

LLRF Control System for the Diamond Storage Ring

Alun Watkins
Senior RF Engineer
Diamond RF Group



Diamond SR LLRF: talk outline

- *Summary of key specs*
- *MO distribution*
- *LLRF hardware and software*
- *Commissioning procedure*
- *First results*
- *Technical challenges*
- *Future work*
- *Conclusions*



Key specifications

Parameter	Value	Comment
Technology	Analogue IQ	EPICS software
RF Frequency	499.654 MHz	
Cavity voltage range	0.125 to 2.5 MV	(per cavity)
Amplitude regulation	0.5 % rms	Over 14 dB range
Phase regulation	0.2 ° rms	Over 14 dB range
Phase control range	$\pm 180^\circ$	
Loop bandwidth	10 Hz to 100 kHz	Open loop unity gain
Loop gain	0 to 40 dB	variable

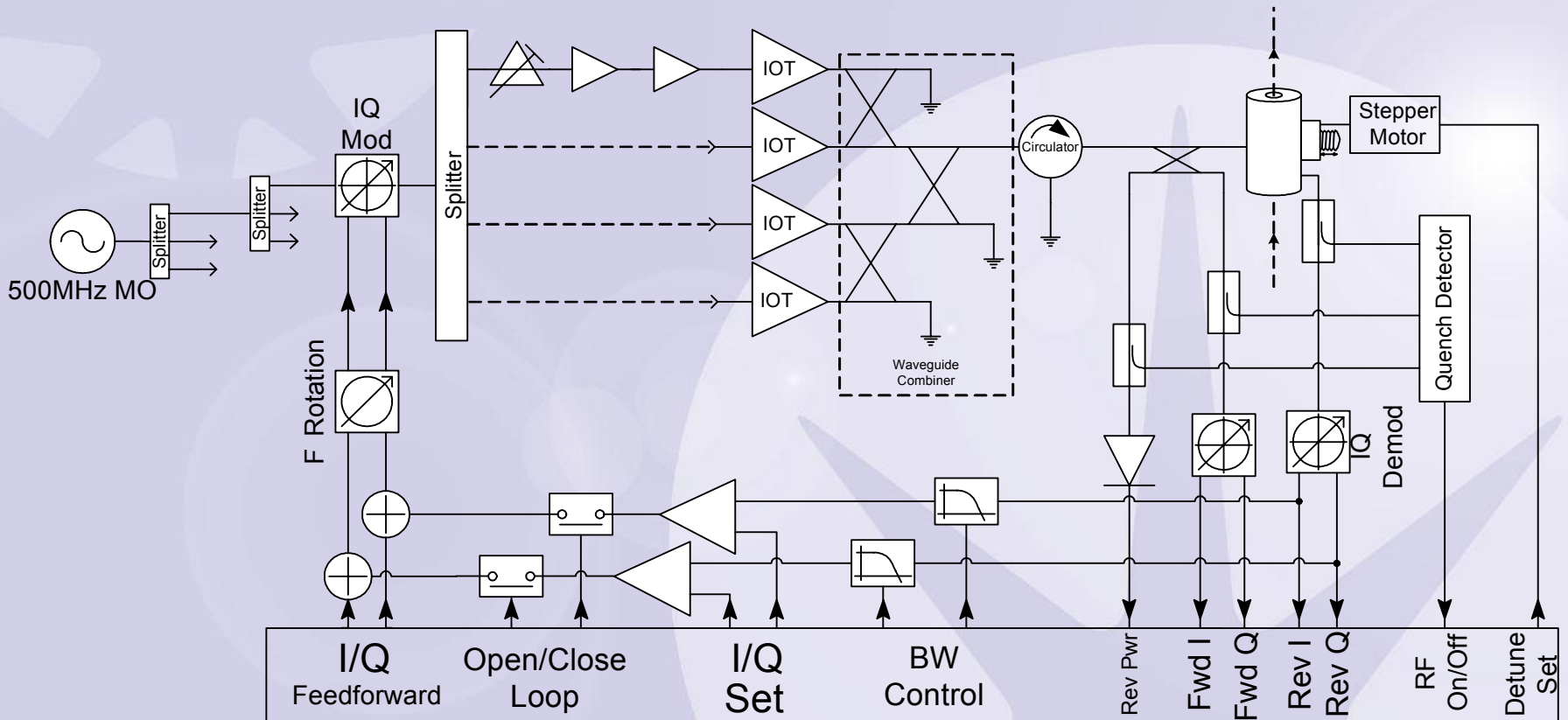
Designed and manufactured by:



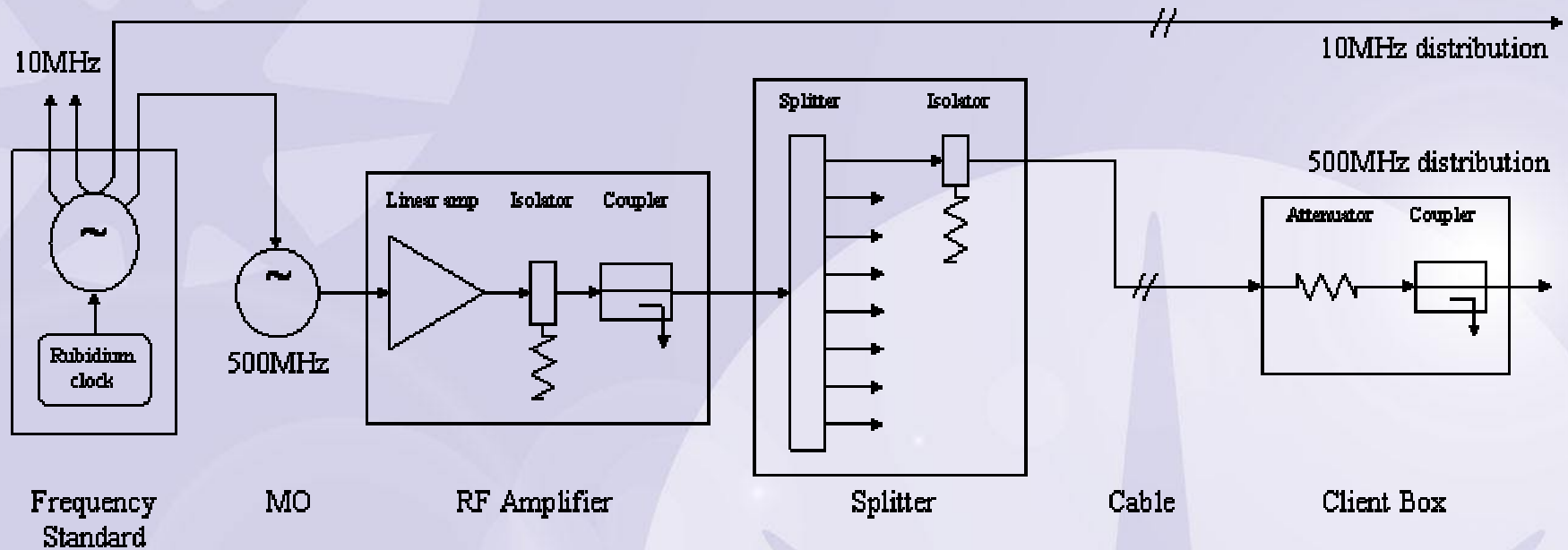
Cryoelectra



RF plant block diagram (1 of 3 amplifiers)



Master Oscillator RF distribution



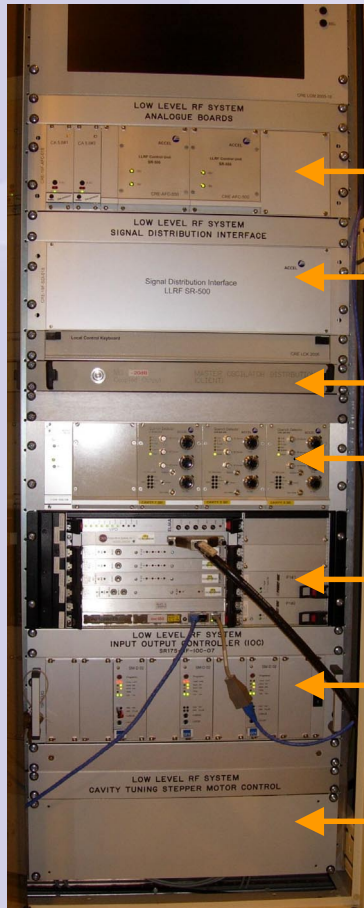
<i>Destination</i>	<i>Cable Length</i>
Linac	10m
Booster	40m
Optics Hutch	80m
Diagnostics CIA	155m
RF Hall	275m

