LBNL LLRF Upgrade for the AWA facility

Larry Doolittle

representing the LBNL team

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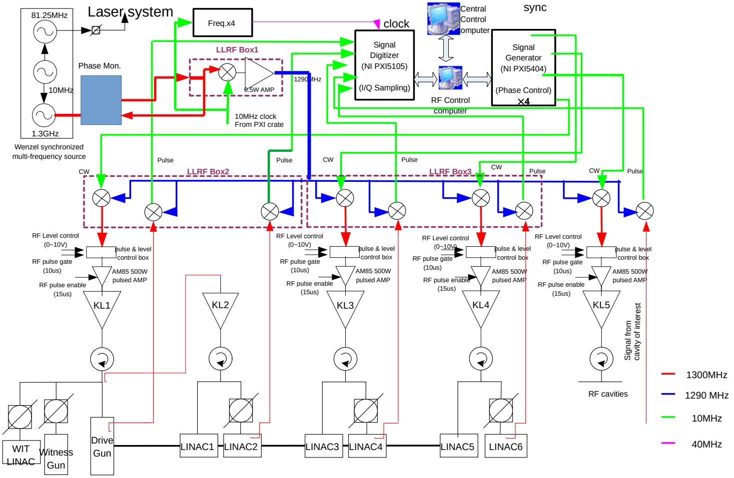
Origin

- AWA has a working LLRF system
  - 5 (+) cavities at 1300 MHz
  - 10 μs pulsed klystrons, 10 Hz
  - difficult-to-understand drift/jitter behavior
- LBNL has deployed high-precision LLRF systems worldwide
  - Most recently at SLAC: 1300 MHz CW
  - Includes experience with drift-compensated phase distribution
- Maybe LBNL can help improve AWA!
  - Hardware
  - Software
  - People!

This talk will describe status of LBNL's contribution to AWA LLRF, still very much in-progress, and also ramble some about LLRF technology in general.

Existing, working AWA RF system



1300 MHz Master Oscillator, 10 MHz IF, “obsolete” hardware

LBNL LLRF Hardware

Deployed at AWA

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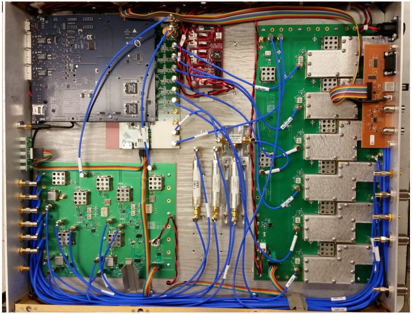
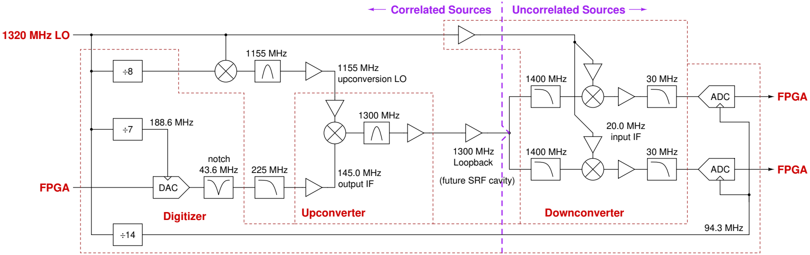




LBNL LLRF Hardware

Demonstrated very high dynamic range, low drift, low crosstalk

- 1300 MHz carrier, variants at other frequencies including 3900 MHz
- -150 dBrad^2/Hz white noise floor
- -110 dBrad^2/Hz @ 1 Hz $1/f$ noise
- 80 to 120 dB isolation between channels
- about 30 MHz RF bandwidth

Unusual Split-LO design bypasses usual compromises in choosing IF

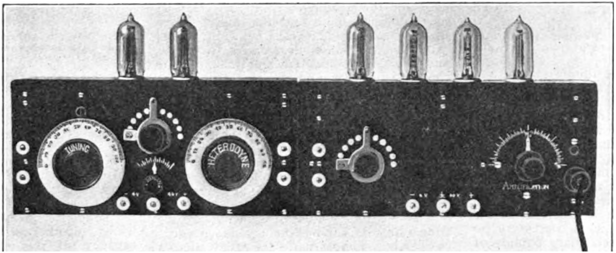
- Low 20 MHz IF for receiver reduces crosstalk & sensitivity to ADC clock jitter
- High 145 MHz IF for transmitter places less stringent requirements on output sideband-select filter
- Circumvents usual problems with isolation between drive & input IF

Not a new architecture!

Superheterodyne Receiver

- Invented by U.S. engineer Edwin Armstrong in 1918
- Overcame serious limitations of triode tubes of the day; their gain at 75 kHz IF was much higher than at 2 MHz RF

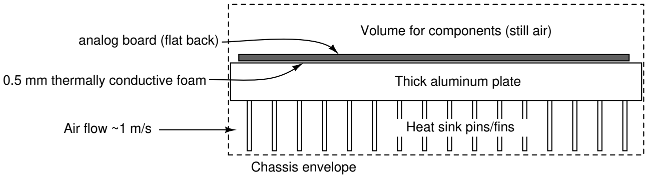
"Superheterodyne receivers have essentially replaced all previous receiver designs." - Wikipedia

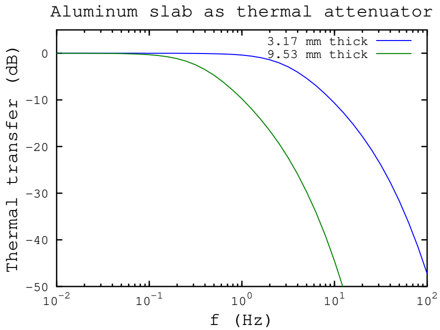


Not counting the ADCs, the RF architecture of both the existing and upgrade LLRF systems would be instantly clear to Armstrong in 1918.

