal

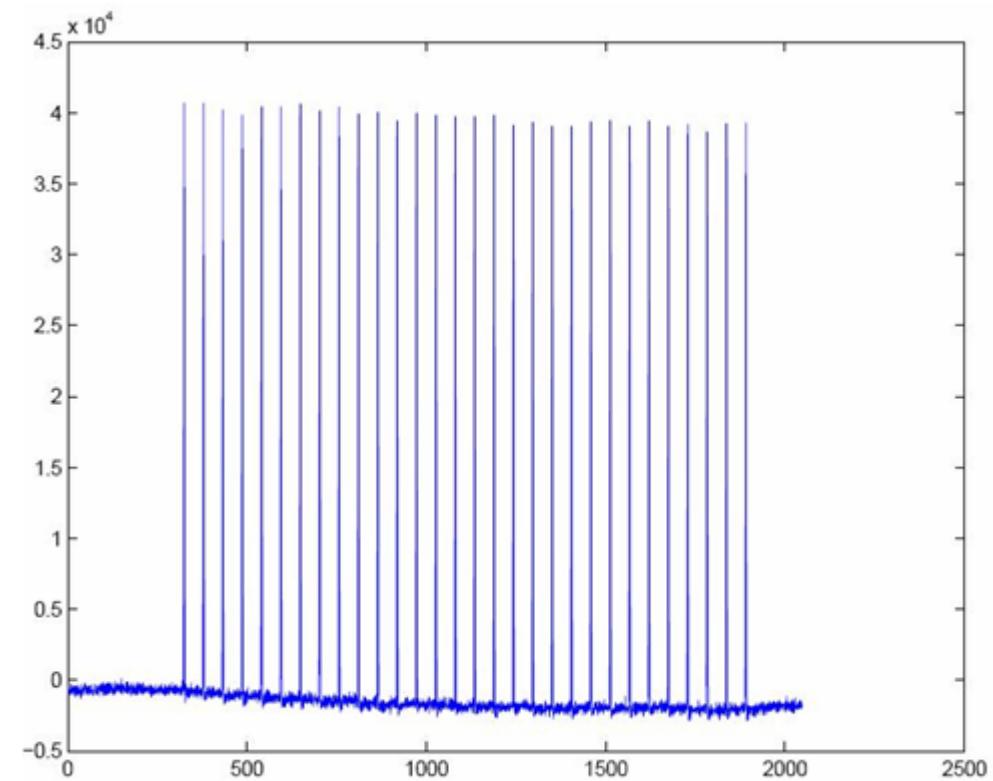


# 30 bunches measured by SIMCON

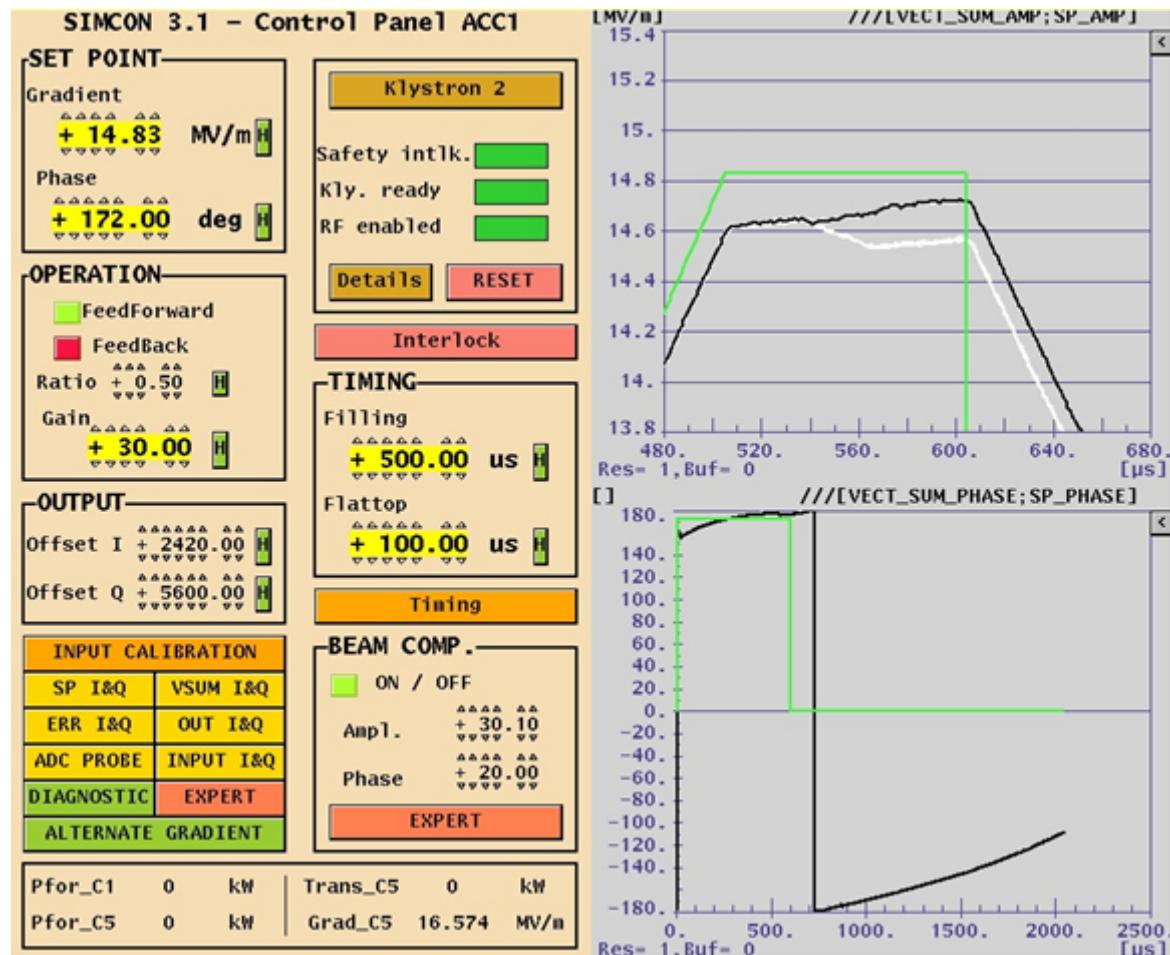
**before – clock=50MHz – local clock**



**after – clock=54MHz – clock from MO**



# Beam load compensation

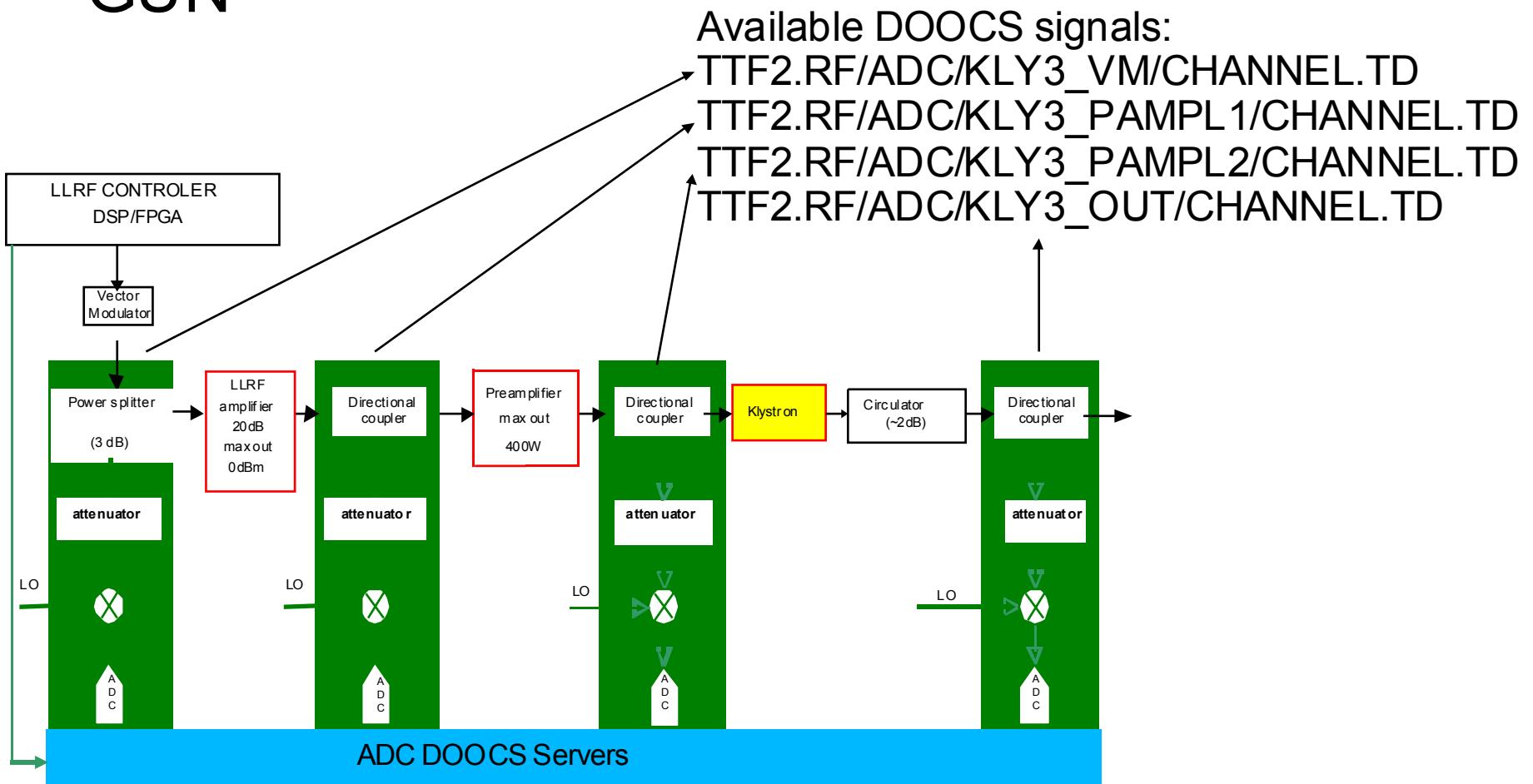


# Klystron nonlinearity compensation

(more general:  
High Power Amplifiers  
nonlinearity compensation)

