WP 9 (Low Level RF)

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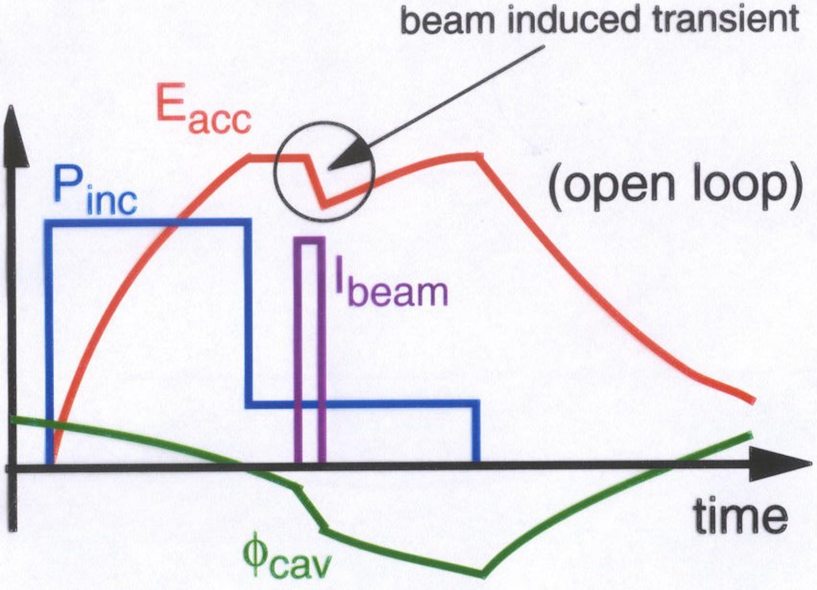
(for the LLRF team)