LBNL LLRF Hardware

Mechanical/Thermal/Acoustic design concept for low-noise, low drift electronics





LBNL DSP

LBNL has been building experience, capabilities, and a code base for accelerator RF DSP for over two decades. Filtering, DDS, up- and down-conversion, PI feedback loops, etc.

Mostly vendor-neutral, synthesizable, regression-tested Verilog HDL published on github under Open Source (BSD) license:

- `https://github.com/BerkeleyLab/Bedrock`

FPGA DSP as an analog component

	DSP	"Real" analog
noise	yes	yes
$1/f$ noise	**no**	yes
drift	**no**	yes
temp. coeff.	**no**	yes
group delay	yes	yes
saturation	yes	yes
distortion	**no**	yes
crosstalk	**no**	yes
imperfect cal.	**no**	yes
power dissipation	yes	yes
simulatable	yes	yes
remote updates	yes	**no**

Short-pulse RF

Pulsed RF normally means only shot-to-shot feedback

$10\,\mu$s is too short for realistic intra-pulse feedback

People do attempt it, but you need a lot of motivation to address difficult issues with latency and calibration

Most of the attention in LBNL's recent LLRF DSP development has been on narrow-band CW SRF cavities. But the capabilities are flexible and do include pulsed/triggered modes.

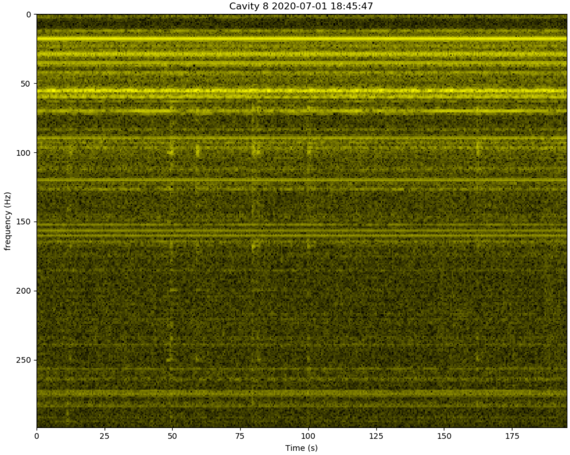
Triggered short-pulse waveforms have been captured at AWA.

Refer to Fermi@ELETTRA for an example of a pulsed RF system using LBNL's technology for phase stabilization.

Microphonics and other disturbances

Pulsed RF normally means only shot-to-shot feedback

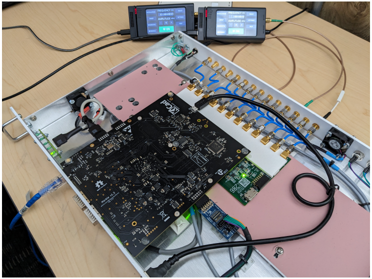
10 Hz repetition rate means disturbances in the audio band are heavily under-sampled.
Very different from CW systems that can fully self-diagnose audio

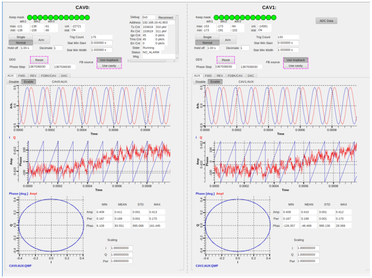


LBNL Hardware and Software

Traditional downconverter-ADC-FPGA stack, 20 MHz IF

FPGA connects directly to EPICS server over Gigabit Ethernet



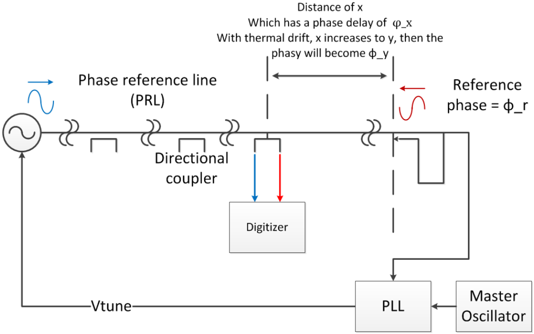


EPICS server and UI prototyping and bench-testing
(downconverter not included)

Experimental Directions

Title says “upgrade” but that’s not a foregone conclusion

- LBNL system starts just as added diagnostics: “witness mode”
  - More evidence typically leads to more understanding
- Capability does exist to drive the system
- Has the flexibility to incorporate drift-compensating RF techniques



Conclusions

Good opportunity for collaboration and building on DOE lab's strengths

Thank You

LBNL team: Qiang Du, Gang Huang, Shreeharshini Murthy,
Lucas Russo, Keith Penney

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