Working Group 2 (WG2): RF Field Control Schemes, RF System Modeling,
RF System Operation
Convener: Stefan Simrock
Charge of WG2:

1. Compile a list of possible algorithms, procedures and diagnostics for each conceptual design (as identified in Charge 3 of WG1). Start with a list of questions. Examples for questions to be answered:

   a) What are the different implementations of a SEL?
   b) Do we need piezo tuners in a high Q_1 cavity, what are the advantages, are they reliable?
   c) Feedforward (FF): when and where to implement. Issues specific to FF?

2. How do we model an rf control system? Subsystem models for amplifiers, cavities, nonlinear effects, mechanical dynamics of the cavity, diagnostics (beam phase, detuning).

   a) Can we make a modeling menu?
   b) Can we develop a generic model applicable to the various schemes?

3. Implementation (realization) of the model in a digital controller

4. If possible compile a checklist which guides the rf system designer to the optimum design

	SEL	GDR	I&Q	A&P	Digital	Analog
Pulsed	M_{11}	M_{12}	M_{13}	M_{14}	M_{15}	M_{16}
cw	M_{21}	M_{22}	M_{23}	M_{24}	M_{25}	M_{26}
Relativistic	M_{31}	M_{32}	M_{33}	M_{34}	M_{35}	M_{36}
Non-relativistic	M_{41}	M_{42}	M_{43}	M_{44}	M_{45}	M_{46}
High Q_L $\sim 10^7$	M_{51}	M_{52}	M_{53}	M_{54}	M_{55}	M_{56}
Low Q_L $\sim 10^6$	M_{61}	M_{62}	M_{63}	M_{64}	M_{65}	M_{66}
High E_{acc}	M_{71}	M_{72}	M_{73}	M_{74}	M_{75}	M_{76}
Low E_{acc}	M_{81}	…	…	…	…	…
High current	M_{91}	…	…	…	…	…
Low current	$M_{10,1}$					
Vector sum	$M_{11,1}$					
Single cavity	$M_{12,1}$					

Tuner Control

List of generic statements for different applications

DESIGNS

SEL

       -good if resonance freq changes over many bw (~10) over turn-on

       -start-up may be slow – (use generator for startup)

       -possibility of running many cavities at high field for conditioning of cavities

       and couplers independently

       -possibility of excitation of other passband and HOM modes

       -phase shift of limiters

       -inherently stable with amplitude (to 1st order)[need limiter or klystron otherwise

        it can go to full power and loose window – interlocks]

       -use two probes (one at each end) to suppress next pass band mode [good idea]

       -tracks resonant freq of cavity

       - minimum amplitude infinitely small

GDR

       -more susceptible to ponderomotive oscillations in open loop

       -better for pulsed operation if delta-f(t) small

       -better to operate VS (vector sum) control

      -Recovery from trip in CW machin

       [always lock SEL phase to ref]

I/Q control

-Coupling if loop phase is wrong

- amp&phase detectors desired in analog systems for monitoring

-noise of IQ detector more than Schottky diode

-    4 quadrant control including zero

-    good for correction of large errors

-control of resonance fluct. – less power to [Bessel function sidebands] large errors

-better control of large beam loading

A&P Control

-less noise on amplitude detection

- more tolerant to loop phase error

[eventually have to use I/Q modulator – inherent limitations

[digital I/Q modulators but limited]

- analog modulator & demodulator nonlinear + offset + noise

Digital

-creates additional delays

-component availability lifetime 5 yr

-more sensitive to EMI

-aging

-maintainability

+flexibility

+feedforward fits naturally

+built-in diagnostics

+suited for superslow systems (water temp.)

[analog radiation will drift – digital will work till it dies]

+radiation sensitive(?)

Analog

　　　+minimum delay

　　　+simplicity +straightforward

　　　+better diagnostics with analog scopes

　　　[systems with many inputs and outputs digital better]

　　　+less resources for R&D

　　　[for simple control system w/o exception and feedforward, analog way to go]

Hybrid system better?

