ADVANCED PHOTON SOURCE LOW-LEVEL RF SYSTEMS

LLRF 05 – Workshop on Low-Level RF – CERN - Geneva, Switzerland

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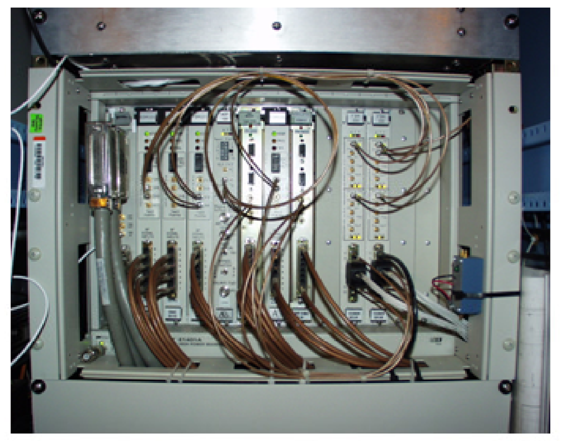
The APS RF Systems

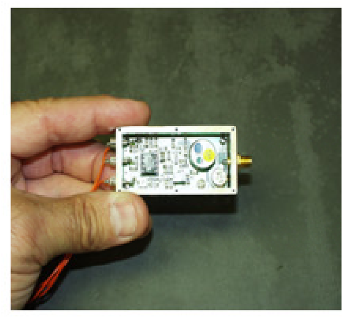
- 450MeV Linac: **FIVE** 2856MHz/45MW peak pulsed rf systems
- PAR (Particle Accumulator Ring): **ONE** 9.77MHz/4kW CW rf system and **ONE** 117.3MHz/3kW peak pulsed rf system
- 7GeV Booster-Synchrotron: **ONE** 352MHz/1.1MW CW ramped rf system
- Storage Ring: **FOUR** 352MHz/1.1MW CW rf systems

APS LLRF Hardware

- VXI packaging
- Separate interface chassis for passive devices such as splitters, directional couplers, etc.
- SMA-Phoenix interconnect cabling between the two sub-assemblies



VXI RF Board Layout:



- Two or four channels of rf measurement/control per board
- RF components housed inside rf-tight enclosures – the remainder of the board is dedicated to EPICS acquisition hardware
- RF connections on VXI front panel using blind-mate Phoenix connectors

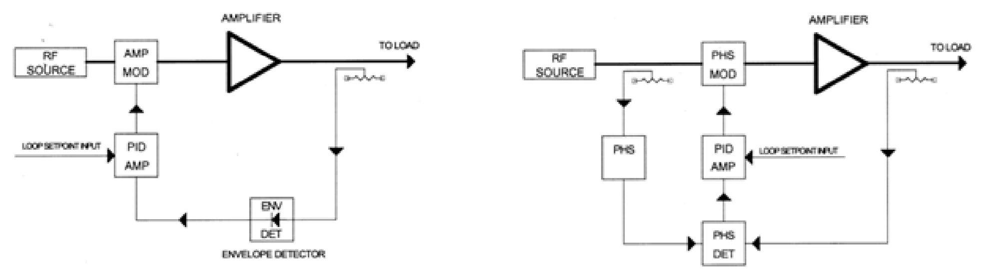
Recent LLRF Hardware Upgrades

- ~ 1998, new-design envelope and phase detector boards to replace the obsolete 1992-version Bruel & Kjaer 3154 VXI User Module – *design of rf sub-assemblies was not changed*
- In 2004, new-design feedback PID amplifier boards to replace the obsolete 1992-version Bruel & Kjaer 3154 VXI User Module, and also to improve analog electronics– *completely new design*
- 2005 -- Upgraded phase detectors to replace the original 1992-version double-balanced mixer phase detector used in rf subassemblies – *using the Analog Devices 8302 rf amplitude and phase measurement IC*

