LLRF for the FLASH 9mA Program

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Scope of work and anticipated degree of difficulty for LLRF

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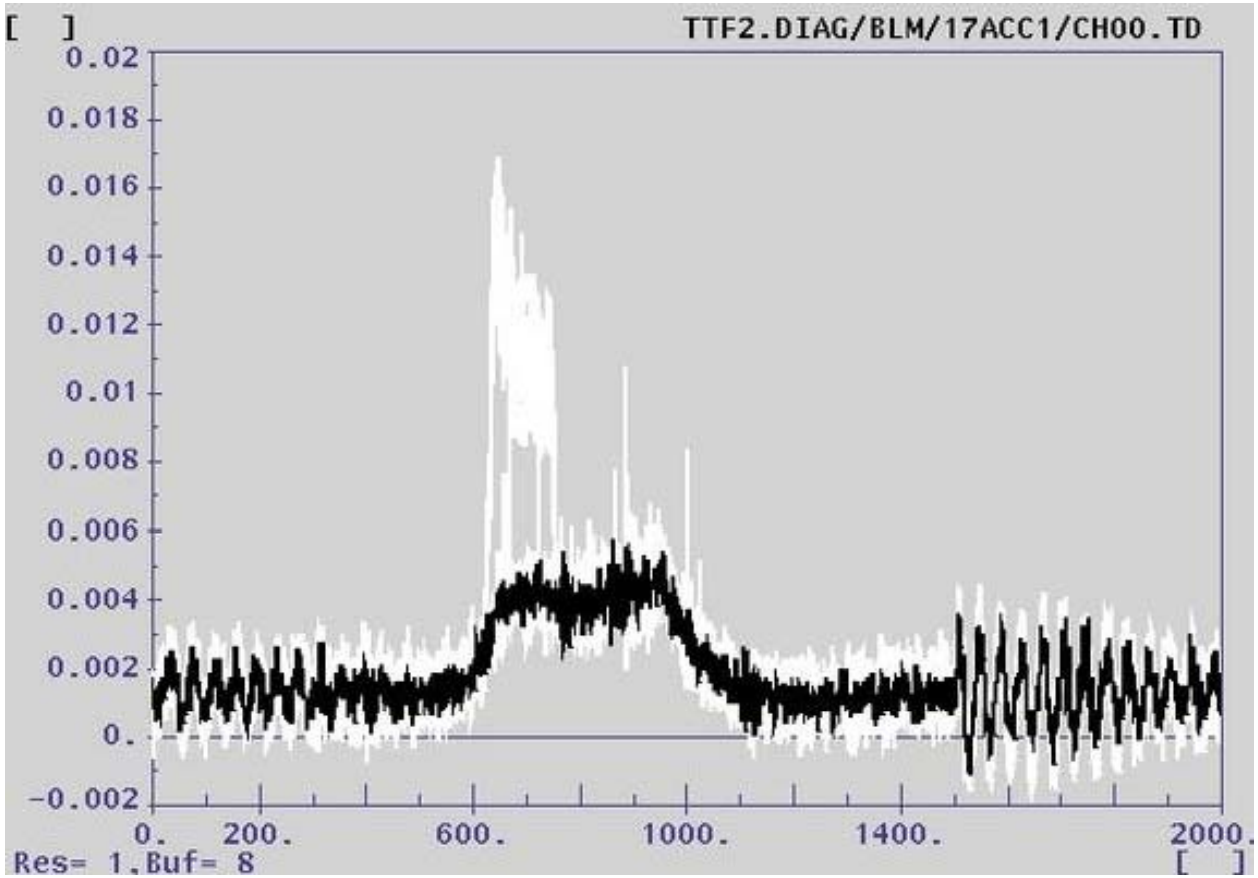
Operating parameters

- Bunch Charge: 3 nC
- Bunch repetition time: 3 MHz
- Number of bunches: 2400
- Beam energy > 700MeV
- RF pulse length (flattop): 800 µs

Problems to get these conditions

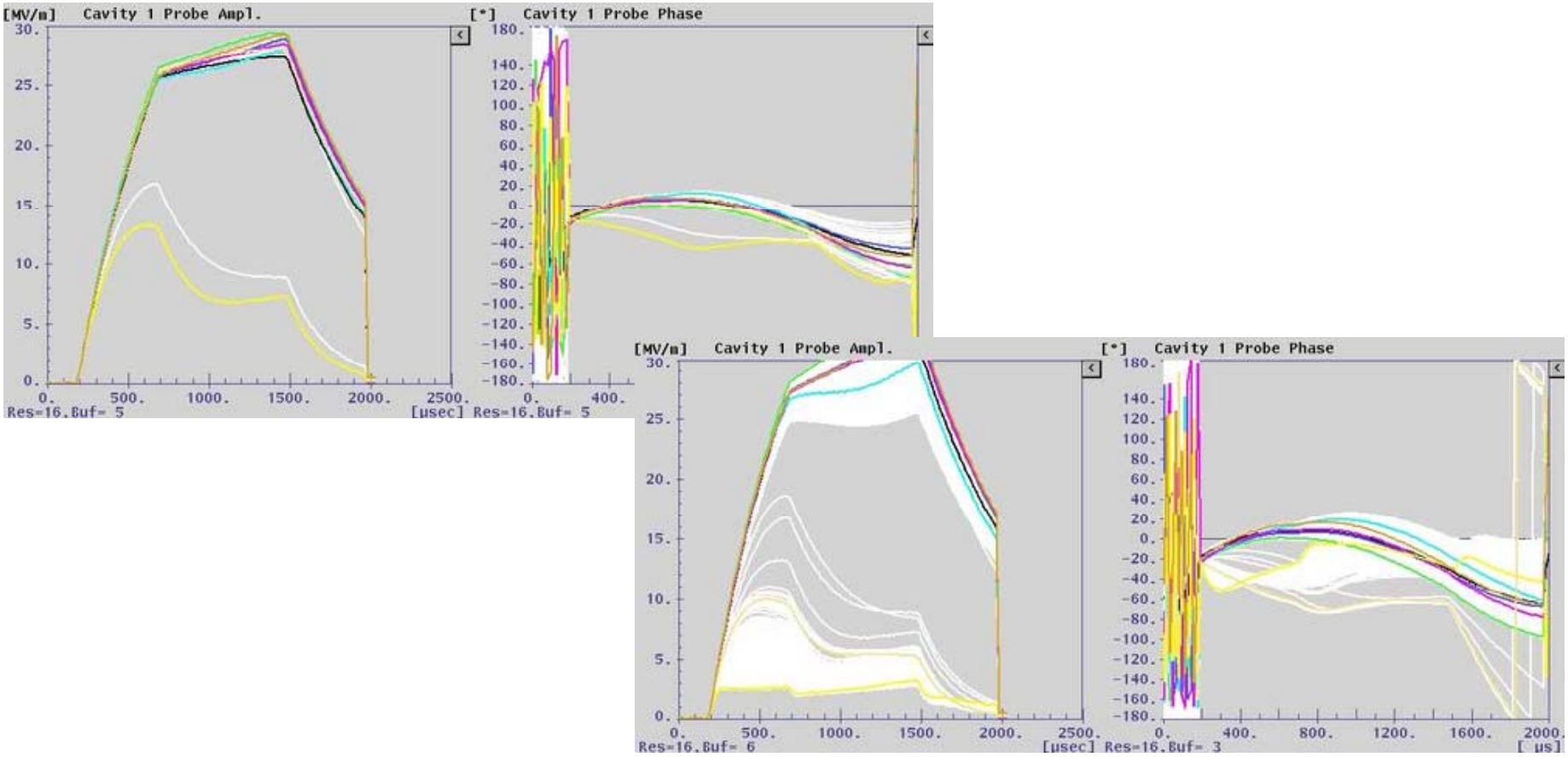
- Pushing machine up to the limits requires exception detection that does not exist and cannot be implemented in current DSP based LLRF controller
  - **No real time quench detection for individual cavities**
  - **No klystron linearization**
  - **No real time beam loading compensation from toroid measurement**