　　　+for maximum bandwidth

APPLICATIONS

PULSED

　　　+SEL if delta-f large (>10bandwidth)

　　　(-GDR "   ")

　　　+SEL needs seeding feature

　　　+digital better – especially for feedforward

　　　+digital lots of diagnostics

　　　+digital better fault recovery

　　　+ thermally reduced parameter changes

　　　- loop phase and gain changes during the pulse [important for designer]

　　　- have no information between pulses

CW

　　　+more time for turn-on

　　　+continuously monitor microphonics

　　　+constant Lorentz force detuning (except turn-on)

　　　[TELSA has Lorentz force detuning transient even on flattop]

　　　+systems less prone to drift

　　　+less need for feedforward, unless beam loading fluctuations

Relativistic

　　　+vector sum control works well

+more tolerant of single point failures

Nonrelativistic
       -vector sum can not perfectly correctly compensate for errors (but still need it)
       -need individual cavity phase adjustment
       -above certain energy can use vector sum (depends on requirements)

High Q
       +SEL desired (large detuning)
       [general statement- hybrid SEL/GDR digital desired everywhere]
       +active tuner control
       +tolerates more signal processing delay [from elect. view, but from mech. view could be moved a
          lot] for same DC gain

High Current
Heavy Beam Loading
       ✎ low Q ✎ small detune ✎ GDR
       ✎ discard amp&phase – large pert. favor I/Q
       ✎ needs feedforward ✎ digital

Low Current
Low Beam Loading
       [energy recovery ?] [TESLA picks Q for Lorentz][ERL may match for other than design beam]
       [problems with dynamic range – hard to do both – nonlinearities – digital?]

Vector Sum

    +digital – calibration

    +SEL – works for vector sum? Turns on like other systems – provides same signal to all cavities, operationally same? How do I diagnose the others?

Single Cavity

    +easier

    -expensive

    -more hardware to maintain

    +microphonics are easier to deal with

    +more fault tolerant

- RF Modeling

    -beam cavity interaction
        [DESY/JLAB uses Matlab +Simulink]
        [very useful – graphical interface made very easy to plug in – easier than writing down
           differential equations]
        -   DT – interactive – req. MacOS – written in C++, hooks into OS
        -   Are Matlab + SIMULINK modules available? Not available on a webpage;
          (very very slow?)]
        -   What do simulate
          -   Linac with many cavities
          -   Control of individual cavity
        Matlab:
        - too slow for whole accel.;
        + good to maintain library
          SS will post on web

