Low Cost, High-Density Digital Electronics for Nuclear Physics

Wojtek Skulski

Principal Investigator

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SkuTek Instrumentation
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Outline

- The company and its capabilities.
  - Customers.
- Hardware progress.
  - New compact instrument FemtoDAQ+.
- Firmware progress.
  - Improved firmware structure.
  - We organized the FW into *Features*.
- Software progress.
  - Portable remote Web GUI.
  - JavaScript and JSON.
- Plans.
- Highlights.
- Acknowledgements.

The company and its capabilities

- The team: two physicists, a senior software engineer, a part time engineering associate, and a manager. We regularly work with a local EE consultant.
- We worked with several interns listed on the Acknowledgements page.

Our focus:

Digital data acquisition (DAQ) for nuclear physics, high energy physics, DM search, etc.

Our capabilities: Anything, what we need to develop a cutting edge instrument.

- Electronic design.
- Firmware development for Field Programmable Gate Arrays (FPGA).
- Software development for embedded processors, especially Embedded Linux.
- Algorithms for pulse processing.
- Algorithm implementation in the FPGA (VHDL, Verilog) and in embedded processors (Pascal, Python, C).
- Processing data from nuclear detectors of any kind.
- Development of simple detector assemblies using scintillators, PMTs, or SiPMs.

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Our customers

National Superconducting Cyclotron Laboratory

Brown University

Progress

Progress

Hardware progress: 2-channel **FemtoDAQ+** is replacing the former FemtoDAQ.

- More powerful FPGA: Spartan-6 LX9 replaced with Artix-7.
- Longer waveforms, faster readout.
- Two analog reconstruction channels can synthesize the signal, possibly after digital filtering, or output an arbitrary analog waveform.
- BeagleBone is replaced with MicroBone Single Board Computer, which is also our product.
- We are considering whether the old FemtoDAQ should not become the “last time buy”.

Firmware progress.

- Unified interface between the FPGA and the Linux MicroBone SBC.

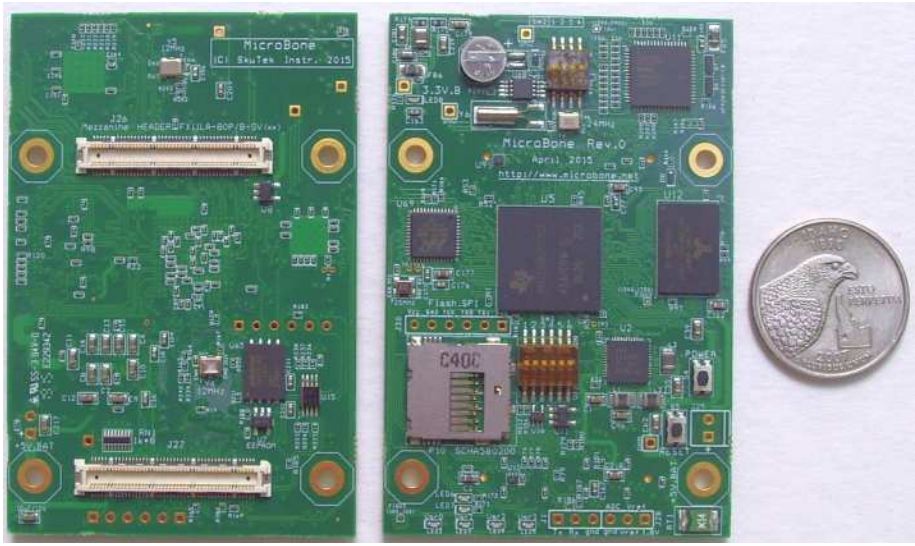
Software progress.

- Web-based GUI for setup and control works with any operating system using the web browser technology.

MicroBone: BeagleBone - Compatible SBC

- After introducing FemtoDAQ+, all our products will now use MicroBone SBC.
- ARM Linux System on Module (SOM) with a low-power 1 GHz ARM processor AM5338.
- It provides embedded Linux with laptop-class performance to all our products.
  - Local data logging, remote display for monitoring and diagnostic.
- Hardware:
  - We added an 8-channel ADC/DAC chip with 12 bit resolution and 5 Volts input / output range.
- Software:
  - Adopted Debian-10 for this SBC.
  - Developed both Python and C capabilities: SBC is its own development system.