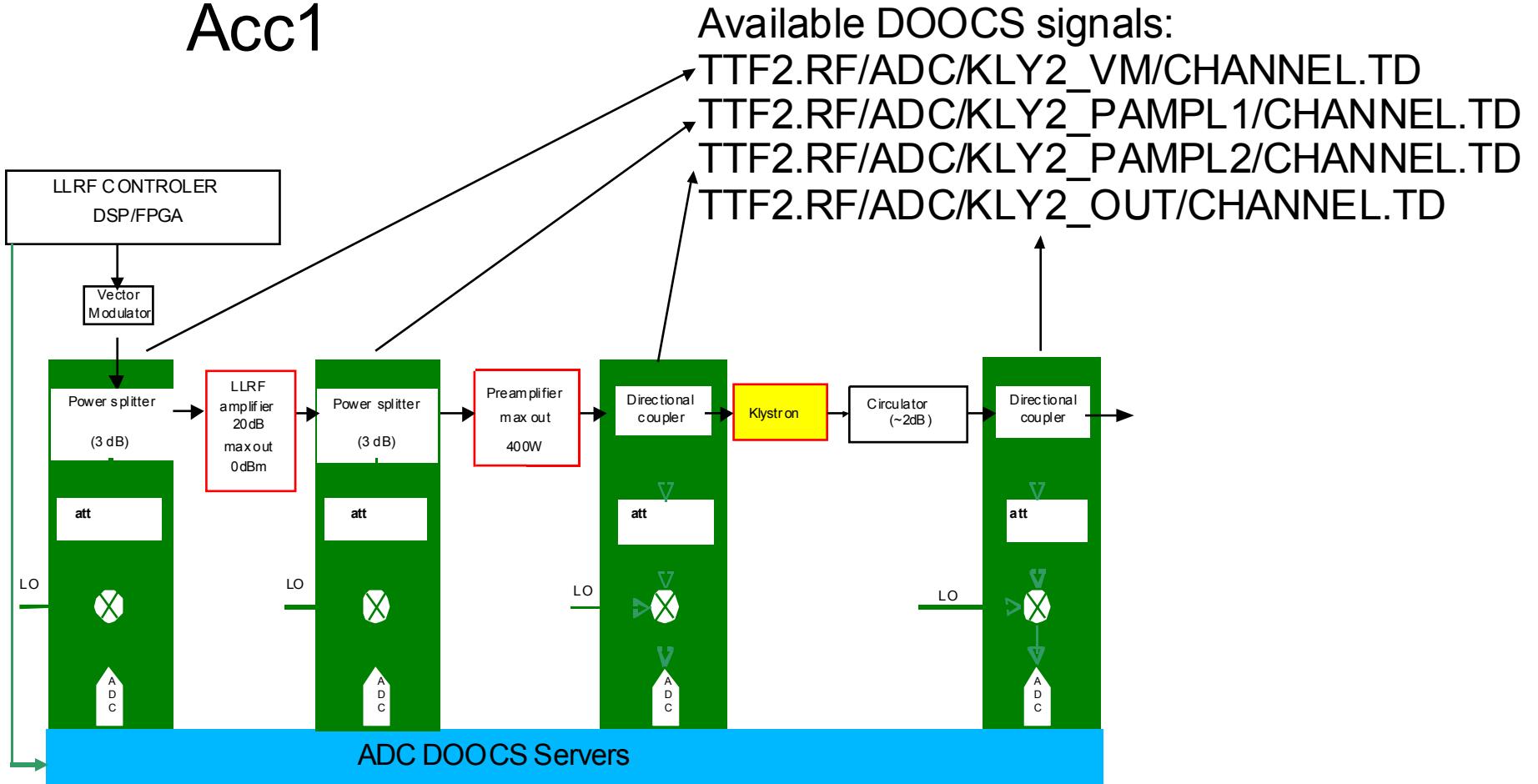
# Current high power amplifiers diagnostic hardware status

## GUN



# Current high power amplifiers diagnostic hardware status

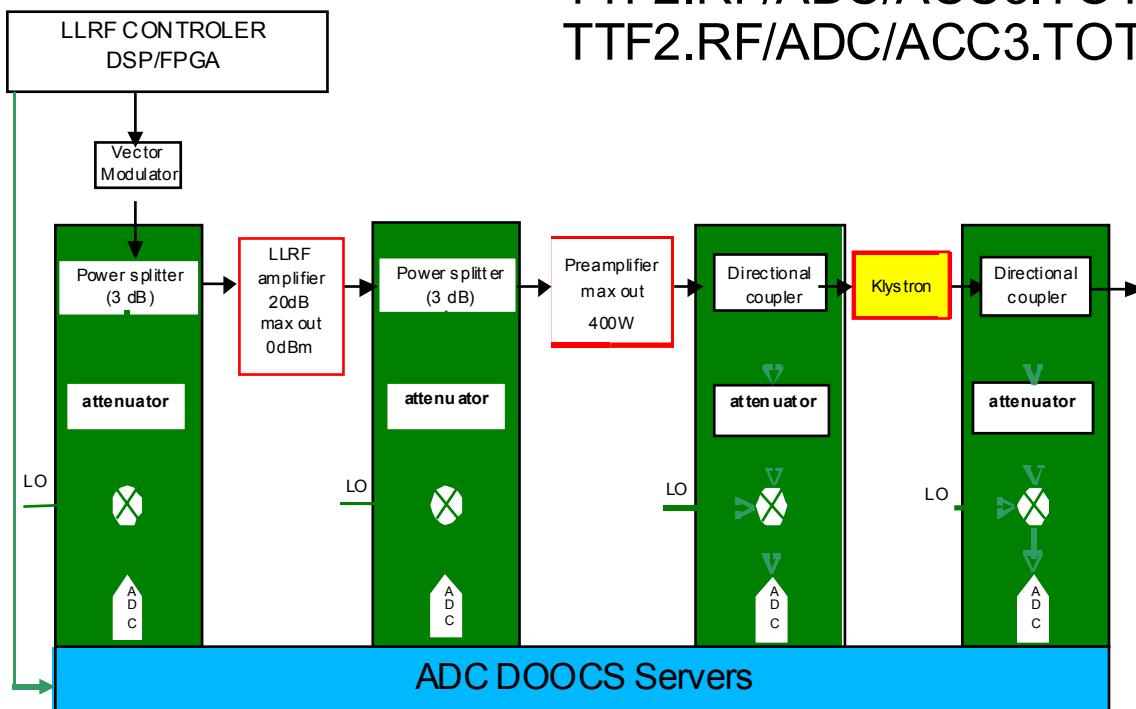
Acc1



# Current high power amplifiers diagnostic hardware status

Acc2\_3

Available DOOCS signals (temporary location):  
TTF2.RF/ADC/ACC3.TOTAL/CH02.TD – DAC output I  
TTF2.RF/ADC/ACC3.TOTAL/CH03.TD – DAC output Q  
TTF2.RF/ADC/ACC3.TOTAL/CH04.TD – after RF gate  
TTF2.RF/ADC/ACC3.TOTAL/CH05.TD – after 1<sup>st</sup> preamp  
TTF2.RF/ADC/ACC3.TOTAL/CH06.TD – after 2<sup>nd</sup> preamp  
TTF2.RF/ADC/ACC3.TOTAL/CH07.TD – after klystron



# Current high power amplifiers diagnostic hardware status

Acc4\_5\_6

Available DOOCS signals (temporary location):

TTF2.RF/ADC/ACC5.TOTAL/CH02.TD – DAC output I

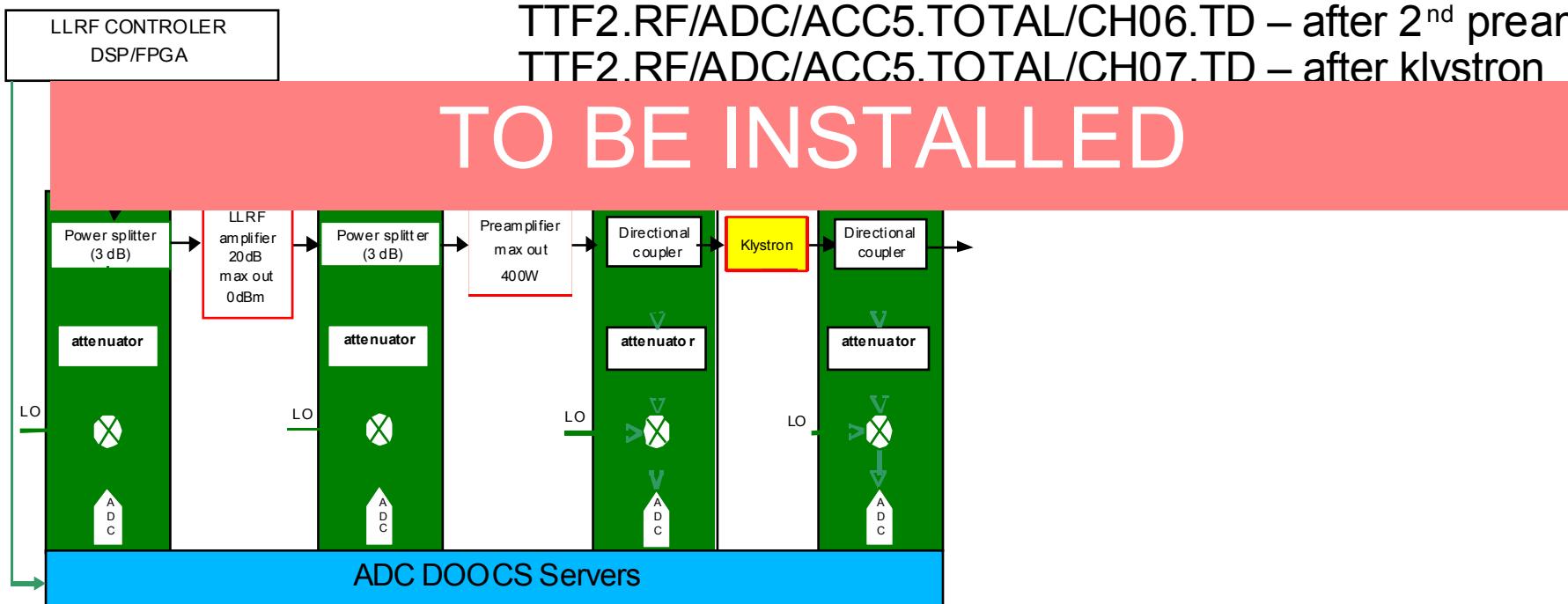
TTF2.RF/ADC/ACC5.TOTAL/CH03.TD – DAC output Q

TTF2.RF/ADC/ACC5.TOTAL/CH04.TD – after RF gate

TTF2.RF/ADC/ACC5.TOTAL/CH05.TD – after 1<sup>st</sup> preamp

TTF2.RF/ADC/ACC5.TOTAL/CH06.TD – after 2<sup>nd</sup> preamp

TTF2.RF/ADC/ACC5.TOTAL/CH07.TD – after klystron



# HPA AM/AM and AM/PM characteristics measurements.

- The set of amplitude-amplitude and amplitude-phase characteristics measurements have been done for the klystron 5 and klystron 2 during last two years.
- The constellation diagram method have been used for the characterization results visualization.
- Basing on achieved characteristics the correction coefficients have been calculated.

