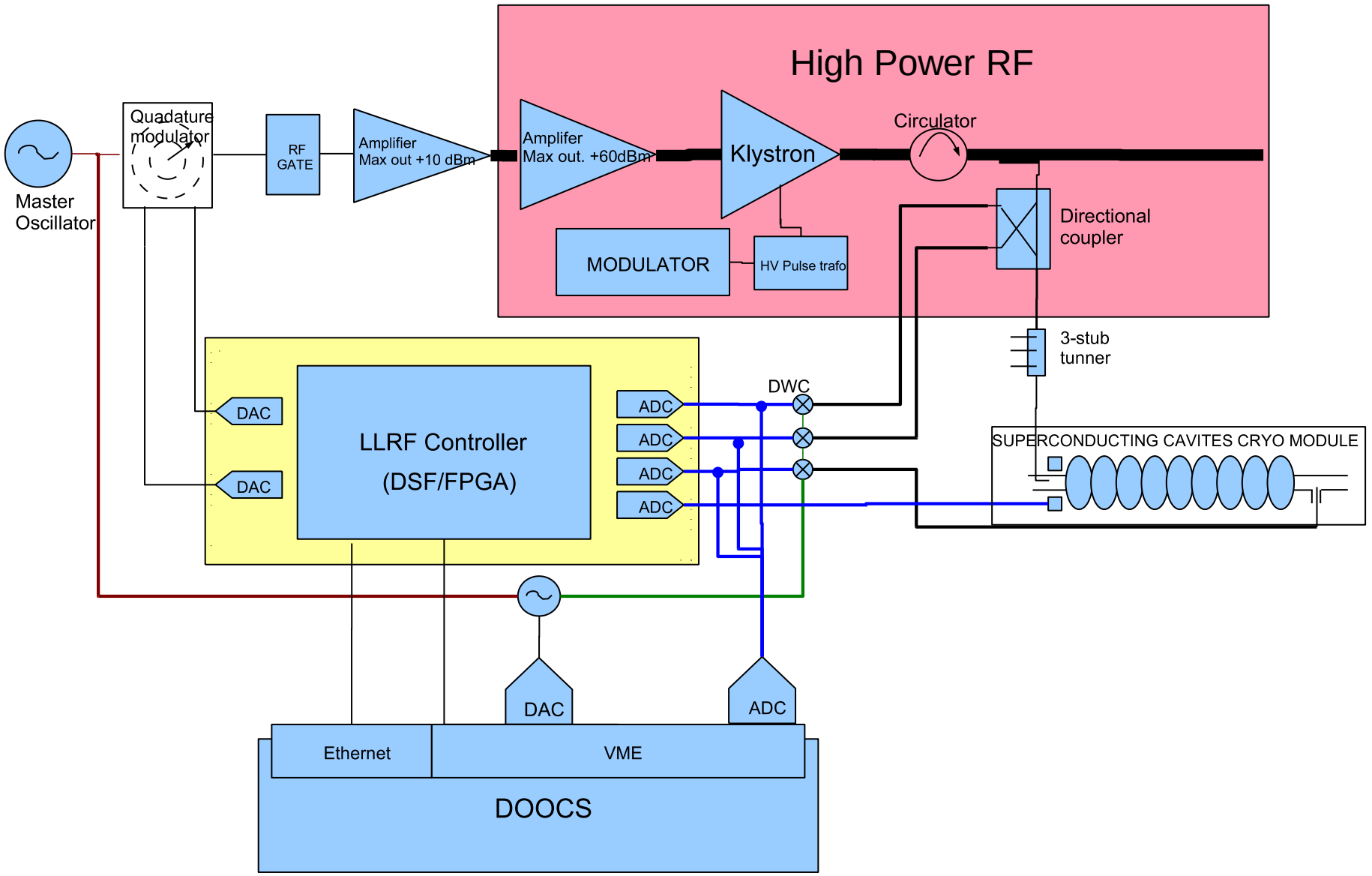
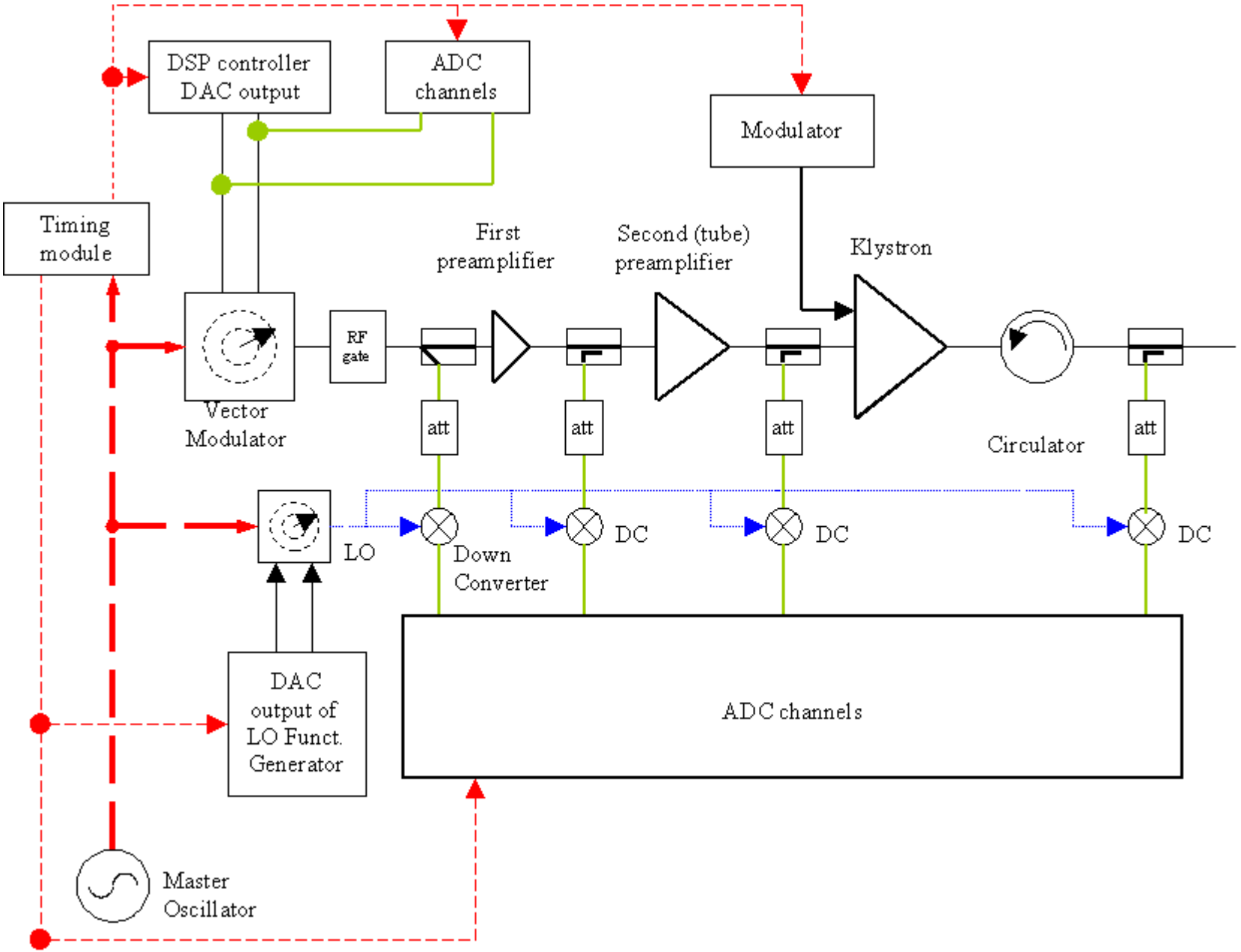
LLRF system high power components diagnostic and nonlinearities cancellations.

