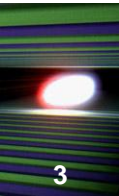# Klystron Lifetime Management System

Łukasz Butkowski

System Integration - LLRF Collaboration Meeting

- Introduction to KLM
- Protection and measurement functions
- Installation at Klystron test stand
- FPGA implementation
- DOOCS server and operation panels
- Results
- Conclusion
- Future plans

■ The klystron is a specialized linear-beam vacuum tube

XFEL: Multi Beam Klystron 10 MW, 10pps, 1.7 ms HV and 1.5 ms RF at 1.3GHz

Very expensive device!

Lifetime of the tube should be in excess of 60,000 hours

Dispenser cathode with beam loading of 2.A/cm^2 can provide average lifetimes of 145,000 hours!

More than 50% of FLASH downtime is caused by Klystron failure,

■ There is a few factors which can reduce lifetime of the tube.

- Bad vacuum indicates ions current, RF and HV breakdown.

- Gun arc can disrupt the cathode electrode and anode surface and can pollute the HV insulator and the active surface of cathode.

- RF breakdown destructs cavity surface and can pollute RF window that increases probability of RF breakdown.

- Work in deep saturation: beam loss, bad vacuum..

Introduction to KLM
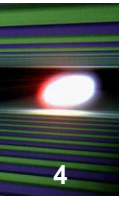
- To prevent occurrence of the destructive factors the fast interlock is required.

  - If klystron parameters are over normal values, RF driving power or/and high voltage should be switched off.

  - System should detect exceptional events and react as fast as possible in order to prevent any damage that could be made. Reaction time: ~200ns.

  - Tube recovery procedure should depend on the kind of event.

- Klystron Life Management system is the fast interlock and measurement system.

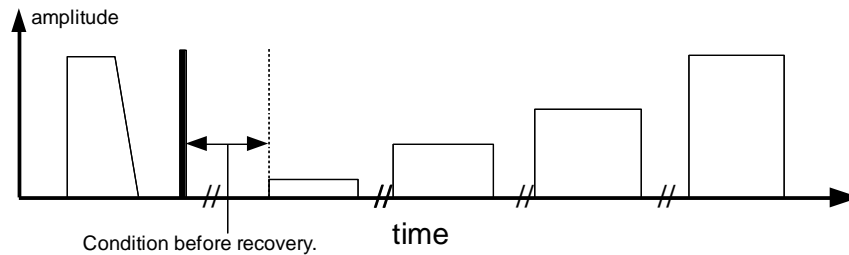# Current Protection and Measurement Functions
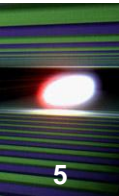
- **Protection functions:**
  - → Correspondence of input and output power, RF breakdown inside tube detection;
  - → Reflection power check, to high reflection power;
  - → Saturation check, to high input power;
  - → High voltage breakdown;
  - ▪ In case of event RF driving signal is switched off and recovery mode is run after it.
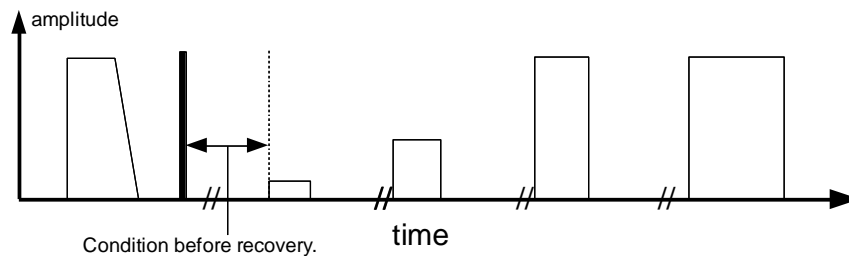
- **Measurement functions:**
  - → Power and phase at klystron outputs and input measurement;
  - → High voltage and klystron current measurement;
  - → Partial discharge measurement;