# High power chain non-linearities characterization

Non-linearities and saturation phenomena:

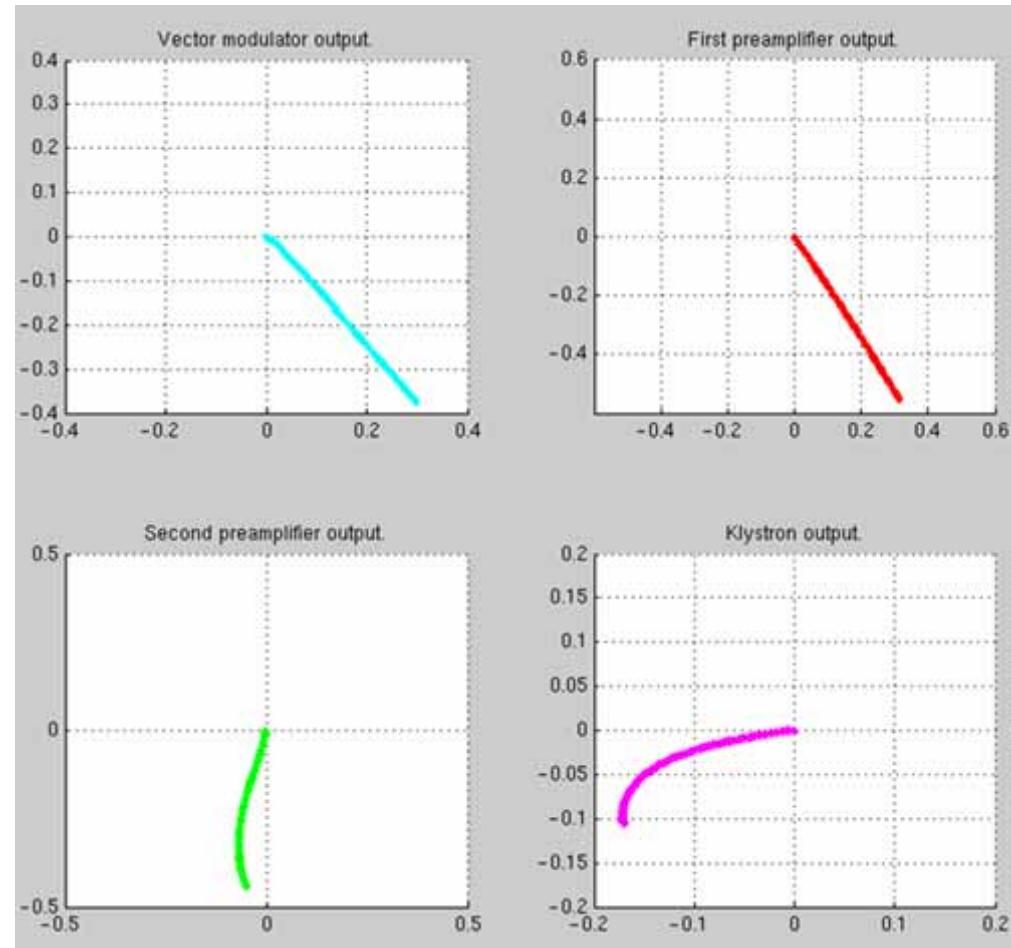
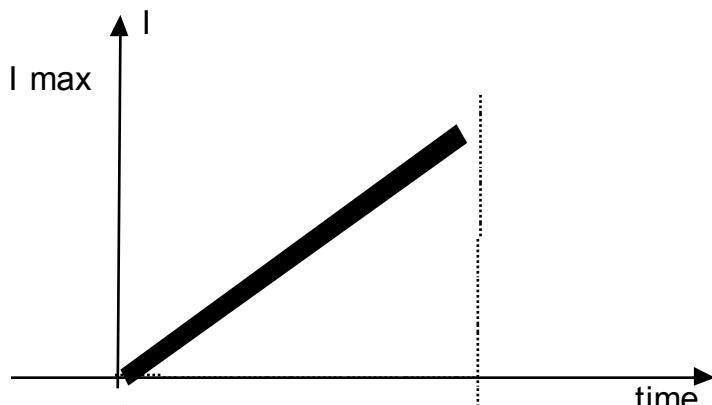
- increasing the driving power  $\Rightarrow$  non-linear amplifier behaviour
- constant increasing of driving power  $\Rightarrow$  saturation
- different saturation level for a different operation conditions

Signal parameters:

Pulse length – 1200 us,

Number of steps – 50,

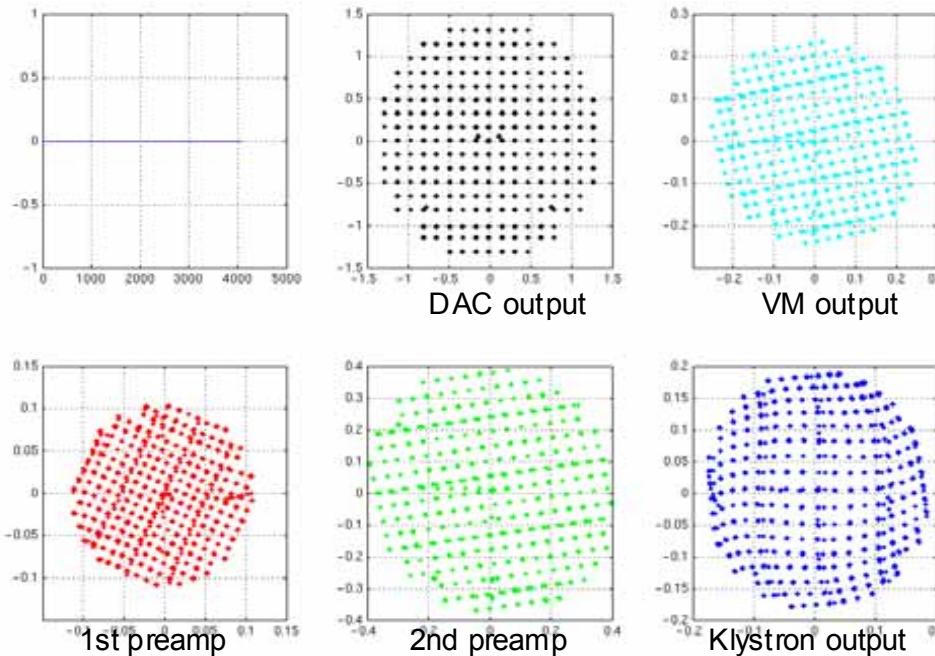
Signal range – 0 up to max. available level



Complex representation of the HP chain devices  
Example for kly. 5 (each axis unit is an ADC voltage)

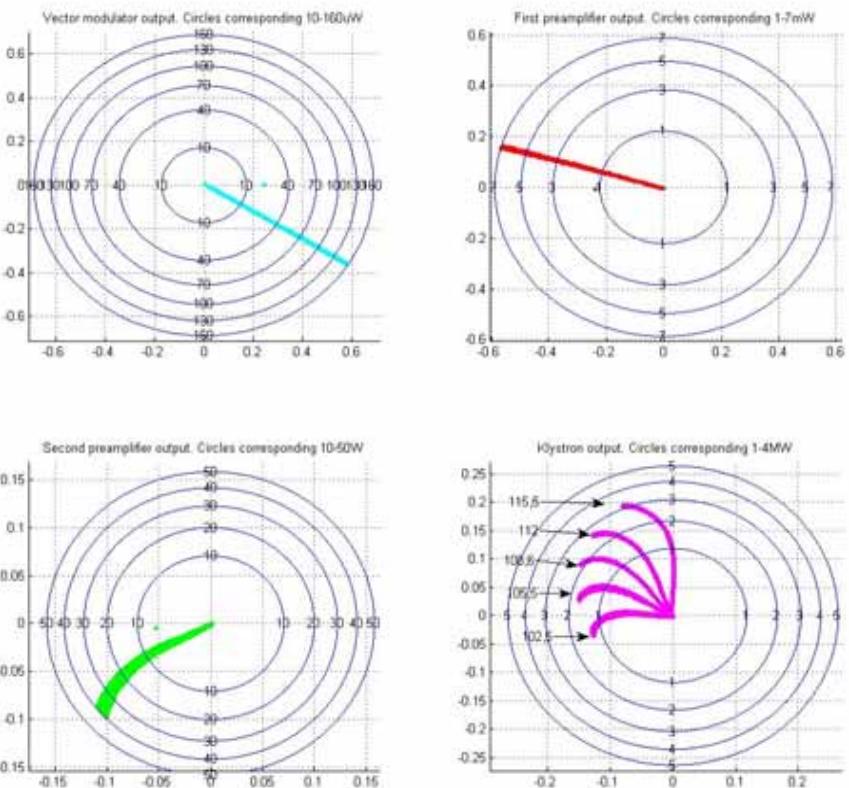
# Results example – klystron 5

KLYSTRON 5

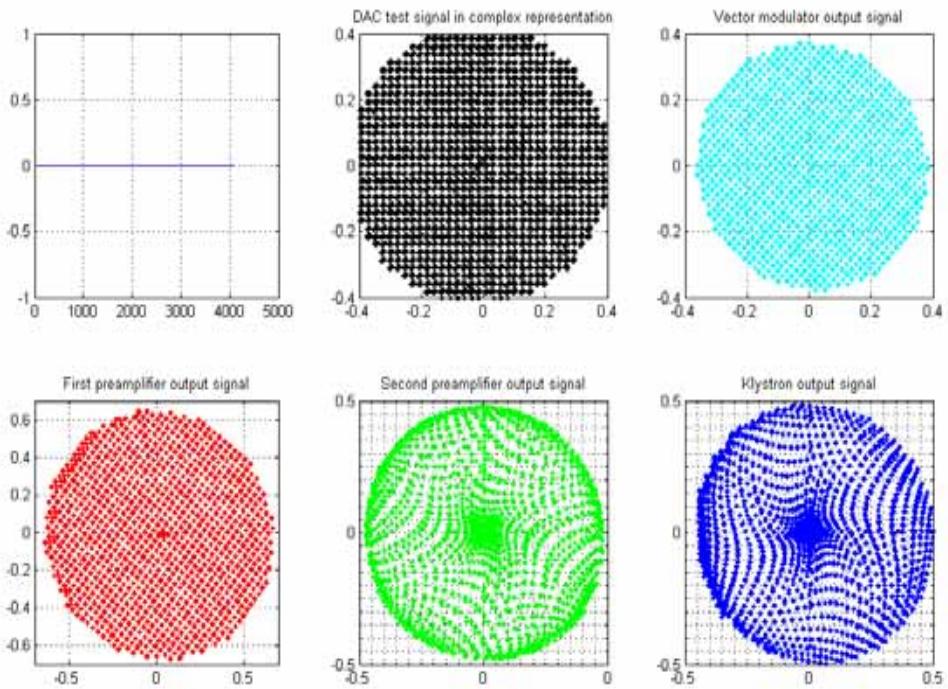


Constellation diagram:  
Grid measurement with 20 steps resolution

Constellation diagram:  
Measurement for one phase ( $Q=0$ ).  
Klystron output characteristics for different HV levels.