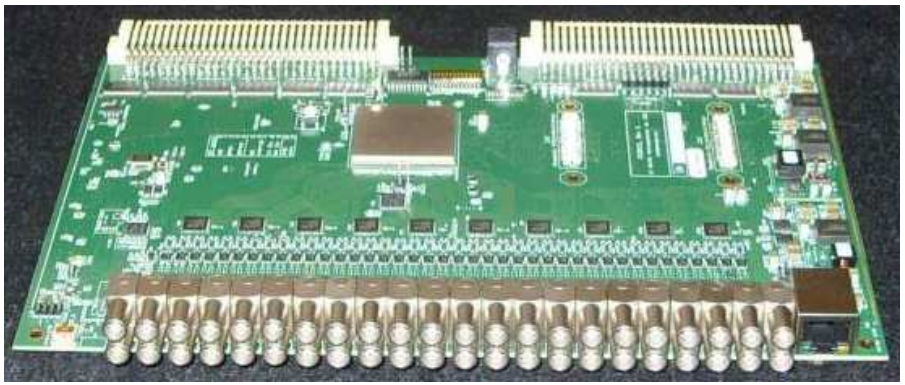
- Easy to embed 2” by 3” size, fits within DAQ module.
- Two 80-pin expansion connectors.
  - Memory interface, USB, GbE, SPI, I^2C.
- 512 megabytes of RAM.
- 1 GHz ARM AM5338 running Linux.
- Two Programmable Real Time processor cores.
- µSD card acting as Solid State Disk, up to 64 GB.
- Eight analog pins: 12-bit ADC or 12-bit DAC each.
- Optional Real Time Clock with battery backup.



Two Markets: Research DAQ & Small DAQ

Our digitizers are using **MicroBone Linux SBC** and **three different FPGA families** to optimize their cost to performance balance. The left column is for research DAQ. The right column is for small applications.

High density digitizer: **40 channels**
Kintex-7
Ethernet readout @ a few MB/s



High density digitizer: **32 channels**
Kintex-7
1G Ethernet at wire speed
10G under development

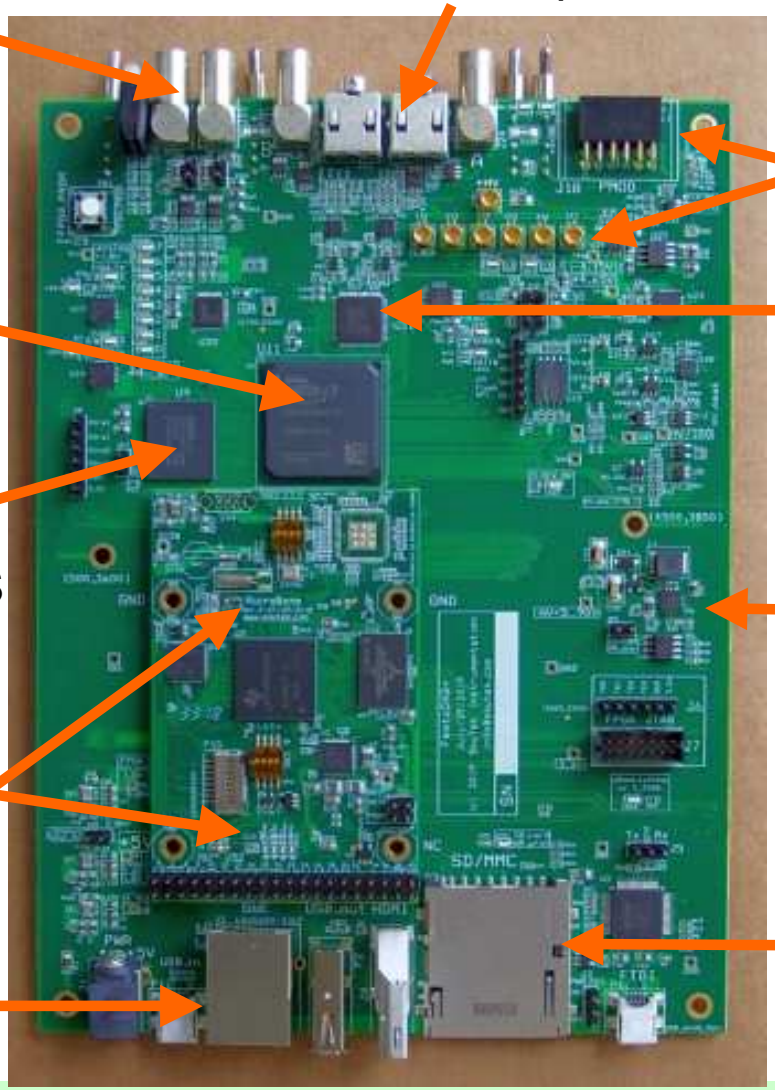
It was presented yesterday.