- Commissioning and operational procedures

    - How does one adjust initial loop phase?]
    - Tune cavities
    - Gradient and Phase calibration
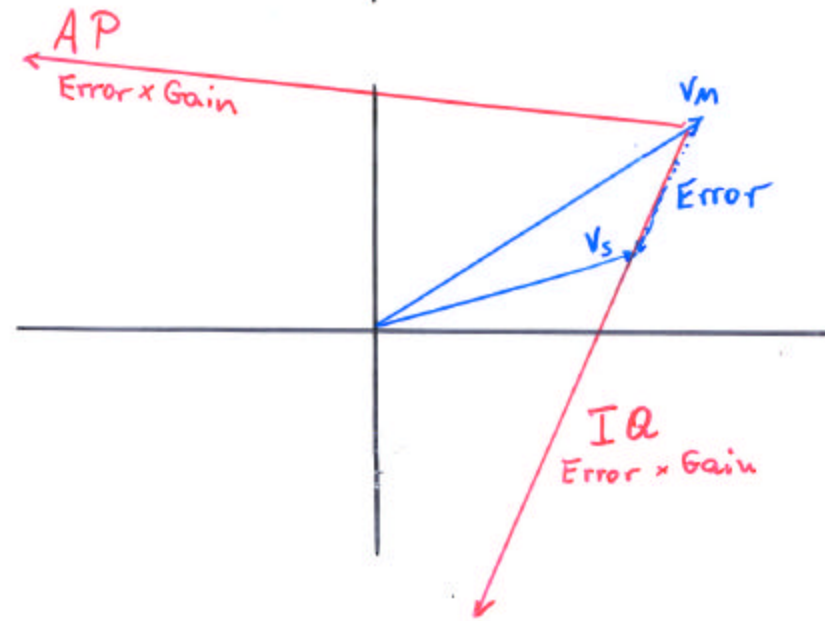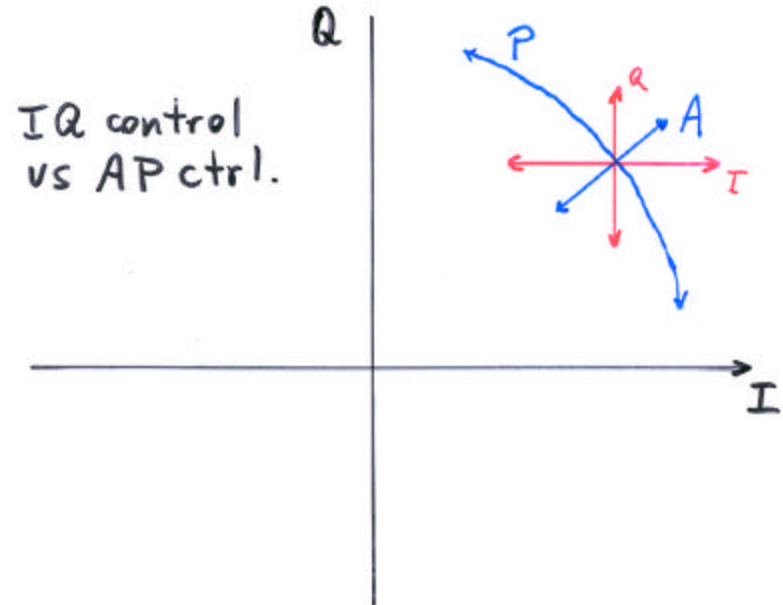   -phase calibration always with beam
        -easier with relativistic beam
        -for protons especially problem with proton changing velocity profile
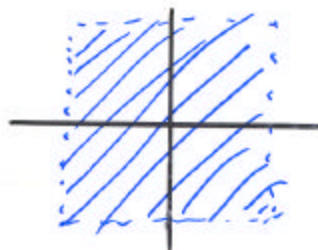
    - Automated Fault Recovery
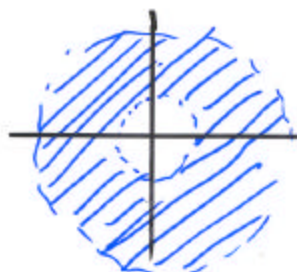   - Presently mostly manual
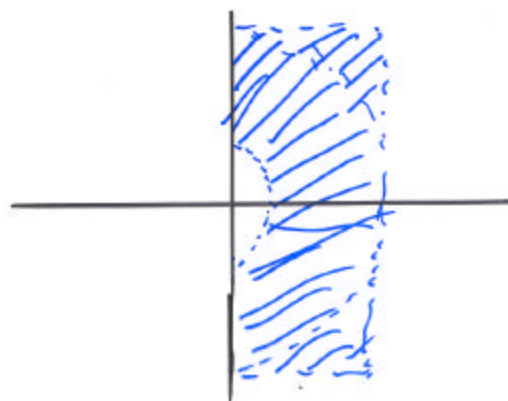
    - Adjustment of Loaded Q's

IQ control vs AP ctrl.

Control Range

IQ

AP

AQ

WG 2 tasks

Commissioning and operational procedures
- Cavity and coupler conditioning
- Check functionality of interlocks
- Loop phase
- Loop gain calibration
- Gradient and phase calibration (or Vector-sum)
- Measurement of beam phase
- Frequency Tuner Control (slow and fast)
- Adjust loaded Q's
- Adjustment of incident waves for vector-sum
- Determine all other relevant rf system parameters
- Evaluate and optimize performance with beam\
- Evaluate performance limitations
- Adaptive Feedforward
- Automated fault recovery
- Waveguide tuner control
- Energy vernier (beam based)

Diagnostic Tools
- Loop phase
- Beam phase
- Beam transient based gradient and phase calibration
- Cavity detuning
- Microphonics
- System identification (all relevant parameters)

Design Choices Made

	Type	Cavities/k		Pulsed/CW	Ana/Dig
Darmstadt	SEL	API	1	CW	A
RIA/ATLAS	SEL	I/Q	1	CW	A
SNS	GDR	I/Q	1	PULSED	DIGITAL
CEBAF	GDR	A/Q	1	CW	A
TESLA	GDR	I/Q	36	PULSED	DIGITAL
CEBAF 12GeV	SEL	I/Q	1	CW	DIGITAL?
ERL	SEL	I/Q	1?	CW	DIGITAL
SPL	GDR	I/Q	1-4	PULSED	DIGITAL
Storage Ring	GDR	I/Q	1	CW	A→DIGITAL