And now for something completely different...

Internet of Things
RF and Instrumentation Platform at Max-IV

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Max-IV RF Group

A little background

- Ph.D in superconducting RF devices from UW-Madison in 1987
- Worked at Fermilab for 23 years
  - Mostly on antiproton stochastic cooling systems (1-8 GHz)
  - Beam damping and stabilization systems
  - Instrument scientist for the 21 cm BAO Cylindrical Radio telescope
- Worked at ESS for 7 years
  - RF Group leader
  - Chief engineer
- Started at MaxIV in 2018
  - As RF group leader
  - Quicky demoted to RF engineer in 1 year (a new record for me)

Why is an RF Engineer Talking about IoT?

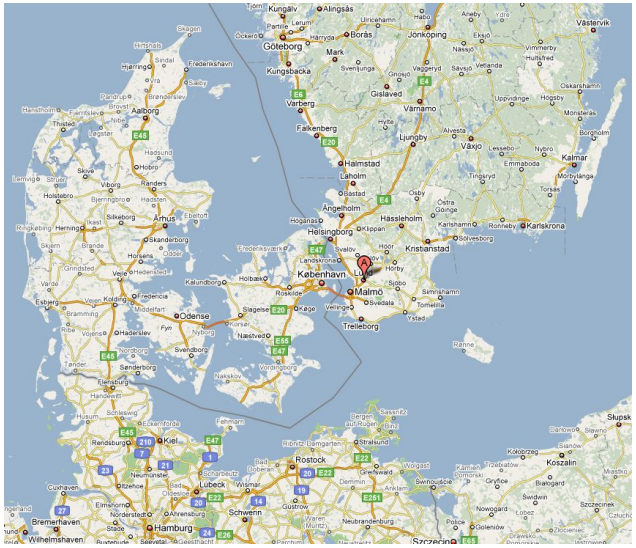
- Most innovations come from skunk works
  - That is, rarely do good ideas come from management
  - They come from engineers working in the lab
- When an engineer comes up with a new idea
  - He is not sure it will work
  - He needs to try things out but he needs help
- Controls both hardware and software are an ***integral parts*** of an RF system
  - But often approached as an afterthought
  - Leading to systems that are difficult to commission and operate

An IoT Control Platform for Skunk Works

- To assist me quickly work through my crazy ideas in the lab,
  - I developed an IoT control platform
  - in which a project could grow in complexity
  - and gradually be implemented into operations
- Why not just use Labview?
  - Don't get me started…
- Why IoT?
  - Most accelerator RF systems have low bandwidth dictated by the synchrotron frequency - no need for GHz digitizers and giant FPGA's
  - With IoT, you can get cheap high performance devices quickly so you are not waiting on the folks in the procurement department
- Why wireless?
  - Try getting the Controls department to pull ethernet cables to a remote service building (or even the tunnel) when you have no priority
    - especially when you are not sure how many cables you will need
    - or if your idea will work
- Why Web based?
  - Imagine an engineer lying on his belly in service building with a tweeky tool adjusting a system and having to go to the control room to change a parameter
  - COVID 19 - Shared computers in control rooms should be a thing of the past

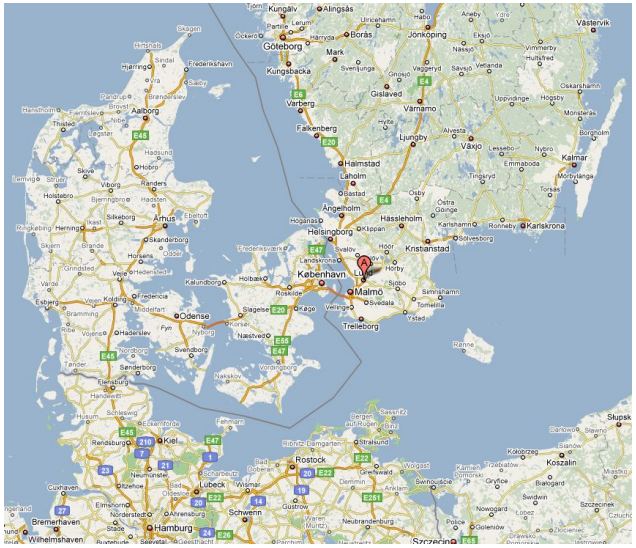
Case Study: Mode 0 Damper at MaxIV

- MaxIV is a 3 GeV synchrotron light source operating at an RF frequency of 100 MHz with enough installed power for over 250 mA of beam current.
- MaxIV is designed to operate in the long bunch mode (bunch lengths > 500 ps rms) using passive third harmonic Landau cavities.