Mid density digitizer: **10 channels**
Spartan-6, remote Web interface

Low density digitizer: **2 channels**
Artix-7, remote Web interface

New FemtoDAQ+ With Artix-7

- Replace the BeagleBone with the MicroBone developed by SkuTek.
- Increase the waveform memory from 64 kB to 2 MB. (Waveforms up to 500 ms @ 100 MSPS.)
- Upgrade Spartan-6 to Artix-7 providing more resources and better performance.



New FemtoDAQ+ With Artix-7

- The prototypes are ready to go!
- We are now working on the remote Web GUI (next section).

80 µs waveforms → Half a second waveforms

Previous FemtoDAQ with BeagleBone

SiPM bias generator
+5V to +90V
in 1.4 mV steps

Logic I/O
coax

Two outputs:
arbitrary wave
generators

Logic I/O, 8 pins
Arranged as PMOD

Two inputs: 50Ω, 1kΩ, 10kΩ
14 or 16 bits, 100 MSPS

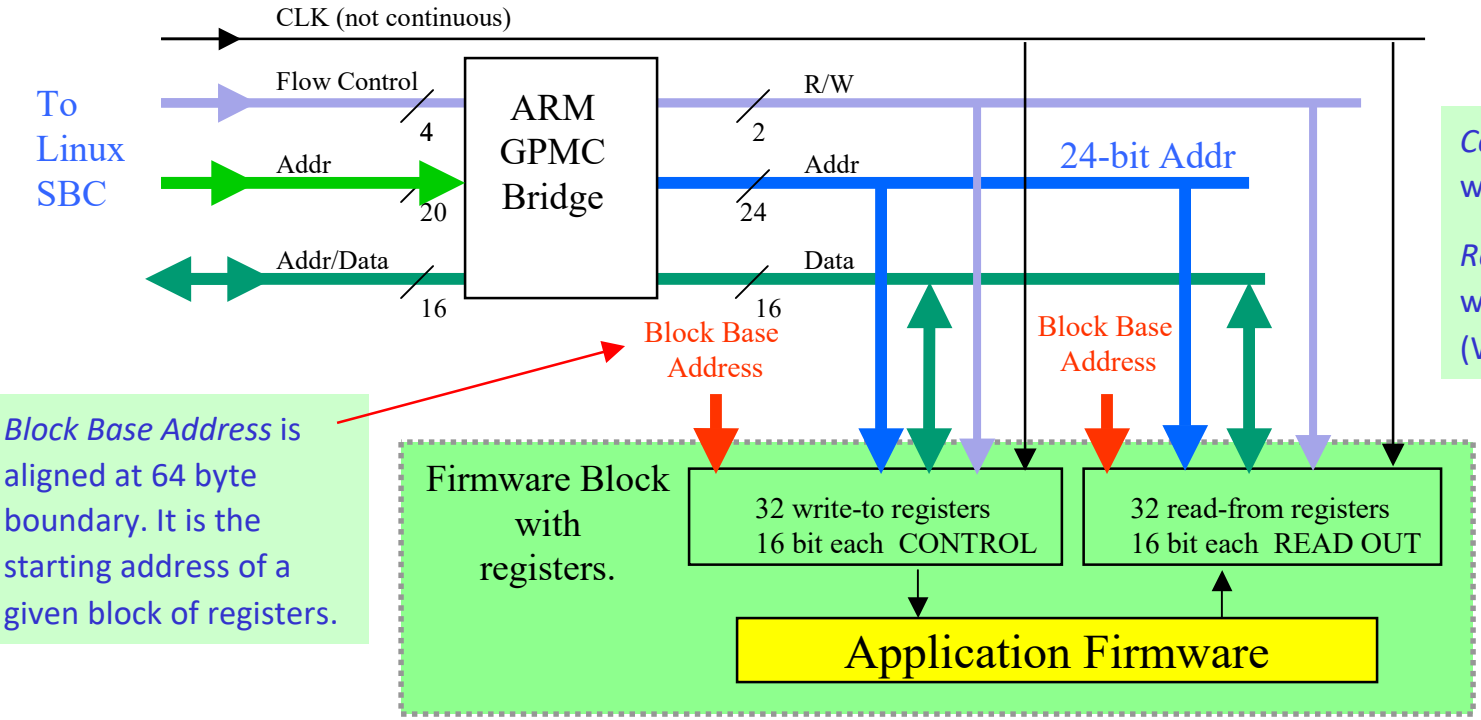
Firmware and Software Progress

Firmware Interface With the Linux SBC

We organize the FW and SW into the *Features* offered by the instrument to the user.