Recovery Modes

■We use recovery modes to reduce damages that could be made when maximum power is on after error and error event is still on. E.g. slow ions.
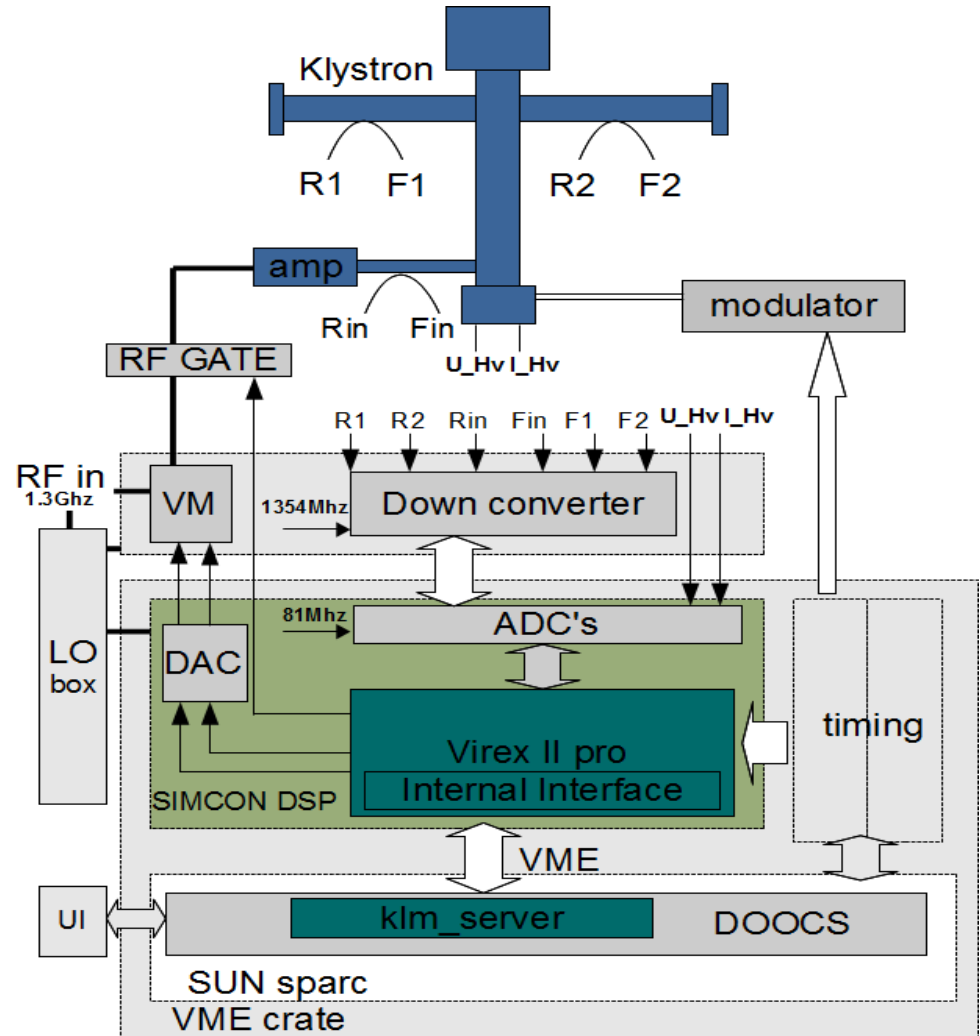
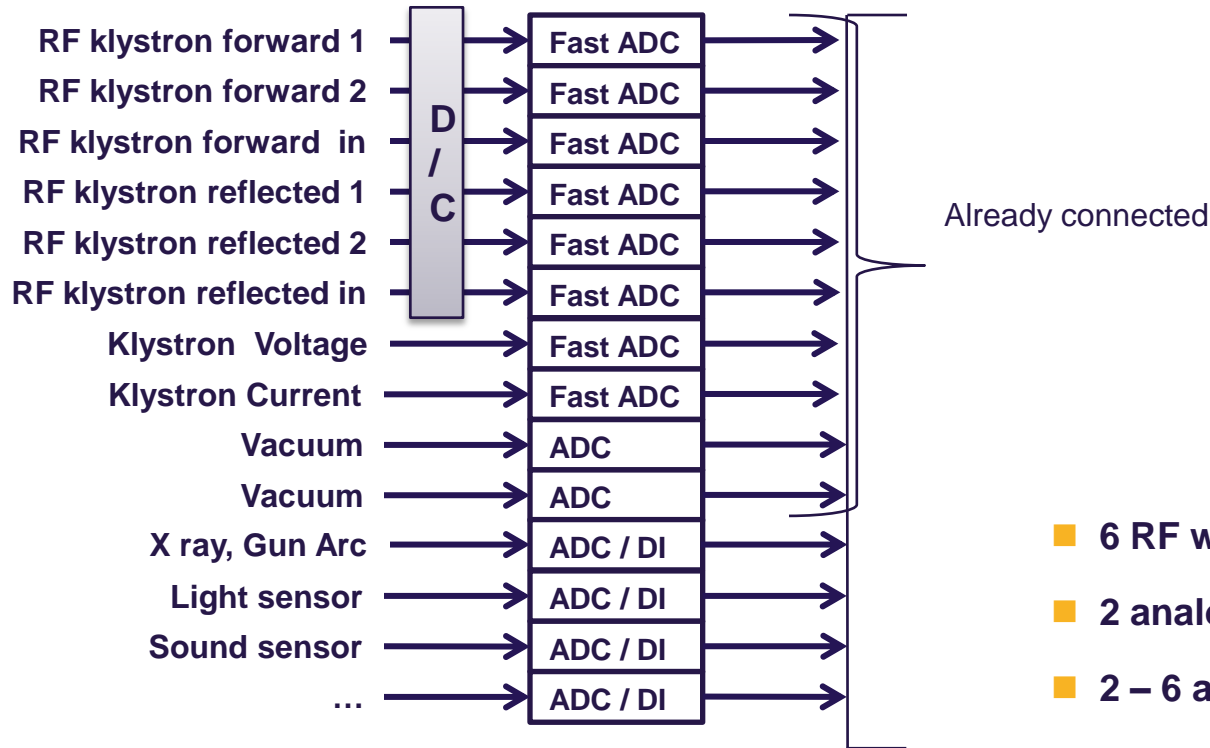■Waveguide breakdown recovery

■Window or tube breakdown recovery.