Case Study: Mode 0 Damper at MaxIV

- MaxIV is a small lab (~ 200 people) with limited human and financial resources.
  - Delay in beamline construction has absorbed the most of the control system resources.
  - There are limited software and IT resources available. (Please take out a ticket…)
- Limited technical resources.
  - Engineers design and build their own electronics boards.
  - ***There are no technicians in the RF Group***
- Limited financial resources.



Case Study: Mode 0 Damper at MaxIV

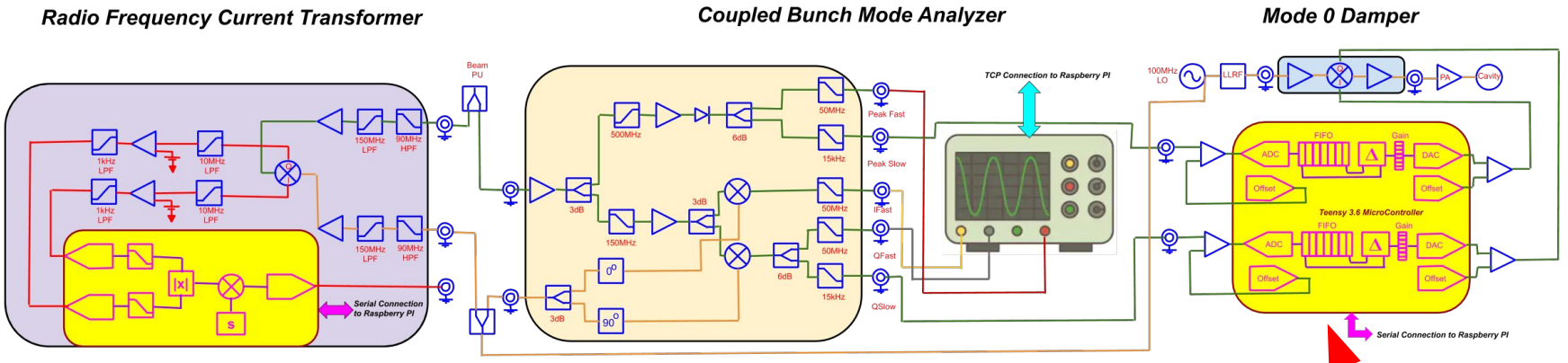
- As of April 2018, it was not possible to operate in long bunch mode past 120 mA because of longitudinal instabilities.
  - MaxIV does possess a longitudinal bunch-by-bunch feedback system but the system was not effective in the long bunch mode.
- It was surmised that the longitudinal instability was a dipole mode 0 coupled bunch mode instability but there were no diagnostics to prove this assertion.

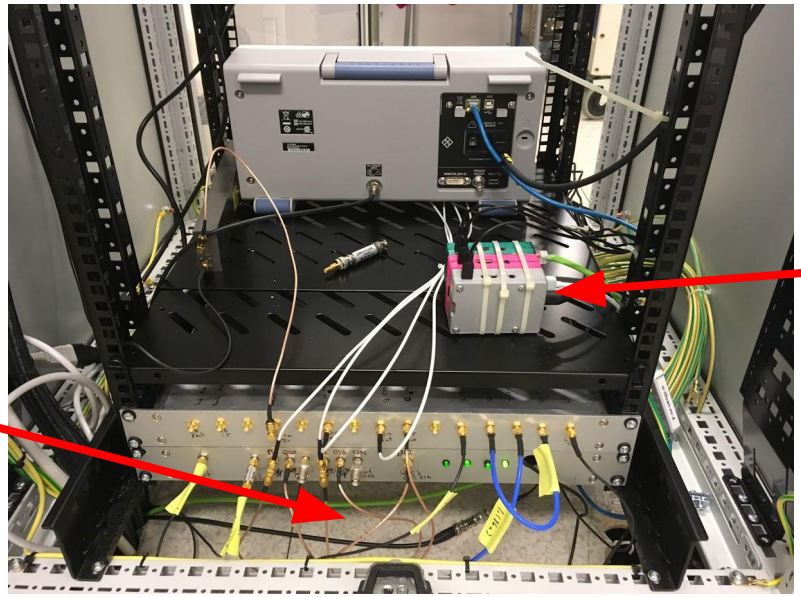
Case Study: Mode 0 Damper at MaxIV

We needed something:

- Quickly
  - using standard off-the shelf hardware and software components
- Easy to install
  - minimal cable plant,
  - minimal rack space,
  - low power,
  - minimal reliance on software and hardware experts
- Cheap
- Reliable
- Remotely configurable but secure