Beam losses



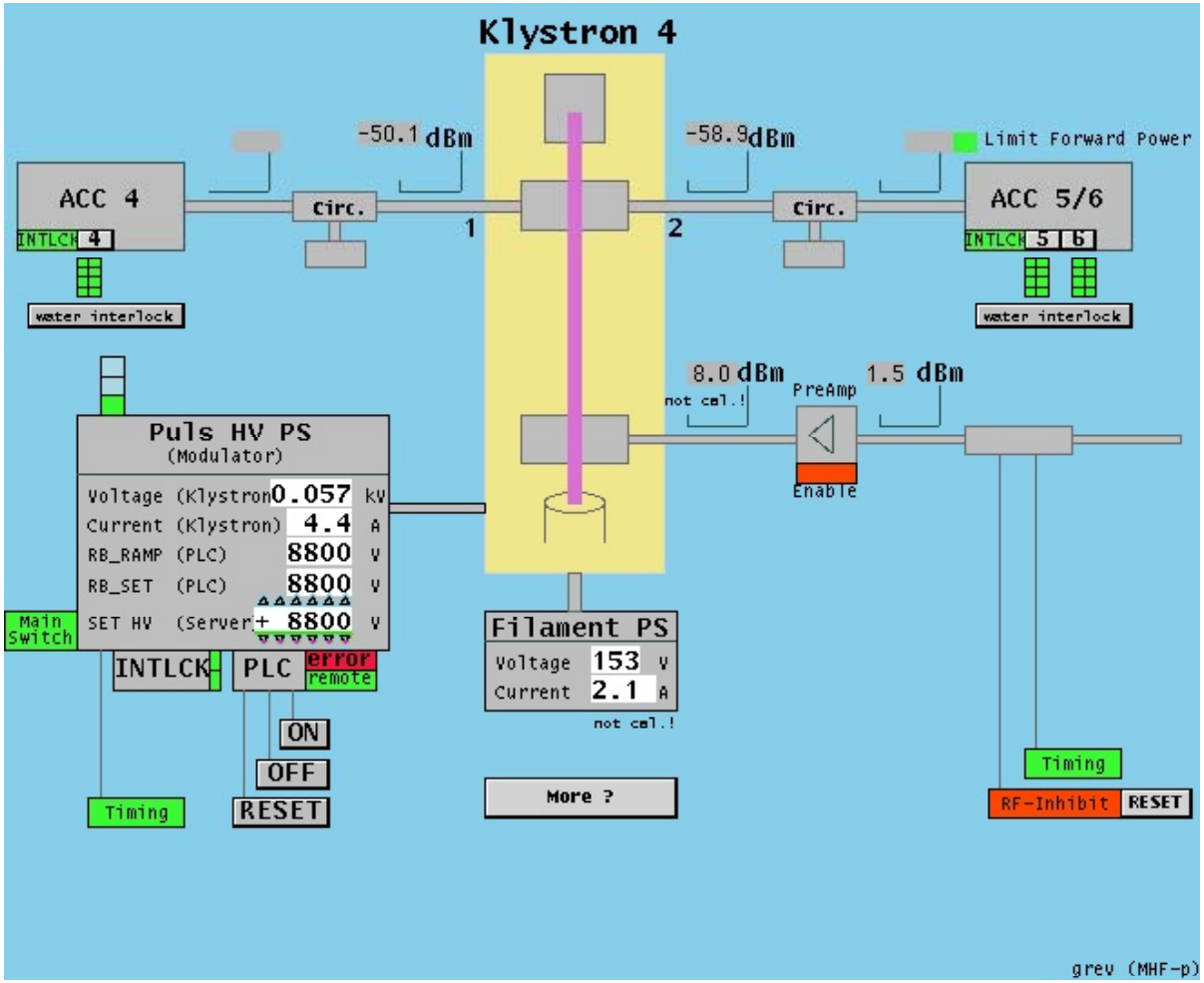
Field instability lead to beam losses that triggers BIS and disables RF operation

Cavity quench



High gradient may cause cavity quenches

Klystron



Difficulties: Kly. 4 high voltage tripped -> 6:30 h - 7:08 h -> 0.5 h down

What must be done? (1)