Master Oscillator RF distribution

- IFR 2040 signal generator
 - 130ms phase/frequency transient, even for 0.1Hz step!
 - IFR looking into the problem (normal noise mode OK)
- In-house built 5W amplifier and splitter
 - ASC311 amp to be replaced with Aerial Facilities unit, due to one failure and internal switcher noise.
- LDF4.5RN-50 phase stabilised cable
 - 275m cable to RF Hall gives approx $-1.2^{\circ}/^{\circ}\text{C}$ (= 6 ppm)
- So far, amplitude and phase stability of MO signal OK
- LDF1 for 10 MHz
 - reference signal useful for locking instrumentation to the MO



LLRF Hardware



LLRF electronics

LLRF/VME interface

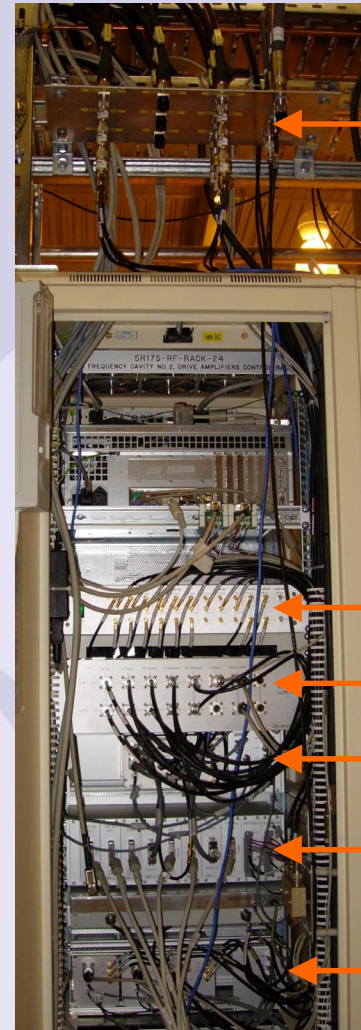
MO Monitor

Quench detector (QD)

Hytec IOC

Stepper motor driver

Stepper motor PSU's



Cavity signal patch-panel

RF preamp & signals to QD

LLRF IO panel

LLRF

LLRF/VME interface

QD

LLRF Software

SR-RF-LLRF-Cavity1

Mode: local Set Parameters

LLRF: ON Frequency Control

RF: ON Pulsed Mode

Manual Filling: Vcav 1.000 MV

Automatic Filling: Vcav max 1.000 MV manual fill

Detuning: OFF Det. Angle -10.0 deg

Status LLRF: LLRF RF Freq. Control CW Mode Softw Quench Det Loop closed Detuning

Interlock: Interlock MO Pgen Quench Limit Switch Motor Driver

Reset Pgen Fault

Reset Quench

Loop Control

Ampl_FF 1.2857 V Ampl. Probe 0.1712 V

PHI_FF -180.0 deg PhiDev -2.0 deg Corr-Phi 0.0 deg P-MO 0.98 dBm

Pprobe 0.000 W VcavDev 0.0047 MV Corr-Vcav 0.0000 MV VcavCal 95.0000 MV sqrt(kW)

measured Vcav [MV] 0.7652

Phi probe[deg] -158.01

Pfor [kW] 6.98

P_ref1: 6.92 kW 68 dBm

SR-RF-LLRF-Cavity1

Frequency Control

Search of Resonance

Tuner remote1

Desired Value 0.00 3602.64

Readback Value 3602.64

Target 3602.64 Hz Position 3602.64 Hz

Drive Motion Stop

Resolution Calibration

Limits Status

Ready Moving Forward Hi Limit Lo Limit Missed

Tuning Loop and Cavity Voltage Calibration

PHI_PID VoltCal max A. Probe

calibr. -12.0 deg 92.000 MV/sqrt(kW) 0.153 V

meas. -4.0 deg 98.000 MV/sqrt(kW)

set -5.0 deg 95.000 MV/sqrt(kW)