The ***Instrument Feature*** consists of Application Logic, the register interface, SBC software, and remote control.

- Internally in the FPGA, the *Feature* is a Firmware Module with Registers for control and read out.
- Registers have addresses in the Linux memory space.
- The Base Address defines where the registers start in the Linux memory space.
- The *Feature* is interfaced to Linux SBC using the ARM General Purpose Memory Controller (GPMC).
- GPMC is a memory bus between the SBC and the FPGA.



Block Base Address is aligned at 64 byte boundary. It is the starting address of a given block of registers.

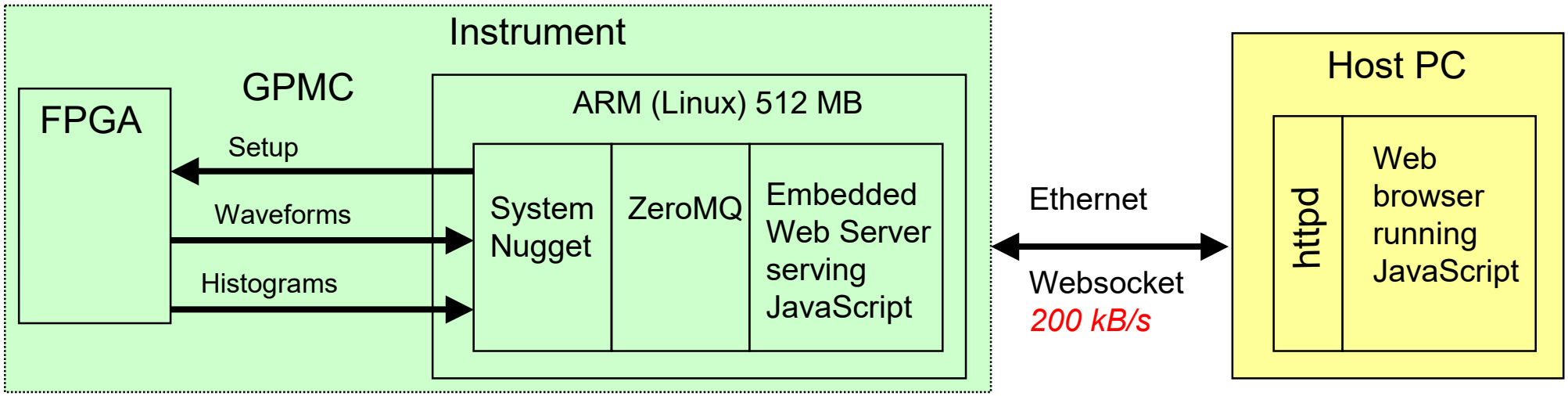
Control: The Write Register which can also be read back.

Read out: The Read Register which cannot be written into. (Writing to it has no effect.)

Block Diagram of the Control Software

The software runs half / half on the Linux SBC and on the remote host PC.