The RF Hardware



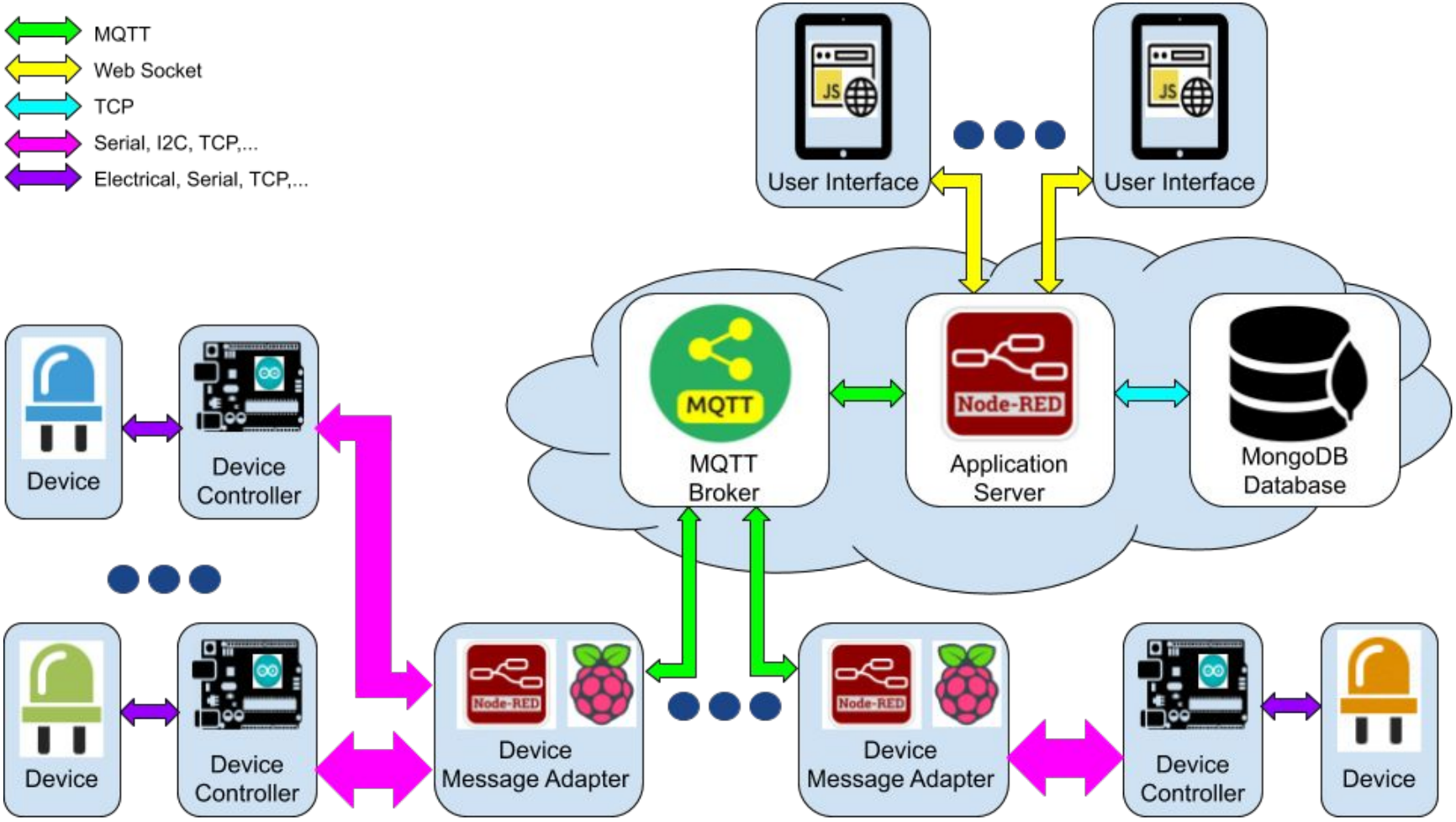


Oh no!
Teensy Microcontroller!

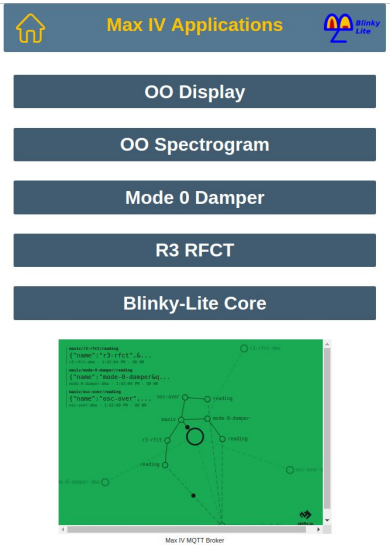
Oh no!
Raspberry Pi's!