Installation at klystron test stand

- System based on VME.
  - Components:
    - SIMCON DSP
    - CPU: SUN Sparc;
    - Vector modulator;
    - RF gate;
    - DW RF 1300Mhz > IF 54Mhz;
    - LO box 1354Mhz, 81Mhz;
    - Timing board

- R1 – reflected power at first klystron arm;
- R2 – reflected power at second klystron arm;
- Rin – reflected power at klystron input;
- Fin – forward power at klystron input;
- F1 – forward power at first klystron arm;
- F2 – forward power at second klystron arm;
- U_HV – klystron high voltage;
- I_HV – klystron current;

Signals for protection

Input	Converter	ADC	
RF klystron forward 1		Fast ADC	
RF klystron forward 2		Fast ADC	
RF klystron forward in	D/C	Fast ADC	Already connected
RF klystron reflected 1		Fast ADC	
RF klystron reflected 2		Fast ADC	
RF klystron reflected in		Fast ADC	
Klystron Voltage		Fast ADC	
Klystron Current		Fast ADC	
Vacuum		ADC	
Vacuum		ADC	
X ray, Gun Arc		ADC / DI	
Light sensor		ADC / DI	
Sound sensor		ADC / DI	
…		ADC / DI	

- **6 RF with fast low latency ADC**

- **2 analog with fast low latency ADC**

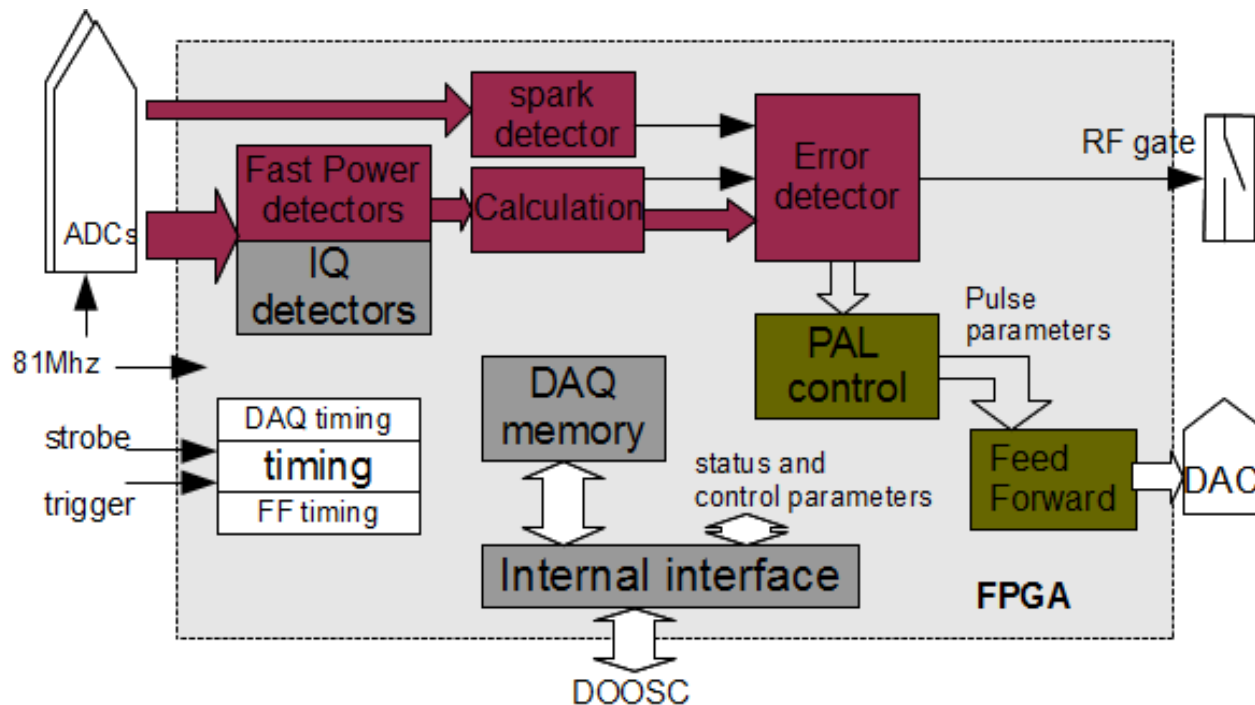- **2 – 6 analog with normal ADC**

- **0 – 4 digital signals**

Klystrons test stand
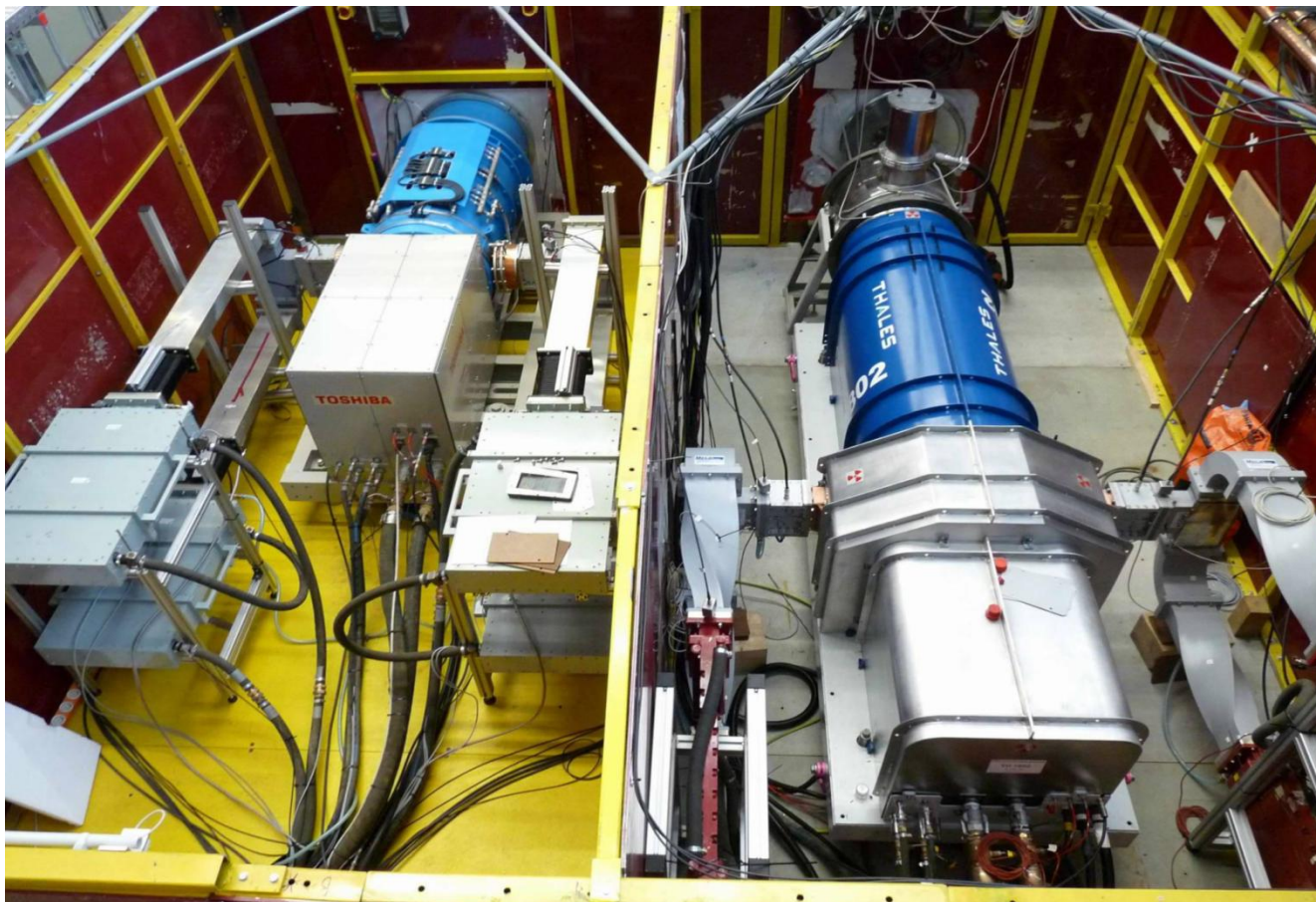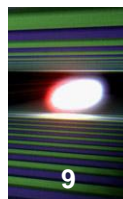
Klystrons at test stand
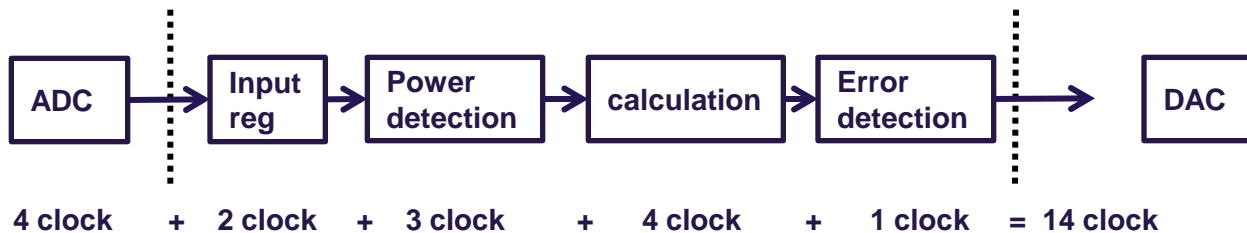
FPGA implementation

- Protection modules
- DAQ modules
- Forward and recovery modes modules

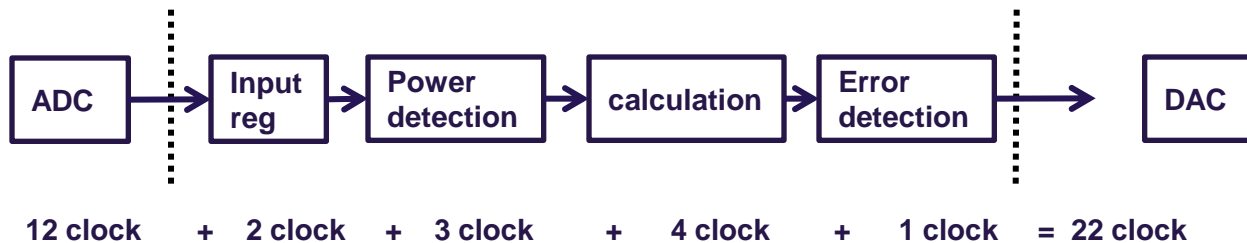- Block diagram of FPGA components

Ddelay path of event detection

- **SIMCON**

  - All calculations are done in a pipeline

| ADC | → | Input reg | → | Power detection | → | calculation | → | Error detection | → | DAC |