- Installation of SmconDSP based LLRF system in ACC456 as parallel system
- Cabling (splitting signals) – partially done already, but some signals were never used by LLRF (e.g. BLM)
- Crate with 9xSimconDSP – can we put 9 SimconDSP in a single crate?
- Downconverters – will we have new downconverters ready for this test?
- Communication between 9 SimconDSP boards – it was never tested before
- Piezo control – partially done already

What must be done? (2)

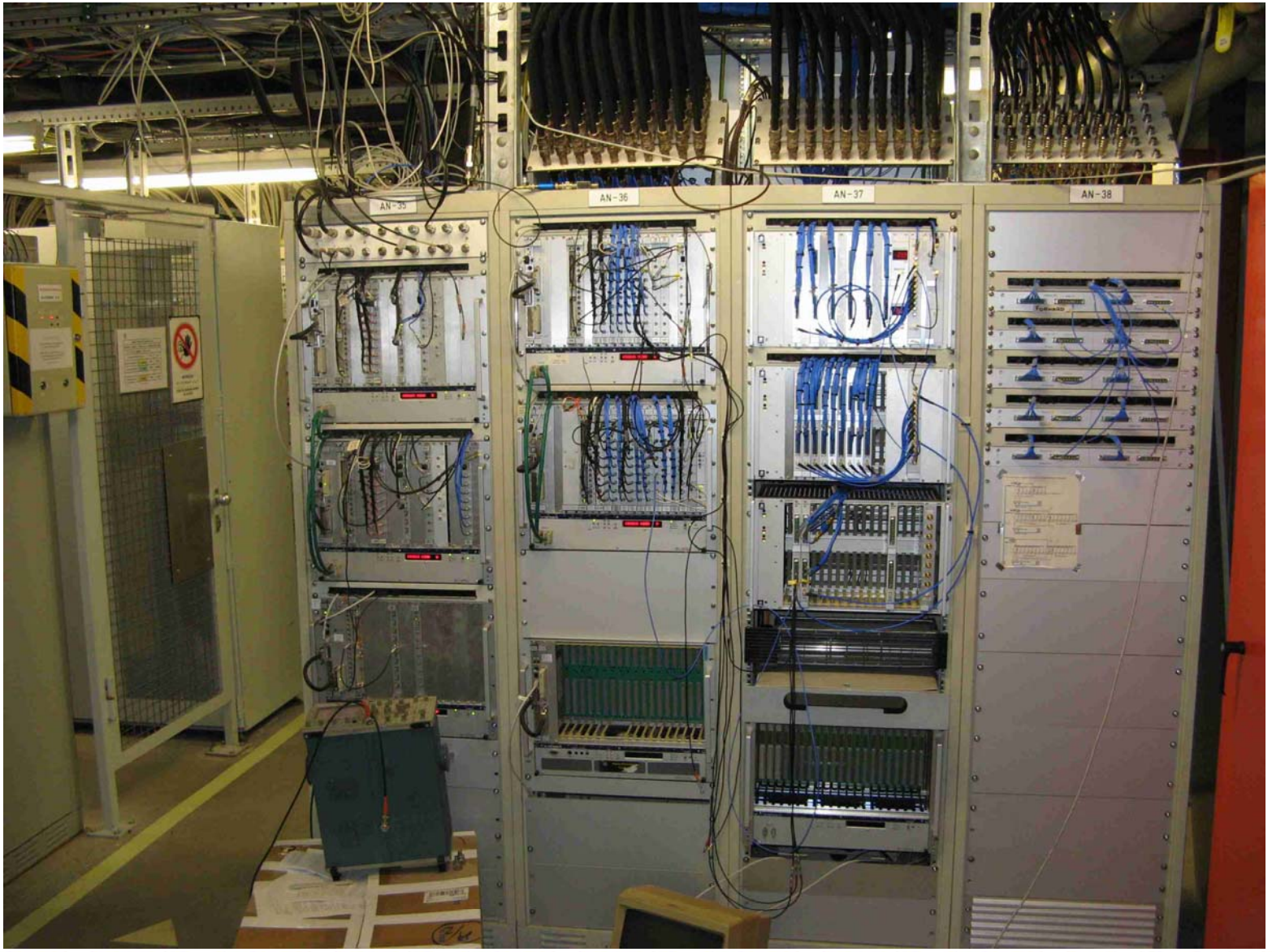
- Software
  - **SimconDSP firmware – was tested in FLASH, but not with all required features**
    - Beam loading compensation not tested with such high beam loading
    - Loaded Q and detuning measurements
    - Quench detection
  - **DOOCS server for this system is needed (what, if the system will not fit in single crate?)**
  - **Matlab scripts for HL algorithms (VS calibration, AFF, klistron linearization, etc.)**
  - **Exception handling (quench detection, klystron trips)**

Expected problems

- MPS interlocks and recovery procedure
- Cavity quenching during long pulses with high gradient
- Klystron saturation
- Klystron HV stability during long pulses with heavy beam loading
- Lorentz force detuning of the cavities during long pulses with high gradient (poor flatness of the field leading to beam losses)
- High rate of klystron trips – recovery automation

- Present LLRF system in ACC456
- Proposal for SIMCON-DSP in ACC456
- Installation of SIMCON DSP
- Procedure for trip recovery
- Prerequisites

Presently installed DSP System



Limitations of DSP System

- **DSP real time computational capacity exhausted**
  - No real time quench detection for individual cavities
  - No klystron linearization
  - No real time beam loading compensation from toroid measurement
- **Number of real time channels limited to 32**
  - No real time action on forward and reflected power
  - Forward and reflected power separately measured by ADC
- **Limited to 1 MHz sampling rate**
  - No averaging for noise reduction
- **Application must be implemented in DOOCS servers**
  - Only pulse to pulse actions possible, 5 Hz difficult

Operational limitations

Downtime

- Beam loss
- Cavity Quench
- Klystron trip
- Coupler trip
- Vacuum trip
- Machine protection