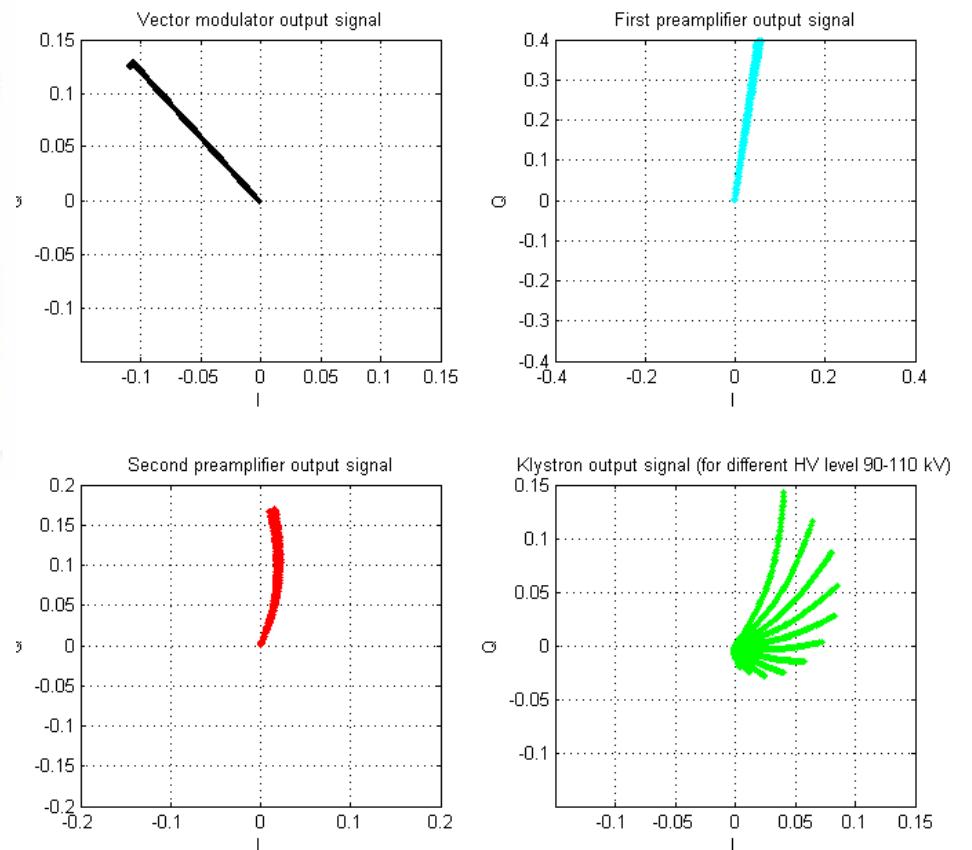


# Results example – klystron 2



Constellation diagram:  
Grid measurement with 50 steps resolution

Constellation diagram measurement:  
Measurement for one phase ( $Q=0$ ).  
Klystron output characteristics for different HV levels.



# HPA's Linearisation algorithm principles.

From the nonlinearity measurement the AM/AM (amplitude to amplitude) and PM/AM (phase to amplitude) of the high power chain can be achieved.

NOTE!! The nonlinearity is only function of input amplitude.

Driving signal representation:

$$Z = Id + Qd = |Z| * [\cos(\phi) + i * \sin(\phi)]$$

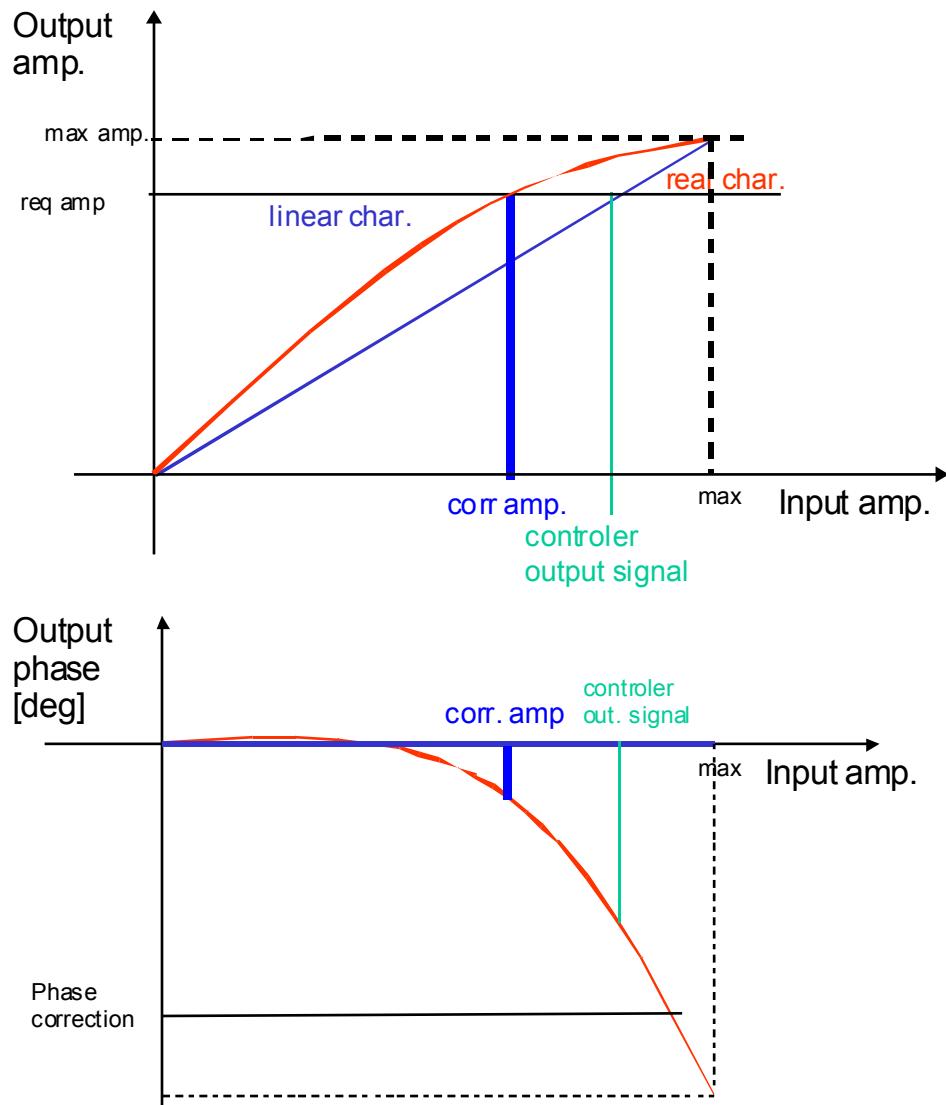
Correction signal:

$$C = Ic + Qc = |C| * [\cos(\theta) + i * \sin(\theta)]$$

From the linearisation both amplitude and phase correction are achieved. Can be realised using the complex multiplication.

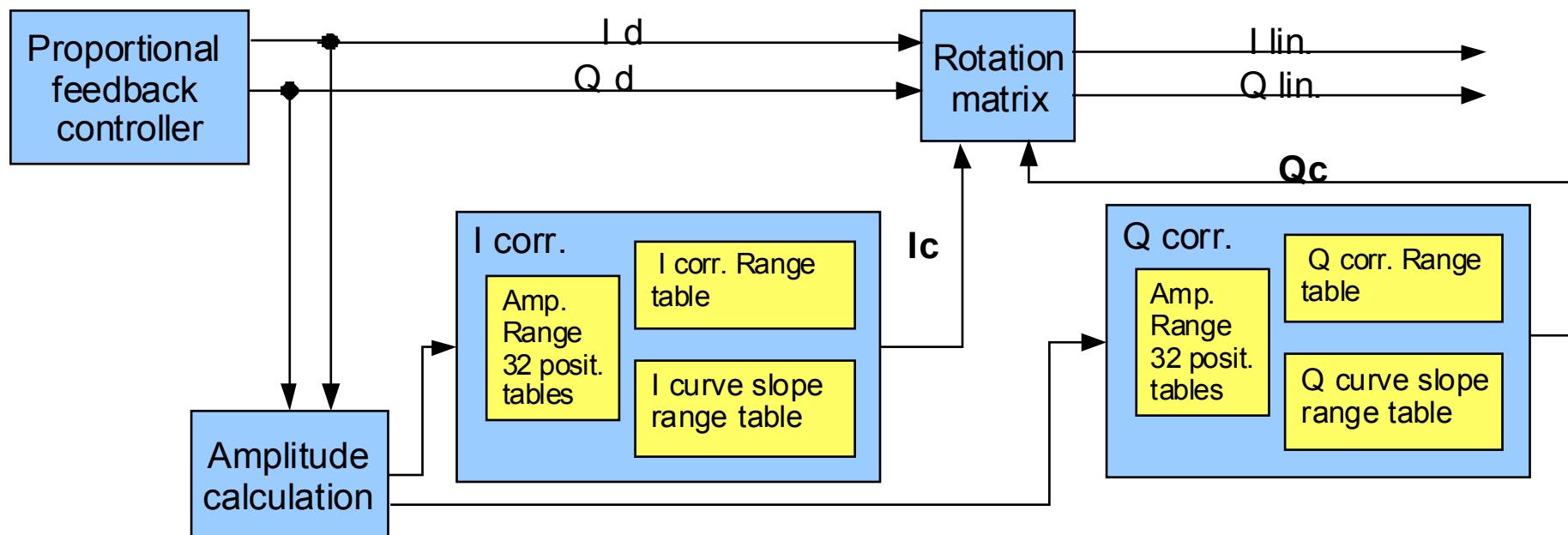
$$C*Z = Idc + i*Qdc$$

$$C*Z = ||Z||*|C||*[\cos(\phi+\theta)+i*\sin(\phi+\theta)]$$



# Linearization tool implementation in LLRF field controller (Simcon).

- The linearization tool realization is based on the set of look-up tables
- The amplitude of the controller driving signal (calculated in the FPGA) is used for addressing the look-up tables with correction coefficients for I and Q. There are 32 word 18bits tables with corrections calculated in the MATLAB from the characteristics achieved during the characterization. In order to minimize the tables size (save the FPGA resources) the tables with linear interpolation between the knots.
- The contents of the tables is updated – according to the changes of the HV level (for instance adjusted by an operator).