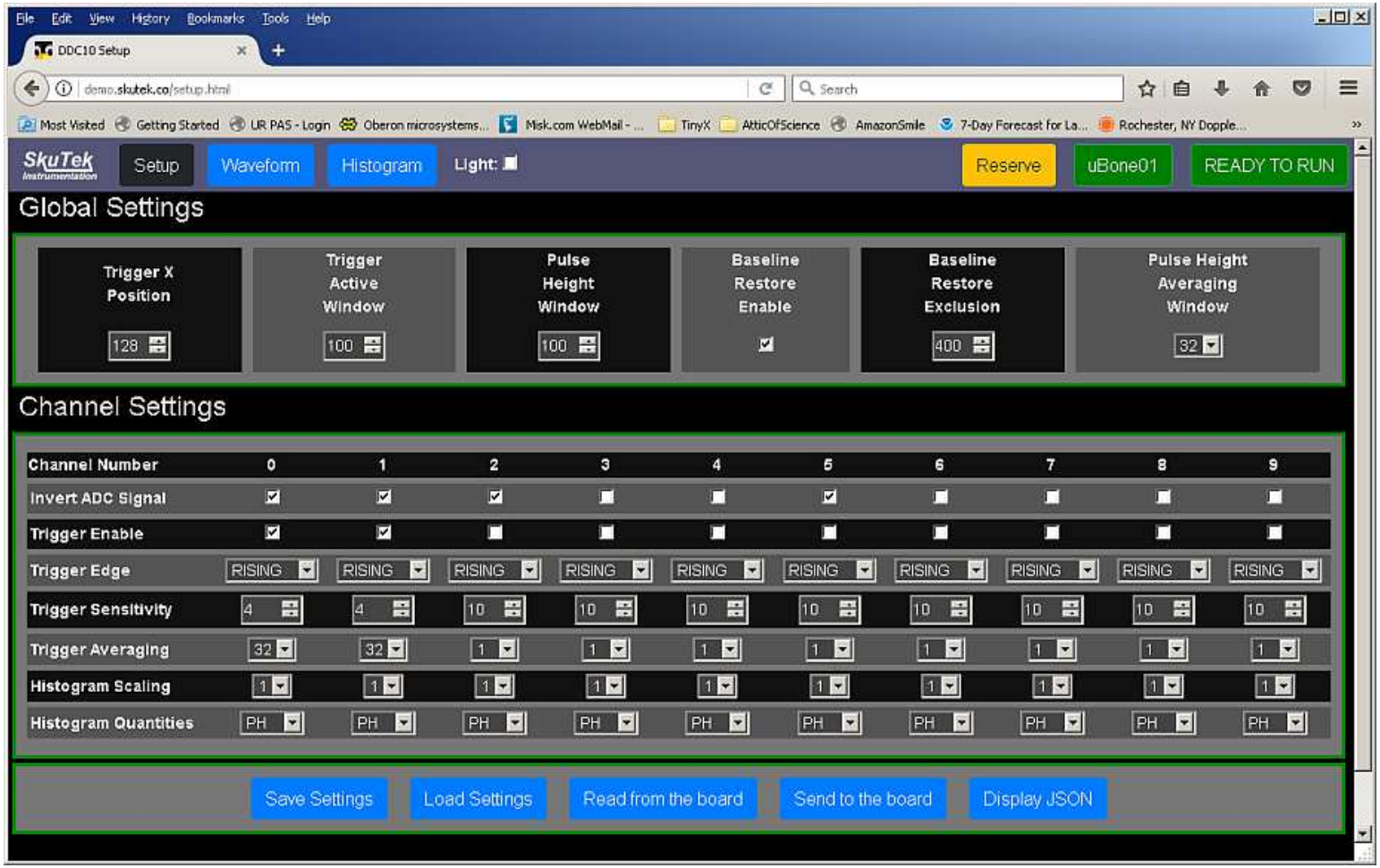
- System Nugget is driving the interface. It is written in C (*about 3,000 lines total*).
- ZeroMQ server communicates between the Nugget and the Embedded Web Server.
  - *ZeroMQ provides reliable inter-process point-to-point communication*.
- Embedded Web Server is serving the JavaScript to the remote browser (*also about 3000 lines*).
- It also sends out the waveforms and the histograms.
- The browser executes the JavaScript and presents the plots to the user.
- The transfer works at ~ 200 kB/s, sufficient for remote display and recording a sample event stream.
- Higher speed ~ 10 MB/s is available while writing to the local SD card or to the NFS mounted disk.



DDC-10 Setup Web Screen

Setting up the *Feature* parameters such as trigger thresholds, energy integration, etc.

- The parameters are written into the *Feature* registers.
- The parameters are passed from this remote host GUI to the SBC, using JSON protocol.
- The setup can be saved to disk.



