LLRF Implementation: digital vs. analog

Hengjie Ma
NSLS II RF Group
Brookhaven National Laboratory
2 - 4 - 2010

Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

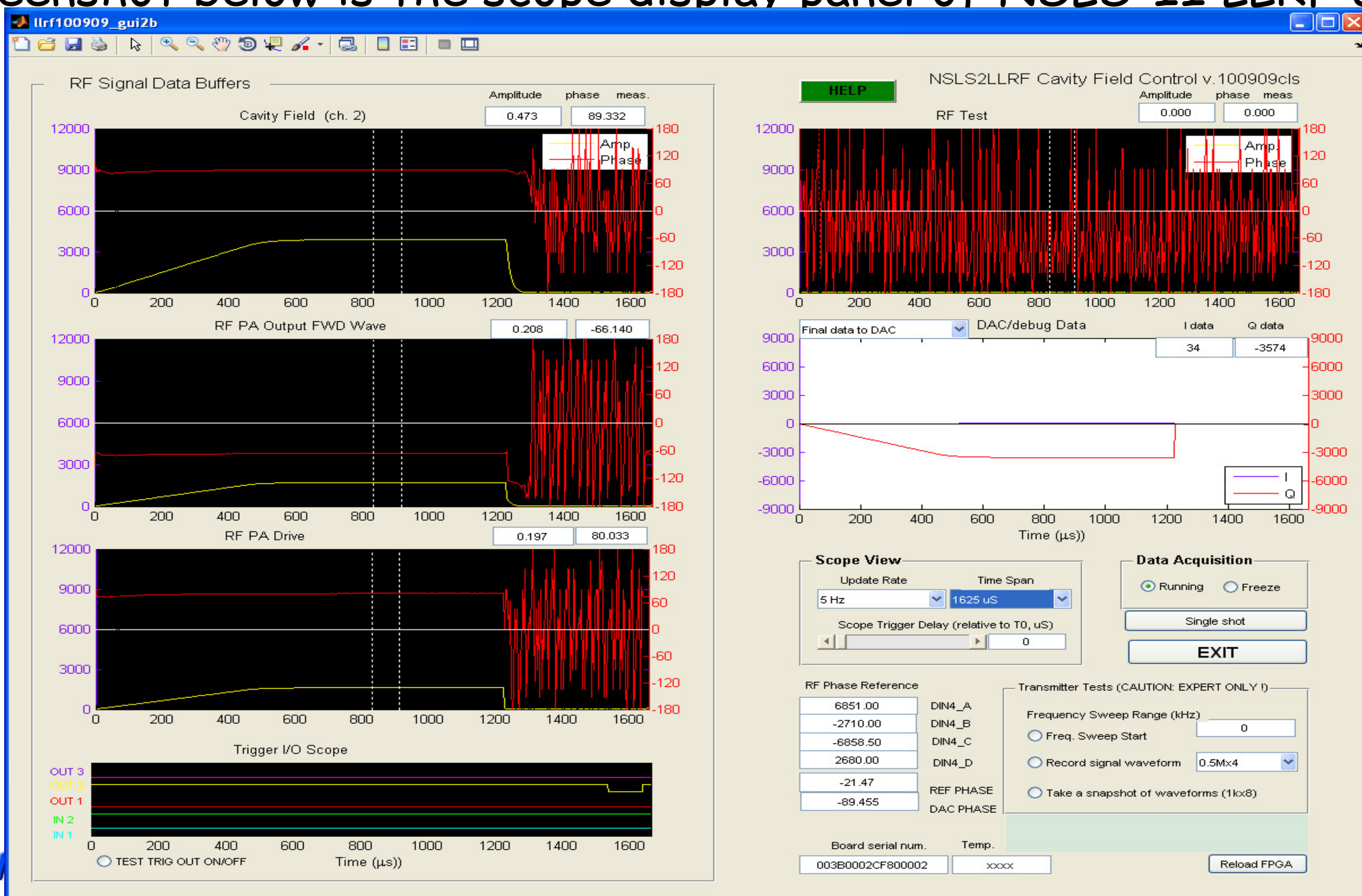
Functionality of a Simple LLRF

- A core function of LLRF is to provide the RF stability in a cavity.
- A simple LLRF for above functionality is a lot like a radio transceiver. Its composition has mainly three parts:
  - Receiver in the front (signal demodulation)
  - Signal processing/controls in the middle (amp/phase detection, scaling, loop phase correction, PID, AGC, AFF, etc.)
  - Transmitter in the back (amplitude/phase modulation etc.)
- A comparison in performance between digital and analog LLRF can be made in these three areas.

