Automation Workshop

<u>Objectives of Workshop</u>

- Define meaning of automation
- Define requirements of LLRF and framework for implementation
- Define operator interfaces
- Define what needs to be automated
- Learn from existing experimental versions
- Identify what is missing and what we don't know
- Develop possible architecture(s) for automation
- Develop strategic plan for automation development
- Agree on common framework for implementation of automation

1st DESY LLRF-Automation Workshop

Time and Date:
Monday, May 22th: 9:30-21:00
Tuesday, May 23th: 9:00-18:00
Wednesday, May 24th: 9:00-12:00

Location:
DESY, 3/304 (Helgoland)

Videoconference:
Available for WUT, TUL, SNS

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- Define meaning of automation
- Define requirements for LLRF and framework for implementation
- Define what needs to be automated
- Learn from existing experimental versions
- Identify what is missing and what we don't know
- Develop possible architecture(s) for automation including interfaces to other subsystems and operator interfaces
- Develop strategic plan for automation development
- Agree on common framework for implementation of automation

Agenda:

1. Session: Opening and Status (Chair A. Brandt)

Mon	09:30-09:45	"Opening, Objectives: What should be automated?" (S. Simrock)
	09:45-10:15	"Ideas Concerning Automation" (M. Hoffmann)
	10:15-10:45	"Requirements for Automation (Strawman)" (S. Simrock)
	10:45-11:00	*Coffee Break*
	11:00-12:00	Discussion Automation
	12:00-14:00	*Lunch*
	14:00-15:15	"Status of Klystron FSM and Test-Results" (B. Koseda)
	15:15-15:45	"Status of LLRF FSM and Test-Results" (A. Brandt)
	15:45-16:15	"Overview Hera Automation" (S. Herb)
	16:15-16:30	Coffee Break
	16:30-17:00	"Overview SNS Automation" (K.-U. Kasemir, via VC)
	17:00-19:00	Discussion
	19:00-21:00	*Social Event*

2. Session: Objectives, Goal (Chair E. Vogel)

Tue	09:00-09:30	"DOOCS and Automation" (K. Rehlich)
	09:30-10:00	"Improving Automation in a User Facility" (M. Huening)
	10:00-10:30	"Procedure-List" (S. Simrock)
	10:30-11:00	"Experience with TTF I Autom. and FLASH Operation" (V. Ayvazyan)
	11:00-11:15	*Coffee Break*
	11:45-12:30	Discussion (Architecture Development)
	12:30-13:30	*Lunch*

3. Session: Concepts, Ideas (Chair M. Hoffmann)

Tue	13:30-14:00	"Automation in an Evolving Environments" (A. Brandt)
	14:00-14:30	"AI support for automation and automation design" (B. Koseda)
	14:30-14:45	*Coffee Break*
	14:45-15:15	"Database for Automation" (M. Wojtowski via VC)
	14:45-17:00	Discussion

4. Session: Outlook, Plan (Chair S. Simrock)

Wed	9:00-9:30	"Summary of the Workshop" (A. Brandt)
	9:30-10:00	"Proposal for an Organization of the Work" (S. Simrock)
	10:00-10:30	Discussion
	12:00	End of the Workshop

Need for automation

From ILC LLRF BCD :

10.7.5 Automation

The operation of the more than 560 linac rf systems will be highly automated by the implementation of a finite state machine finite state which has access to high level applications including the adjustment of the loop phase, vector-sum calibration, frequency and waveguide tuner control, and exception handling. The area of automation is viewed as a major area of R&D needed for the successful operation of the accelerator complex. The needs of RF system automation will help to define the structure and complexity of the control system.

Thesaurus

Main Entry: Automation

Part of Speech: *noun*

Definition: mechanization

Synonyms: computerization, industrialization, mechanization

Source: *Roget's New Millennium™ Thesaurus, First Edition (v 1.2.1)*

Other Definitions

- The art of making processes or machines self-acting or self-moving. Also pertains to the technique of making a device, machine, process or procedure more fully automatic.
- Making a process automatic eliminating the need for human intervention
- Substitution of human labour and skill with machinery, self-regulating devices or computers
- Automation (ancient Greek: = self dictated) or industrial automation is the use of computers to control industrial machinery and processes, replacing human operators. It is a step beyond mechanization, where human operators are provided with machinery to help them in their jobs. The most visible part of automation can be said to be industrial robotics. ...