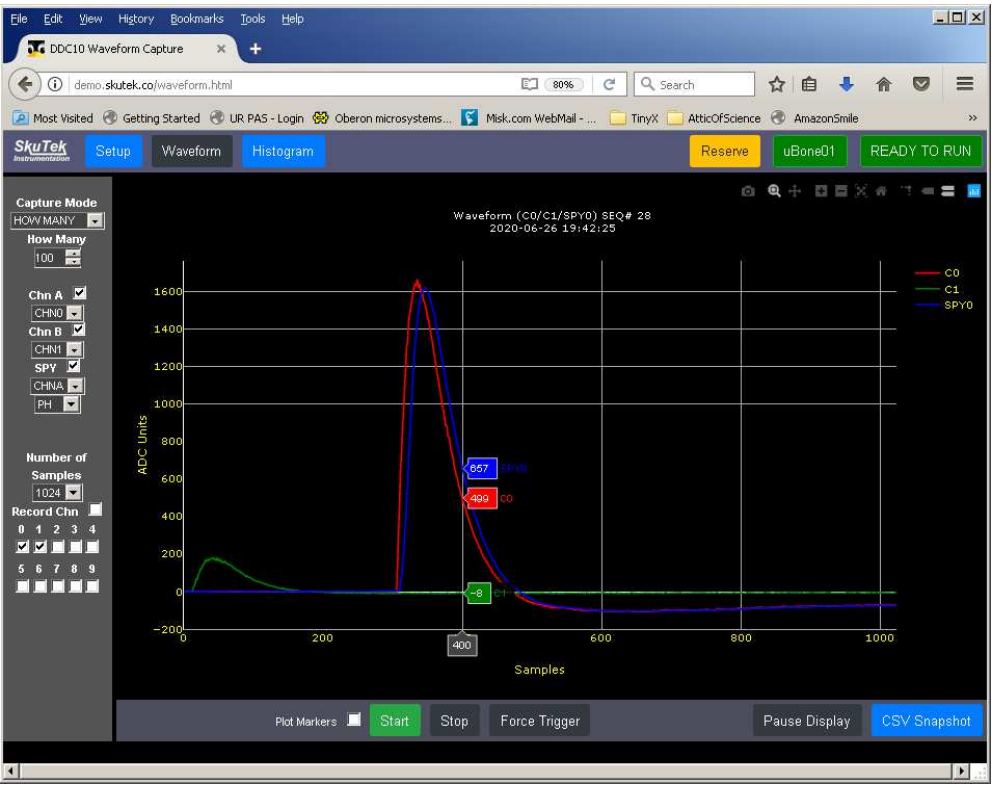
Web Setup Implementation with JSON

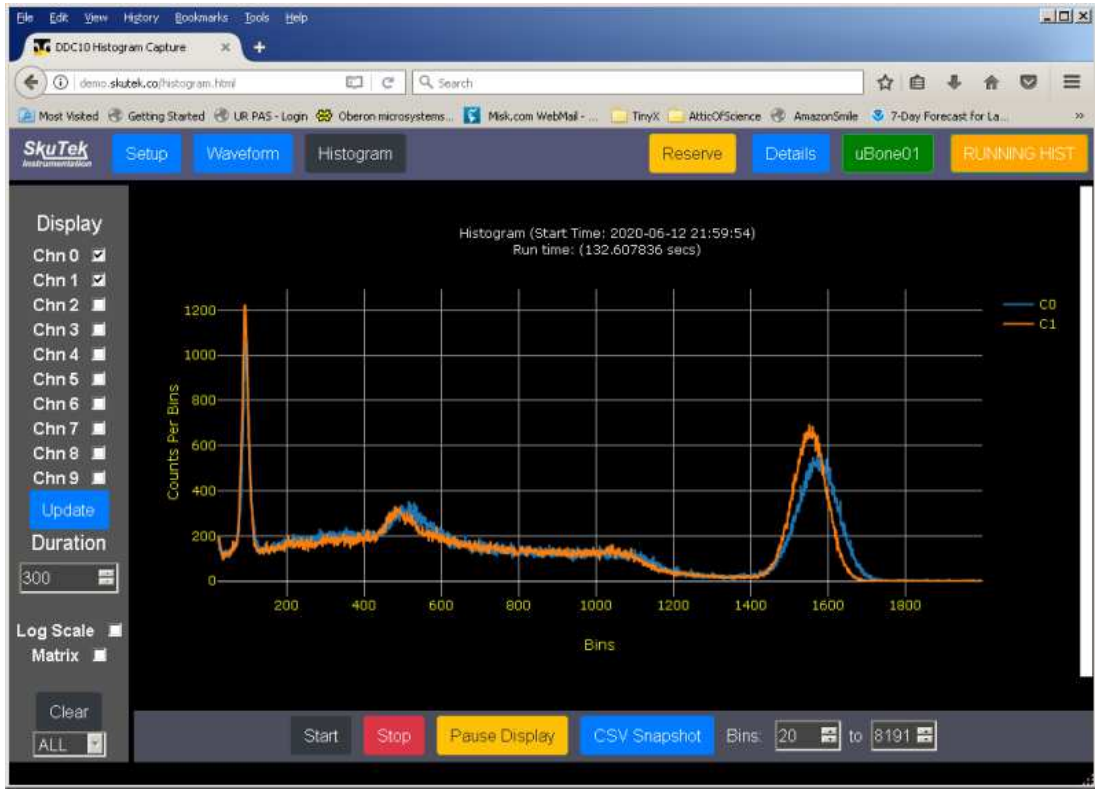
JSON Protocol is used in this scripted web GUI.