High power components of LLRF control loop

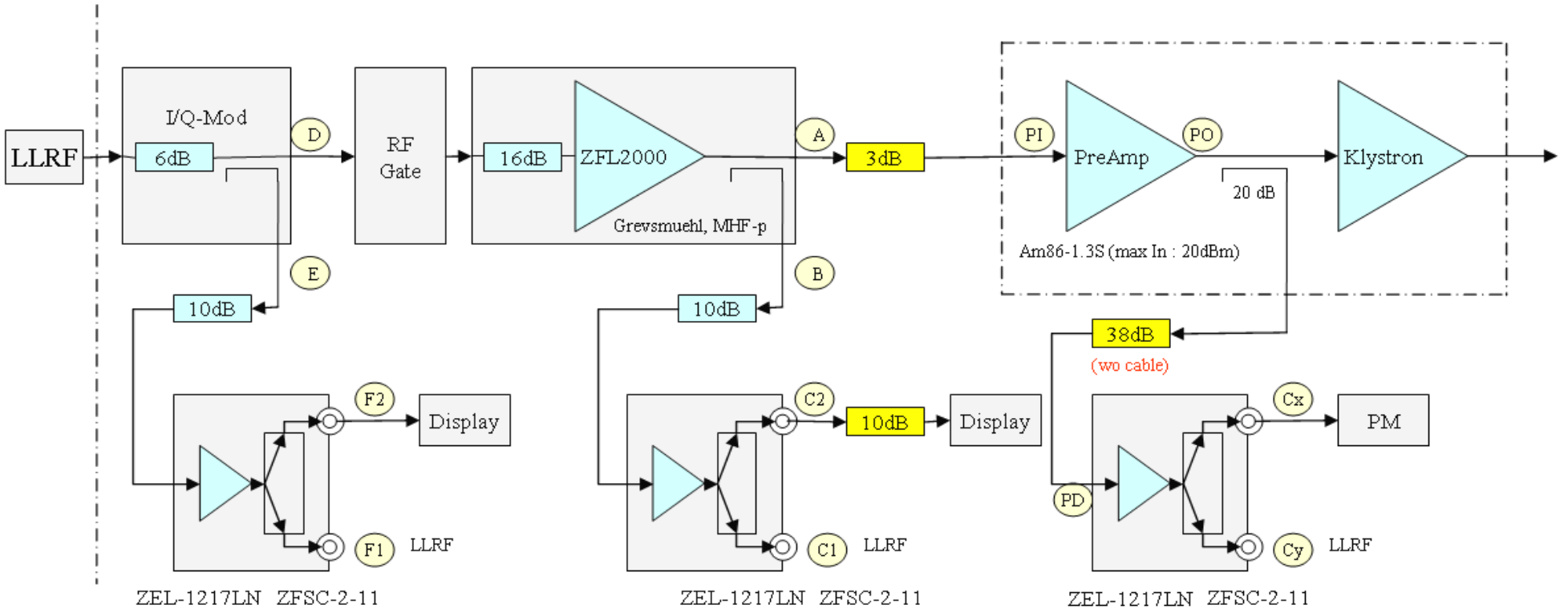


The transfer characteristics nonlinearities detection in High Power Amplifiers Chain



RF station 4

Load / Feedforward on / Feedback off / FSM off
SP_HV=10200V / SP_MV=5..25MV / SP_Phase=56.3
Measurement at Filling Time Region
02. 12. 2008



From previous configuration (see first slide)

D	-2.8	dBm
E	-21.6	dBm
F1	-11.6	dBm
F2	-10.8	dBm
Display	-9.5	dBm

Display → D	6.7	dB
Display → A	7.7	dB
Display → PI	3.4	dB
C2 → PI	5.4	dB

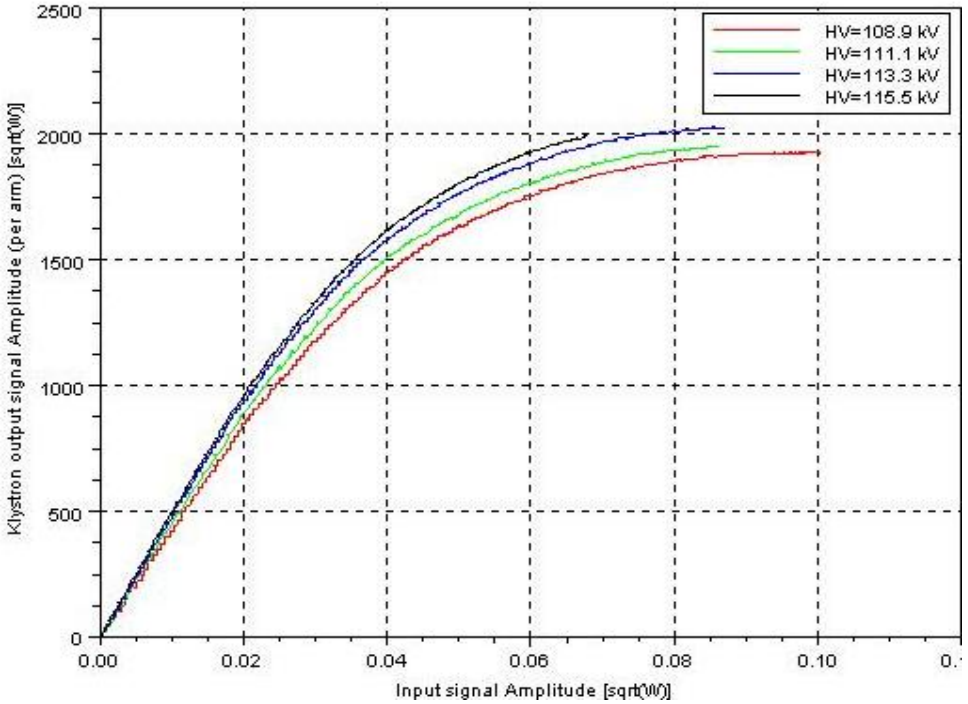
A	2.7	dBm
B	-18	dBm
C1	-6.7	dBm
C2	-7	dBm
Display	-5	dBm