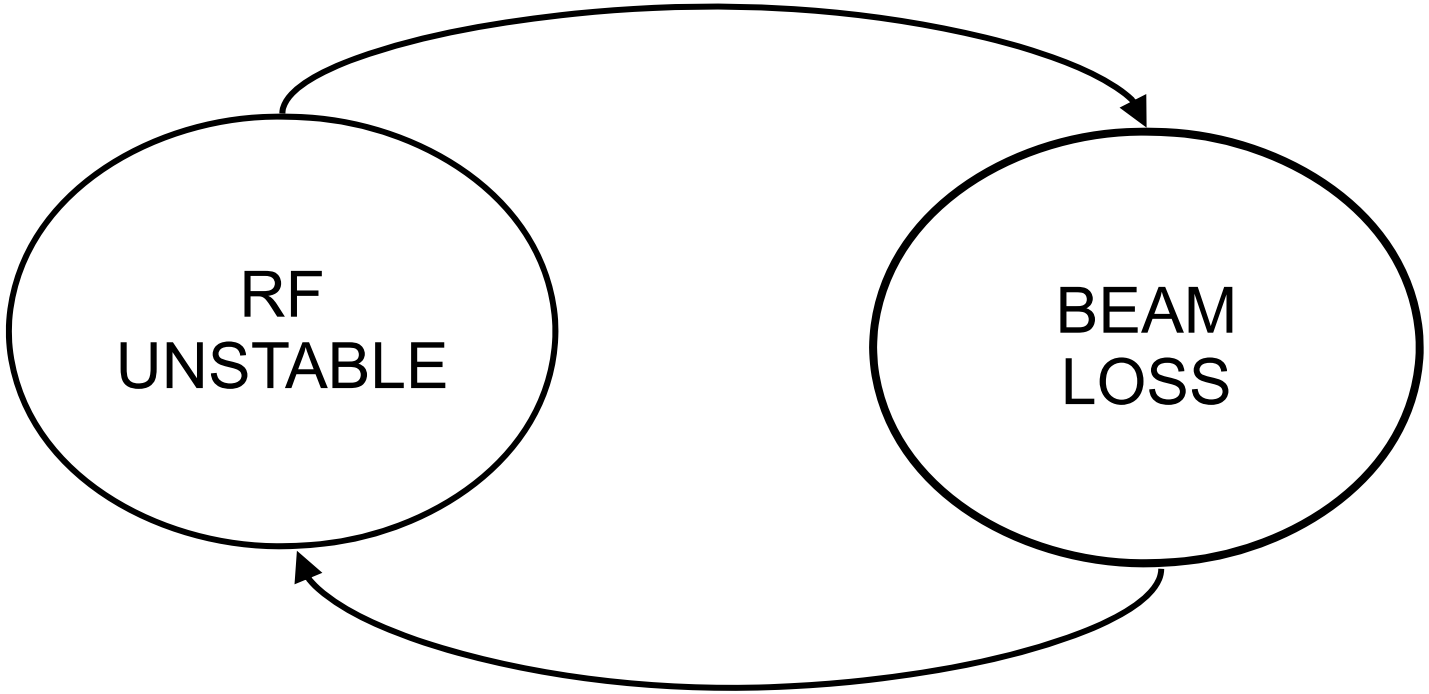
Field regulation

- Klystron saturation
- VS calibration
- Beam current fluctuations
- Cavity tuning

Procedure Errors

- Loop phase/gain set
- VS calibration (rot. matr.)
- Resonance control
- Beam loading compensation
- Feedforward table set
- Error limits table (VS except.)