- JSON is plain ASCII text which is parsed by the SBC.
- It does not have to come from a web browser.
- Other applications can send JSON.
- JSON is well structured.
- JSON can be understood by humans.
- Other protocols can be implemented as well:
  - Plain HTTP.
  - Direct calls of Python functions under Jupyter.
  - Direct calls of Python functions under RPyC.
  - Python scripts executed at command prompt.
  - Command line calls of C utilities.

Remote Web GUI Interface

- The waveform and histogram displays can be shown in any browser, any operating system.
- One can even use a cell phone. Not really encouraged, but it works.
- The GUI does **not** require any software installation on the remote host. It runs in the browser.
- Multiple users can connect to the same instrument.
- We use a “virtual sticky note” to warn against access conflicts.

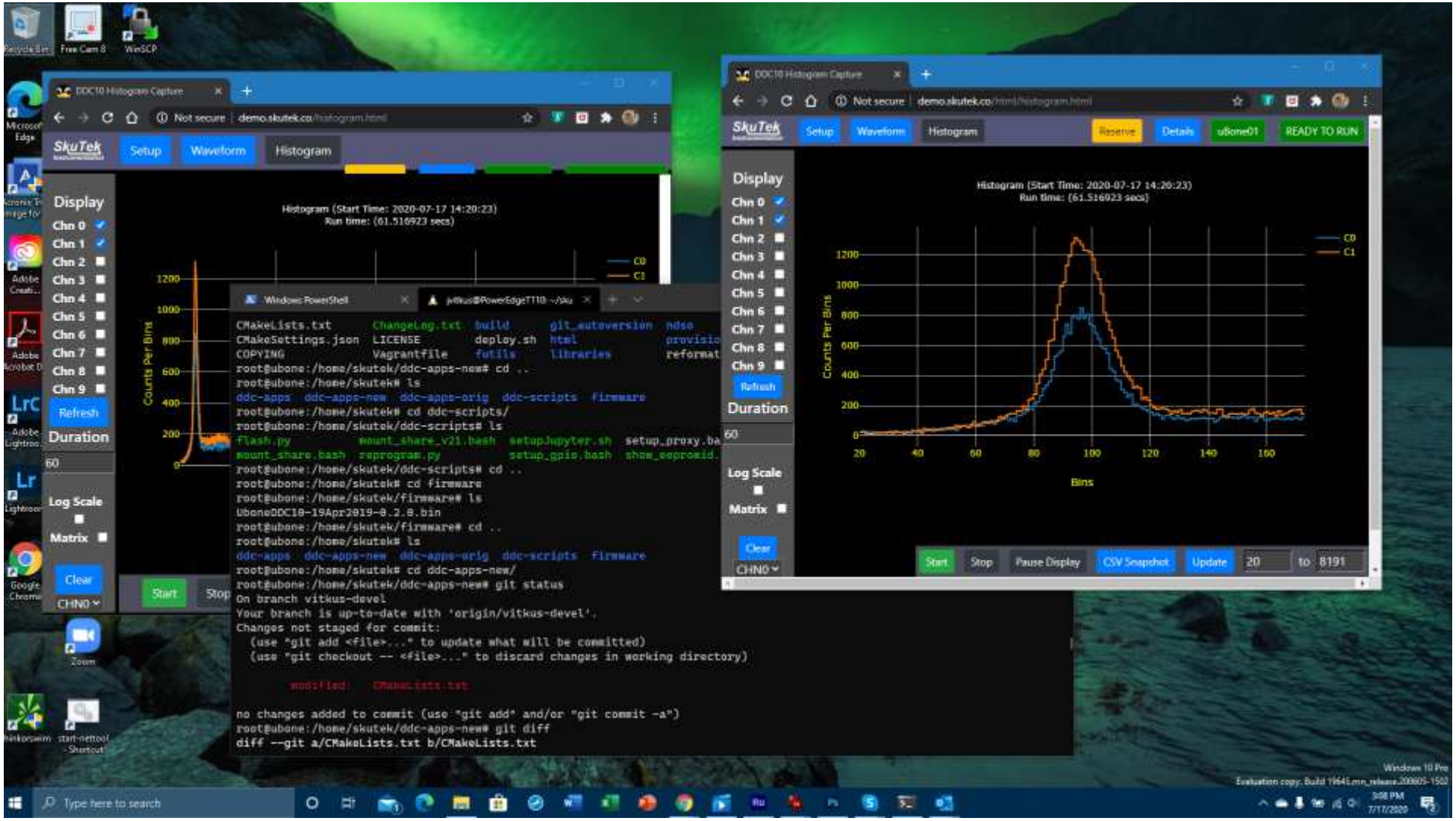




Remote Web GUI Interface

The multiple histogram display is shown in multiple browsers under Windows 10.

The SSH terminal can be used for diagnostic, copying the files, mounting NFS volumes, etc.



Summary

SkuTek Instrumentation

Summary of Technical Achievements

- Hardware:
  - We added a new FemtoDAQ+ to our digitizer family.
  - FemtoDAQ+ will offer significantly better performance than the previous FemtoDAQ.
  - All our products will uniformly use the same MicroBone SBC for setup and control.
- Firmware:
  - We developed a unified approach to organizing the firmware around Instrument Features.
  - A Feature consists of the Application Firmware, Register Interface, Software Driver, and UI.
  - The Register Interface will use the General Purpose Memory Controller of the AM5338 chip.
    - Adoption of the GPMC was one of the main motivations for developing the FemtoDAQ+.
- Software:
  - We adopted a unified web-based JavaScript technology for instrument setup and control.