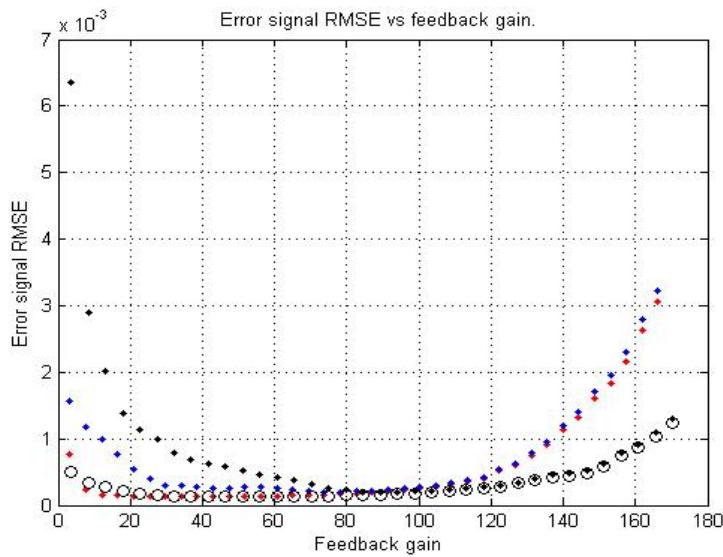


# Tool tests results in ACC2&3 and MTS.

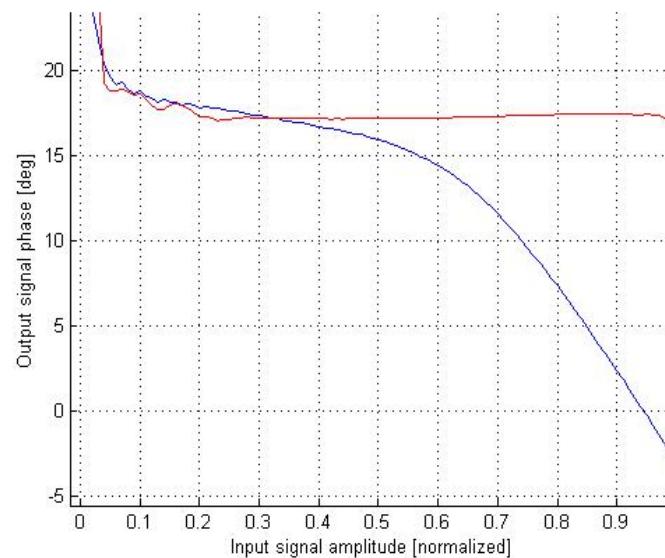
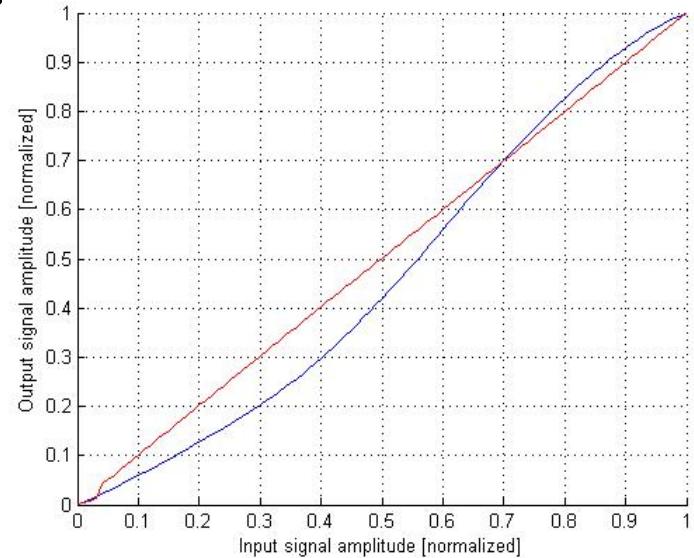
- The set of in-situ tests were performed in the MTS and the FLASH in order to evaluate performance of different configuration of linearization tool.
- During the characterization phase the nonlinearities of the amplitude and phase characteristics have been determined for the different HV level of the klystron modulator.
- Achieved data was processed and used for the correction coefficients calculation. Depending on tested variant of configuration the tables with 4, 8, 16 or 32 positions were up-loaded to the FPGA.
- Although the most often used configuration was 32 positions tables with linear interpolation, others were also possible but required the LLRF controller reconfiguration (recompilation).

# Examples of tool tests results in MTS

Amplitude and phase characteristics of MTS HPC nonlinearities (blue trace) and linearized characteristics (red trace). Characteristics for modulator HV level 9,4kV

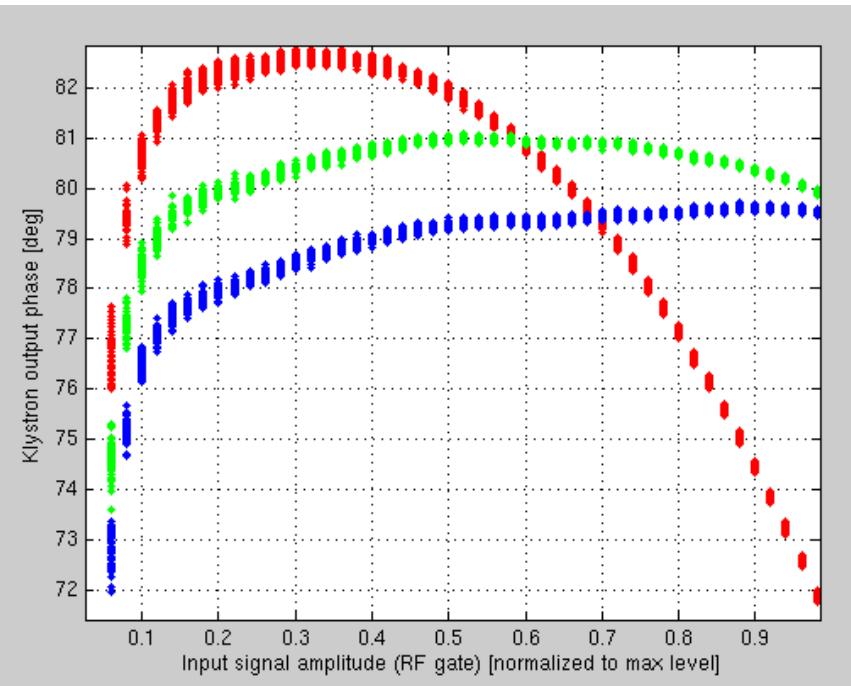
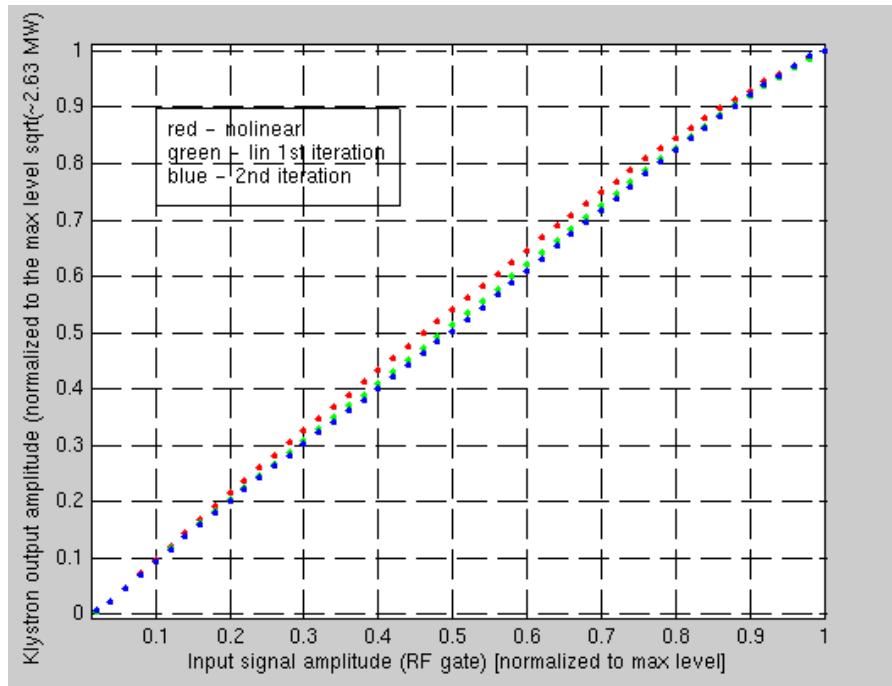


Study of the RMS error of vector sum error signal in function of LLRF feedback loop gain.  
Black traces – with linearisation  
blue and red trace – without linearization



# Klystron 5 HPC linearisation results

- Linearisation test had been performed using Simcon(FPGA) controller,
- Correction tables were „on”
- HV level – 10800 (value on PLC) about 110kV
- Two iteration of the linearization were performed.



# Current work – linearization tool implementation in ACC1 LLRF feedback controller.

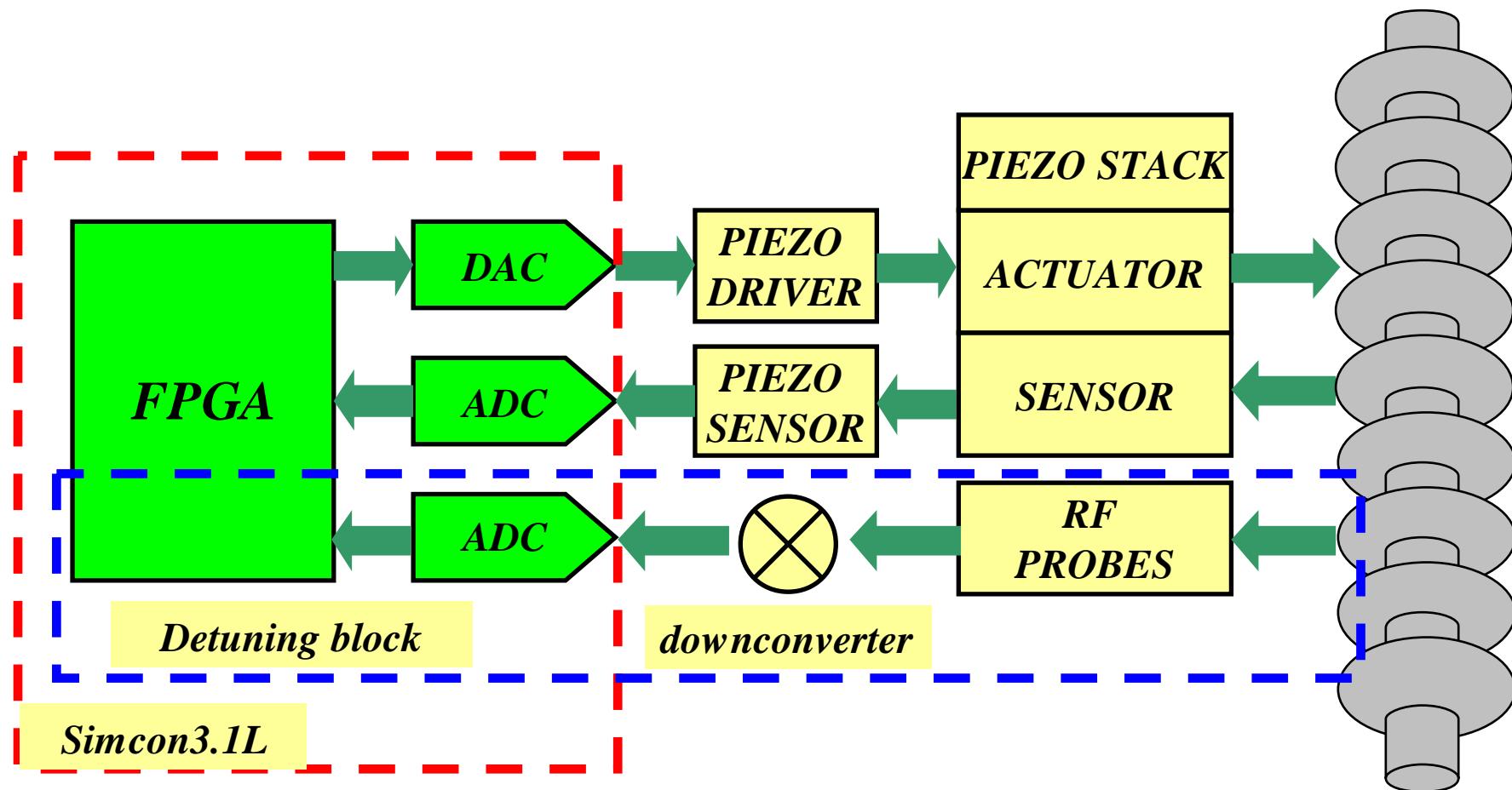
- Linearization tool will be installed in the ACC1 LLRF control loop controller.
- Appropriate modification of the controller structure, dedicated controller DOOCS server, and Matlab scripts have been done.
- The offline tests of the tool performance is planned for July and August 2007.
- In-situ tests before regular operation will be performed during August-September 2007 accelerator study period in FLASH.