Main Problem

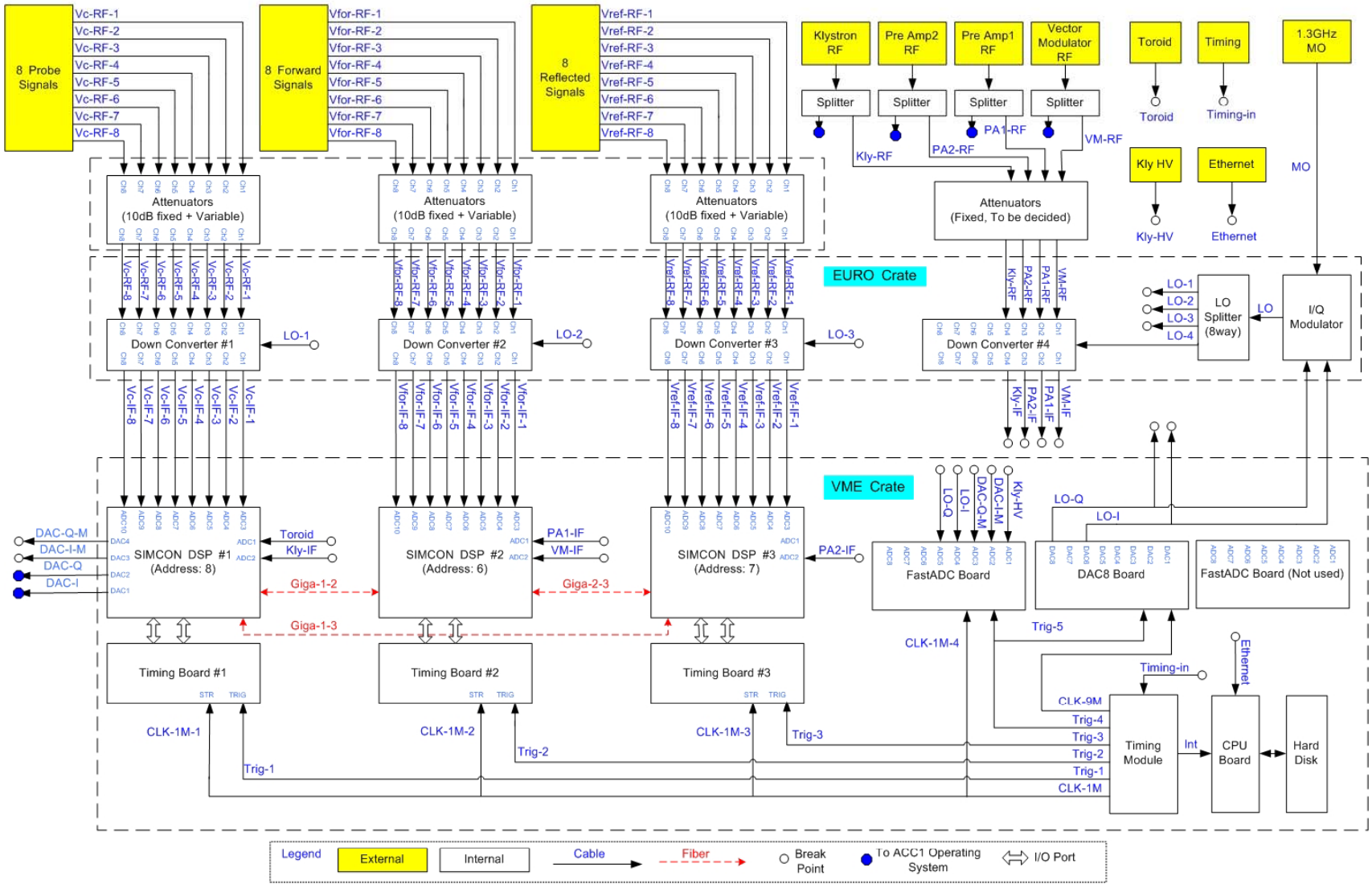


Possible improvements with SIMCON-DSP

- Real time applications
  - Cavity quench detection and handling
  - Klystron linearization
  - Toroid based beam loading compensation
  - Piezo tuner control (! Pulse to pulse)
  - Adaptive feedforward (rf + energy)
- Other applications to assist operators
  - Loop phase and loop gain
  - Vector-sum calibration with heavy beam loading
    - Requires corrected/calibrated V_inc, V_ref
  - Loaded Q and detuning measurement during pulse
- Improved field measurements
  - High IF and faster sampling rate (averaging !)

Configuration of SIMCON-DSP in ACC1

SIMCON DSP Development System at ACC1



Procedures

1. Setup rf with long pulses 10% from gradient limit
2. Establish optics for few bunch operation, 3nC, 3MHz
3. Increase number of bunches
4. Adjust optics for minimum beam loss
5. Adjust feedforward in rf system based on energy measurement and beam loss profile
6. Adjust threshold for beam loss trip according to dose rate measurement
7. Repeat 3. through 6. until 2400 bunches
8. Increase gradient until trip occurs (→ beam/rf inhibit)
9. Recover from trip
10. Repeat 8. and 9. until maximum gradient is reached
11. Operate for several hours

Exisiting prerequisites

1. A sufficient number of SIMCON-DSP boards (9 boards are needed to control 24 cavities) are available. It was planned to use them with cavity simulators in the lab but installation at FLASH would allows software development with real signals. The development would take place open loop. Some time at FLASH needs to be negotiated to close the loop.
2. In ACC4,5,6 the connections for probe, forward and reflected power are already in preparation using power splitters for the ATCA evaluation. The directional couplers are already available and waiting for installation. Cabling has been partially installed. The space for the VME crate exists in one of the high power rf racks.
3. An LO generation box for the high IF scheme is prepared by Petr Morozov for ACC1 and can be duplicated for ACC4,5,6.

Existing prerequisities

4. A SIMCON-DSP based hardware platform has been installed in ACC1 and is ready for software application development. The same framework can be used in ACC4,5,6.
5. Control of ACC4,5,6 has been already successfully demonstrated with 9 SIMCON-DSP boards. Three SIMCONs have been used for control, the others for detuning measurements and piezo control using forward and reflected power.
6. There is a strong synergy between software needed for the 9mA test and the LLRF development for the XFEL. Some priorities may have to be revised.

Missing

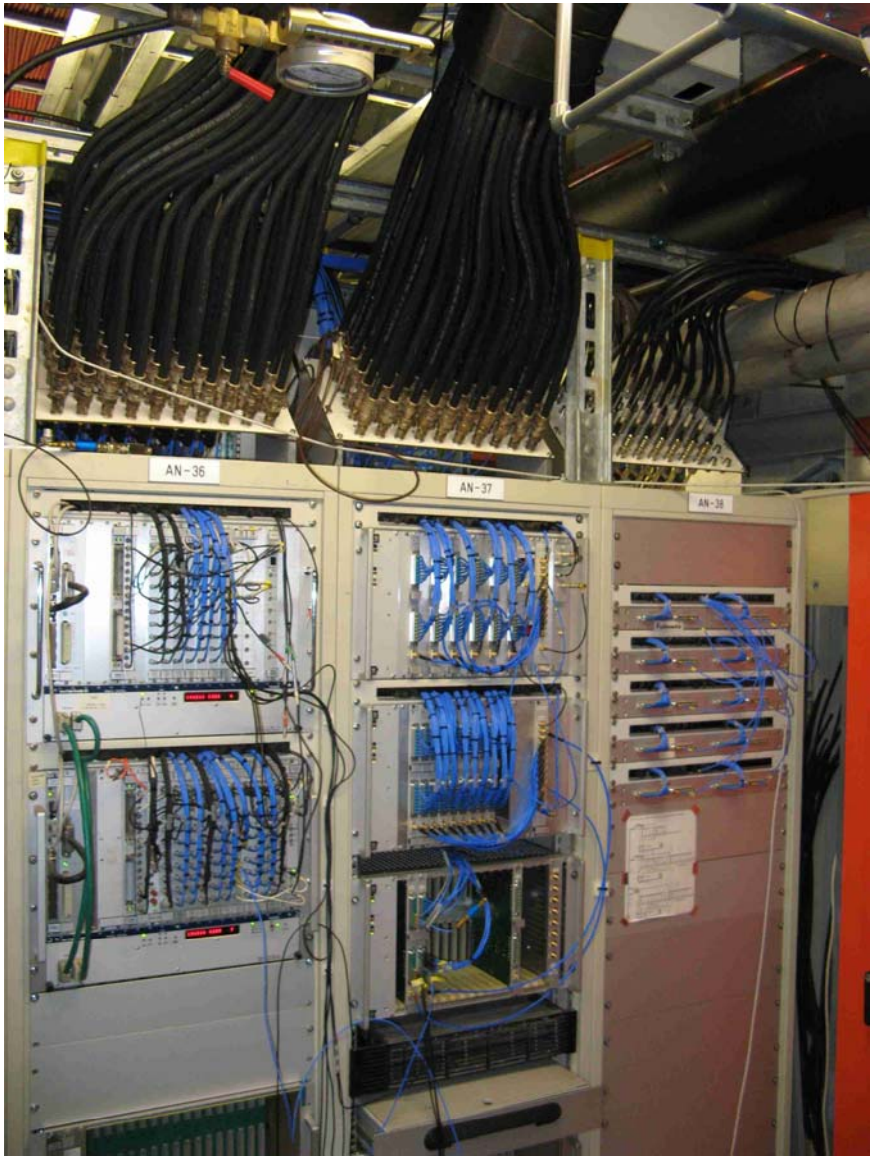
1. Downconverters (10 boards) will be needed. The plan is to buy the ATCA compatible downconverters (mezzanine cards for RTM carrier module) from Cryoelectra (will be needed for the ATCA system). For the setup with SIMCON additional adaptors (available) will be needed.
2. The MCS group (Kay Rehlich) should assume responsibility for the DOOCS servers needed for this system. MSK has no dedicated personnel available for the DOOCS server development and maintenance. Most of the existing servers have been developed by students and future maintenance is unclear.
3. The installation work (planning, organisation, maintenance) for the LLRF system has been traditionally assigned to Thomas Froelich. Since his availability is very limited (due to increasing work with klystron) he will need some help.