PI	-1.6	dBm
PO	48.9	dBm
PD	24.3	dBm

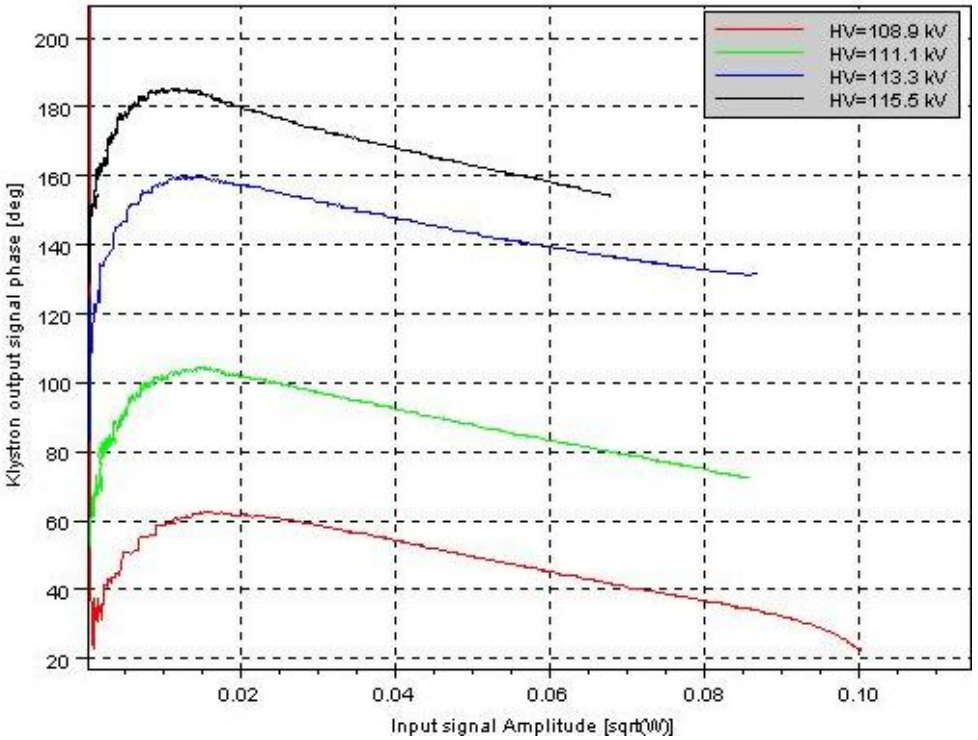
Directional Coupler : ANAREN 1F0625-20
ZFL2000 : 20 dB / In 5 dBm / Out 16 dBm / IP3 25 dBm
ZEL1217LN : 20 dB / In 13 dBm / Out 10 dBm / IP3 25dBm