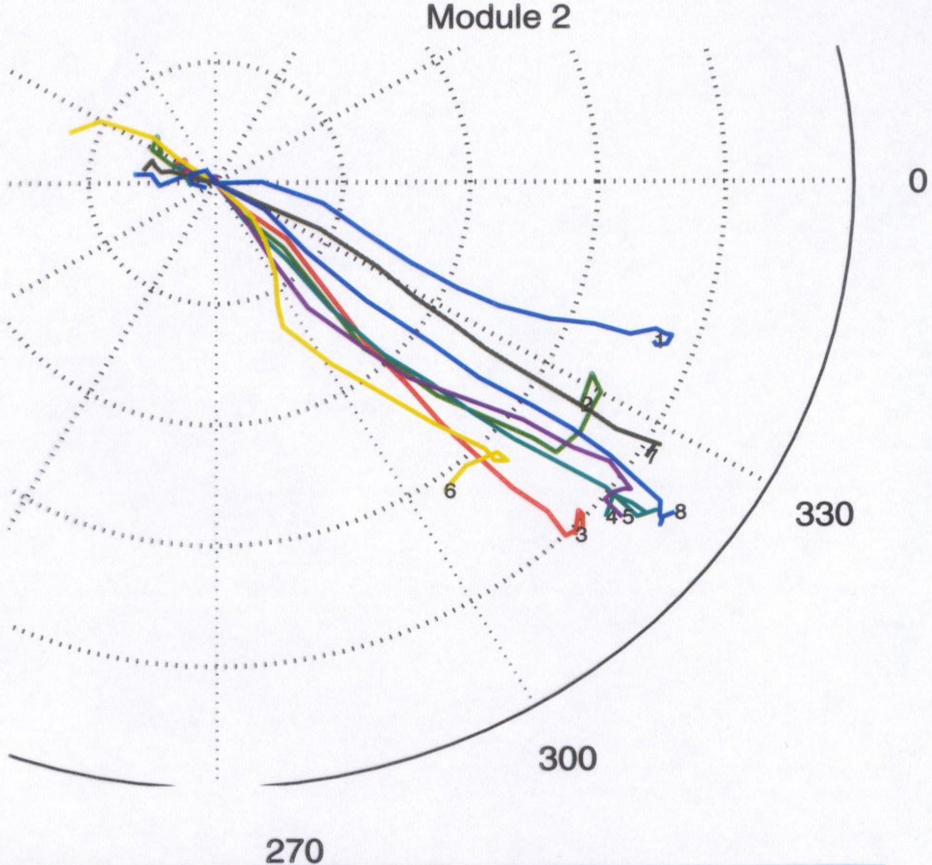
DESY

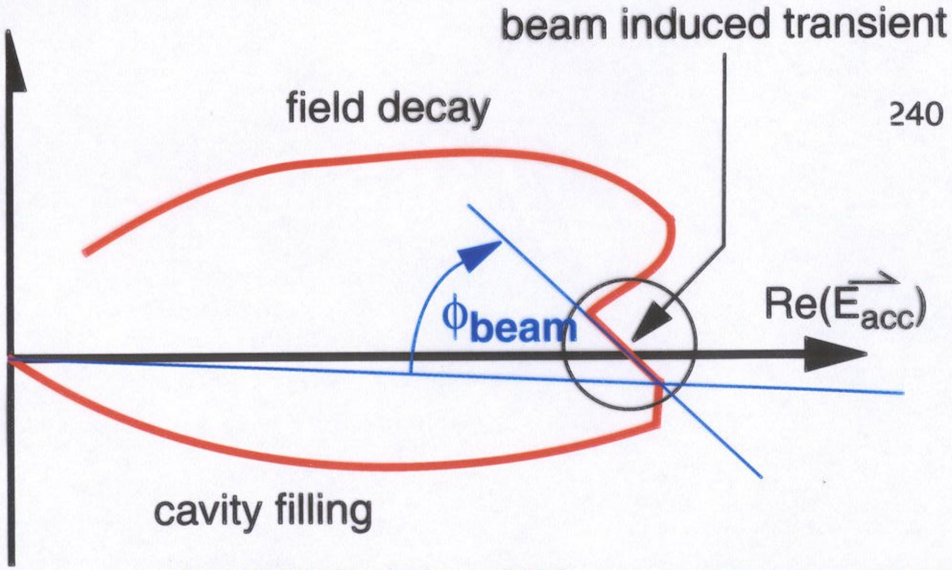
Single Bunch Transient Detection

- Detection of the transient of a single bunch (1 nC) with magnitude of about 2e-3 with a resolution of a few percent in amplitude and few degrees in phase.
- This requires development of new hardware (microwave, analog, digital) with high bandwidth and low noise.
- Conceptual idea is to subtract delayed probe signal from original probe signal so that nulled difference signal can be amplified at 1.3 GHz. Transient is detected with high speed I/Q demodulator.