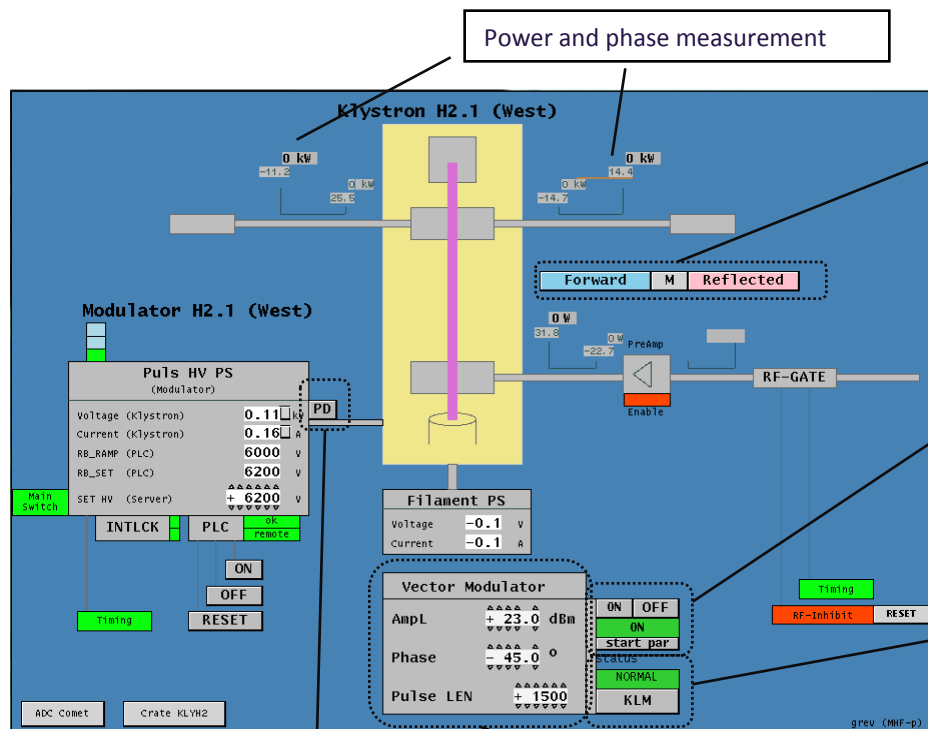**4 clock + 2 clock + 3 clock + 4 clock + 1 clock = 14 clock**

  - Every clock cycle caclulation is done,
  - Delay of error detection is 14 clocks (10 clock of FPGA)
  - For 81 MHz IF clock 14 * 12 = 168 ns (+ DAC or RF gate) of delay

- **Struck**

| ADC | → | Input reg | → | Power detection | → | calculation | → | Error detection | → | DAC |

12 clock + 2 clock + 3 clock + 4 clock + 1 clock = 22 clock

  - For 81 MHz IF clock 22 * 12 = 264ns (+ DAC or RF gate) of delay, **144ns is only ADC !!**

DOOCS panels

- ## Main klystron operation window.
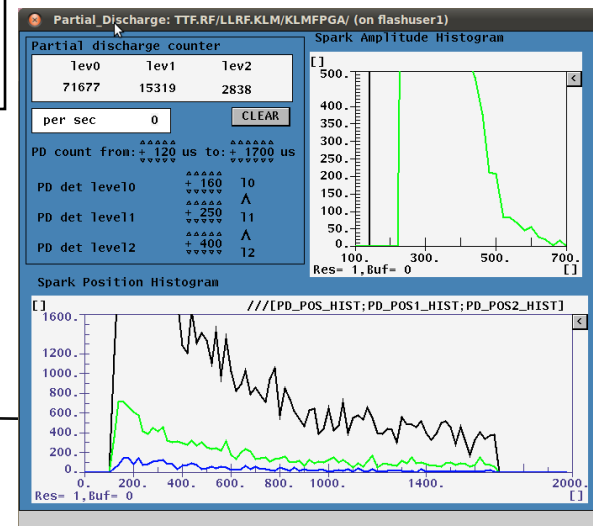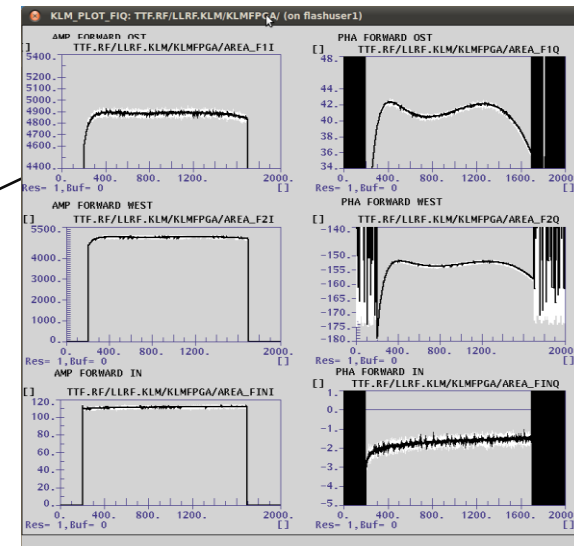