Transfer characteristics (AM/AM & PM/AM) nonlinearities identification

AMAM Nonlinearity



AMPM Nonlinearity



FLASH Klystron 4 (10 MW), one arm read-out. 30.08.09@DESY

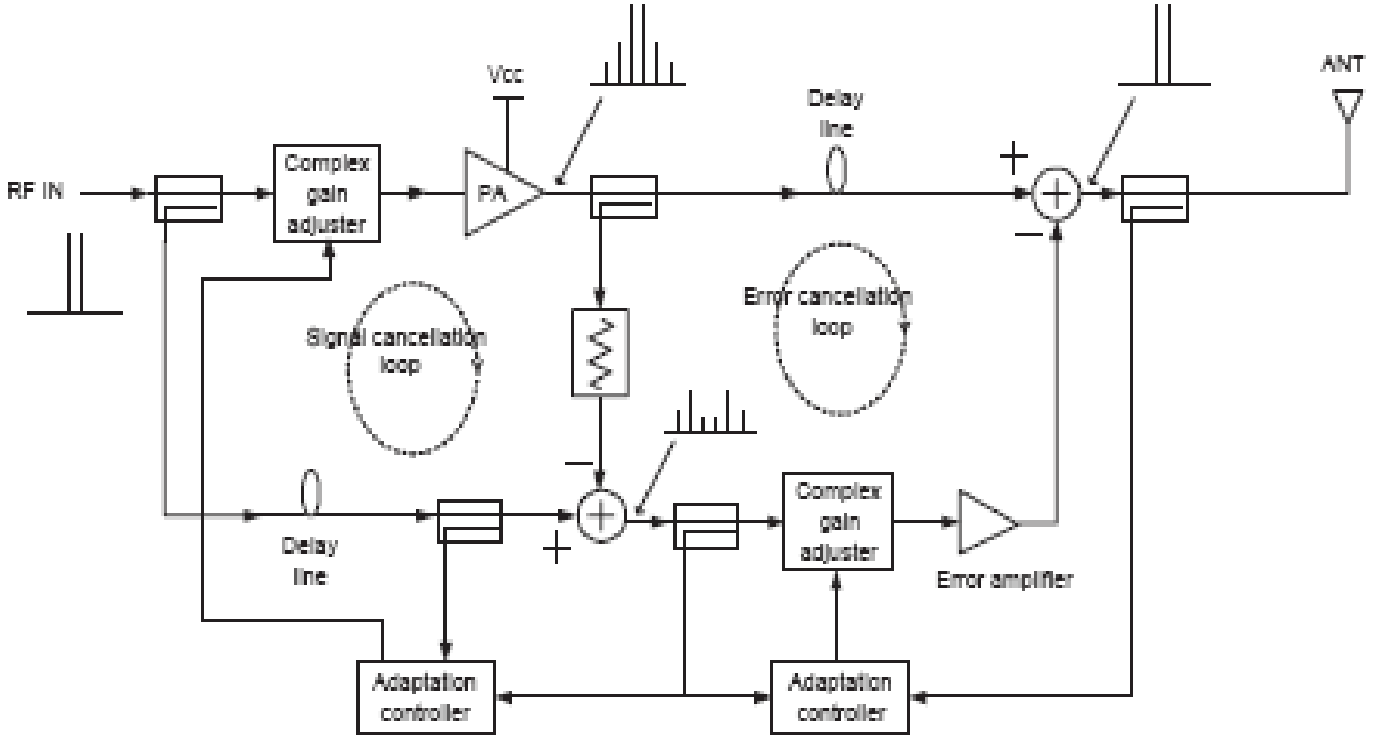
Operation of 24-32 cavities leads to operation in high nonlinear regions.

Different klystron cathode HV level causes saturation point placement change.

Smaller cathode HV requires higher input signal levels → preamplifiers saturation.