Beam Transient based Phase and Gradient Calibration



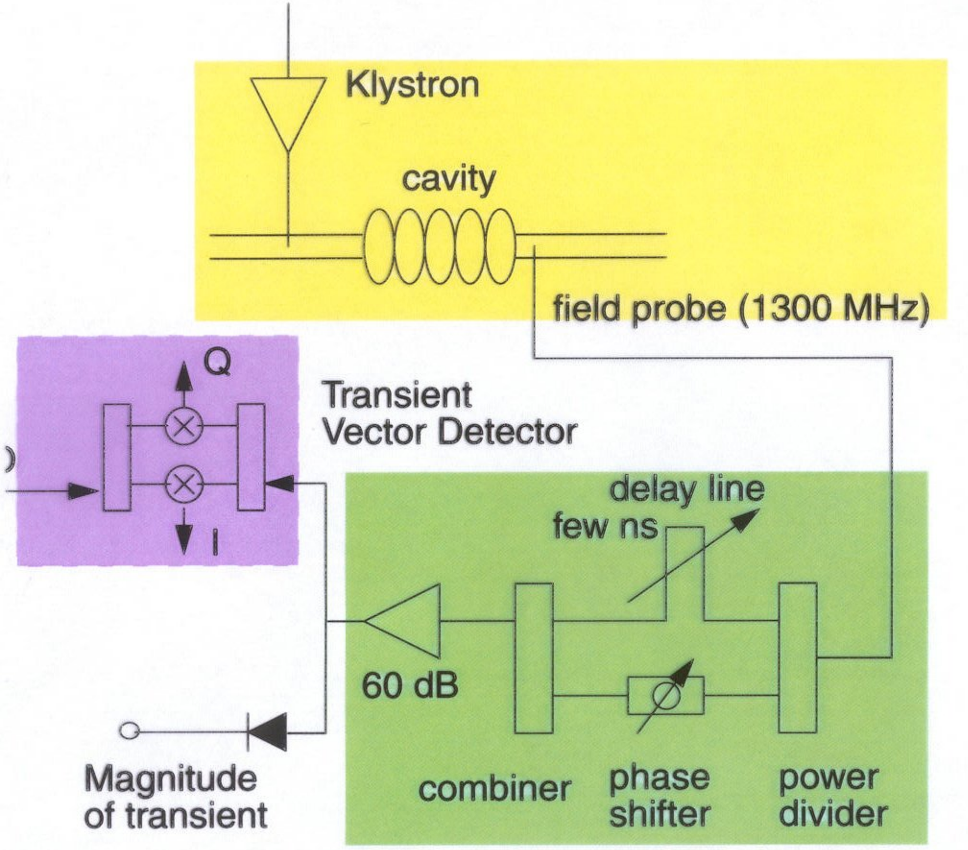




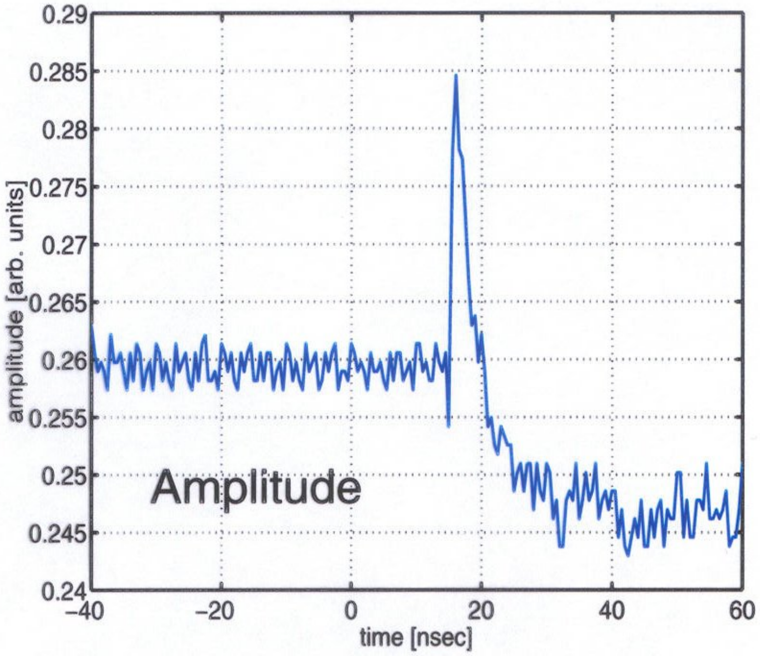
for $\Delta t << \tau_{cav}$:

$$\Delta V_{ind} = I \cdot \Delta t \cdot \left(\frac{r}{Q}\right) \cdot \pi \cdot f$$

Single Bunch Transient Detection



Principle of high resolution transient detector



Single Bunch Transient (ΔA/A=0.1%)

Design Optimization: Cost & Reliability

- Reduce cost of LLRF system by application of state of the art COTS.
- This leads to compact design. Address hardware and software issues.
- Reliability studies include electronic components, packaging including connectors, thermal and radiation effects.
- Protoype of critical components is produced and studied in climate chamber.

Highly Stable Frequency Distribution

- The FEL and Linear Collider require a high phase stable reference to ensure that the rf signals of laser, rf gun, and accelerating cavities are synchronized to better than 1 picosecond. Therefore the frequency distribution over the whole size of the accelerator (about 300 meters for TTF II, and 30 km for TESLA) must provide the necessary frequencies at many rf stations with the correct power level while guaranteing sufficient stability.

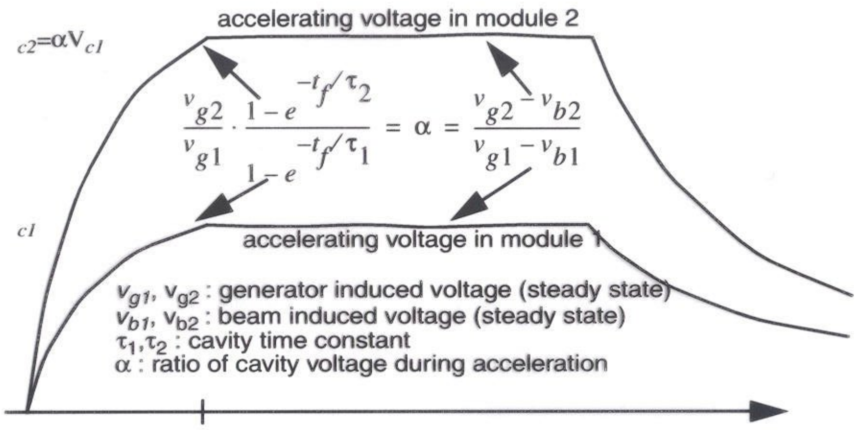
- The proposed approach combines a coaxial distribution system with a fiber optic monitoring system.