- [,C:tE`meiFEn] (-ion 名词后缀)n.自动仪，自动控制

RF Systems for XFEL

- RF Gun
- Injector
- 3rd harmonic cavity
- Main Linac

Scope of RF Control

total number of klystrons / cavities	~ 30/ 1,000
per rf station (klystron):	
# cavities / 10 MW klystron	~ 32
# of precision vector receivers (probe, forward, reflected power)	~ 100
# piezo actuator drivers / motor tuners	~ 32/32
# waveguide tuner motor controllers	~ 32
# vector-modulators for klystron drive	1
Total # of meas. / control channels	3,000 / 3,000

RF Control Requirements

- Maintain Phase and Amplitude of the accelerating field within given tolerances to accelerate a charged particle beam
  - up to 0.01% for amplitude and 0.01 deg.for phase

- Minimimize 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

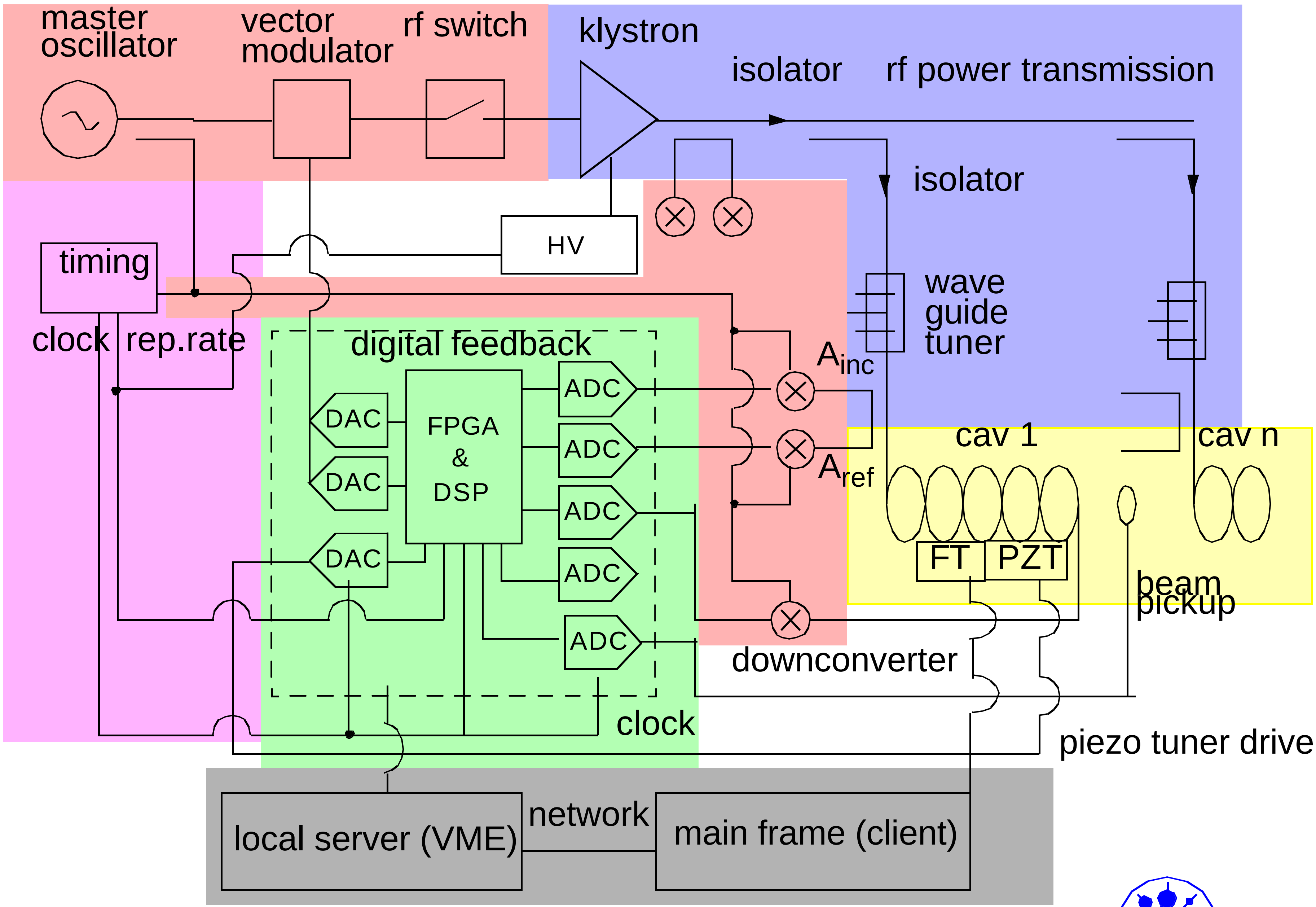
Requirements RF Control

- Reliable
  - not more than 1 LLRF system failure / week
  - minimize LLRF induced accelerator downtime
  - Redundancy of LLRF subsystems
  - ...
- Operable
  - “One Button” operation (State Machine)
  - Momentum Management system
  - Automated calibration of vector-sum
  - ...
- Reproducible
  - Restore beam parameters after shutdown or interlock trip
  - Recover LLRF state after maintenance work
  - ...

Requirements RF Control

- Maintainable
  - 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 32 cavities - within given tolerances
  - Minimize peak power requirements
  - ...