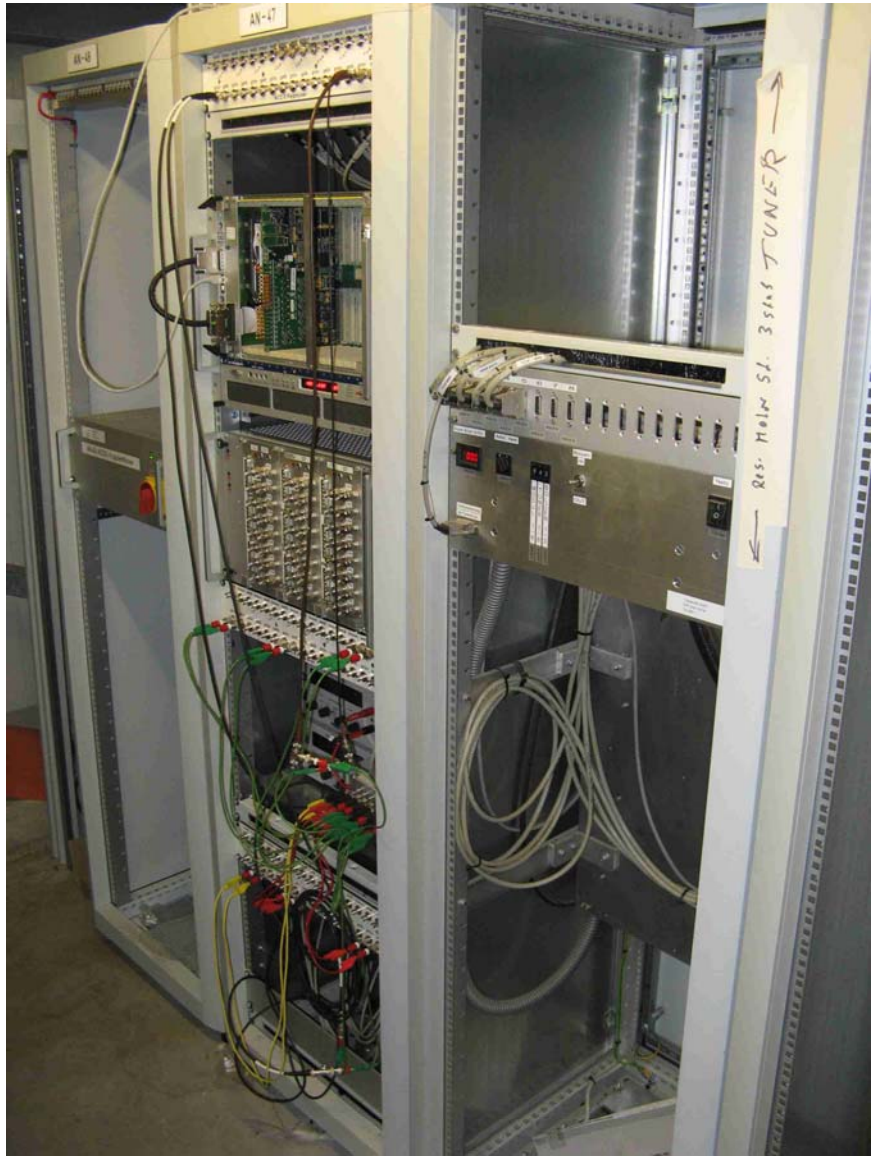
Missing

4. Need timing module from the MCS group.
5. Some cabling is needed
   a) Cabling from ACC4,5,6 to the BIS system is required.
   b) Cabling from SIMCON-DSP System to vector-modulator
   c) 9 MHz FLASH timing signal (from MCS)
   d) Toroid signal for beam loading compensation
   e) Klystron forward power (for linearization)
6. LLRF team needs a few more people (see Project Progress Review June 2008). This includes the collaboration agreements. We are working on it.