- Goal is the design, construction and evaluation of such a system with real beam.

Performance optimization at Different Gradients

- Development of simulation model for vector-sum control of superconducting cavities.
- Implementation of real-time model on high performance computation platform (DSP or FPGA based). Performance evaluation with different operating parameters for cavities and controller.

Operation at Different Gradients



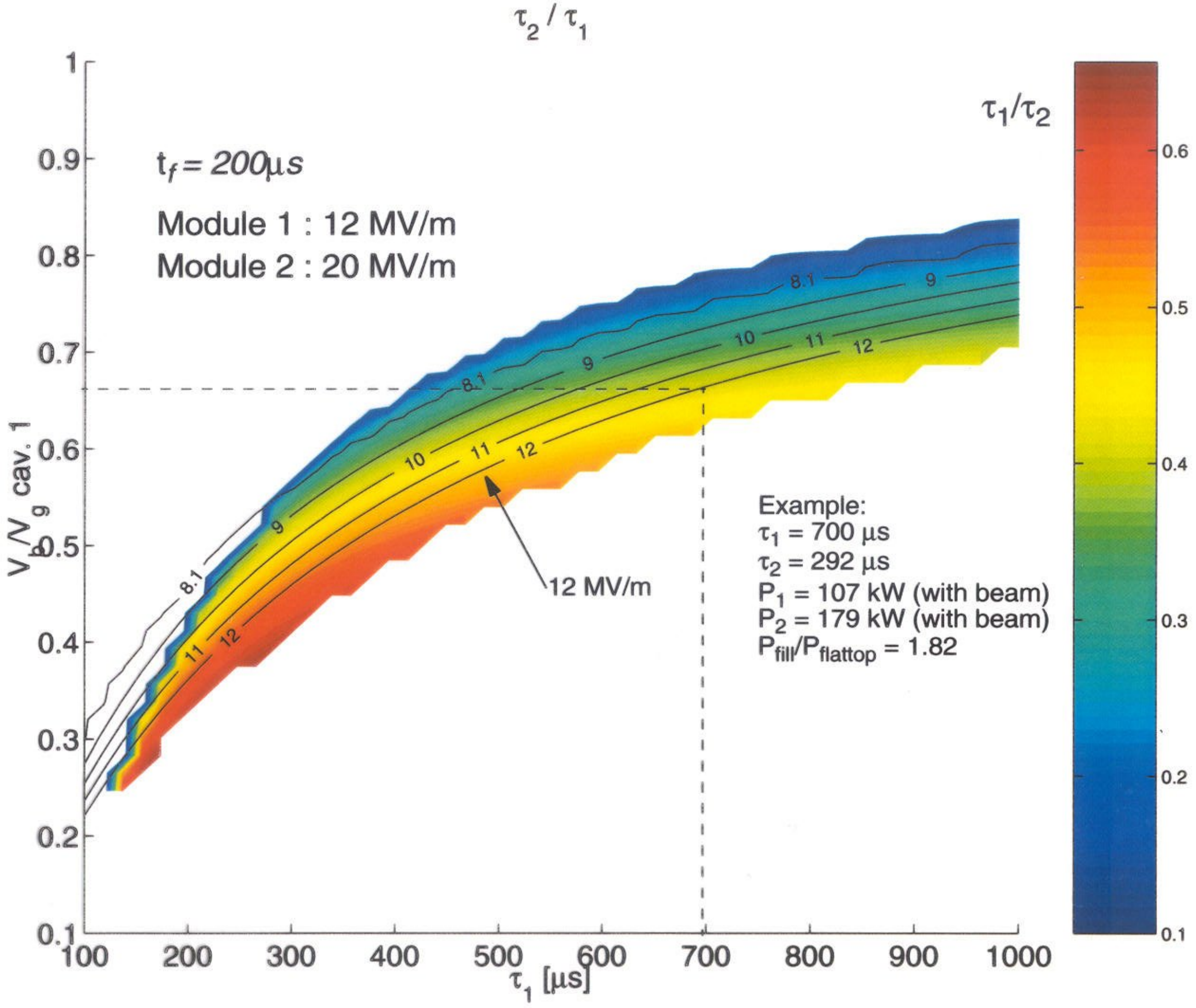
$$\frac{v_{g2}}{v_{g1}} \cdot \frac{1-e^{-t_f/\tau_2}}{1-e^{-t_f/\tau_1}} = \alpha = \frac{v_{g2}-v_{b2}}{v_{g1}-v_{b1}}$$

v_{g1}, v_{g2} : generator induced voltage (steady state)
v_{b1}, v_{b2} : beam induced voltage (steady state)
τ_1,τ_2 : cavity time constant
α : ratio of cavity voltage during acceleration

peration at different gradients is only ossible in narrow parameters range:

gradient
beam current

eviation from this conditions leads to opes on individual gradients.