Architecture of digital RF Control



A Frequency generation

(1) Stable reference frequency oscillator
(2) Phase locked Oscillator (various frequencies)
(3) Power supply
(4) Diagnostics
(5) Control system interface

B. Frequency and Reference Phase Distribution

(1) Phase stable transmission line
(2) Temperature stabilization
(3) Power distribution (directional couplers)
(4) Phase stability monitoring and correction

C. Cavity Field Control

(1) Detectors for accelerating field
 (a) downconverter
 (b) A&P detector
 (c) I/Q detector
(2) Controllers for klystron drive
 (a) A&P modulator
 (b) vector-modulator
(3) Digital Feedback/Feedforward
 (a) Fast analog IO (ADC/DAC)
 (b) Signal Processors (FPGA,DSP)
(4) Feedback/Feedforward Algorithms
(5) Interlock system
(6) Diagnostics
(7) Interface to control system

D. High Power Amplifier

(1) RF power source
(2) Power supply
(3) Interlocks
(4) Diagnostics
(5) Interface to control system

E. Power Transmission System

(1) Transmission line (coaxial, waveguide)
(2) Circulator, Isolator
(3) Power dividers
(4) Directional coupler (Monitor)
(5) Waveguide (coaxial) window
(6) Pressurisation system

F. Accelerating System

(1) Cavity
(2) Fundamental Coupler
(3) Higher Order Mode Coupler

G. Cavity Frequency Tuning System

(1) Cavity tuner (fast and/or slow)

H. Machine Protection System
I. Personnel Safety System
J. Control System Interface

Linac RF Subsystems

LLRF Control Algorithms

A. FIELD CONTROL ALGORITHMS

(1) Feedback
- (a) PID filter
- (b) Kalman filter
- (c) adaptive filters
- (d) optimal controller

(2) Feedforward
- (a) beam loading compensation

(3) Beam based feedbacks
- (a) rf phase feedback
- (b) beam energy feedback
- (c) bunch length feedback

(3) Klystron linearization

(4) Exception handling
- (a) quench detection and handling
- (b) error from beam loading

B. LLRF System Measurement Algorithms

(1) Loop phase rotation matrix

(2) Field calibration rotation matrix
(based on rf, beam based transients, and spectrometer)
- (a) gradient calibration
- (b) phase calibration

(3) Vector-sum calculation

(4) Meas. of incident phase (vector-sum !)

(5) Beam phase measurement

(6) forward/reflected power calibration
- (a) correct for directivity of couplers

(7) Cavity detuning
- (a) average during pulse
- (b) detuning curve during pulse

(8) Loaded Q

LLRF Control Algorithms

D. High level procedures

(1) Adaptive feedforward
  (a) response matrix or T.F. based
  (c) robustness
  (d) different beam modes
(1) System identification
  (a) beam phase and current
  (b) loaded Q
  (c) incident phase
(3) Waveguide tuner control
(4) Momentum management system
(5) Field control parameters optimization
(6) Operation at different gradients
(7) Operation at the performance limit
  (a) maximize availability
  (b) maximize field stability
(8) Hardware diagnostics
(9) On-line rf system modelling
(10) Automated fault recovery
(11) Finite state machine