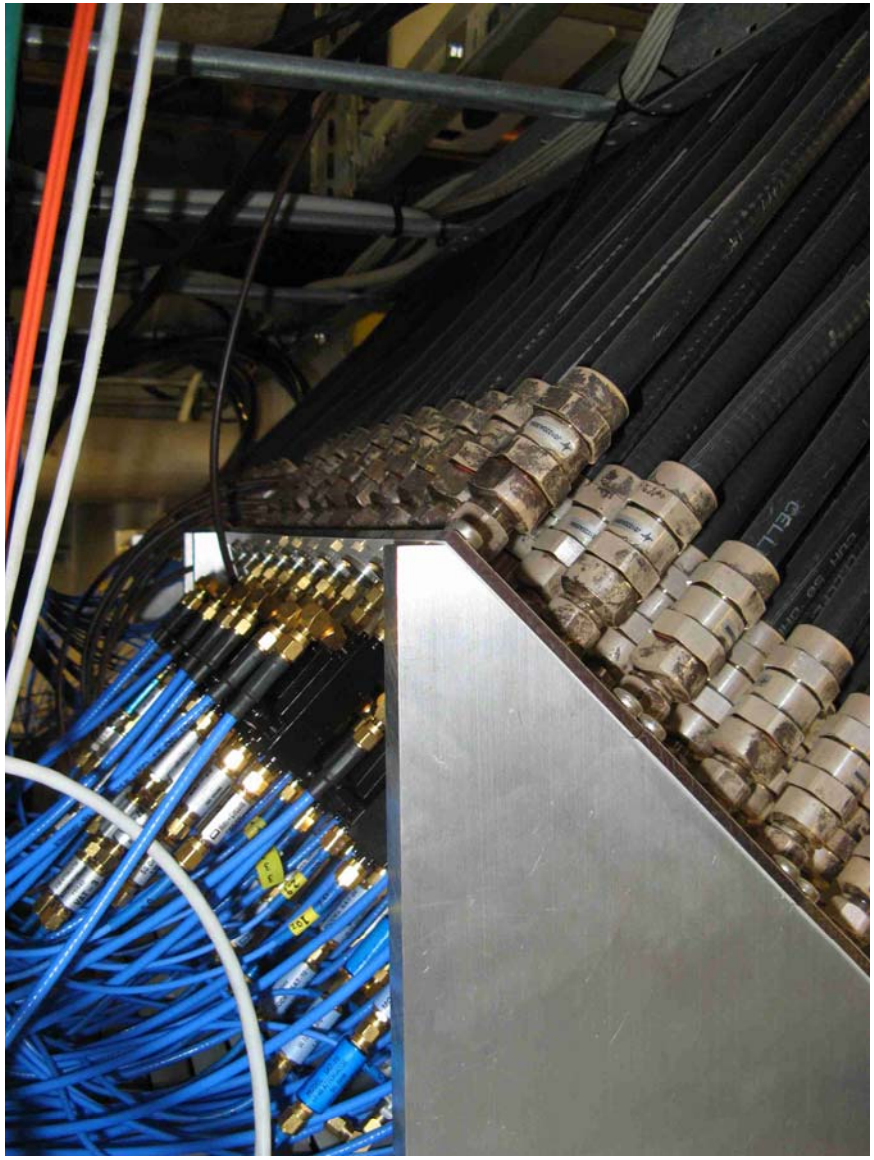
Rackspace and cabling

ACC23 andACC456 LLRF





Splitting signals in ACC456

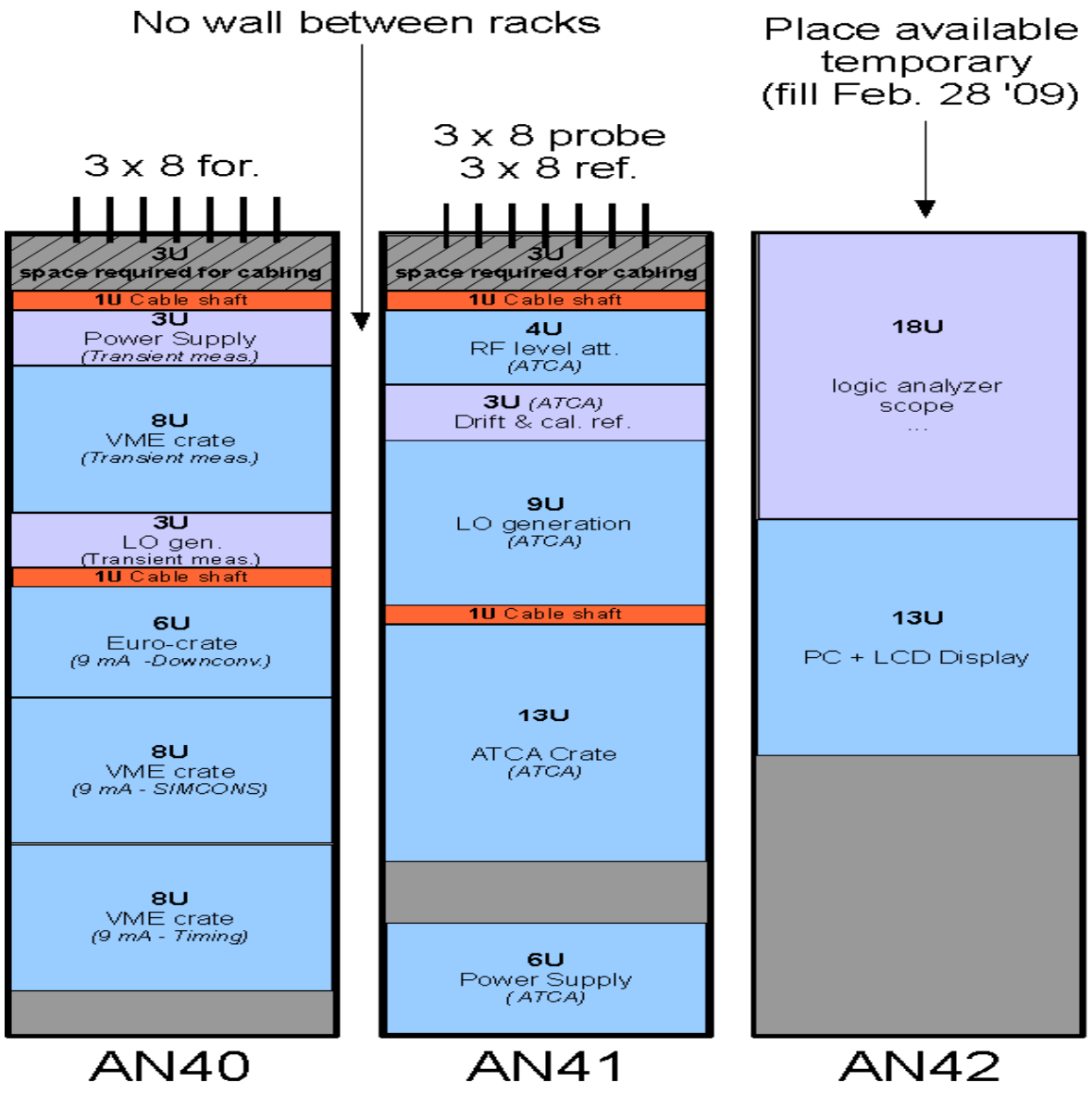


Plans for Installation in ACC456 and Options for ACC23

Plan for Hardware Installation ACC456

- 10 x SIMCON-DSP (inst. in parallel to existing DSP system
  for 24 x (probe, forw., refl. Power)
- Downconverters from Cryoelectra
  (mezzanine boards for RTM in ATCA installed with adapter board in VME ?)
- LO options
  - present 250 kHz scheme
  - high IF (54 MHz) scheme