Example:
τ_1 = 700 µs
τ_2 = 292 µs
P_1 = 107 kW (with beam)
P_2 = 179 kW (with beam)
$P_{fill}/P_{flattop}$ = 1.82

Multichannel Downconverter

- Develop low cost and compact high-performance multi-channel downconverter with high degree of linearity, excellent signal to noise ratio, high bandwidth, low offset and LO-IF leakage.

- Downconverter could make use of commercial analog multipliers such as RF2411 or AD8343.

Study Radiation Effect on Electronics

- Improve reliability, performance, and lifetime of LLRF system in radiation environment.

- Address hardware and software issues. Radiation impact studies include performance degradation in analog circuits, single event effects in digital electronics, and total dose effects leading to complete failure.

- Protoypes of critical components are produced and studied in radiation environment.

Aluminum doped GaAs Light Emitting Diode (LED) as a cost effective and reliable Fast Neutron Detector for High Energy Particle Accelerator Applications

High energy neutrons produce „displacement damage“ in Light Emitting Diodes (LED) which results in the reduction of „light output“ of the LED (Figure 1).

On the other hand, high energy photons cause no such damage in the LEDs (Figure 2).

The above findings have been utilized to develop an inexpensive fast neutron detector for a myriad of applications in High Energy Pareticle Accelerator Monitoring.

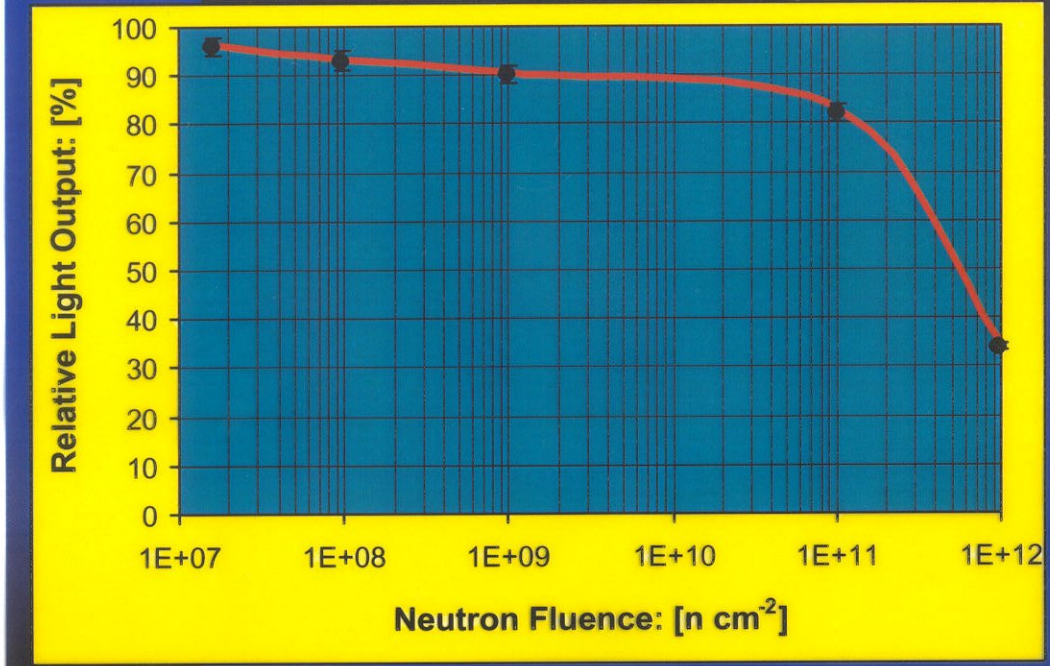
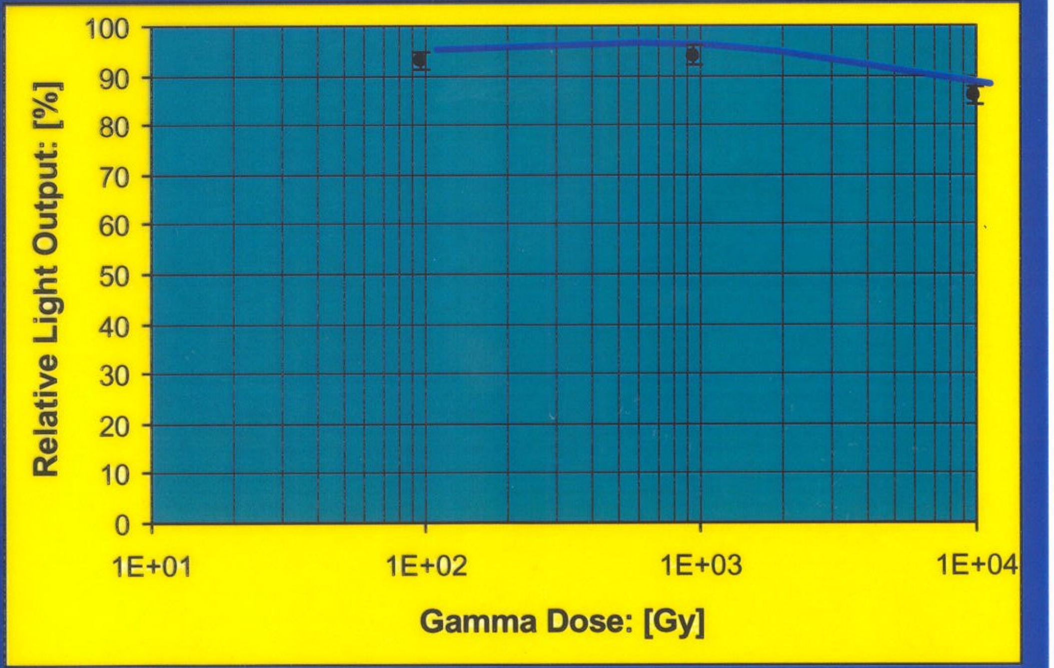