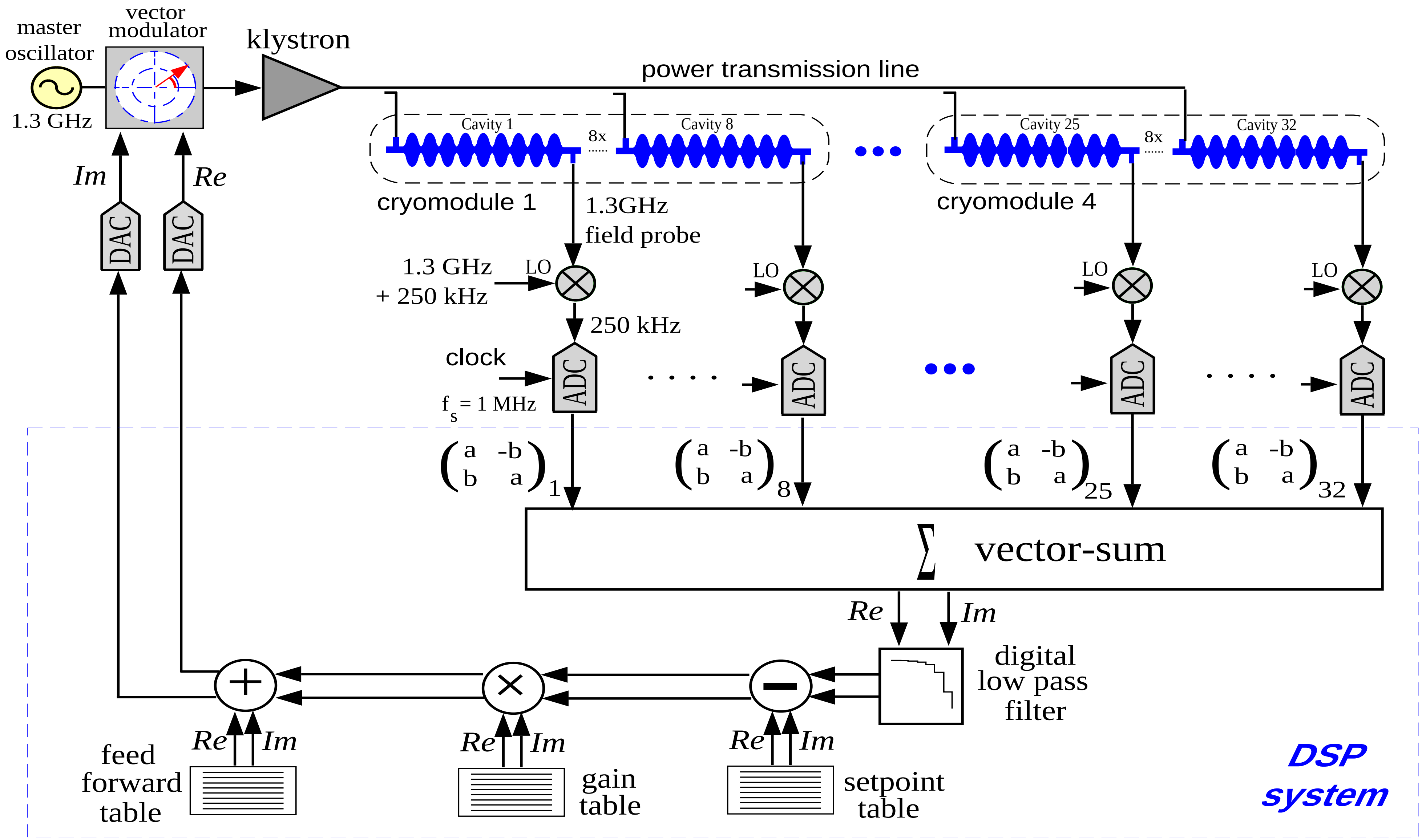
C. Cavity Resonance Control

(1) Slow tuner
  (a) maintain average resonance frequency (pre-detuning)
  (b) maximize tuner lifetime
(2) Fast tuner (ex. piezoelectric tuner)
  (a) dynamic Lorentz force compensation
  (b) microphonics control
  (c) minimize rf power required for control

E. Other

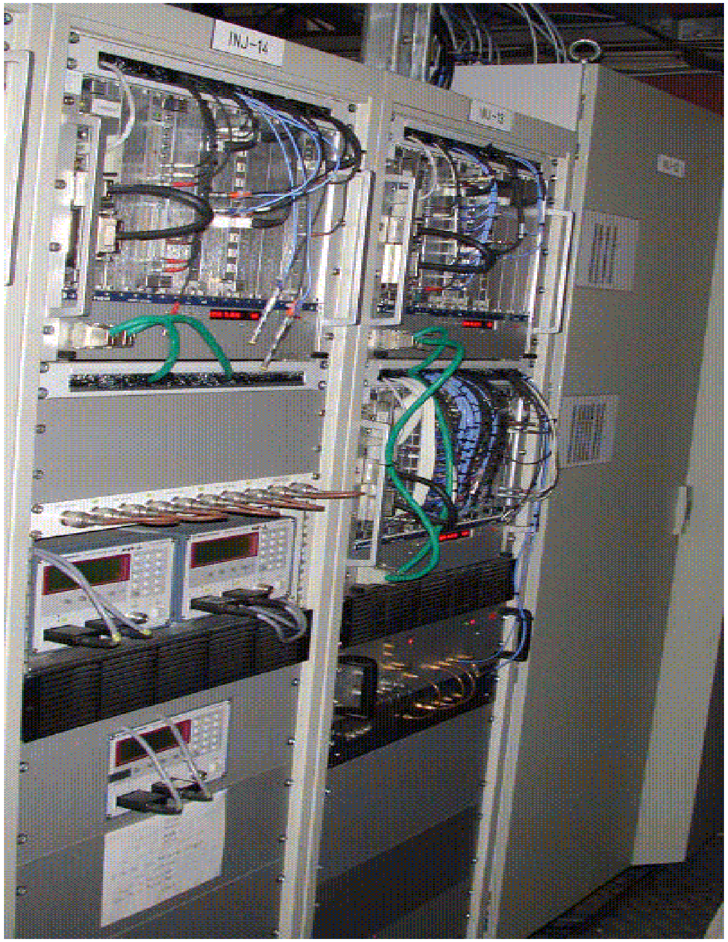
(1) RF System Database
  (a) calibration coefficients
  (b) subsystem characteristics
(2) Alarm and warning generation
(3) Control System functions