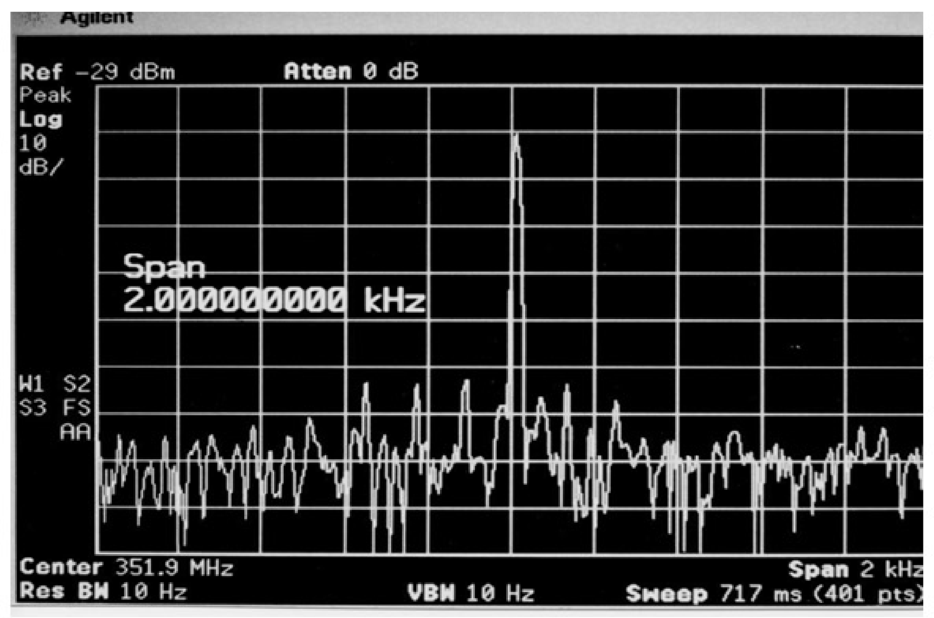
The APS Low-Level RF Systems

APS LLRF Systems are **entirely analog**, *with some use of EPICS-based software scripts to provide simple automation*

- ***Direct amplitude and phase measurement/control at the operating frequency (351.93MHz, 117.3 MHz, 9.77MHz)***
  - Linearized envelope detectors
  - Double-balanced mixers with leveling amplifiers used for phase measurement
  - Varactor-diode phase shifters used for phase control