Figure 1:

Relative light output of the GaAs-LED shown as a function neutron fluence. The LEDs were irradiated with mono-energetic fast neutrons (ca. 60 MeV) at Harper Hospital Medical Cyclotron, Detroit, USA.

Figure 2:

Relative light output of the GaAs-LED shown as a function of gamma dose. The LEDs were irradiated with (^{60}Co) gamma rays at Hahn Meitner Institute Berlin.



Finite State Machine

- The automation of the LLRF system will be implemented in the framework of a finite state machine (FSM) which is a well established industrial standard. The Finite State Machine (FSM) concept has been integrated into DOOCS to simplify the automation of the accelerator operation.

- The first step will be the definition of the superstates, sub-states, flows, entry-, during-, and exit-procedures, entry conditions, timer and event triggered procedures etc..

- The next step is the description of the applications to be used by the FSM. Then the above functionality will be implemented as FSM server in DOOCS and the required application programs will be developed.

Data Management for DOOCS

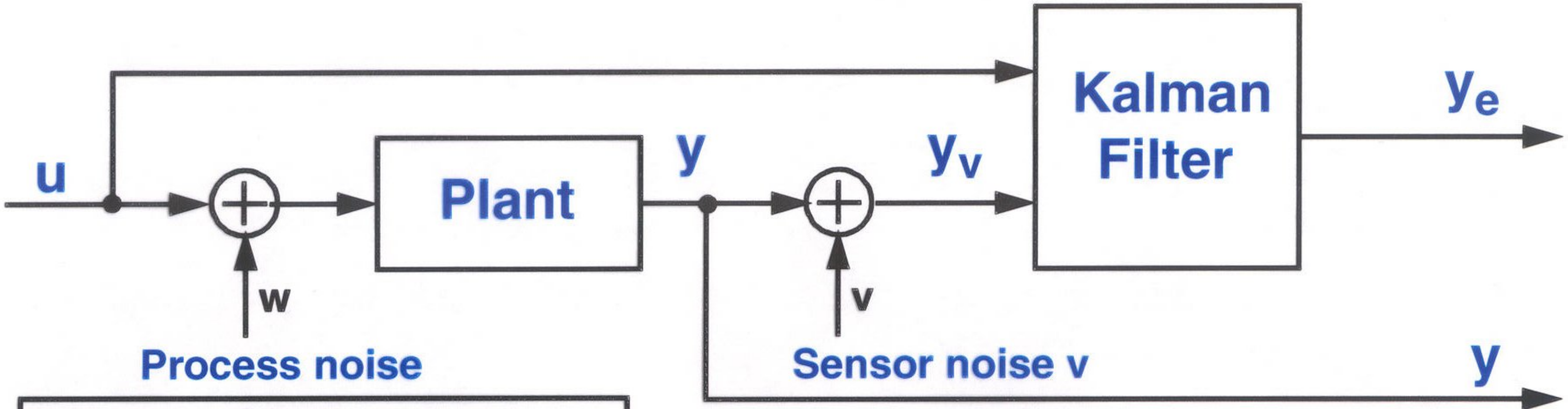
- The operation of an accelerator requires calibration of operating parameters such as gradient and beam phase, and operation close to permitted limits.
- A feature similar to a database is therefore needed to store and retrieve all the component data necessary to derive the calibration parameters or compensate for hardware imperfections.
- The datatypes includes single valued parameters but also matrices possibly in multiple dimensions. Data entry and access should be userfriendly.
- The data management system should be easy to maintain and support reliable and reproducible operation of the accelerator.