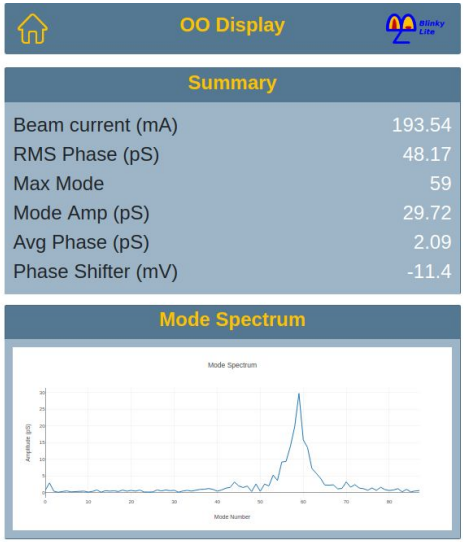
Could really use a skilled technician here

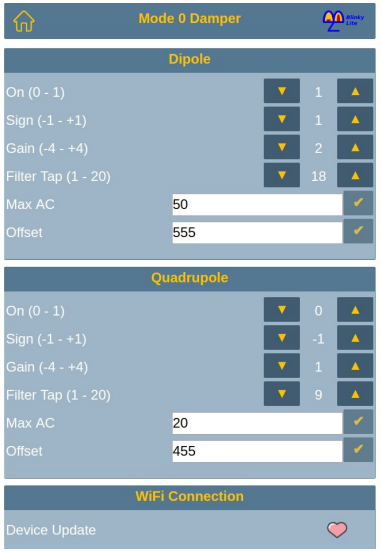
System Architecture

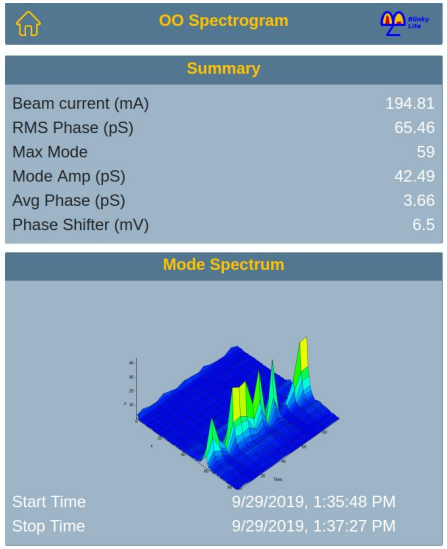


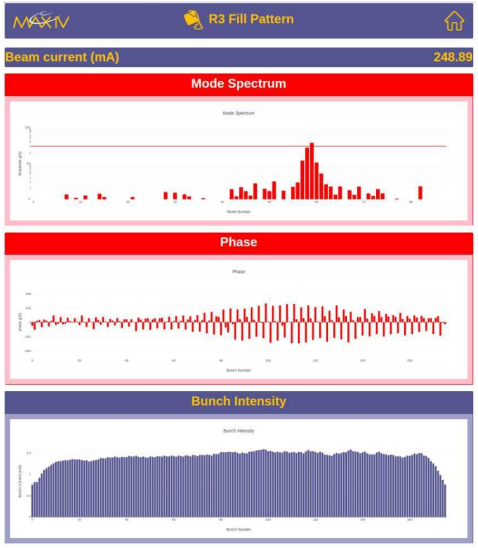
Mode 0 Web Software

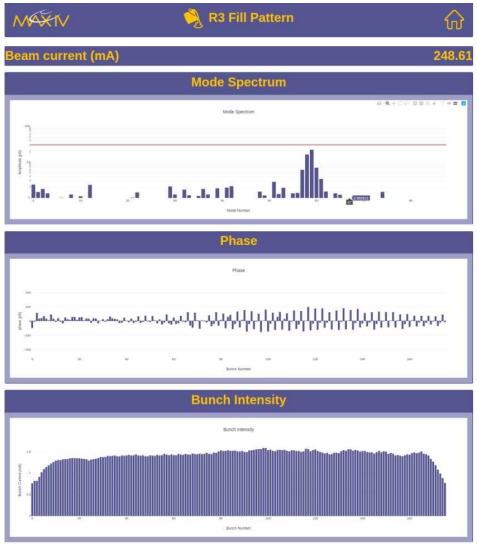


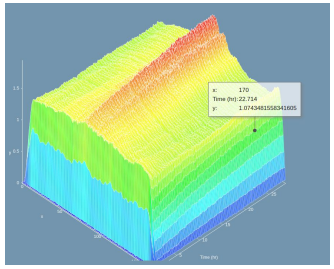