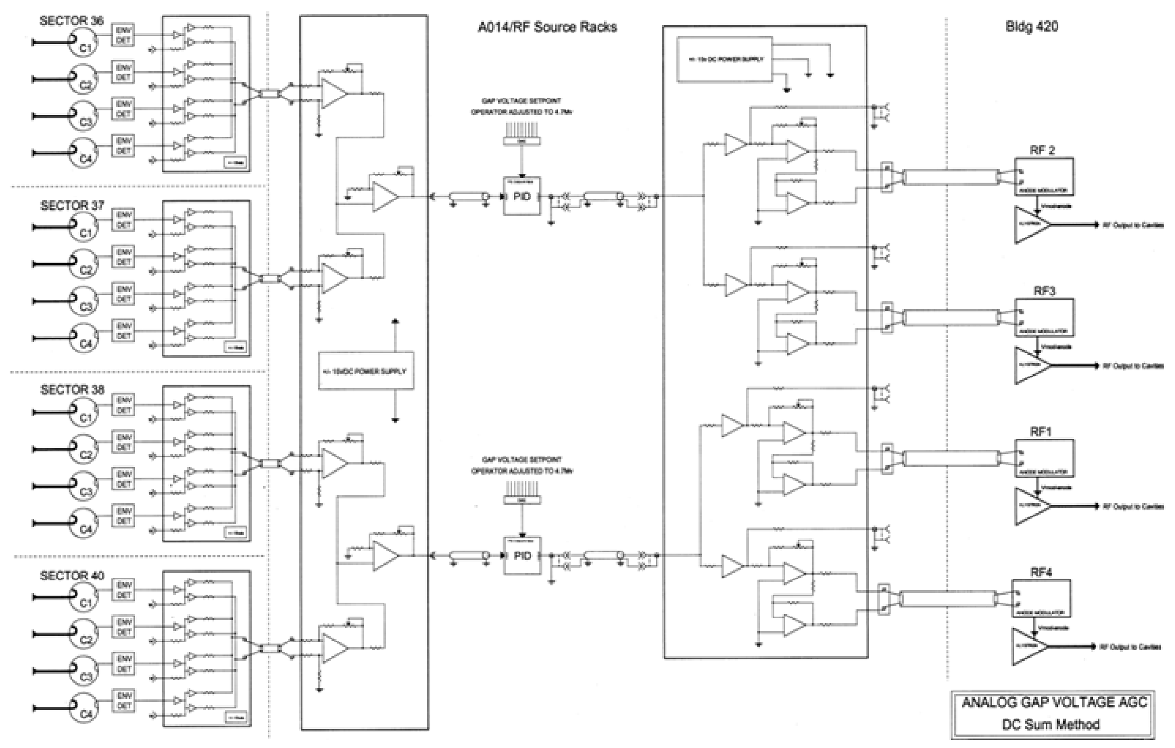
Incidental AM and PM Suppression



RF Cavity Field Probe Signal

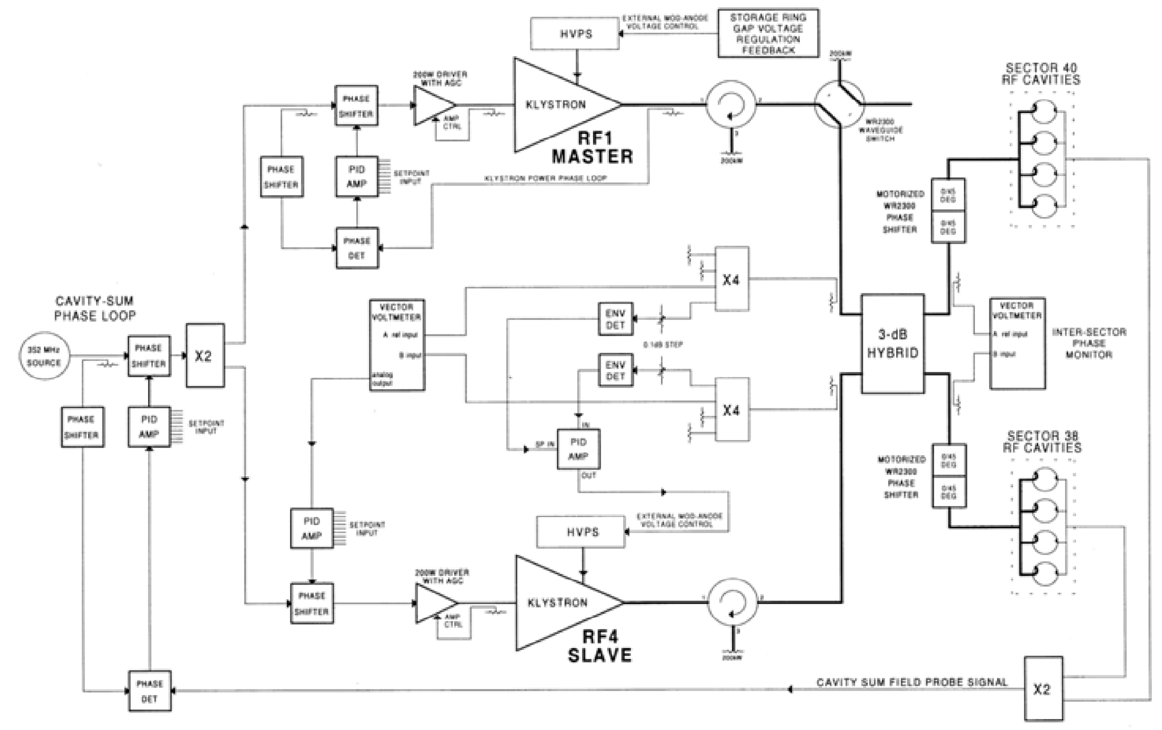
- LLRF phase and amplitude control reduces incidental Nx60Hz AM and PM on cavity gap voltage
- Typical sideband level is –50dBc, indicating ~1° p-p phase jitter and less than 1% amplitude variation