Different linearization techniques

Feedforward linearization



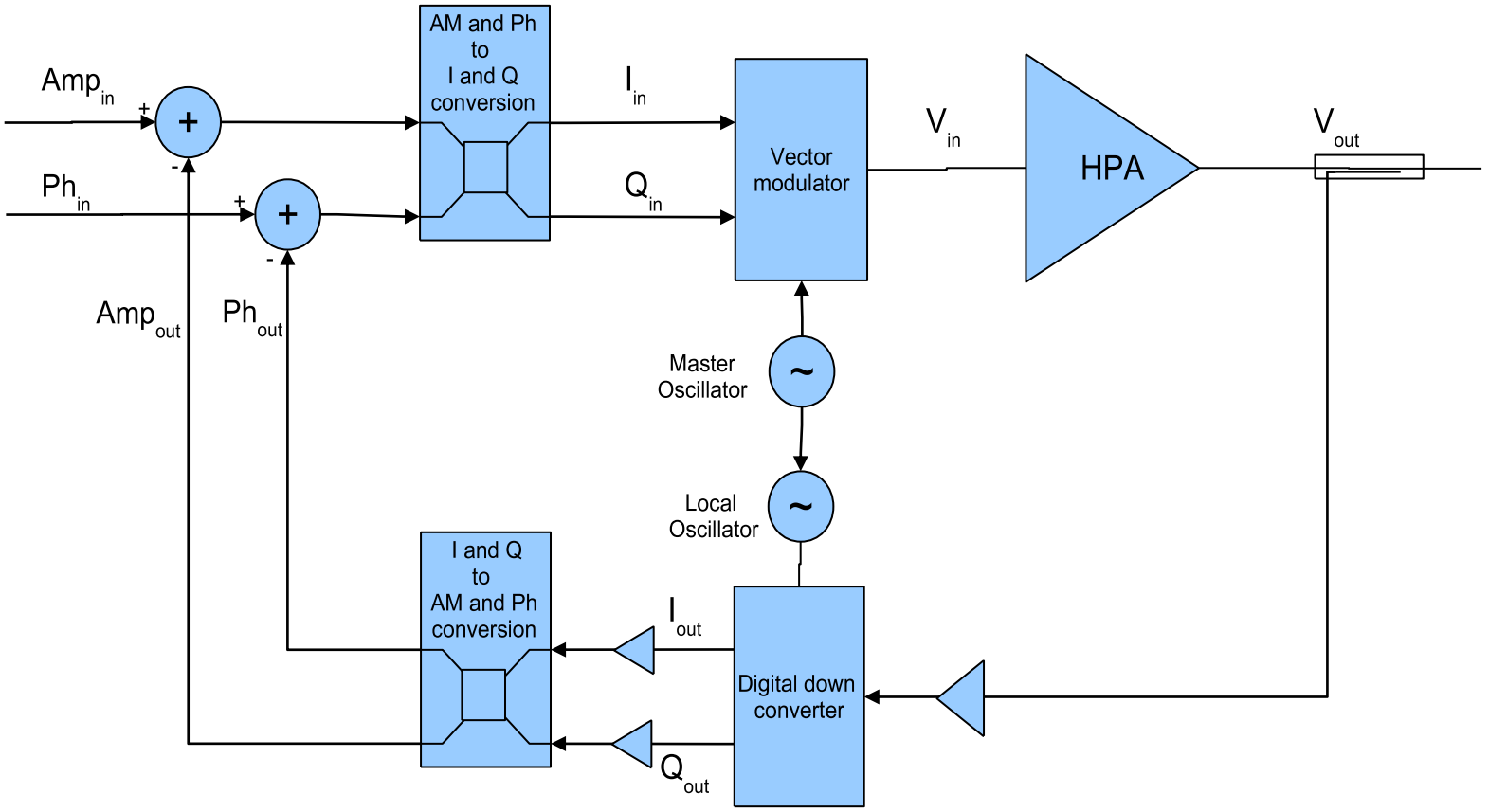
High power amplifier nonlinearities compensated by error amplifier.

Two control loops required:
- signal cancellation,
- error cancellation.

Fast and accurate HPA imperfections compensation, but:
- limited flexibility for adaptation to new working conditions,
- additional delay introduced to the control loop