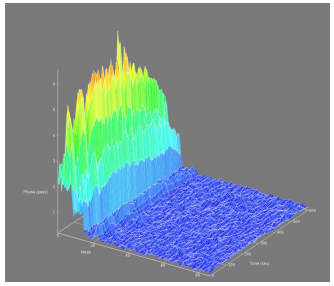


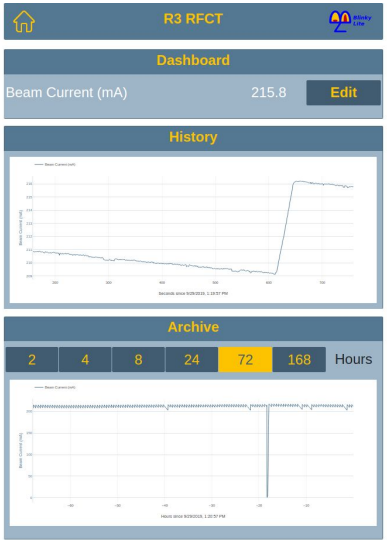






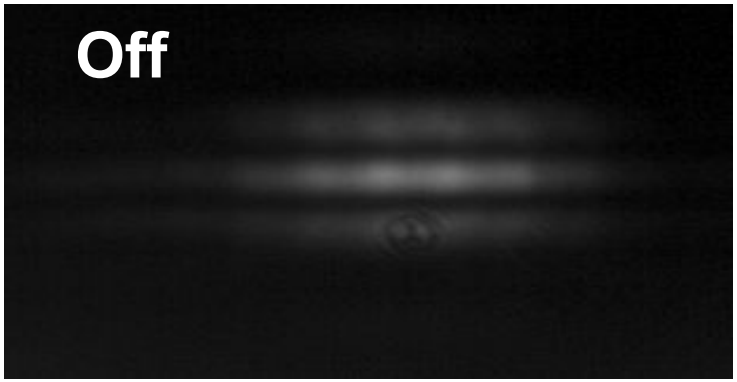


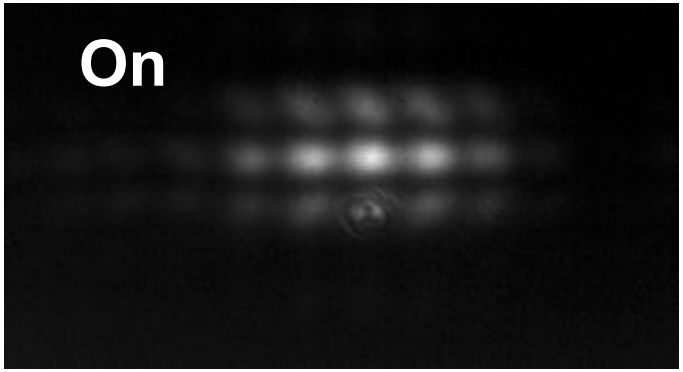


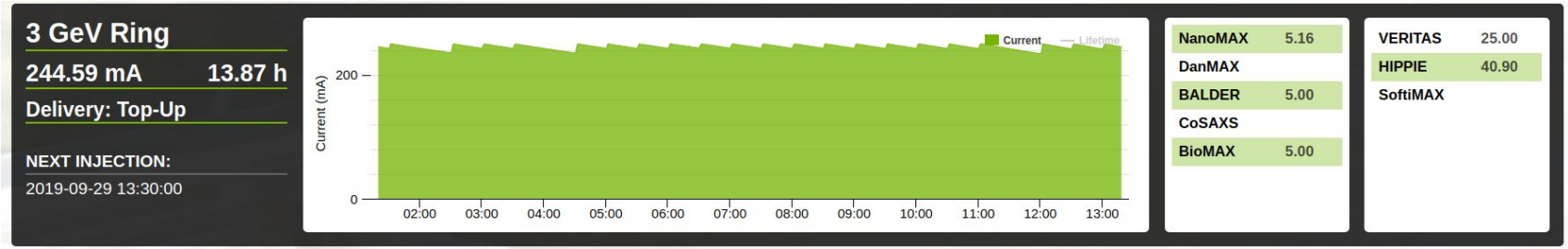


The Results

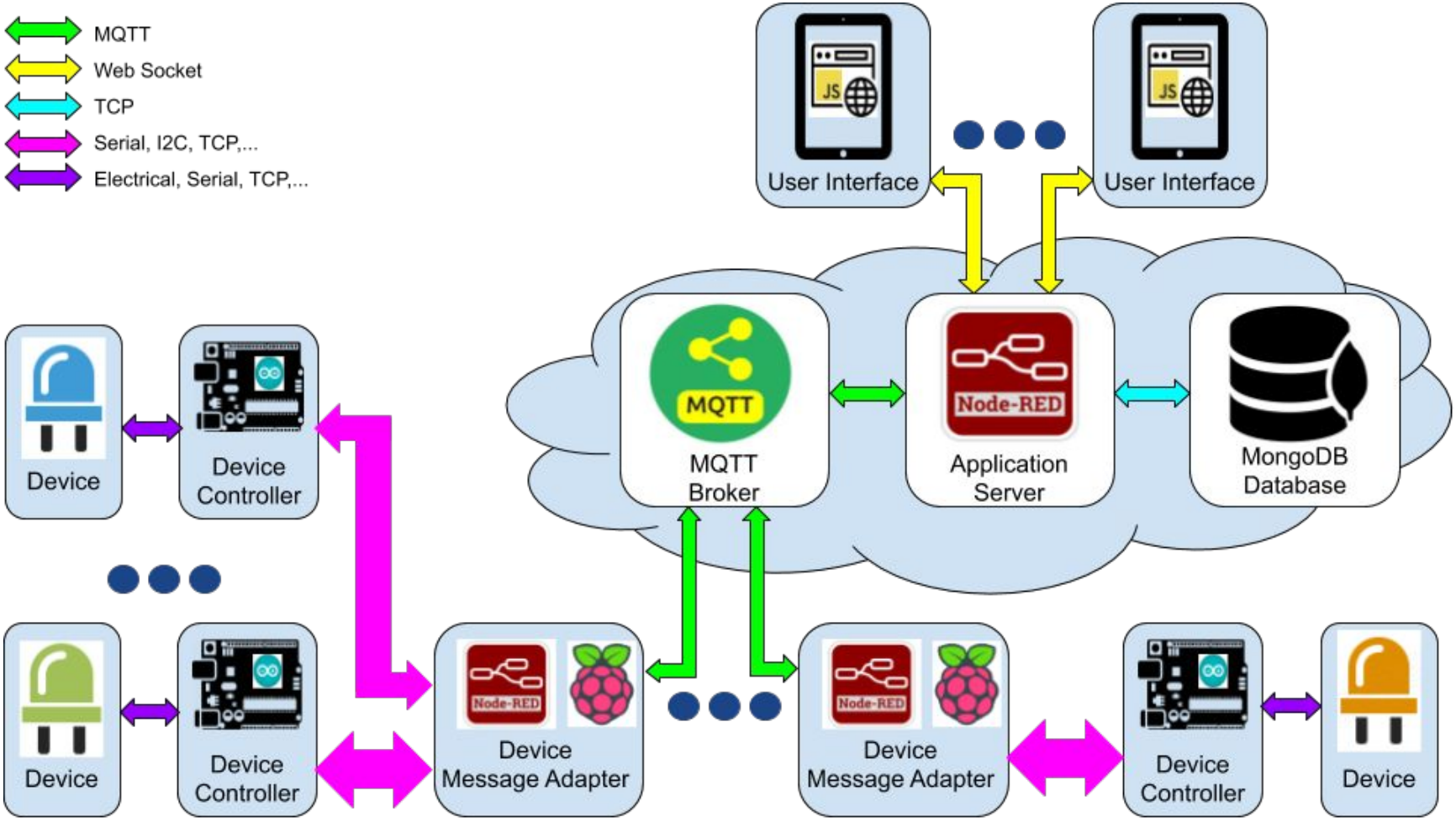
- I begun working at MaxIV in April 2018
- In June 2018, the coupled bunch mode analyzer was commissioned and Mode 0 instability identified.
- In September 2018, the Mode 0 damper commissioned
- In October 2018, long bunch operation at 250mA at MaxIV was put into routine operations
- As of Nov 2020, there have been no failures with the Mode 0 system