Development of Optimal Controller

- Modern control theorie has developed established methods for the design of optimal controllers. Following definitions of the optimal control criteriae these techniques should be applied to synthesize the optimal controller for rf control for superconducting cavities.

- The optimal controller should guarantee best performance and robustness in presence of beamloading, Lorentz force detuning and microphonics while operating close to saturation of the klystron and performance limit of cavities and couplers.

Principle Kalman Filter (steady state)



Discrete Plant:

$x[n+1]=Ax[n]+B(u[n]+w[n])$

$y[n]=Cx[n]$

Noisy output measurement: $y_v[n]=Cx[n]+v[n]$

Measurement update:

$$\hat{x}[n|n]=\hat{x}[n|n-1]+M(y_v[n]-C\hat{x}[n|n-1])$$

Time update: $\hat{x}[n+1|n]=A\hat{x}[n|n]+Bu[n]$

The correction term is a function of the innovation, i.e. the discrepancy

$$y_v[n+1]-C\hat{x}[n+1|n]=C(x[n+1]-\hat{x}[n+1|n])$$

The innovation gain matrix M is chosen to minimize steady-state covariance of the estimation error given the noise covariances $E(w[n]w[n]^T)=Q$ and $E(v[n]v[n]^T)=R$

Exception Handling

- Operation of superconducting cavities close to the performance limit will increase the trip rate due to the machine protection system.
- Typical trips include couplers sparcs, cavity quench, klystron sparcs or other faults caused by operation with high power.
- An exception handling system must be implemented with in the rf control system to minimize the trip rate and recovery time.
- Also unexpected beam loss or other sudden changes in operating parameters must be processed by the exception handler.

Robust RF Gun RF Control

- The normal conducting RF gun requires special control considerations such as low latency in the feedback loop, controller for temperature of the of the rf gun resonator, and interlock scheme.

- Due to the lack of a field probe, the cavity field must be determined by a precision measurement of incident and reflected wave.