Digital Control at the TTF

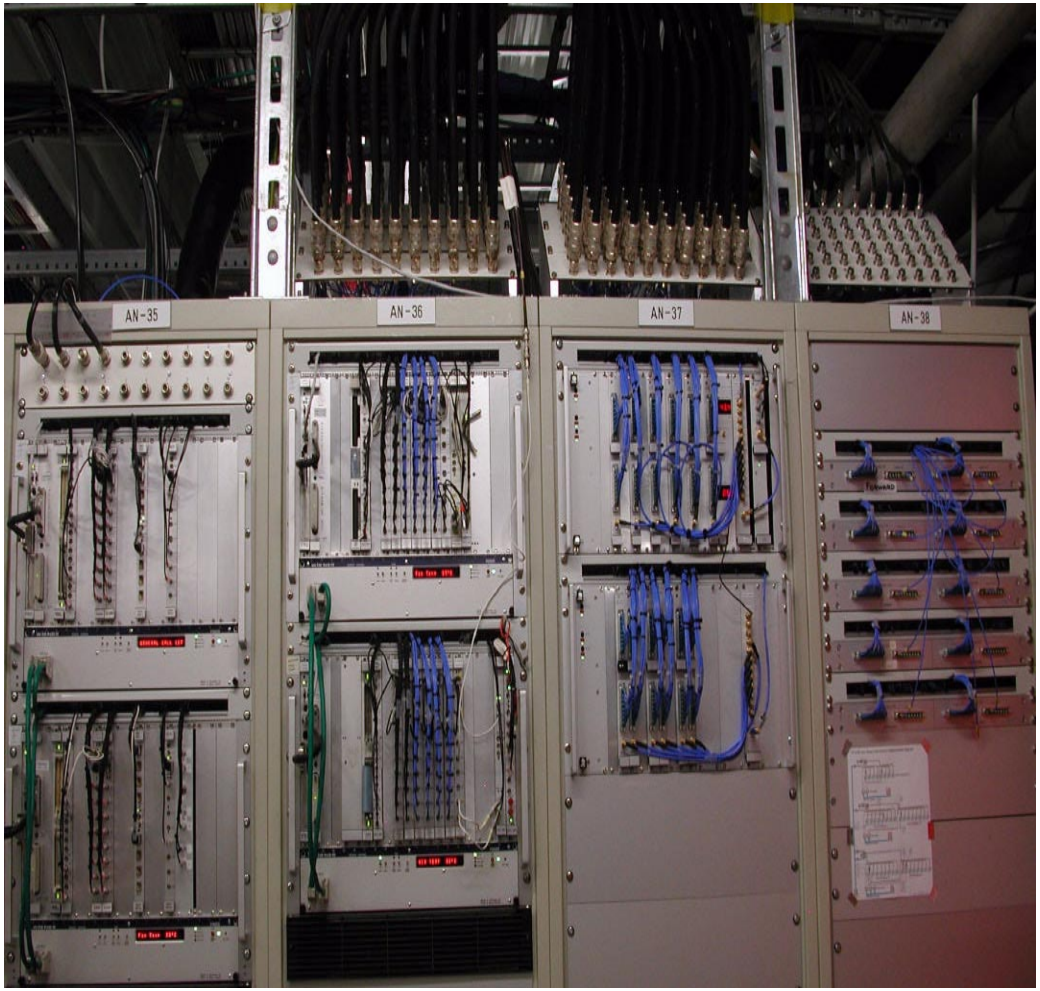


Digital Feedback Hardware

Gun and ACC1



ACC2, ACC3, ACC4 & ACC5



Choices of Automation

- Sequencer
- Event handler
- Finite State Machine
- Stateflow

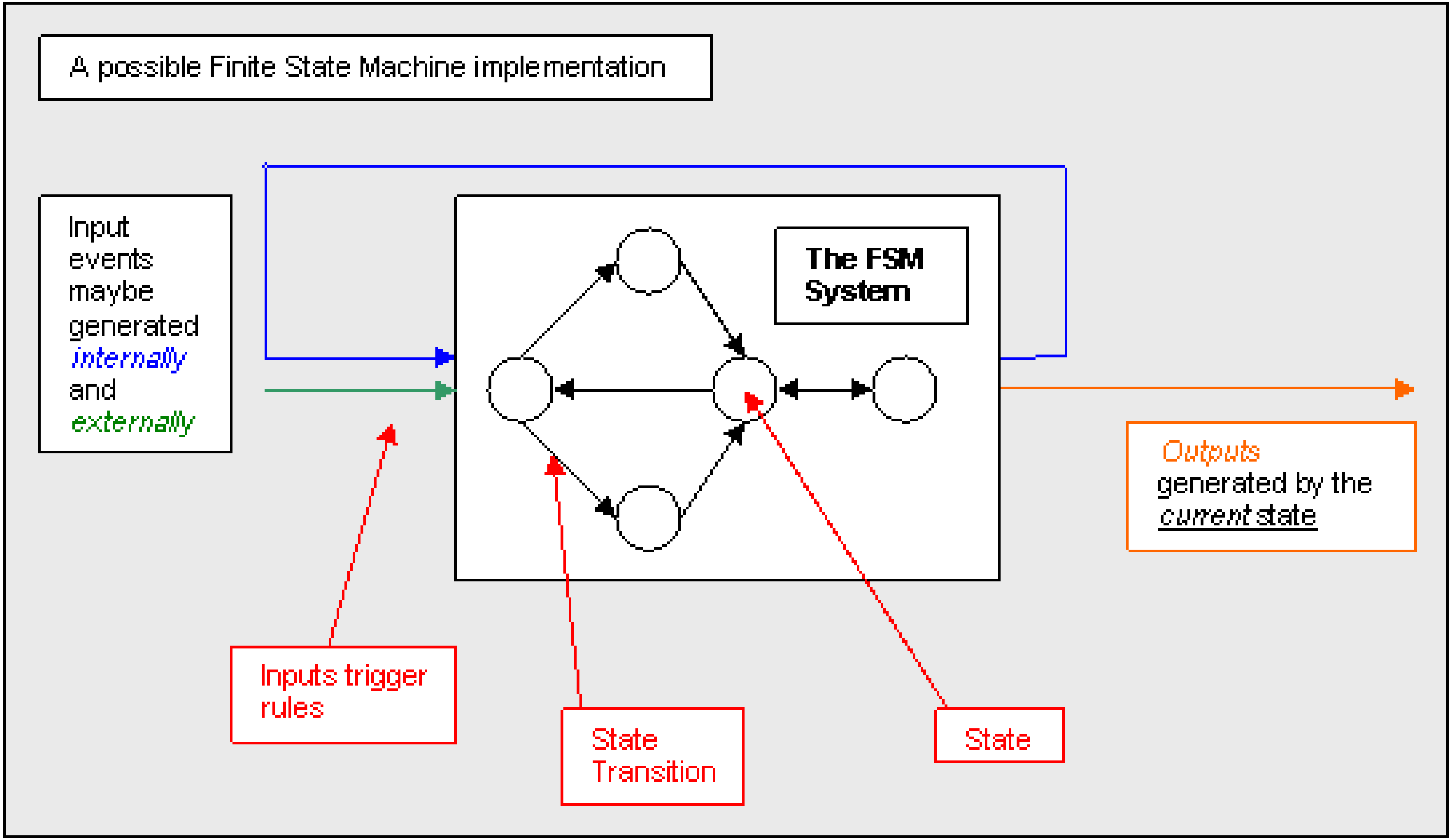
Advantages of FSM

- Their simplicity make it easy for inexperienced developers to implement with little to no extra knowledge (low entry level)
- Predictability (in deterministic FSM), given a set of inputs and a known current state, the state transition can be predicted, allowing for easy testing
- Due to their simplicity, FSMs are quick to design, quick to implement and quick in execution
- FSM is an old knowledge representation and system modeling technique, and its been around for a long time, as such it is well proven even as an artificial intelligence technique, with lots of examples to learn from
- FSMs are relatively flexible. There are a number of ways to implement a FSM based system in terms of topology, and it is easy to incorporate many other techniques
- Easy to transfer from a meaningful abstract representation to a coded implementation
- Low processor overhead; well suited to domains where execution time is shared between modules or subsystems. Only the code for the current state need be executed, and perhaps a small amount of logic to determine the current state.
- Easy determination of reachability of a state, when represented in an abstract form, it is immediately obvious whether a state is achievable from another state, and what is required to achieve the state.