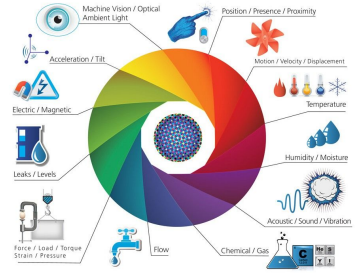


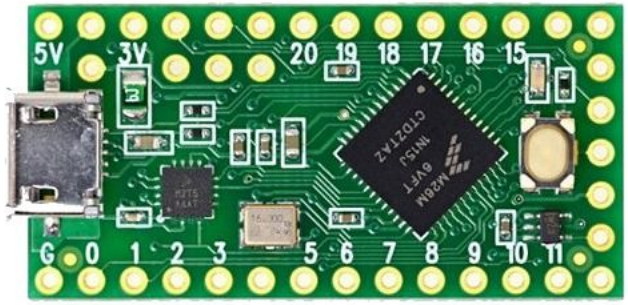
My IoT Architecture



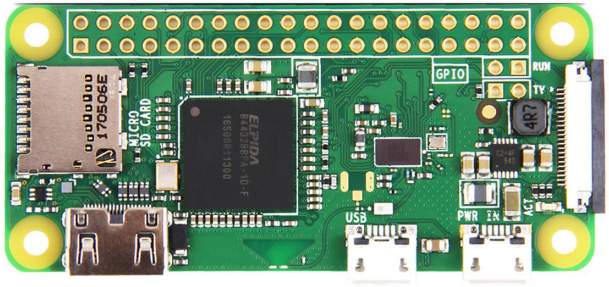
IoT Components

- Device
  - Plethora of IoT sensors and actuators
- Device Controller
  - Interfaces directly with device sensor and/or actuator through ADC, PWM, Digital I/O or DAC pins
  - Communicates (serially, I2C,...) to the Device Message Adapter (DMA)
  - Usually programmed using the Arduino IDE
- Device Message Adapter (DMA)
  - Communicates with a number of Device Controllers
  - Concentrates and scales device data
  - Translates data to and from the MQTT broker
  - Programmed in Node.js with the Node-RED programming environment





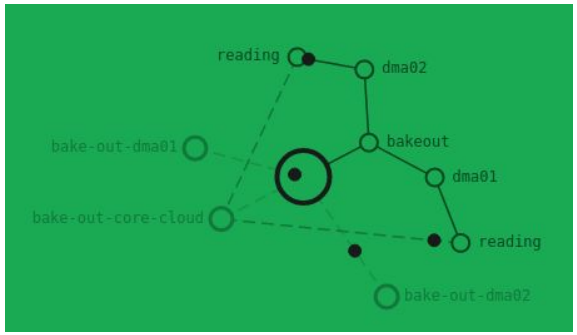
Teensy LC Device Controller

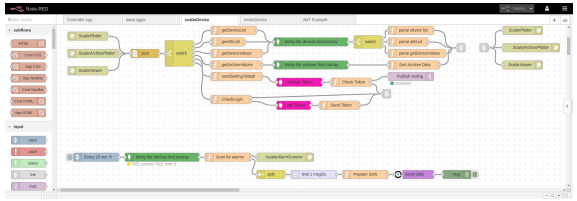


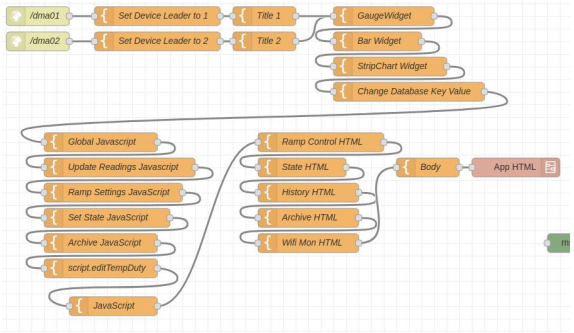
Raspberry Pi Zero DMA

IoT Components

- MQTT Broker
  - *Can be cloud based*
  - Receives and transmits messages to DMA's
  - Receives and transmits messages from to the WAS
- Web Application Server (WAS)
  - *Can be cloud based*
  - Collects and transmits data to DMAs and user applications
  - Archives data to MongoDB database
  - Serves user applications
  - Handles authentication
- MongoDB database
  - *Can be cloud based*
  - Archives data
  - Records are JSON documents
    - matches well with Node.js and Node-RED
    - Non-relational - easy to extend
- User Application
  - Web based for easy deployment
    - mobile first but not mobile only
  - Written in Javascript
  - Communicates to the Web Application server via web-sockets







System Features

- Cloud capable - Cloud deployments give enhanced:
  - Accessibility and deployment capability,
  - Along with enhanced reliability and security (https:// and wss://),
- Layered authentication
  - JSON Web Tokens for client-server transactions
  - Authenticated MQTT broker for server-device transactions
- JSON Device configuration
  - Flexible data types (scalar, vector, text, images, blobs,...)
  - Human readable and configurable
- MQTT and Websocket communication
  - Publish-subscribe instead of polling protocols
- SMS Alarm notification
- Graphical Node-Red code environment
  - Re-usable code
  - Self documentation