(NSLS-II digital LLRF controller)

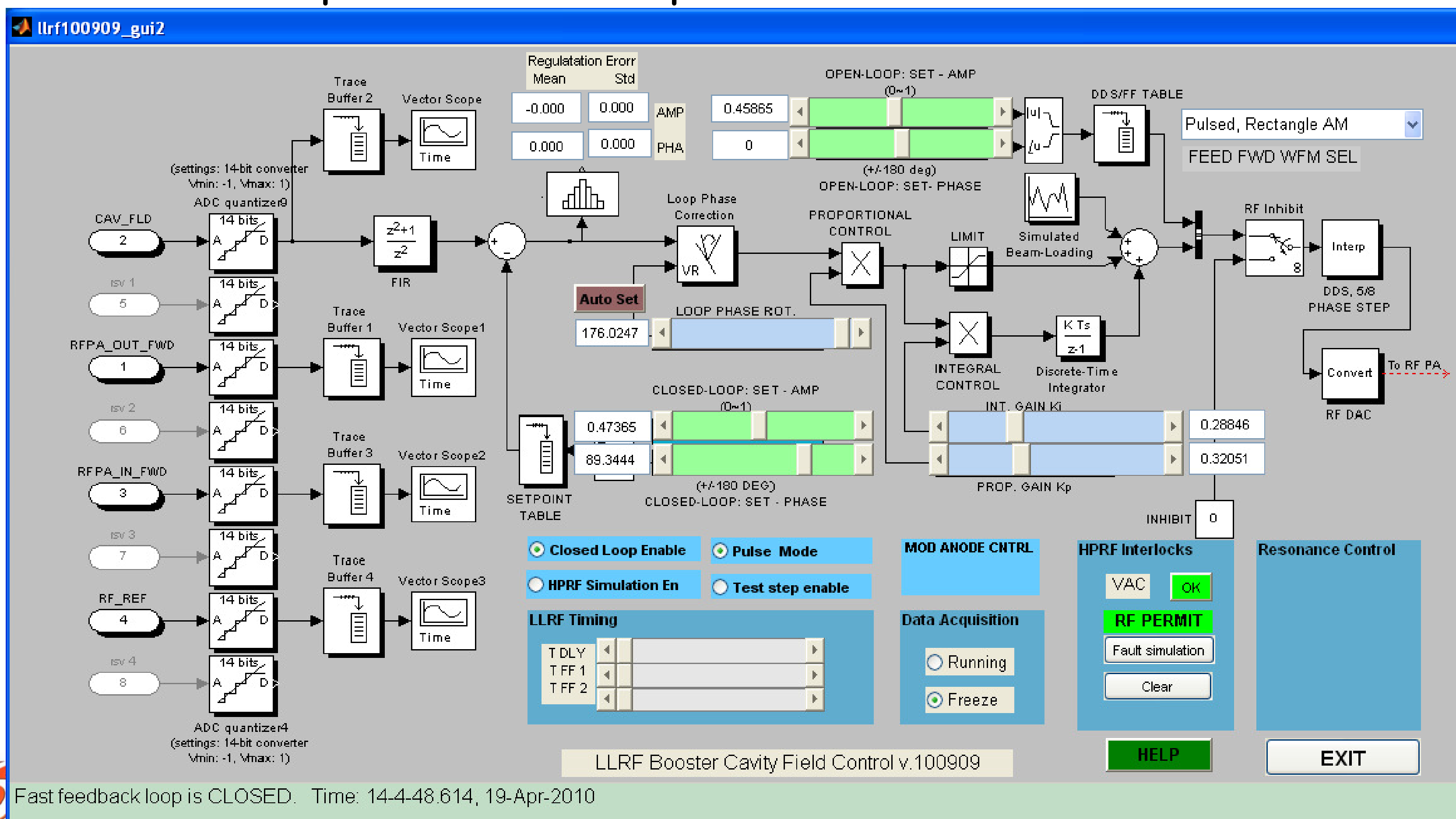
Benefit/features of a digital LLRF (1)

- A digital LLRF typically offers signal waveform data buffers for display and archive, very useful for RF operation and diagnosis. The screenshot below is the scope display panel of NSLS-II LLRF GUI.