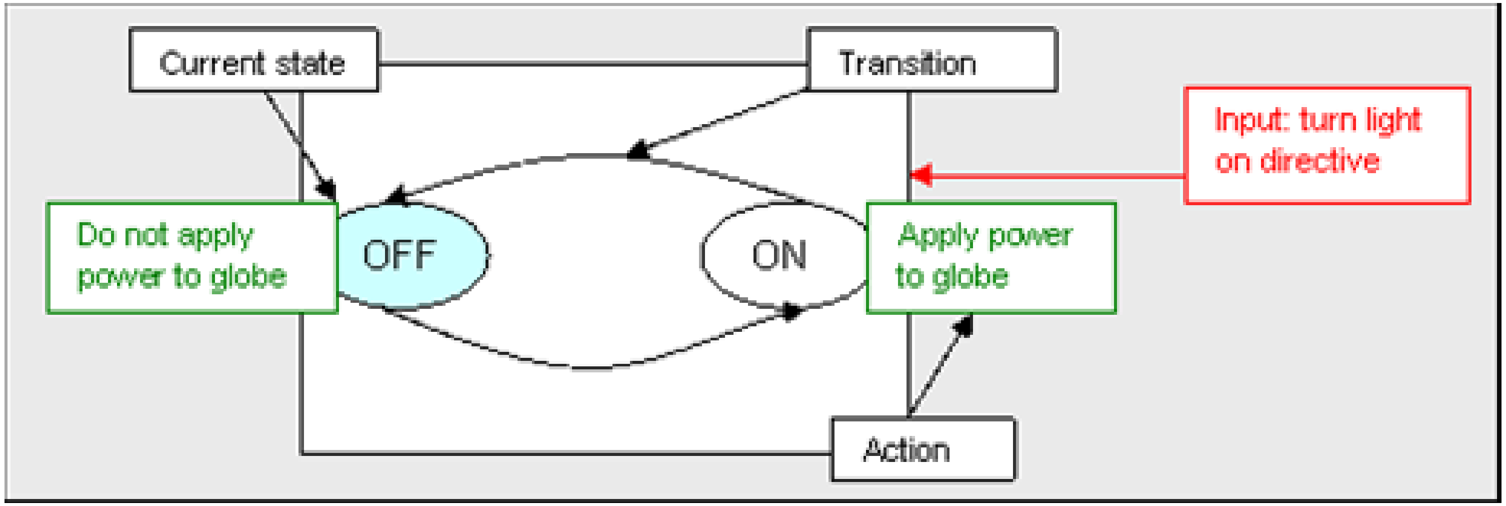
Disadvantages of FSM

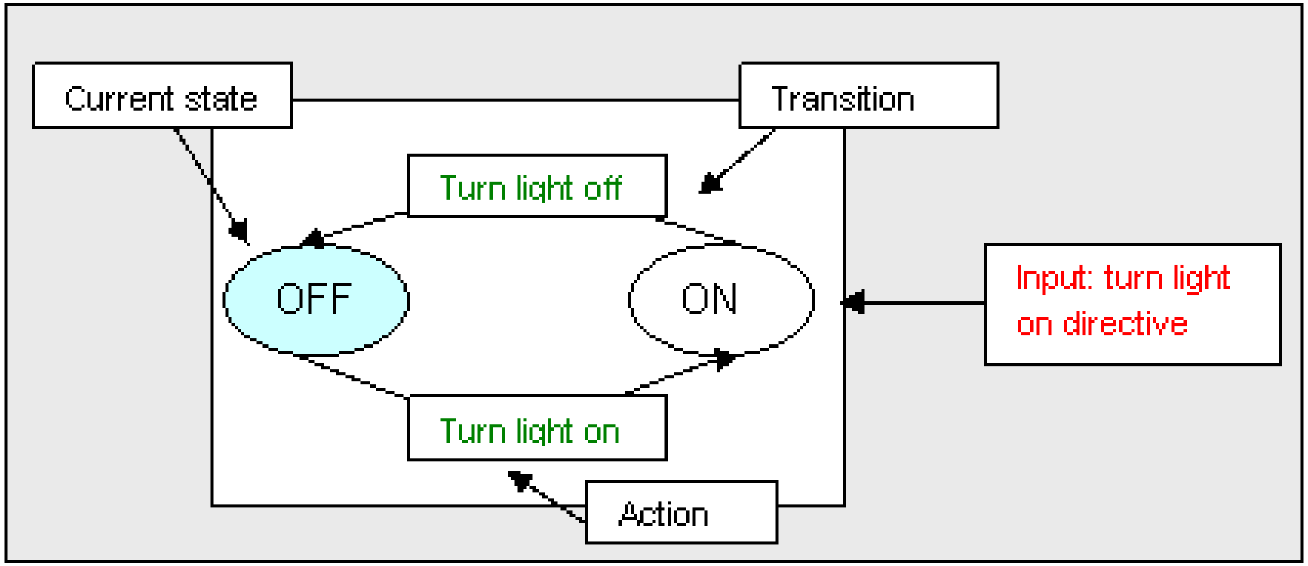
- The predictable nature of deterministic FSMs can be unwanted in some domains such as computer games (solution may be non-deterministic FSM).
- Larger systems implemented using a FSM can be difficult to manage and maintain without a well thought out design. The state transitions can cause a fair degree of "spaghetti- factor" when trying to follow the line of execution
- Not suited to all problem domains, should only be used when a systems behavior can be decomposed into separate states with well defined conditions for state transitions. This means that all states, transitions and conditions need to be known up front and be well defined
- The conditions for state transitions are ridged, meaning they are fixed (this can be over come by using a Fuzzy State Machine (FuSM))

