LLRF Control System for the Diamond Storage Ring

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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**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Analogue IQ</td>
<td>EPICS software</td>
</tr>
<tr>
<td>RF Frequency</td>
<td>499.654 MHz</td>
<td></td>
</tr>
<tr>
<td>Cavity voltage range</td>
<td>0.125 to 2.5 MV</td>
<td>(per cavity)</td>
</tr>
<tr>
<td>Amplitude regulation</td>
<td>0.5 % rms</td>
<td>Over 14 dB range</td>
</tr>
<tr>
<td>Phase regulation</td>
<td>0.2 ° rms</td>
<td>Over 14 dB range</td>
</tr>
<tr>
<td>Phase control range</td>
<td>± 180°</td>
<td></td>
</tr>
<tr>
<td>Loop bandwidth</td>
<td>10 Hz to 100 kHz</td>
<td>Open loop unity gain</td>
</tr>
<tr>
<td>Loop gain</td>
<td>0 to 40 dB</td>
<td>variable</td>
</tr>
</tbody>
</table>

*Designed and manufactured by:* [ACCEL](#) [Cryoelectra](#) [Diamond](#)
RF plant block diagram
(1 of 3 amplifiers)
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°/°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

ESLS-RF’06 28th Sept 2006
LLRF Software

ESLS-RF'06 28th Sept 2006
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:
  - Voltcal = Vcav/\sqrt{Probe}
  - Vcav is found from \sqrt{4*Pfor*R/Q*Q_0} at resonance
- Verify correct detuning operation
First results

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

<table>
<thead>
<tr>
<th>Settings</th>
<th>Amplitude Stability</th>
<th>Phase Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rms</td>
<td>pk-pk</td>
</tr>
<tr>
<td>LLRF only</td>
<td>0.09%</td>
<td>-</td>
</tr>
<tr>
<td>1.35 MV IQ gain=50, BW=0</td>
<td>0.12%</td>
<td>0.86%</td>
</tr>
<tr>
<td>1.0 MV IQ gain=70, BW=0.5</td>
<td>0.13%</td>
<td>0.86%</td>
</tr>
<tr>
<td>1.0 MV, IQ gain=70, BW=0.5 Detune = 20°</td>
<td>0.12%</td>
<td>1.15%</td>
</tr>
</tbody>
</table>
First results

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

Forward power variations of $>10\%$ - need to reduce
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
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