Power and phase measurement

Buttons for display current output power plots
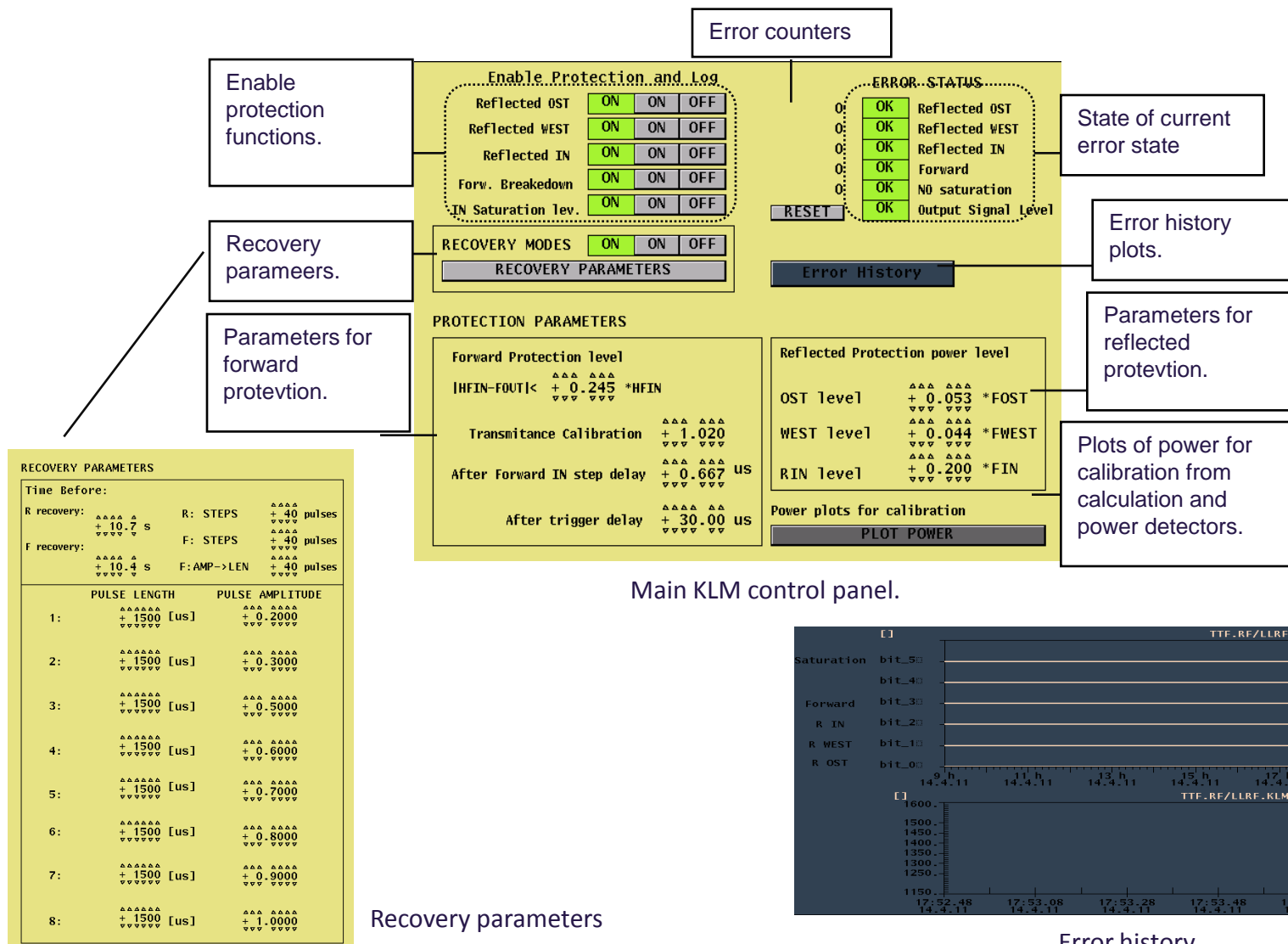
Buttons for switch on and off RF signal and set startup parameters.
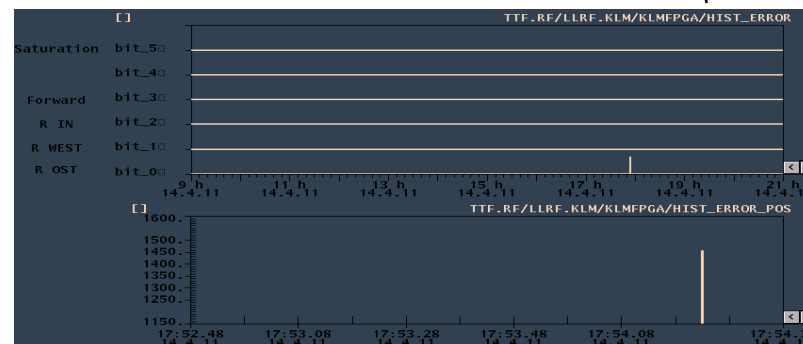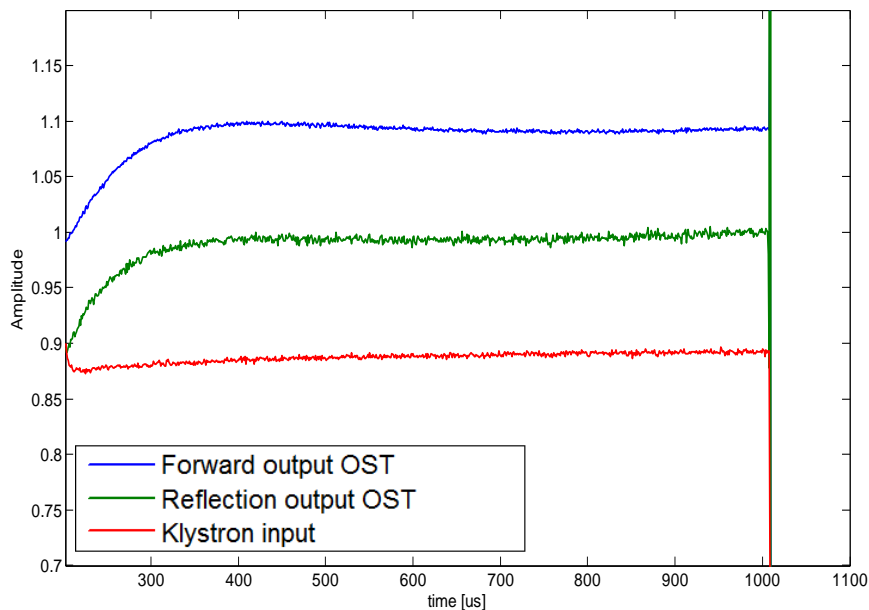
State of KLM system and button for main KLM window.

