Requirements for LLRF Control

LLRF Lecture Part1

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Requirements for ILC

- Center-of-mass energy: 500 GeV. Upgradeability to 1 TeV

- The reliability should allow the total luminosity of 500 fb^{-1} within the first four years of operation

- Energy scans between 200 GeV - 500 GeV. Energy change should take less than 10% of data taking time

- Beam energy stability and precision should be below the tenth of percent level

- e⁻ and e⁺ source

- Injectors
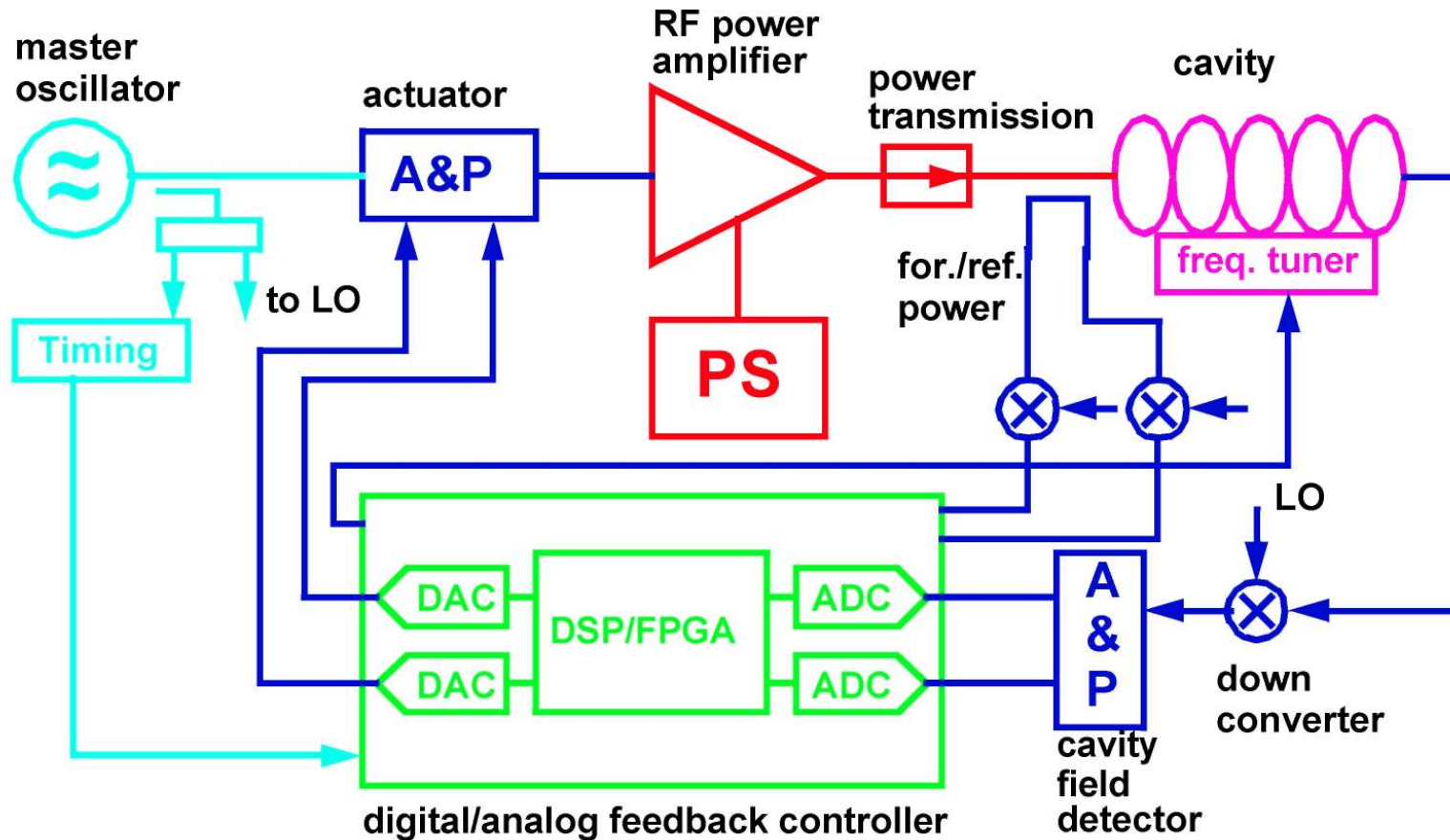
- Damping Rings

- Main Linacs

- Crab cavities at IP
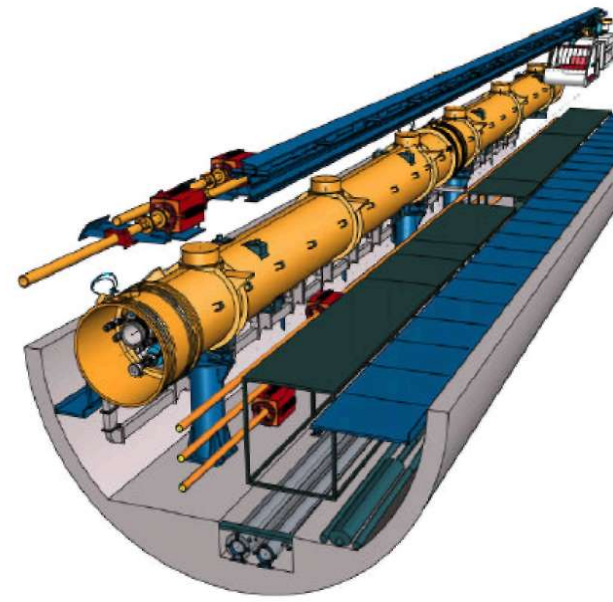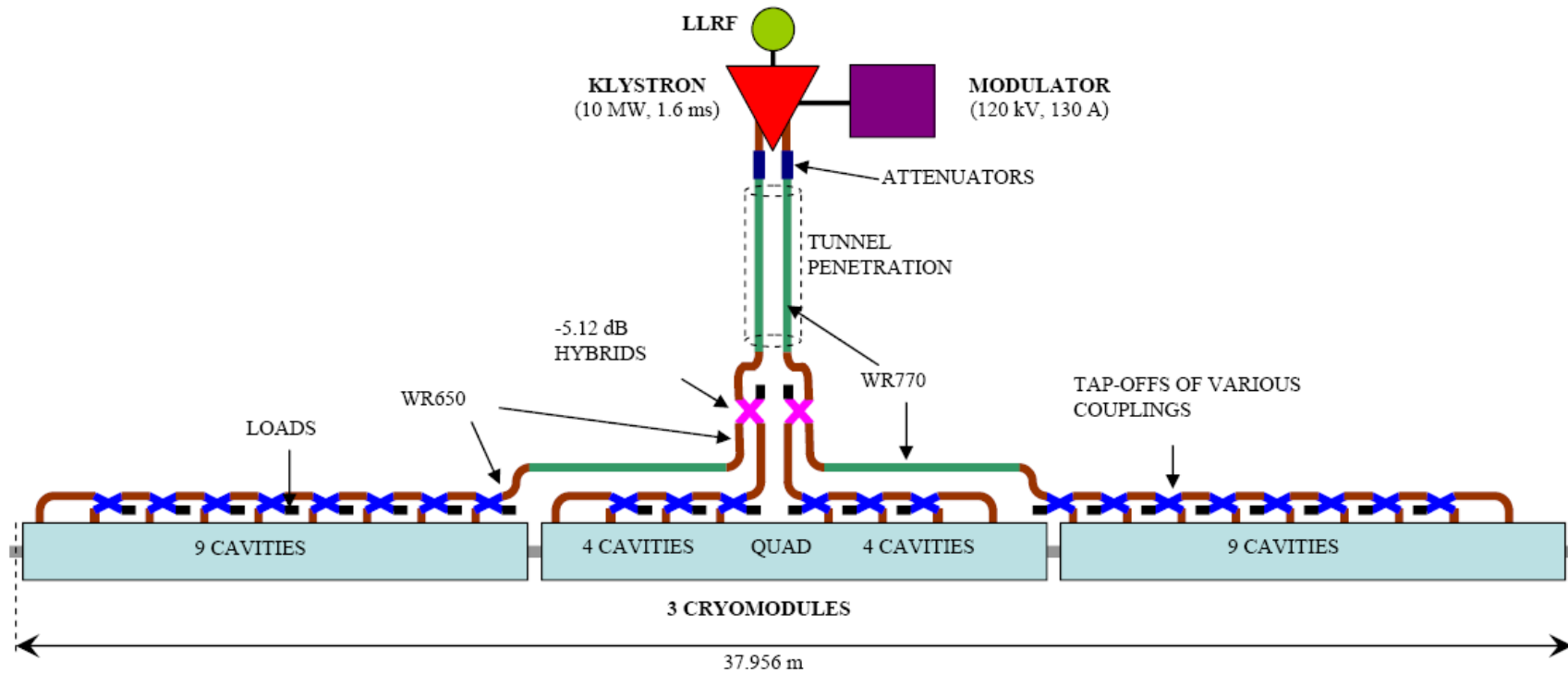
LLRF System Context