System Features

Eight web-based core applications

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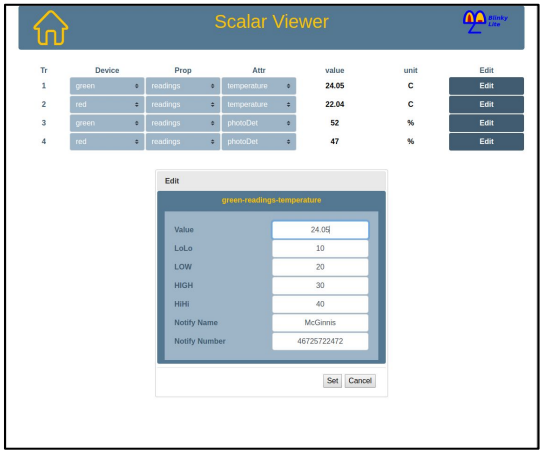

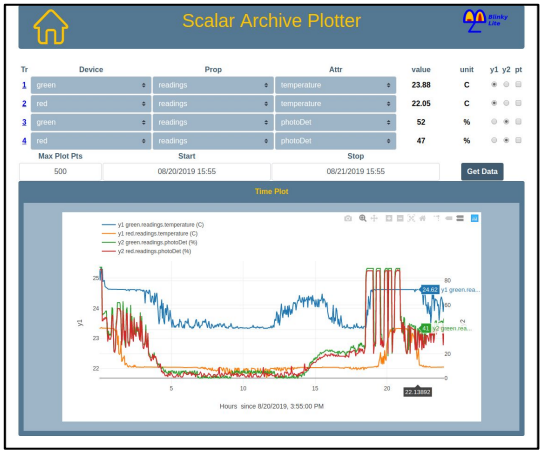

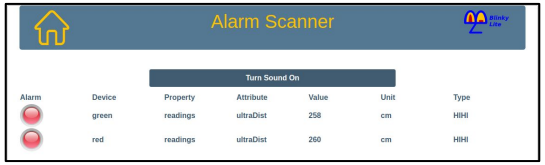

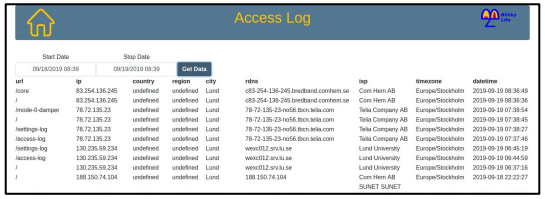

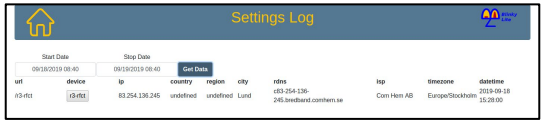

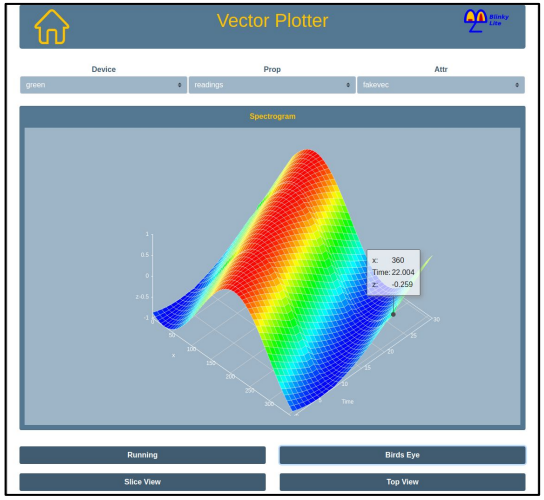

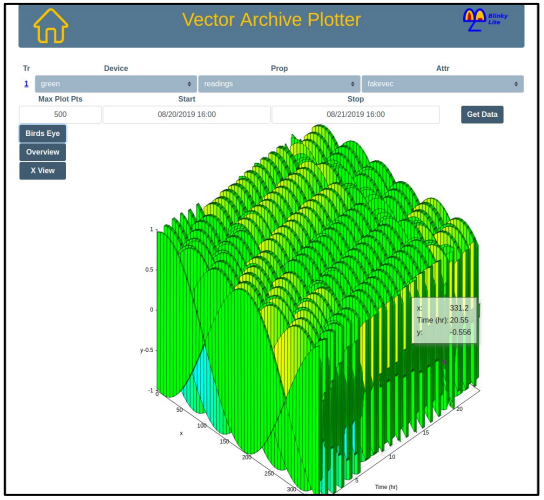

Summary

A skunk works IoT Control Platform made by and for RF Engineers

- **Extremely reliable and robust control**
  - Based on high performance but inexpensive IoT computing placed *close* to the devices to control.
- **Web Accessibility**
  - Applications are web-based giving control from anywhere in the world.
- **Flexibility**
  - Based on open source for easy customization
- **Easy to implement**
  - Designed for non-experts who have beginner knowledge in Javascript.
- **Easy to interface with TANGO and EPICS**
  - Robust RESTful Interface