Different linearization methods

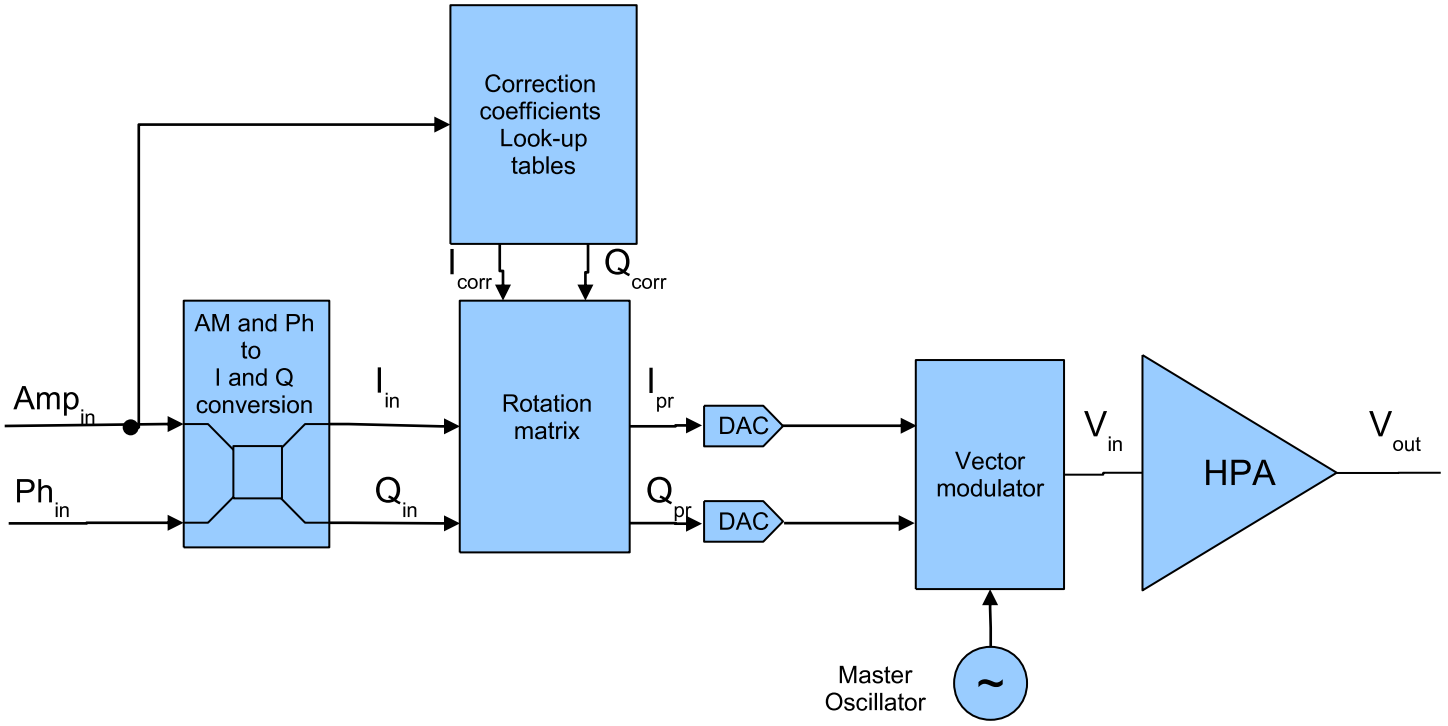
Digital cartesian/polar feedback loop



- Simple PID based feedback loop can be used for the nonlinearities cancellation.
- Realized in polar or Cartesian coordinates.
- LLRF stability limitations (bandwidth, additional delay, etc.)

Different linearization methods

Digital predistortion



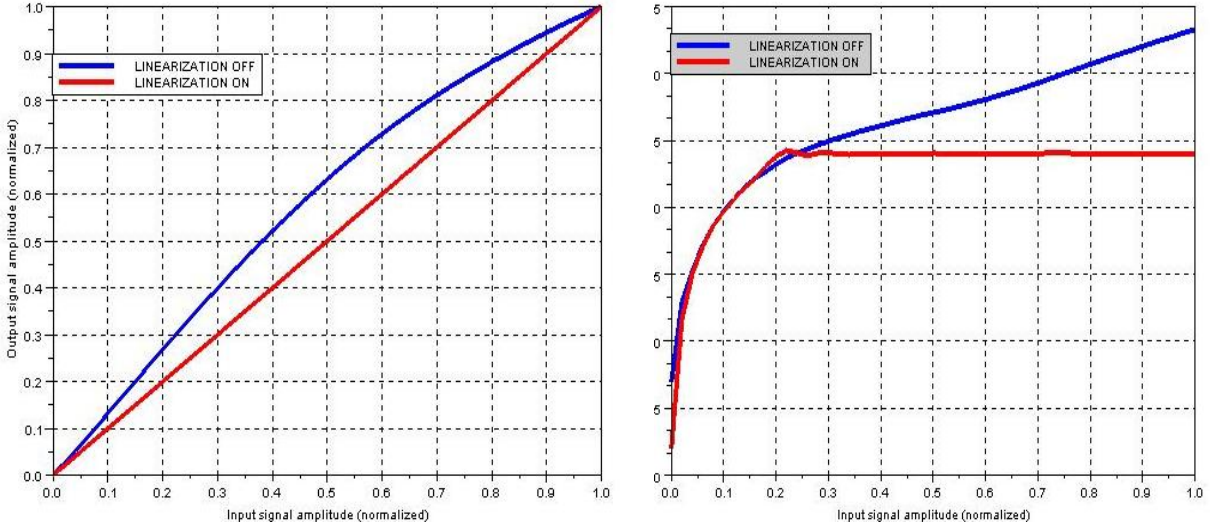
- Predistortion introduce input signal correction due to before measured nonlinearities,
- realized mainly as a LLRF controller functional block,
- can be easily adapted to new working parameters value (but requires devices characterization effort),