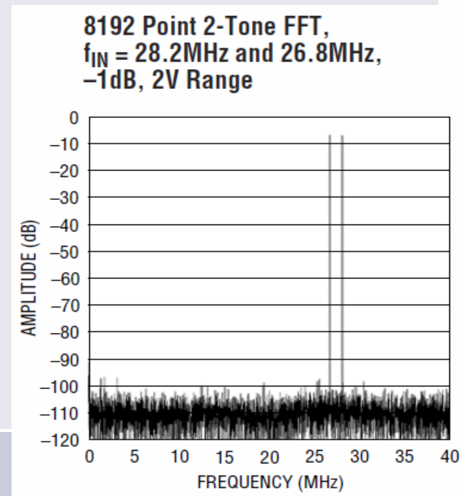
Benefit/features of a digital LLRF (2)

- A digital LLRF allows RF engineer to conveniently access various control parameters to optimize the RF performance. Screenshot below is the operator control panel of NSLS-II LLRF GUI.



Input receiver front : demodulation

Implementation	Analog	Digital
device	Power detector, phase detector, passive/active vector demodulator etc.	14 or 16-bit high-speed ADC, amplitude/phase demodulation through IQ or near-IQ sampling, DDC etc.
Detector Linearity	True linear type is hard to find Limited operating power range. Intercepted at lower end, and saturated at high end.	True linear over a wide dynamic range (>80dB) Example: LT2299 14-bit, 80Msps SFDR: 90dB, I_{MD}: 90 dB
Meas. Accuracy	Poor, may need correction tables	~1.2LSB, INL
HW complexity	Easy to implement, hard to optimize for linearity, dynamic range	Generally simple, but we need new skills



In digital system all input waveforms available for real time display and in history buffer for post-mortem

Mid-section: signal processing/control

Implementation	Analog	Digital
device	By Op-Amp circuits, comparators, filters, multipliers/dividers, phase shifters,	FPGA or ASIC digital hardware to run the signal processing/control algorithms, from simple to sophisticated.
Processing Accuracy	Generally low, have to deal with problems like zero-drifts, and non-linearity.	Generally high, only limited by the length of the computing word
HW complexity	Simple but limited in performance. Experts getting older.	Generally simple, all processing can be done on one device, digital signal processing mature, easier to find experts (taught in Universities!)

In digital system, signal processing can be made visible by exporting variables and displaying them

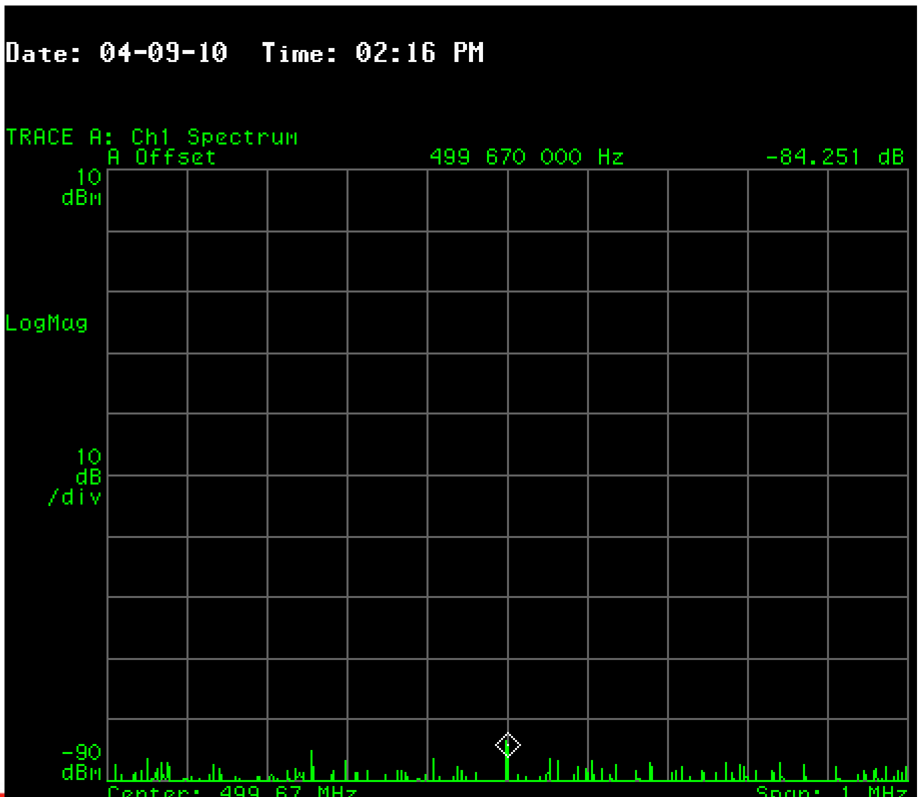
Transmitter output: modulation (1)