# Conclusions.

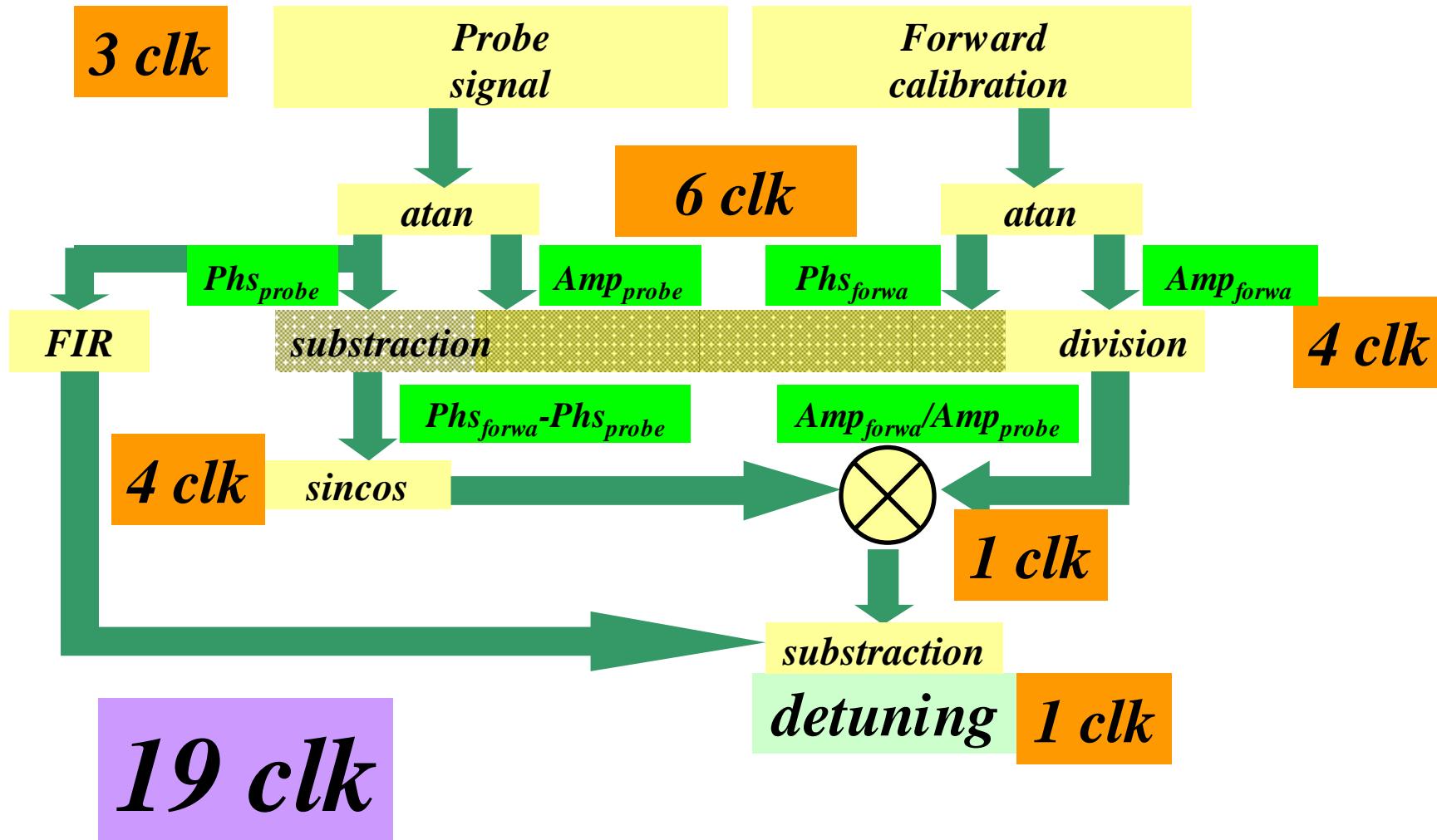
- Diagnostic setup installation ready for the high power chain amplifiers examination has been prepared for most of the FLASH modules.
- Linearization method that can be implemented in standard LLRF feedback loop controller have been developed and tested.
- Successful tests of the linearization tool have been performed in the MTS and the HPC of ACC2&3.
- Tool implementation in ACC1 field controller is in progress.