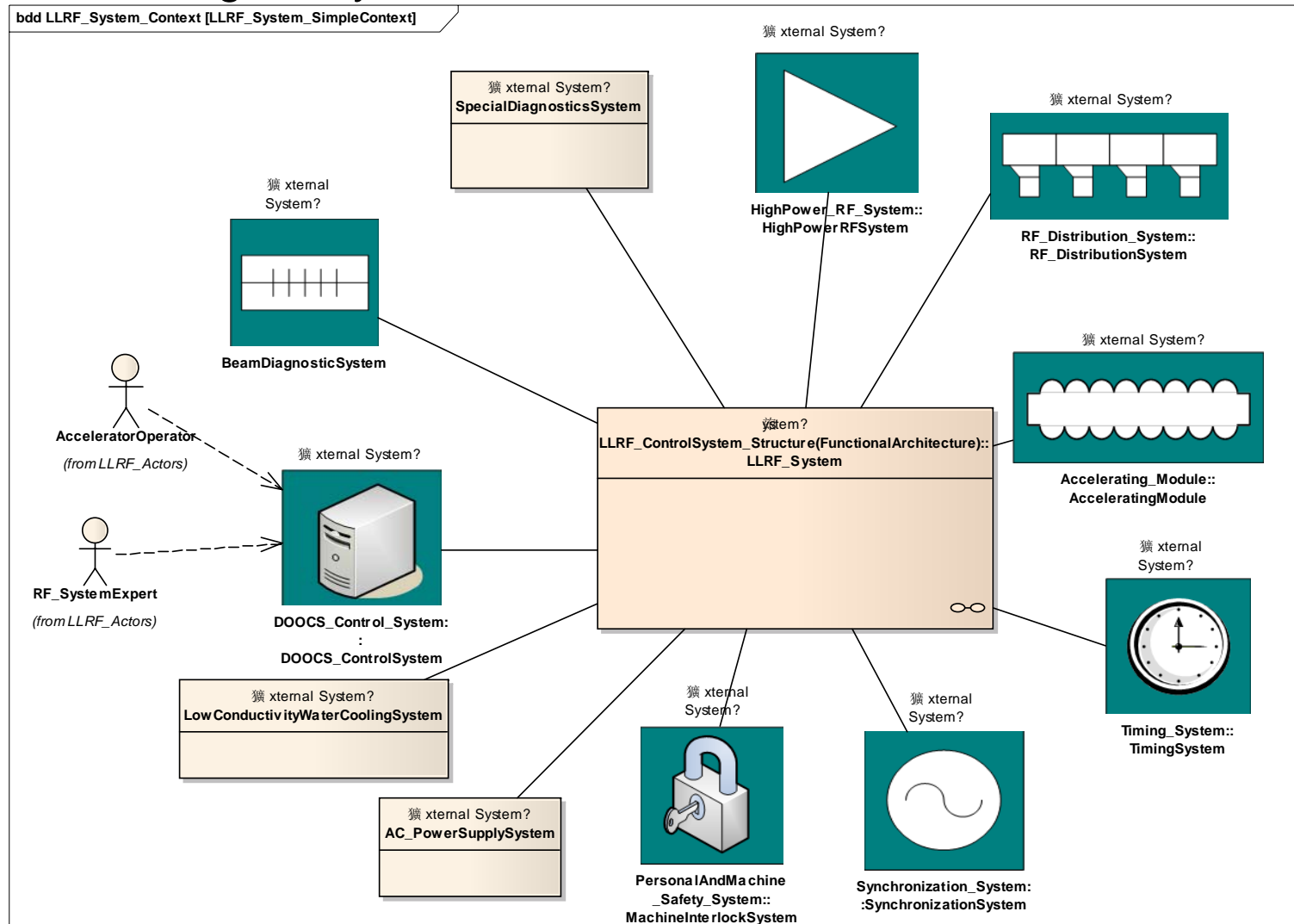- Interacting subsystems and actors to LLRF