Elements of FSM

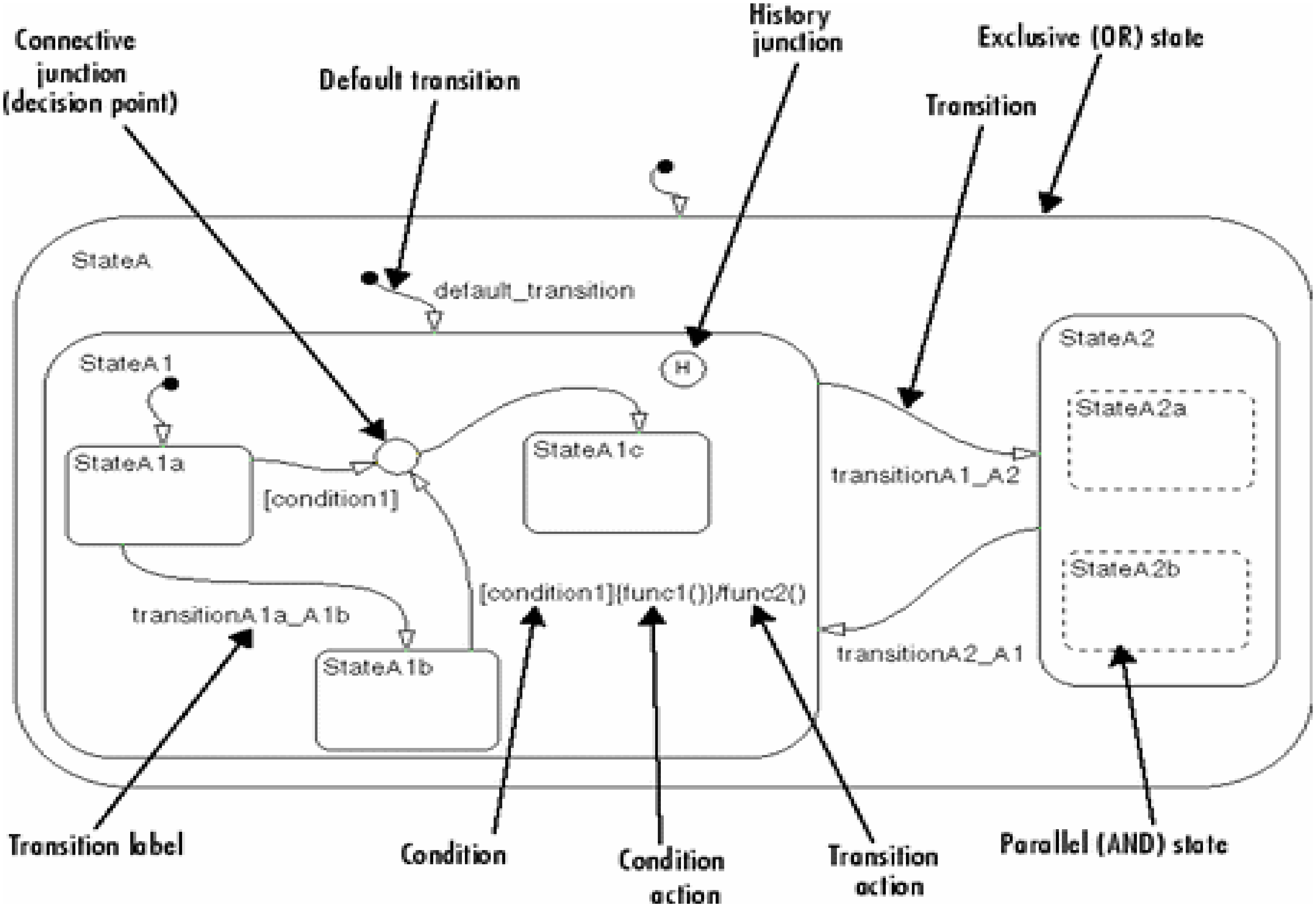


Moore and Mealy FSM





Stateflow



Connective junction (decision point)
Default transition
History junction
Exclusive (OR) state
Transition
StateA
default_transition
StateA1
H
StateA1a
StateA1c
[condition1]
transitionA1_A2
StateA2
StateA2a
StateA2b
transitionA1a_A1b
[condition1]{func1()}/func2()
transitionA2_A1
StateA1b
Transition label
Condition
Condition action
Transition action
Parallel (AND) state

What needs to be automated

- Procedure (sequence of complex actions), example: turn on rf
- Application (complex action or calculation), example: adaptive feedforward
- Algorithm (calculation; signal_in => signal out); example: measure cavity detuning
- Function (simple action); example: turn on/off rf switch
- Signals and Parameters

Elements of FSM

- Define
  - Superstates, simple states (hierachy, parallelism, history)
  - Flows
  - Conditions
  - Events
  - Signals and Parameters

Types of Signals

Signals

- physical signals measured (analog and digital)
- physical signal calibrated (analog and digital)
- derived signals measured
- raw control signals
- derived control signals
- system parameters
- timing
- events
- warnings
- alarms
- llrf interlocks
- other subsystem interlocks

Procedures

- rf commissioning
  - .. initial
  - .. after long shutdown
  - .. after maintenance day

- rf operation
  1. Turn on relevant subsystems and set their parameters
  2. turn-on for user operation with nominal settings
     for short bunch trains (1-30)
     - 500 fill, 800 flat-top, QL=3e6, Eacc = 20 MV/m
  3. turn-on for user operation with short rf and HV pulses
     for short bunch trains (1-30)

- rf system maintenance
- rf system debugging and trouble shooting

Procedures (Cnt'd)

- special procedures
  - .. coupler warm and cold conditioning
  - .. cavity conditioning

- control of llrf related subsystems
  - .. master oscillator and frequency distribution
  - .. LO- oscillator generation
  - .. timing system (trigger, clocks)
  - .. klystron and modulator
  - .. cryogenics
  - .. cavity, coupler and frequency tuner
  - .. machine protection

Requirements for Automation

- Framework for implementation must
  - be modular (it must be easy to add procedures)
  - easy to maintain and to troubleshoot
  - easy to learn
  - automatically adapt to ‘state’ of accelerator
  - Support development of new algorithm by permitting direct access to all parameters
  - Allow operational changes
  - be compatible with XFEL Control System
  - well documented
  - Provide interfaces for other subsystems and operators (especially higher level FSM)

Prerequisites for Automation

- Well understood LLRF system
- Documentation of all procedures and signals
- Framework for implementation defined and available
  - Communication protocols
  - Graphical and textinterface for implementation