# Detuning measurement and Piezo control

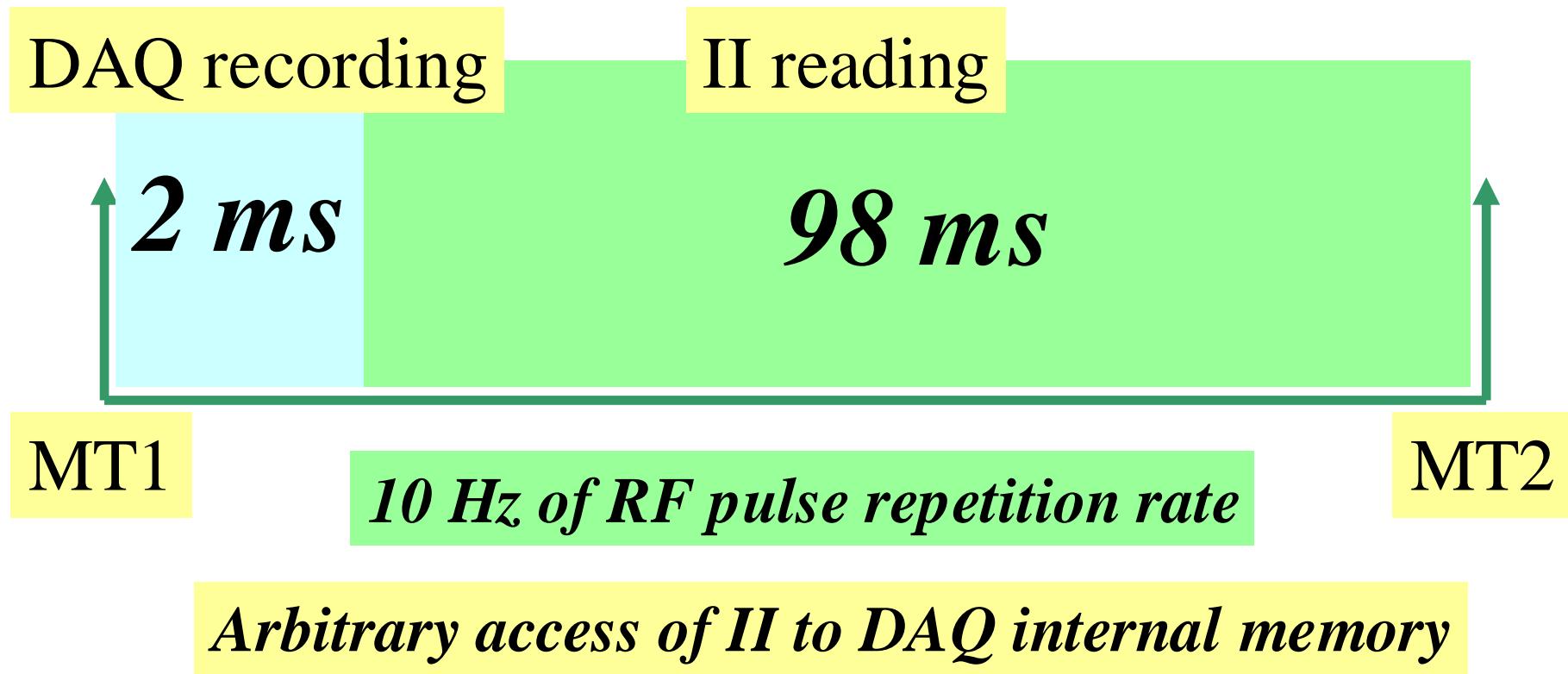
# Detuning compensation control system



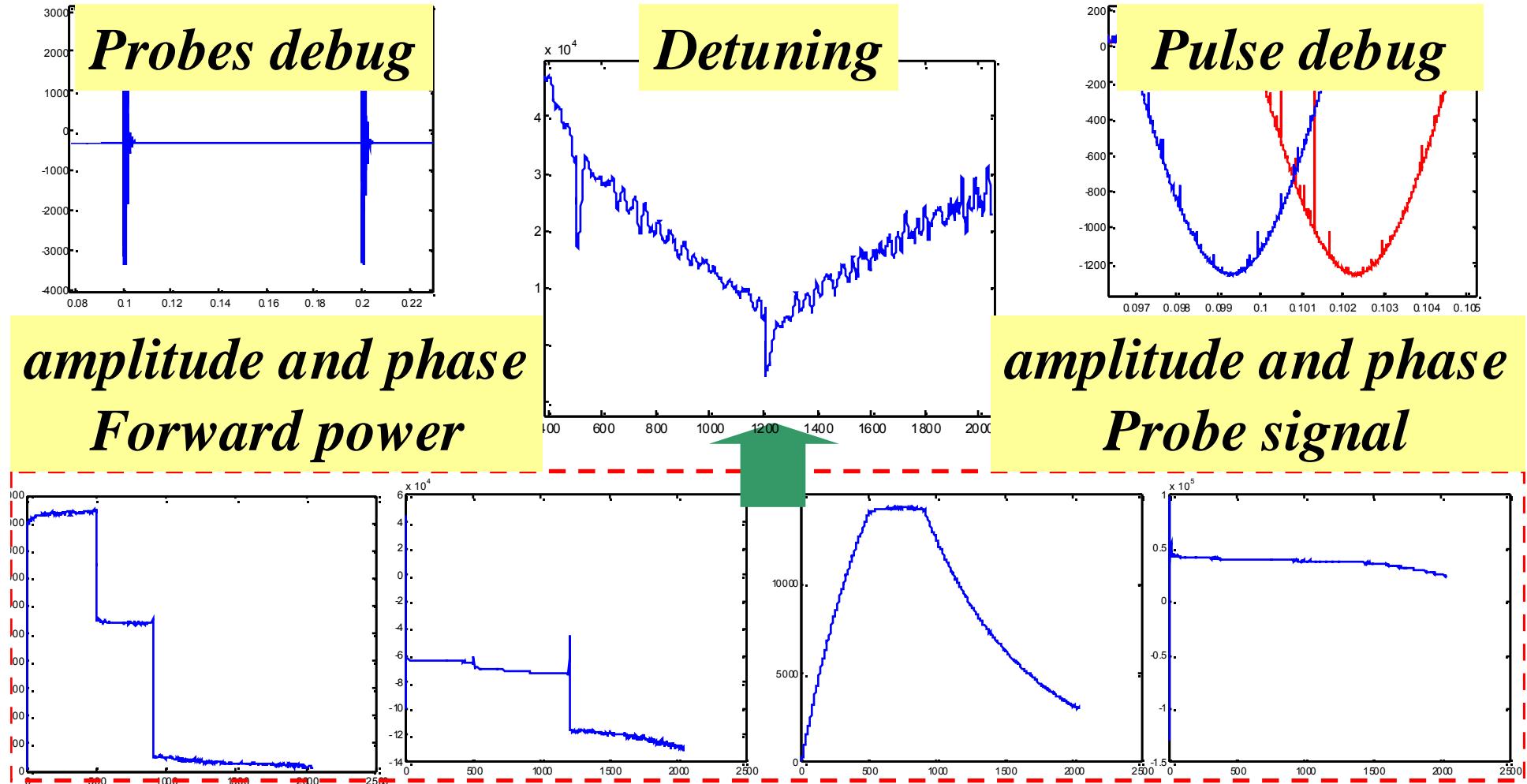
# Detuning computation block



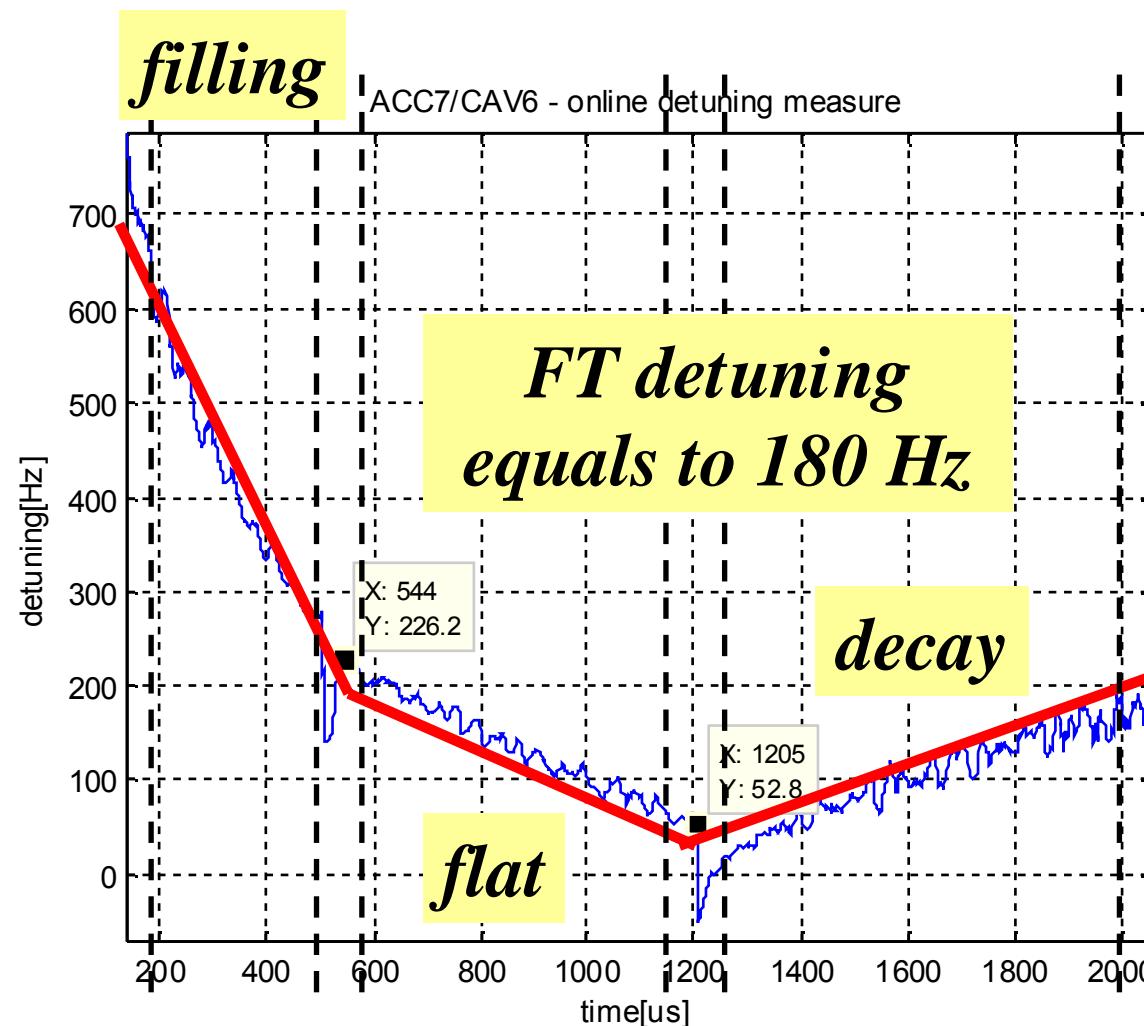
# Data acquisition block



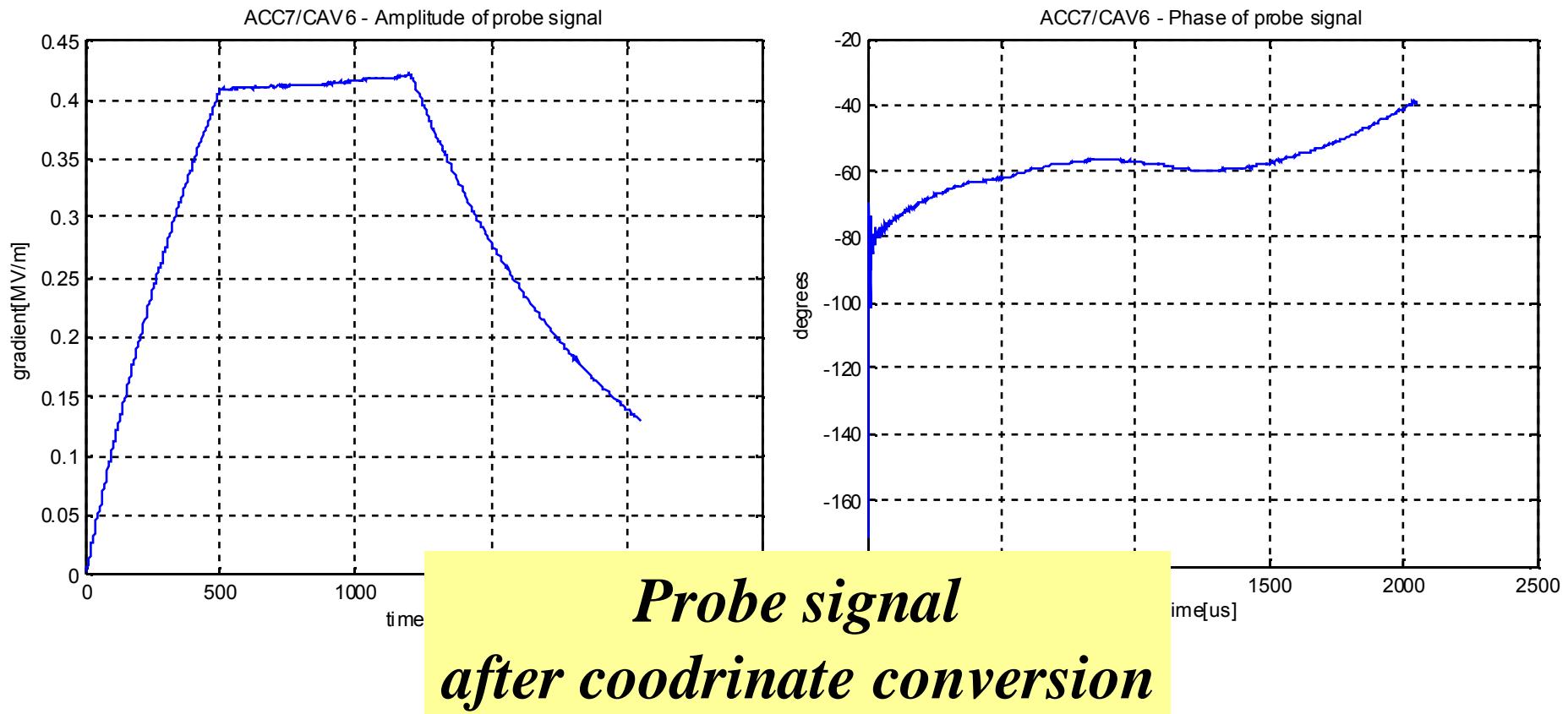
# Measurements in ACC7/CAV6



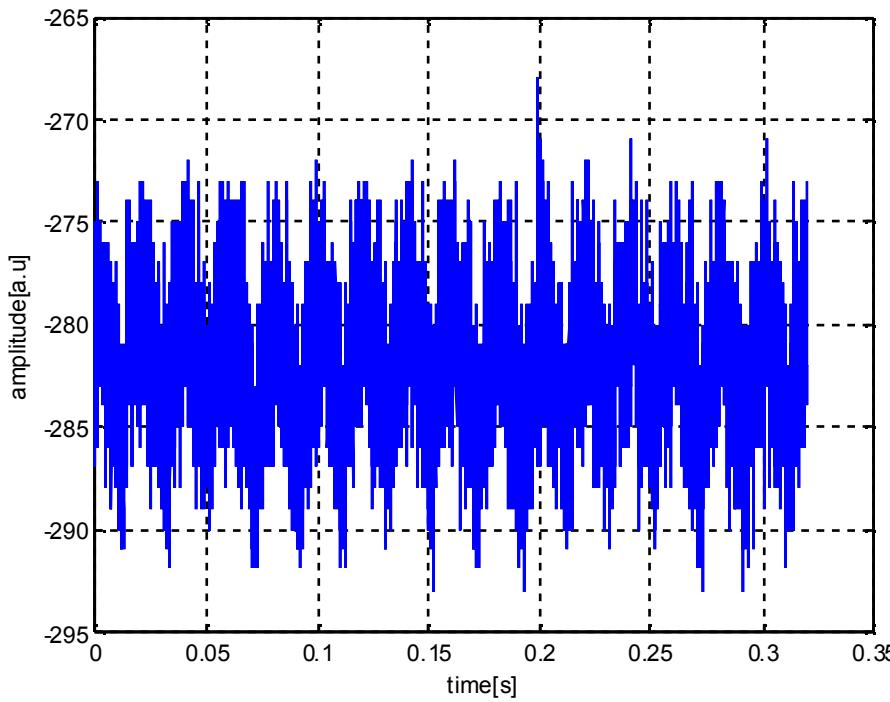