Scope of Main Linac RF

total number of klystrons / cavities per linac	~ 280/ 7,280
per rf station (klystron):	
# cavities / 10 MW klystron	~ 26
# of precision vector receivers (probe, forward, reflected power, reference line, beam)	~78
# piezo actuator drivers / motor tuners	~ 26/26
# waveguide tuner motor controllers	~ 26
# vector-modulators for klystron drive	1
Total # of meas. /control channels per linac	~22,000 / ~22,000

LLRF System Requirements Overview

- Maintain Phase and Amplitude of the accelerating field within given tolerances
    - up to 0.07% for amplitude and 0.24 deg. for phase

- Minimize Power needed for control

- RF system must be reproducible, reliable, operable, and well understood.

- Other performance goals
    - build-in diagnostics for calibration of gradient and phase, cavity detuning, etc.
    - provide exception handling capabilities
    - meet performance goals over wide range of operating parameters

LLRF System Requirements – Field Stability

- Derived from beam properties
  - energy spread
  - Emittance
  - bunch length (bunch compressor)
  - arrival time

- Different accelerators have different requirements on field stability (approximate RMS requirements)
  - 1% for amplitude and 1 deg. for phase (example: SNS)
  - 0.1% for amplitude and 0.1deg.for phase (linear collider)
  - up to 0.01% for amplitude and 0.01 deg. for phase (XFEL)

- Note: Distinguish between correlated and uncorrelated errors

TABLE 3.9-1
Summary of tolerances for phase and amplitude control. These tolerances limit the average luminosity loss to <2% and limit the increase in RMS center-of-mass energy spread to <10% of the nominal energy spread.

Location	Phase (degree)		Amplitude (%)		limitation
	correlated	uncorr.	correlated	uncorr.	
Bunch Compressor	0.24	0.48	0.5	1.6	timing stability at IP (luminosity)
Main Linac	0.35	5.6	0.07	1.05	energy stability ≤0.1%

• Field stability requirements (@ ML and BC) are < 0.24deg. for phase and 0.07% for amplitude
• In order to satisfy these requirements, feedback (FB) with proper feed forward (FF) control will be carried out.

Functional Requirements

- **Measurements**
  - Signals
  - Conditions
  - Components characterization

- **Control actions**

- **Diagnostics**

- **Generate events**

- **Exception detection and handling**

- **Automation (of operational procedures)**

- …

Non-Functional Requirements

- ## Reliability
  - not more than 1 LLRF system failure / week
  - minimize LLRF induced accelerator downtime
  - Redundancy of LLRF components
  - ...

- ## Operability
  - "One Button" operation (State Machine)
  - Momentum Management system
  - Automated calibration of vector-sum
  - ...

- ## Reproducibility
  - Restore beam parameters after shutdown or interlock trip
  - Recover LLRF state after maintenance work
  - ...

Non-Functional Requirements (C'tnd)

- ## Maintainability
  - Remote diagnostics of subsystem failure
  - "Hot Swap" Capability
  - Accessible Hardware
  - ...

- ## Well Understood
  - Performance limitations of LLRF fully modelled
  - No unexpected "features"
  - ...

- ## Meet (technical) performance goals
  - Maintain accelerating fields - defined as vector-sum of 26 cavities - within given tolerances
  - Minimize peak power requirements
  - ...

Summary

In this part, we have learnt:

- The basic ILC requirements

- The RF system architecture and LLRF context

- LLRF functional and non-functional requirements

Reference

[1] ILC_RDR_Volume_3 – Accelerator

[2] The ISO/IEC 9126 Standard for the evaluation of software quality

[3] Tim Weilkiens. Systems Engineering With SysML/UML: Modeling, Analysis, Design. Elsevier Science & Technology Books, 2008