Reset

PID control

actual Setp.: PHI_PID + PSI 5.0 deg PID off

Tuning Sensitivity start 4.0 deg PID-Param

stop 2.0 deg

Exit



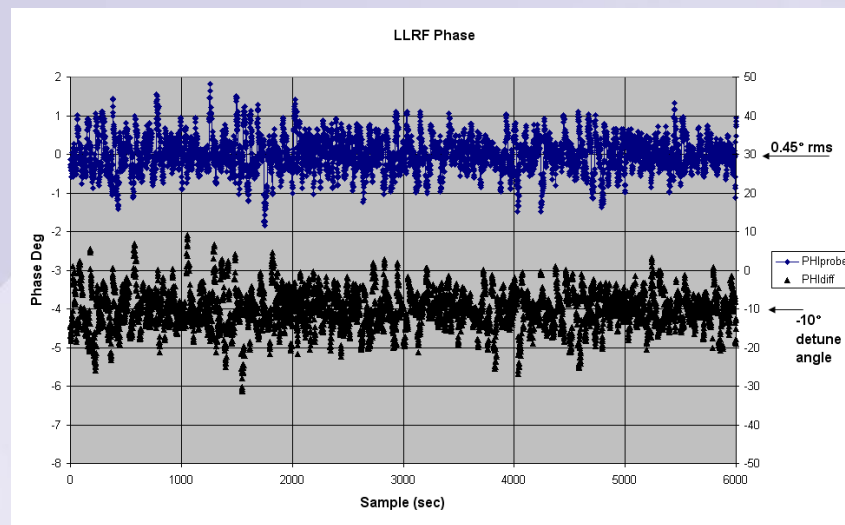
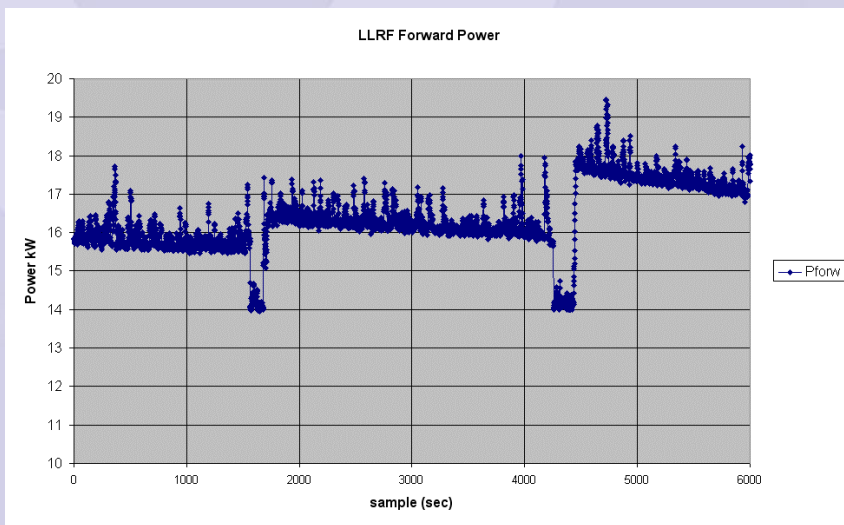
Commissioning procedure

- Calibrate modulator and demodulators
- Calibrate RF paths (pickup cables and amplifier gain)
- Measure cavity tuner step/Hz
- Optimise PID parameters and motor speed in motor record
- Zero phase between forward and probe signals at resonance
- Determine 'Voltcal' factor for the cavity probe:
 - $\text{Voltcal} = V_{\text{cav}}/\sqrt{P_{\text{probe}}}$
 - V_{cav} is found from $\sqrt{4 * P_{\text{for}} * R / Q * Q_0}$ at resonance
- Verify correct detuning operation



First results

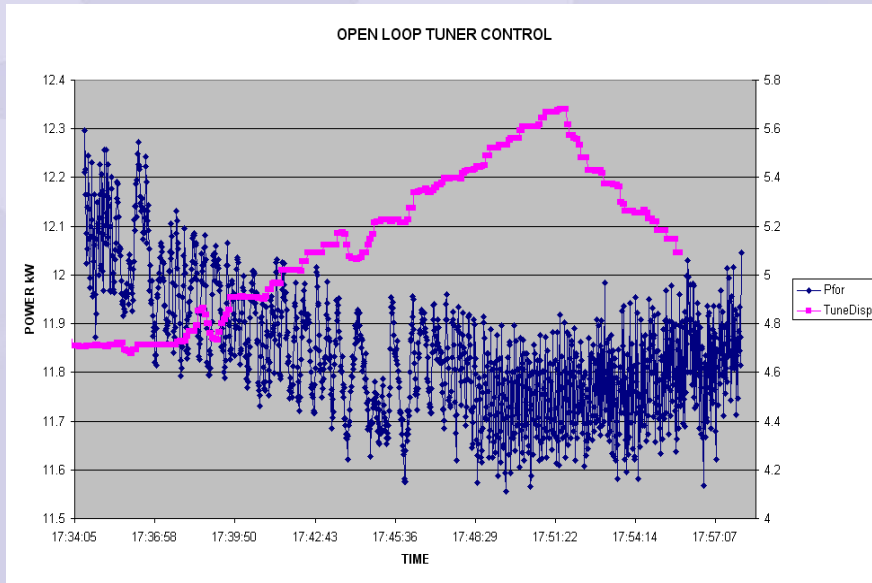
Results using EPICS 'strip tool' (1sec sample rate):