# Detuning measurement



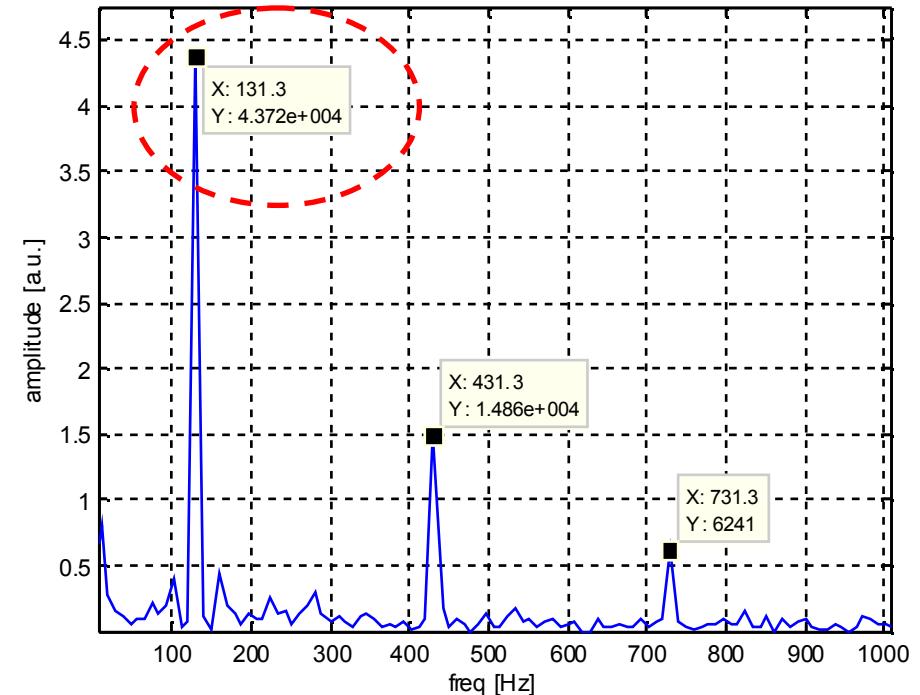
# Amplitude and Phase measurement



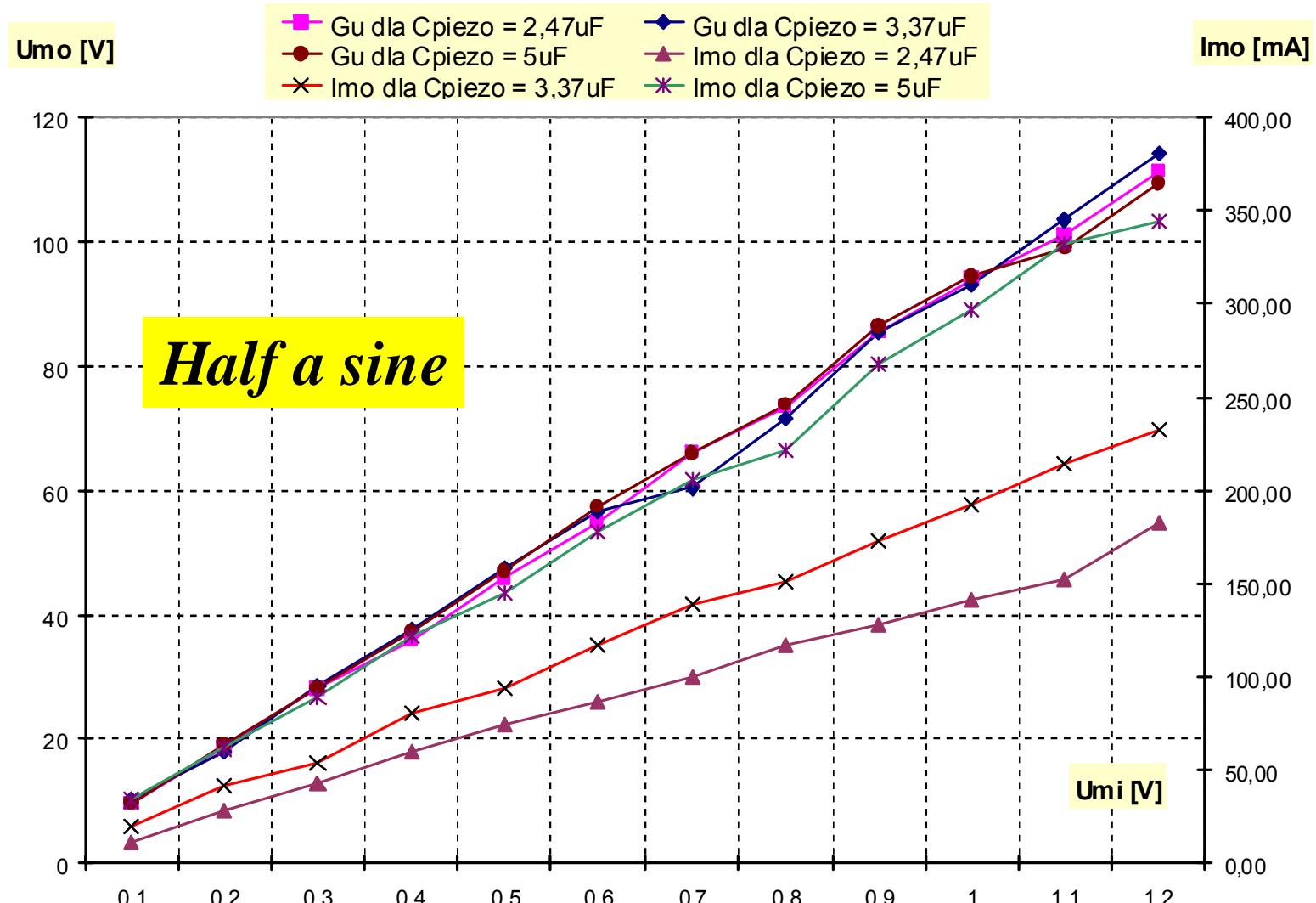
# Micromachined Microphones



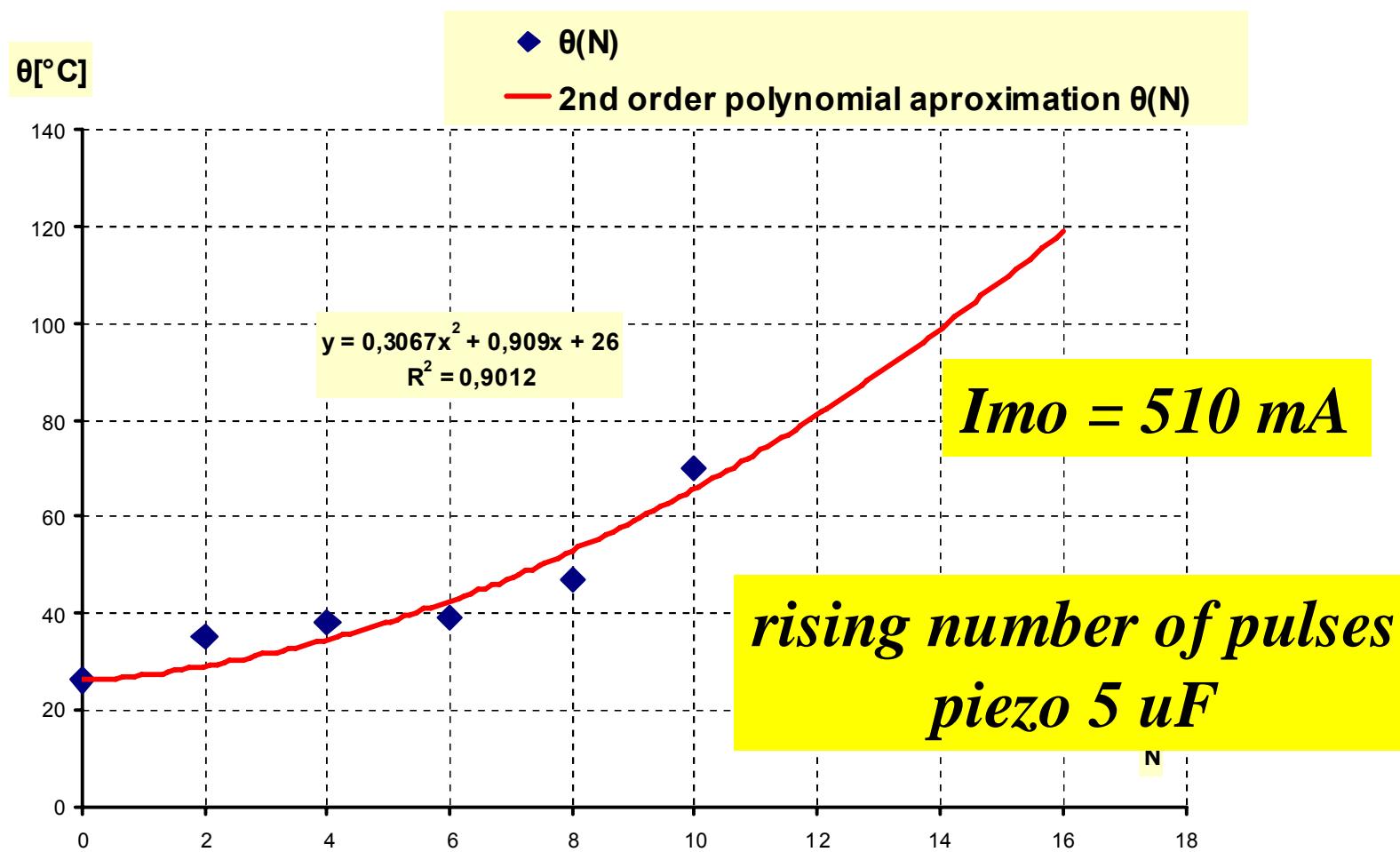
*mechanical cavity resonance  
around 130 Hz*



# Piezo driver results (1)



# Piezo driver results (2)



# Piezo driver results (3)