Storage Ring Gap Voltage AGC System



Klystron mod-anode voltage is modulated to regulate cavity gap voltage

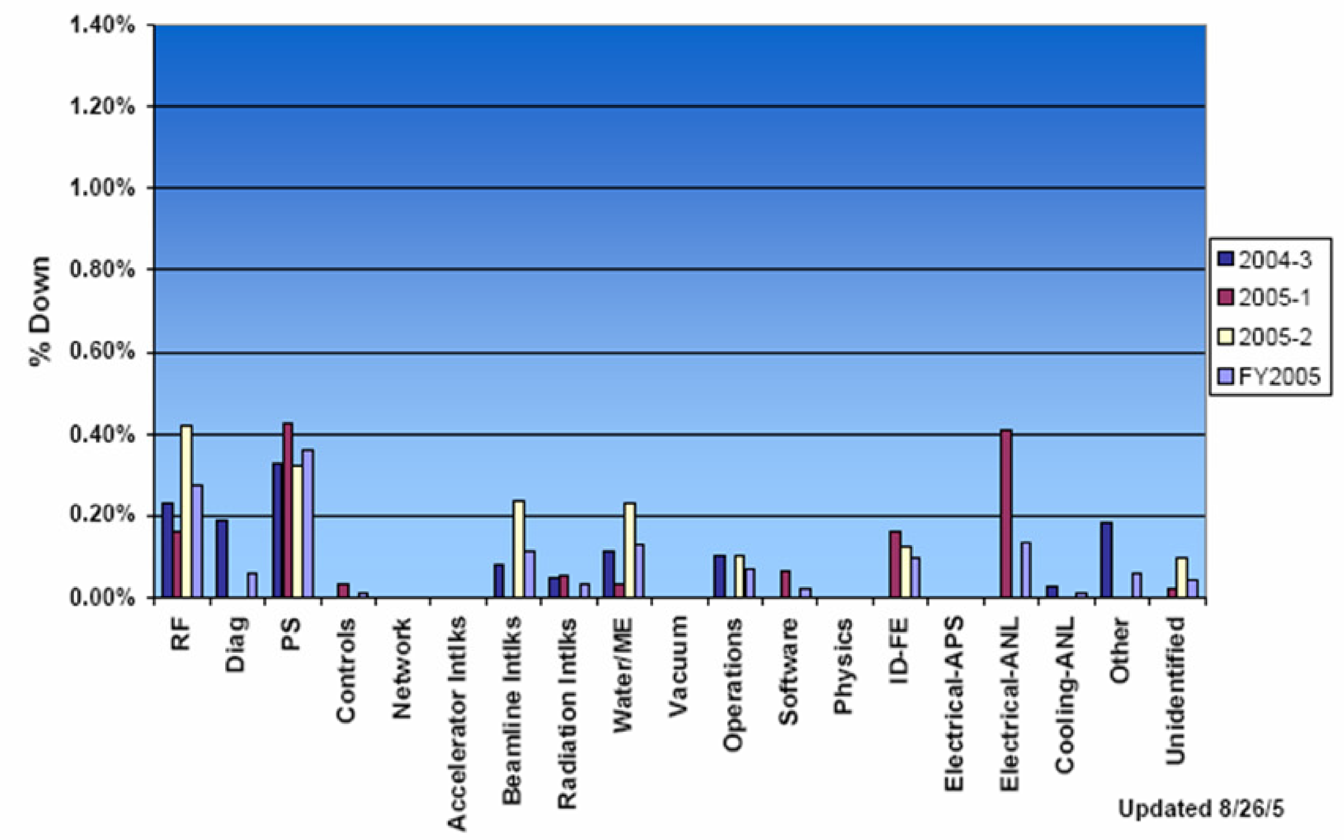
Parallel-Klystron Control



Analog loops maintain correct amplitude and phase relationships between two rf stations operating in parallel

FY 2005 Downtime by System

Data through Run 2005-2



- RF downtime allotment is 0.9%, and 200 hours mean time to beam loss

This includes all rf systems, from Linac to Storage Ring

- Typical rf downtime for an 1600 hour run is >0.5%
- Lowest rf downtime on record was 0.05%

Most Common LLRF Failures

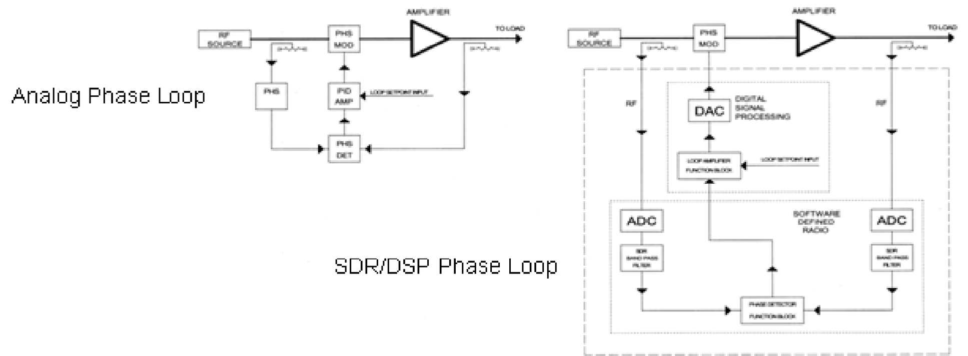
- **Intermittent rf connections -- ~ 3 per year**
- **LLRF board failures -- ~ 1-2 per year**
- **VXI crate power supply failure –** ***once rare but becoming more common***
- **Software induced faults – *most common problem*** – approximately 10-15 faults per year:
  - **Network communication problems with rf hardware**
    - -- Incompatibility with GPIB-controlled equipment
    - -- Network-level upgrades that are incompatible with rf hardware
  - **Reboot-related system configuration errors**
    - -- Installation of incorrect system settings (loss factors, setpoints, etc) upon an IOC reboot
  - **The use of automated control scripts that are not compatible with rf system hardware**

Future Low-Level RF Plans

Proposals have been submitted for the following projects *which will require state-of-the-art LLRF performance and capabilities:*

- DSP/FPGA Upgrade to the PAR 117.3MHz Pulsed LLRF Systems
- APS Short X-Ray Pulse Upgrade:
  - Storage Ring upgrade intended to provide a transverse kick to the beam bunches and thereby generate ultra-short (picosecond) x-ray pulses
  - Will utilize SC crab cavities and CW rf system to provide transverse kick to bunch
  - Will require a sophisticated *state-of-the-art* low-level rf system to achieve 0.05° and 0.05% amplitude control requirements

- FY2006 LDRD proposal to design a LLRF system utilizing Software Defined Radio and DSP techniques:



  - Digitize baseband rf signal directly
  - Use data manipulation to perform all modulation, demodulation, and processing functions required to meet specifications: *0.5° phase and 0.5% amplitude control*
  - Possibly achieve extremely wideband programmable frequency agility?