Implementation	Analog	Digital
device	Vector modulators (passive and active, such as AD834, RF MicroDevices RF2480)	14 or 16-bit high-speed DAC or direct-digital synthesizer (DDS), Output RF amplitude/phase control through data manipulation
Control Linearity	linear only within a limited dynamic range.	Typically, linear over 80dB dynamic range
Control Accuracy	vary	good
HW complexity	Simple- system on a chip	simple

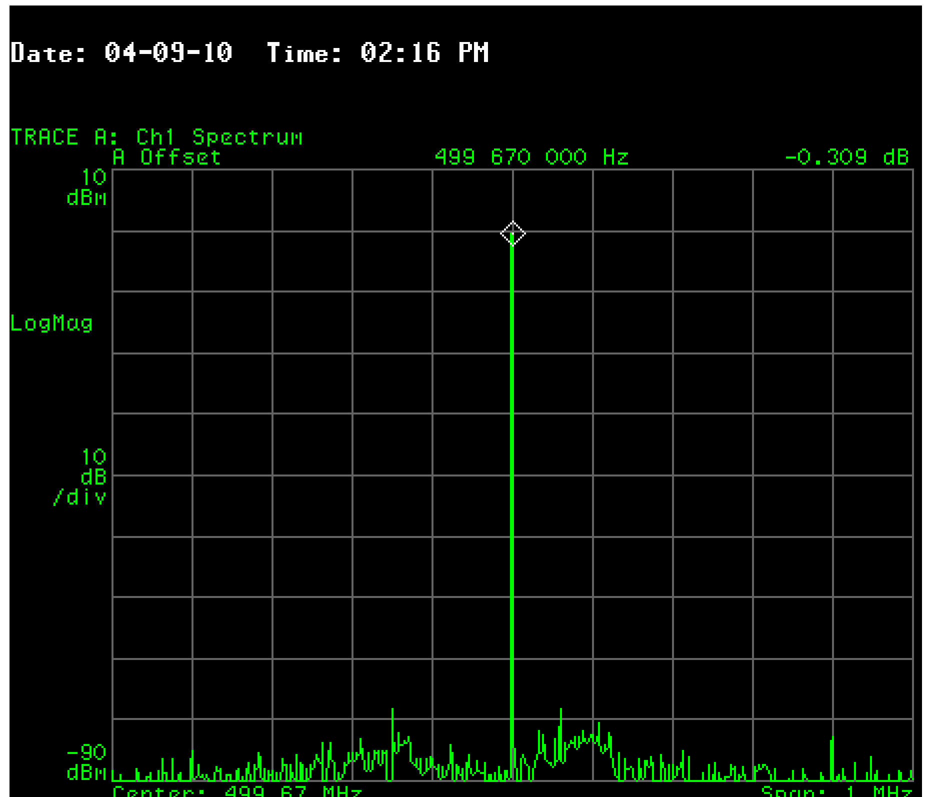
Transmitter output: modulation (2)

A digital LLRF can have a wide output control dynamic range, > 80dB for a 14-bit output DAC, which is difficult to achieve with an analog vector modulator. A wider output control range means a wider range of LLRF power level control.

Amp. Control at min position



Amp control at Max position



Analog vs. digital

- In most cases, the digital implementation of LLRF has big advantages over analog in both performance and convenience.
- Good RF/analog circuits are still essential for a success of digital LLRF (signal conditioning, scaling, clocking, etc.)
- There are always be occasions where the signal processing/control has to be done with special analog circuits.
- By nature, digital LLRF is a mixed-signal system. An engineer would need a good knowledge in both digital and RF/analog electronics in order to develop a digital LLRF.

Low-level RF System: desirable features

- More input/output channels (RF, analog, and digital)
  - the more the better, to be able to handle the current and future needs.