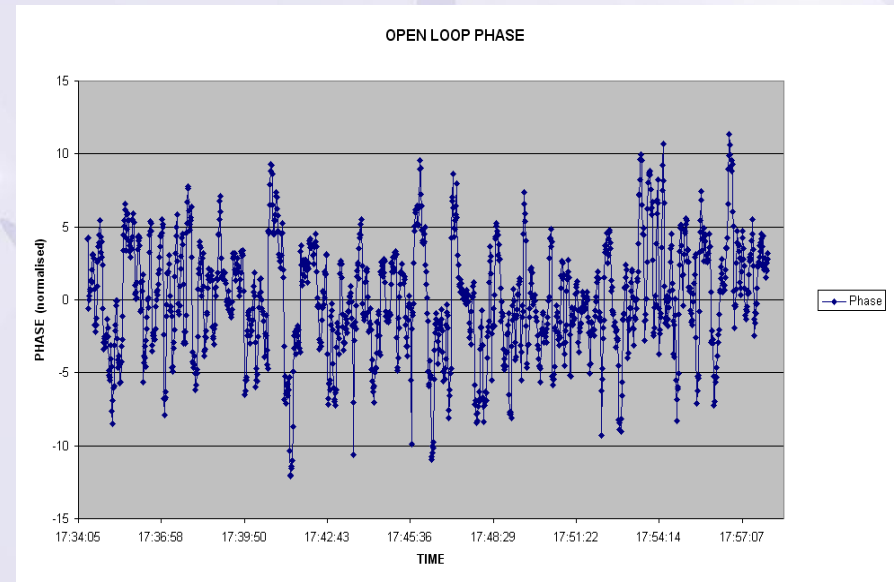
Settings	Amplitude Stability		Phase Stability	
	rms	pk-pk	rms	pk-pk
LLRF only	0.09%	-	0.05°	-
1.35 MV IQ gain=50, BW=0	0.12%	0.86%	0.53°	4.80°
1.0 MV IQ gain=70, BW=0.5	0.13%	0.86%	0.23°	2.06°
1.0 MV, IQ gain=70, BW=0.5 Detune = 20°	0.12%	1.15%	0.18°	1.53°



First results



Forward power variations of >10 %
- need to reduce



Phase stability under tuner control $\sim \pm 15^\circ$: need to investigate contributions from tuner, cryogenics, amplifier etc.

Technical challenges

- Tuner problems: backlash, hysteresis, EPICS motor record not easy to master.
- Amplifier gain change with power and temperature
 - open loop error in predicted power output from the LLRF
 - also gain change with IOT configuration (e.g. 2 or 4 IOT's)
- Closed loop error: ~100 kV, analog offsets (and no dc integrator term?)
- Accurate power calibration: coupler, calorimetric, LLRF
 - which one is giving the true reading?
- Loop gain and BW dependant offset
 - can we add a look-up table?



Future work

- Improve operation of tuner loop
- Optimise loop gain and BW for regulation
 - requires better measurement of amplitude and phase stability than through EPICS
- Look for interaction with beam on higher BW settings
- Develop ‘Operator friendly’ control screen
 - combined within a combined Storage Ring RF plant screen?
- Improve calibrations of forward power and cavity voltage
- Reduce noise on Pforward and Pprobe phase readings
- Provide training and operating instructions



Conclusions

- Tuner improvement is the most urgent requirement
- Target spec of 0.5%, 0.2° rms was realistic (for an analog system)
- Offsets and values that require 'tweaking' may be the main drawbacks of our analogue system
- Require the development of a simplified operator interface
- Hardware reliability has been excellent



Acknowledgements

Diamond SR RF Group:

Morten Jensen
Shivaji Pande
Matt Maddock
Simon Rains
David Spink

Diamond Controls Group:

Paul Hamadyk