Different linearization techniques

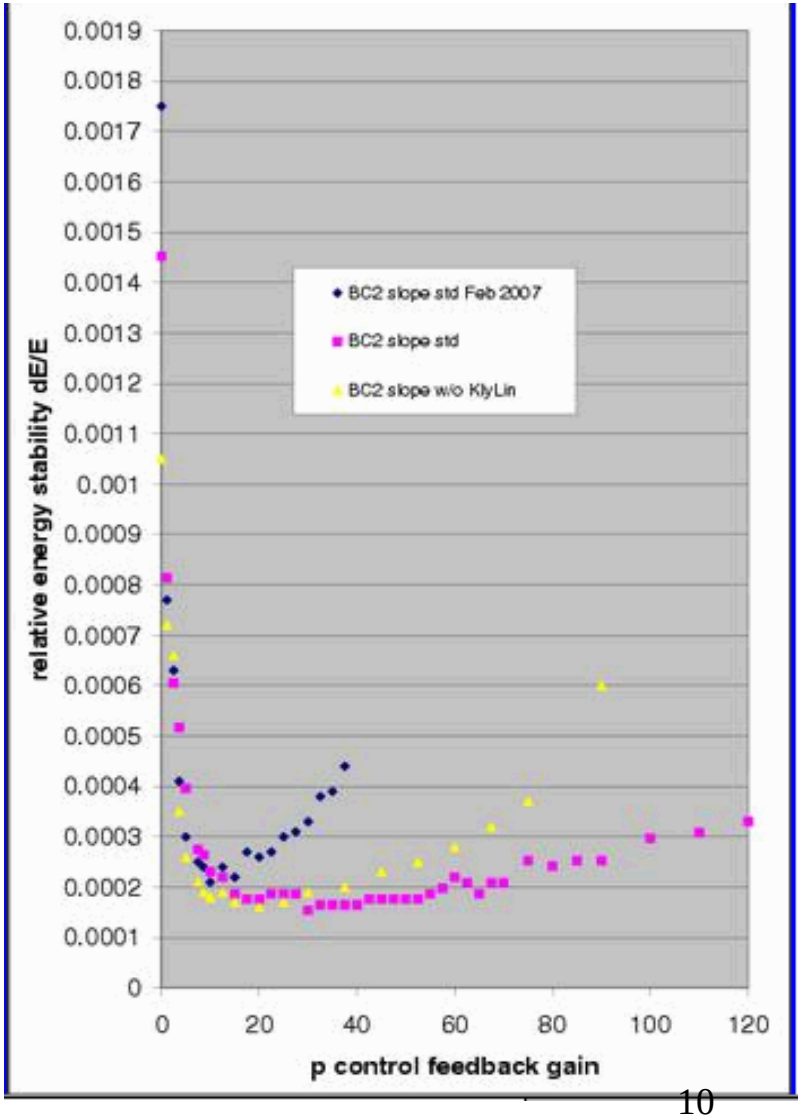
	Feed-forward	Feedback	Predistortion
Linearization accuracy	High	High (dependent on implementation)	High (dependent on implementation)
Implementation cost	High	Low	Low
Implementation complexity	High	Low	Low
Adaptation to different work conditions (HV level change)	Difficult	Easy	Easy (transparent to the accelerator work)
Influence on the external feedback loop	Low	Strong (limits LLRF feedback performance)	Low
Maintenance cost	High	Low	Low (only software maintenance)
Reconfiguration	Difficult	Easy	Easy

High Power Amplifiers Chain transfer characteristics

Amplitude and Phase transfer characteristics



Linearization influence on beam energy stability (FLASH exp.)



Amplitude and phase characteristics deviations reduction