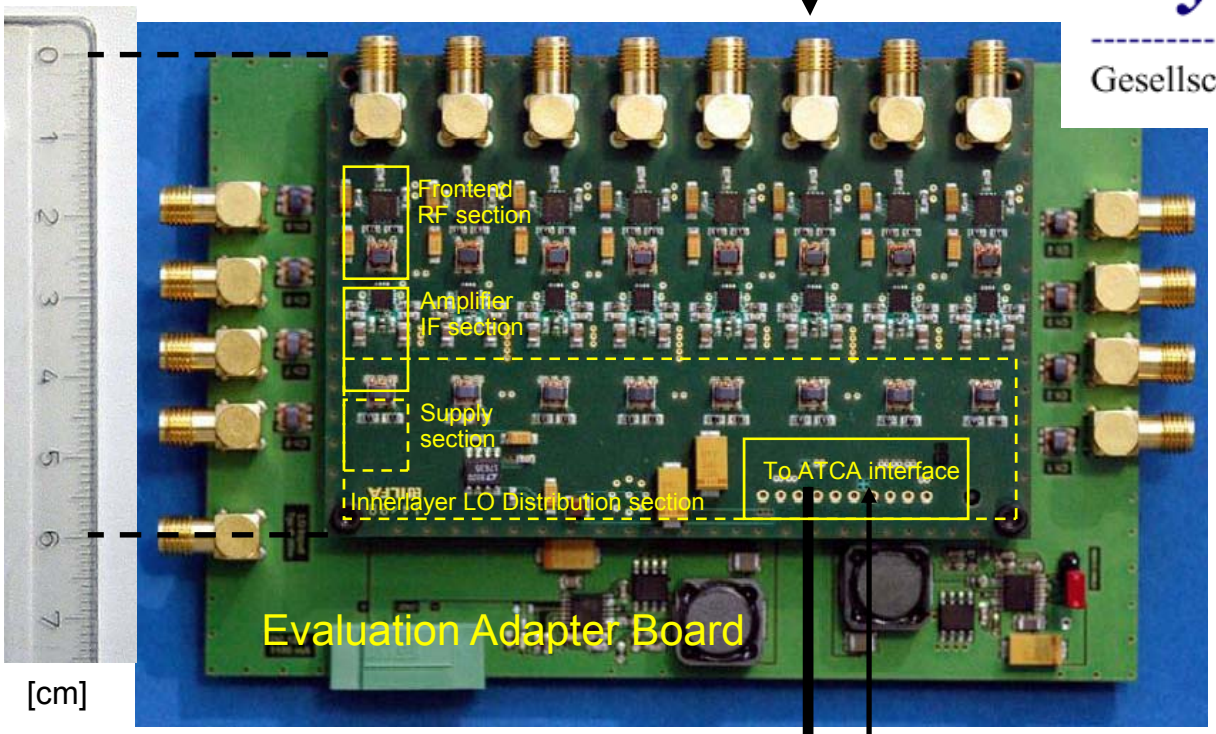
Update (1)


No wall between racks
Place available temporary (fill Feb. 28 '09)
3 x 8 for.
3 x 8 probe
3 x 8 ref.
3U space required for cabling
1U Cable shaft
3U Power Supply (Transient meas.)
8U VME crate (Transient meas.)
3U LO gen. (Transient meas.)
1U Cable shaft
6U Euro-crate (9 mA -Downconv.)
8U VME crate (9 mA - SIMCONS)
8U VME crate (9 mA - Timing)
3U space required for cabling
1U Cable shaft
4U RF level att. (ATCA)
3U (ATCA) Drift & cal. ref.
9U LO generation (ATCA)
1U Cable shaft
13U ATCA Crate (ATCA)
6U Power Supply (ATCA)
18U logic analyzer scope ...
13U PC + LCD Display
AN40
AN41
AN42

Cryoelectra downconverter

- Very compact **R**ear **T**ransition **M**odule (RTM) :

RF inputs (8 channels):
1300MHz, +0dBm input power



LO input:
[1310MHz, 1350MHz]

Cryoelectra

Gesellschaft für kryoelektrische Produkte mbH

Receiver Type : LT5527 (Gilbert-Mixer)
RF: 1300MHz , <10dBm
LO: [1310MHz, 1350MHz], 10dBm

CHARACTERISTICS	RATING
IF Frequency, MHz	1 - 50
Conversion Loss, dB	-2 (typ)
Noise Figure (incl. the accessory card), dB	18 (typ)
IF Spurious Signals, dBc	<-60
IF Filter cut-off, MHz	60
IF Harmonic Distortion (IF < 15 MHz, RF input power < 0 dBm), %	1
IF Harmonic Distortion (IF > 30 MHz, RF input power < 9 dBm), %	0.25
Inter-Channel Crosstalk, dB	>65

Options for Hardware Installation ACC23

- Option 1: Installation similar to ACC456 but only probes connected (requires space and cabling to be done)
- Option 2: Temporary installation of SIMCON-DSP system instead of DSP system using IF signals from present system
- Option 3: Use installed DSP system with some possible software improvements

Algorithms (Software)

- Implement synchronous data acquisition for SIMCON and DSP and LLRF ADC systems
- Feedforward
  - Adaptive feedforward (3 methods)
  - Toroid based beam loading compensation
  - MIMO controller with adaptive FF
- Inform LLRF in advance about expected I_beam for next pulse
- Higher Feedback gain (20 → 100)
  - Requires thoughts on suppression of 8/9 pi-mode
- Robustness against parameter variations
- Increase speed of adaptive feedforward