Vector modulator settings.

Partial discharge.

DOOCS panels

Error counters

Enable protection functions.

Recovery parameers.

Parameters for forward protevtion.

State of current error state

Error history plots.

Parameters for reflected protevtion.

Plots of power for calibration from calculation and power detectors.

Main KLM control panel.
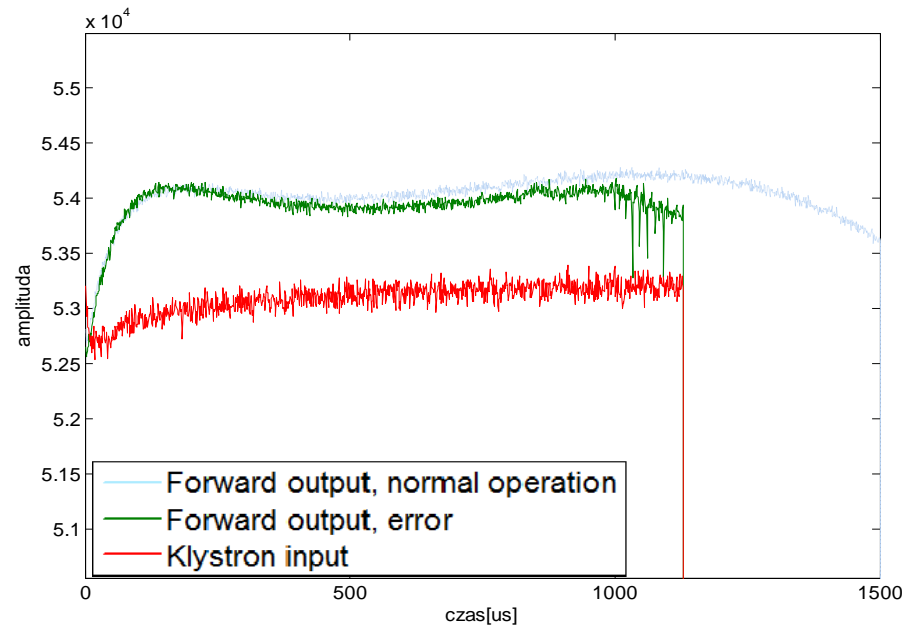
Recovery parameters

Error history

Results

In case of event all measured data is stored on HD for future analysis.