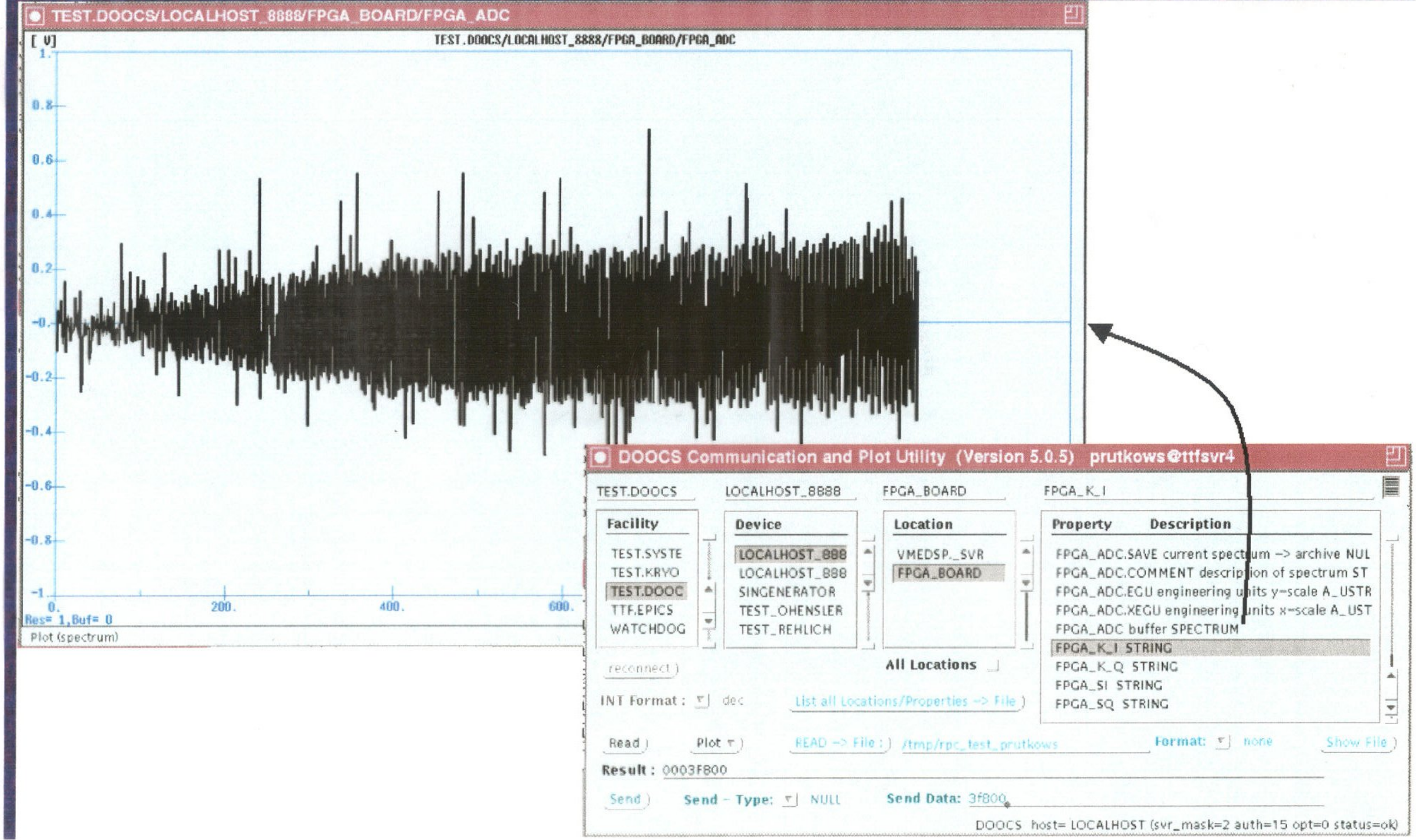
- Cavity detuning is measured during field decay as the slope of the time varying phase with respect to the frequency reference.

Cavity and RF GUN controller

- **Based on FPGA XILINX Virtex 2**
  - Response < 100 ns (32 cavities)
  - Feedforward

- **Nallatech board**
  - 2 ADC @ 65 MHz
  - 2 DAC @ 65 MHz
  - Virtex XC2V3000

Cavity controller, DOOCS



TEST.DOOCS LOCALHOST_8888 FPGA_BOARD FPGA_K_I

Facility	Device	Location
TEST.SYSTE	LOCALHOST_888	VMEDSP._SVR
TEST.KRYO	LOCALHOST_888	FPGA_BOARD
TEST.DOOC	SINGENERATOR	
TTF.EPICS	TEST_OHENSLER	
WATCHDOG	TEST_REHLICH	

Property	Description
FPGA_ADC.SAVE	current spectrum -> archive NUL
FPGA_ADC.COMMENT	description of spectrum ST
FPGA_ADC.EGU	engineering units y-scale A_USTR
FPGA_ADC.XEGU	engineering units x-scale A_UST
FPGA_ADC	buffer SPECTRUM
FPGA_K_I	STRING
FPGA_K_Q	STRING
FPGA_SI	STRING
FPGA_SQ	STRING

INT Format : dec

READ -> File : /tmp/rpc_test_prutkows Format: none

Result : 0003F800

Send - Type: NULL **Send Data:** 3f800

DOOCS host= LOCALHOST (svr_mask=2 auth=15 opt=0 status=ok)

Cavity simulator

- **Based on FPGA XILINX Virtex 2**
  - Implemented electrical and mechanical model of cavity
  - Step mode
  - Continuous mode
- **Access via Matlab**
- **Access via DOOCS**

Cavity simulator