  - The GUI is portable to any operating system. It can even run on a cell phone.
  - Running the GUI does not require installing any software on the target host.
  - The GUI is using JavaScript which can run in any browser.
  - GUI can setup the instrument and save the configuration.
  - Light weight experiments can be performed under the new GUI with storage of data to disk.
  - Regular event files can be written to the SD card or to NFS mounted disk.

Future Plans

- Continue development of firmware and software for our digitizers.
- Adopt the new web-based technology in all our products.

Highlights of The Final Products

- A **family of digitizers**, from 2 up to 40 channels per unit, 14 or 16 bits @ 100 MSPS.
  - The versions with 250 MSPS are under development. The boards are assembled.
  - The digitizers with more than 16 channels will stay at 100 MSPS because of power.
- The 32-channel digitizer will be compatible with the GRETA / GRETINA / DGS environment.
  - This project was presented yesterday.
- Other digitizers are targeting small labs, education, and T&M markets.
- Very low noise: RMS about 160 microvolts, that is ~ 1.3 LSB @ 14 bits.
- Setup, monitoring, and diagnostic with on-board **Linux** Single Board Computer (SBC).
  - SBC can also perform **readout** at the rate ~ a few megabytes per second.
  - SBC can write **formatted event files** directly to NFS mounted disks.
  - SBC can monitor the detector signals with **low latency** in near **real time**.
  - SBC can show an **interactive display** of waveforms and histograms **in any browser**.
- A **variety of options** for the control software and GUI to be executed by the Linux SBC.
  - SSH, command line, Python, Jupyter, and Remote Python Call (RPyC).
  - JavaScript GUI compatible with any browser, any host platform (even a cell phone).

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