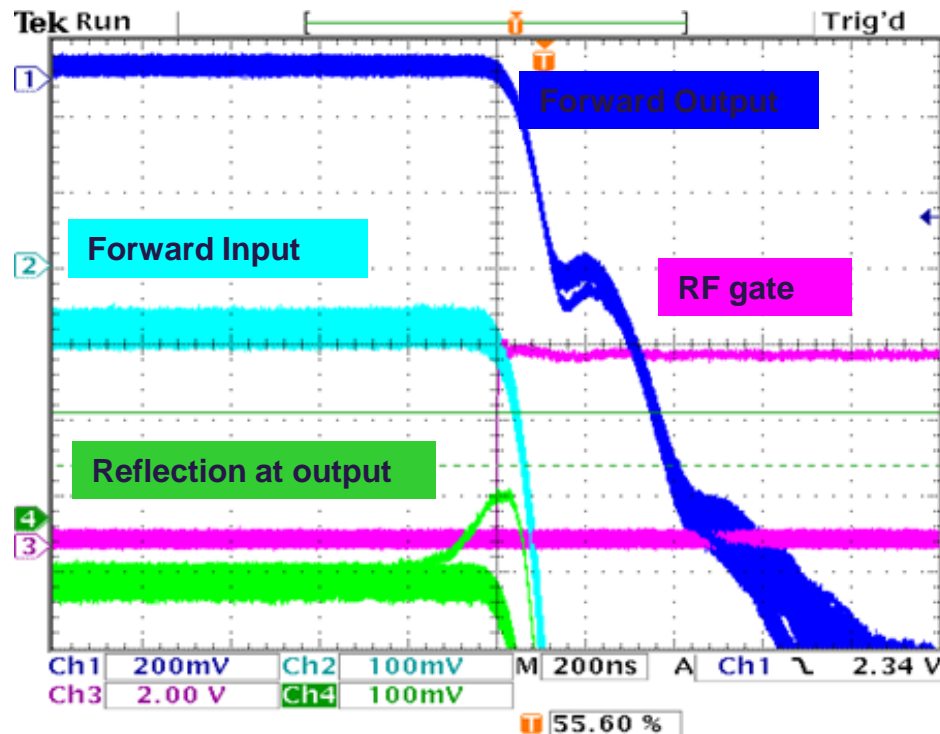**To high reflection event detection.**

Forward power breakdown event.

Results

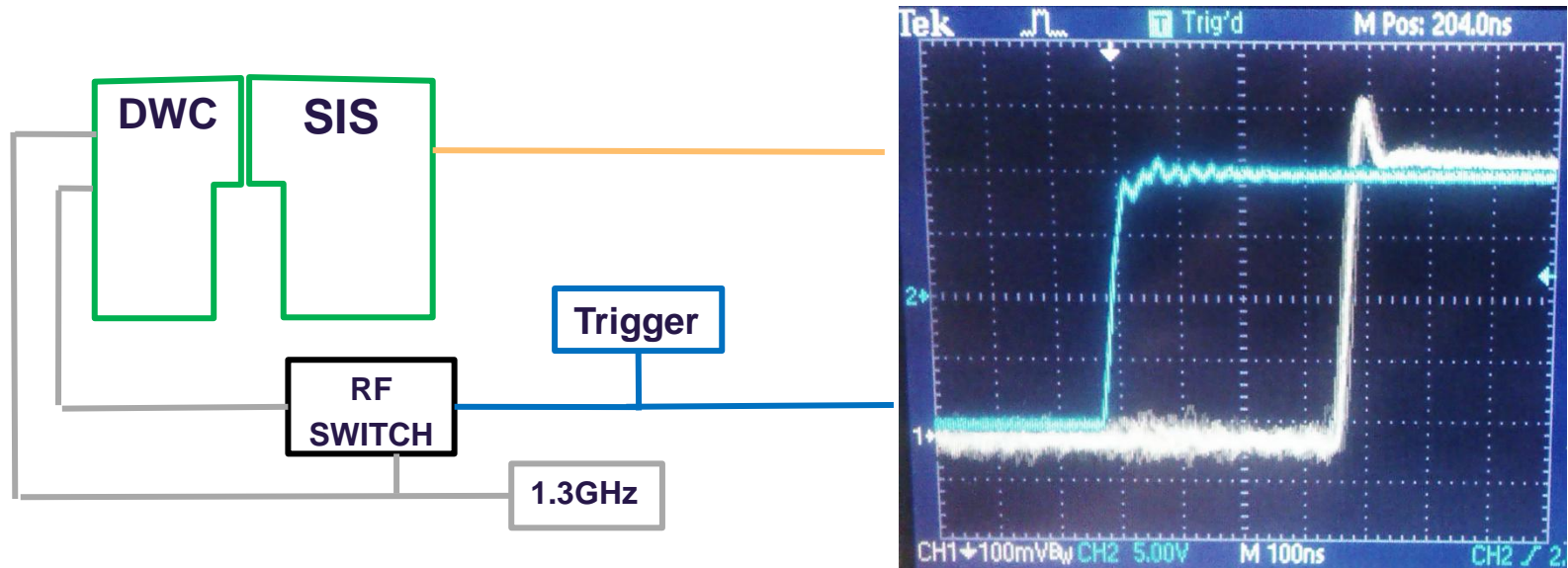## Reaction of KLM system implemented on SIMCON is: 200ns – 250ns

To high reflection event detection.

SIS8300 delay time

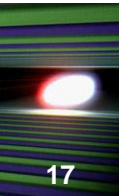KLM was implemented on SIS8300 and tested in the laboratory,

■ Delay time test setup for SIS8300

Delay time = RF switch + cable + DWC + SIS = 380ns
(~20ns)

- The necessary software and hardware for KLM system was developed, the transfer matrix of RF system including the klystron, RF amplifier and directions couplers was measured.

- KLM system based on SIMCON board, since October 2010 is in operation on Klystrons Test Stand.

- The reaction time on the RF events is about 250 ns.

- One of the possible recovery procedure after RF events was tested.

- SIS8300 board is not good for fast interlock system.

Future plans
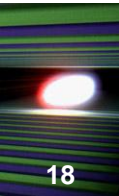
- Implementation on uTCA (part of software already done)
  - Installation at Klystron test stand;
- Installation at FLASH, to verify event detection and then enable protection functions;
- Add protection and measurements of
  - Vacuum
  - Light and sound sensors
  - X ray sensors
- Develop new hardware for xTCA, more suitable for fast interlock system.

Thank you for attention