

And now for something completely different...



Internet of Things RF and Instrumentation Platform at Max-IV

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Max-IV RF Group

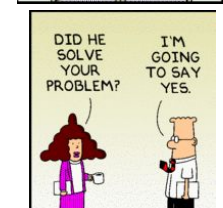
A little background

- 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
 - Quickly 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

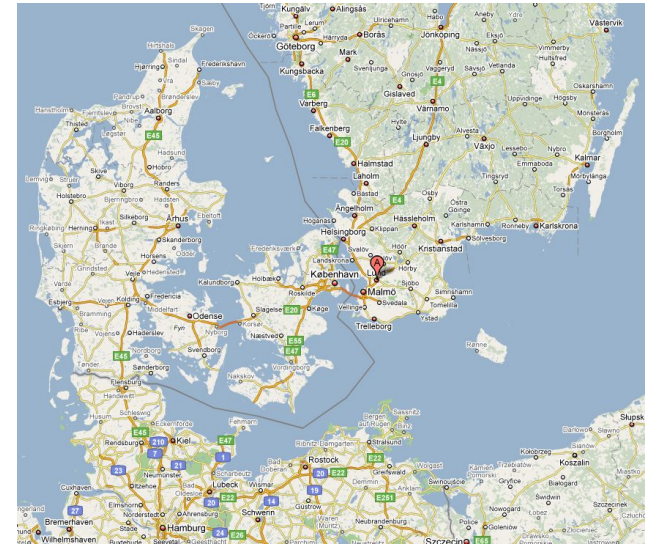


An IoT Control Platform for Skunk Works

- 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

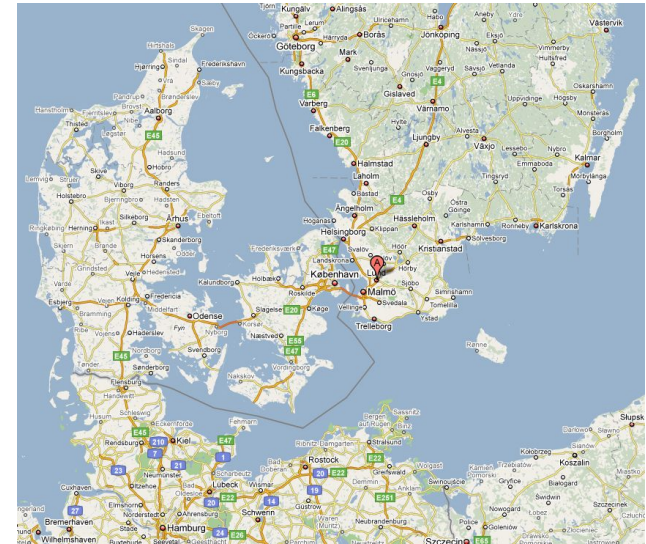
Case Study: Mode 0 Damper at MaxIV

- 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.

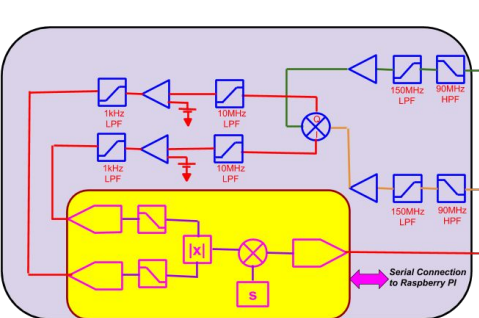
Case Study: Mode 0 Damper at MaxIV

We needed something:

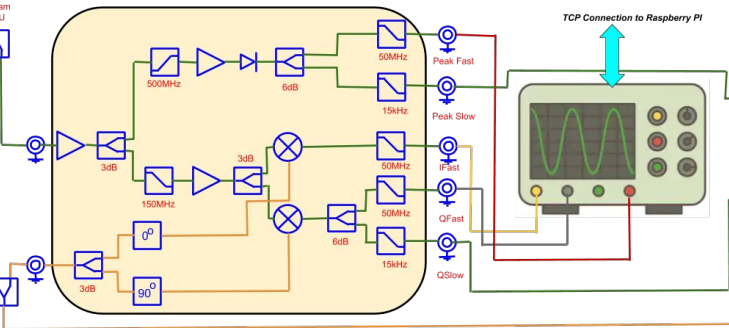
- Quickly
 - using standard off-the shelf hardware and software components
- Easy to install
 - minimal cable plant,
 - minimal rack space,
 - low power,
 - minimal reliance on software and hardware experts
- Cheap
- Reliable
- Remotely configurable but secure

The RF Hardware

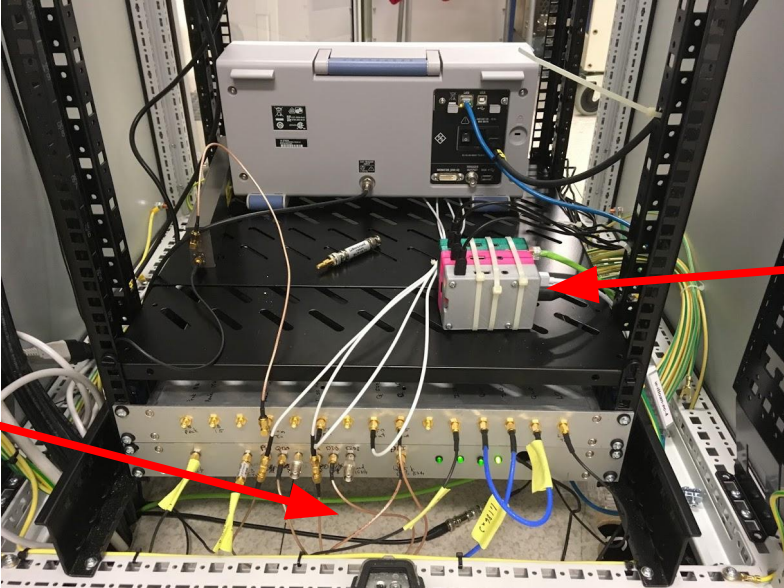
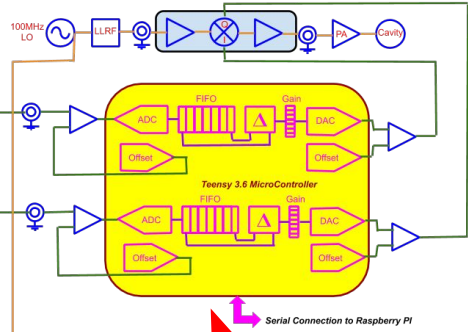
Radio Frequency Current Transformer



Coupled Bunch Mode Analyzer



Mode 0 Damper



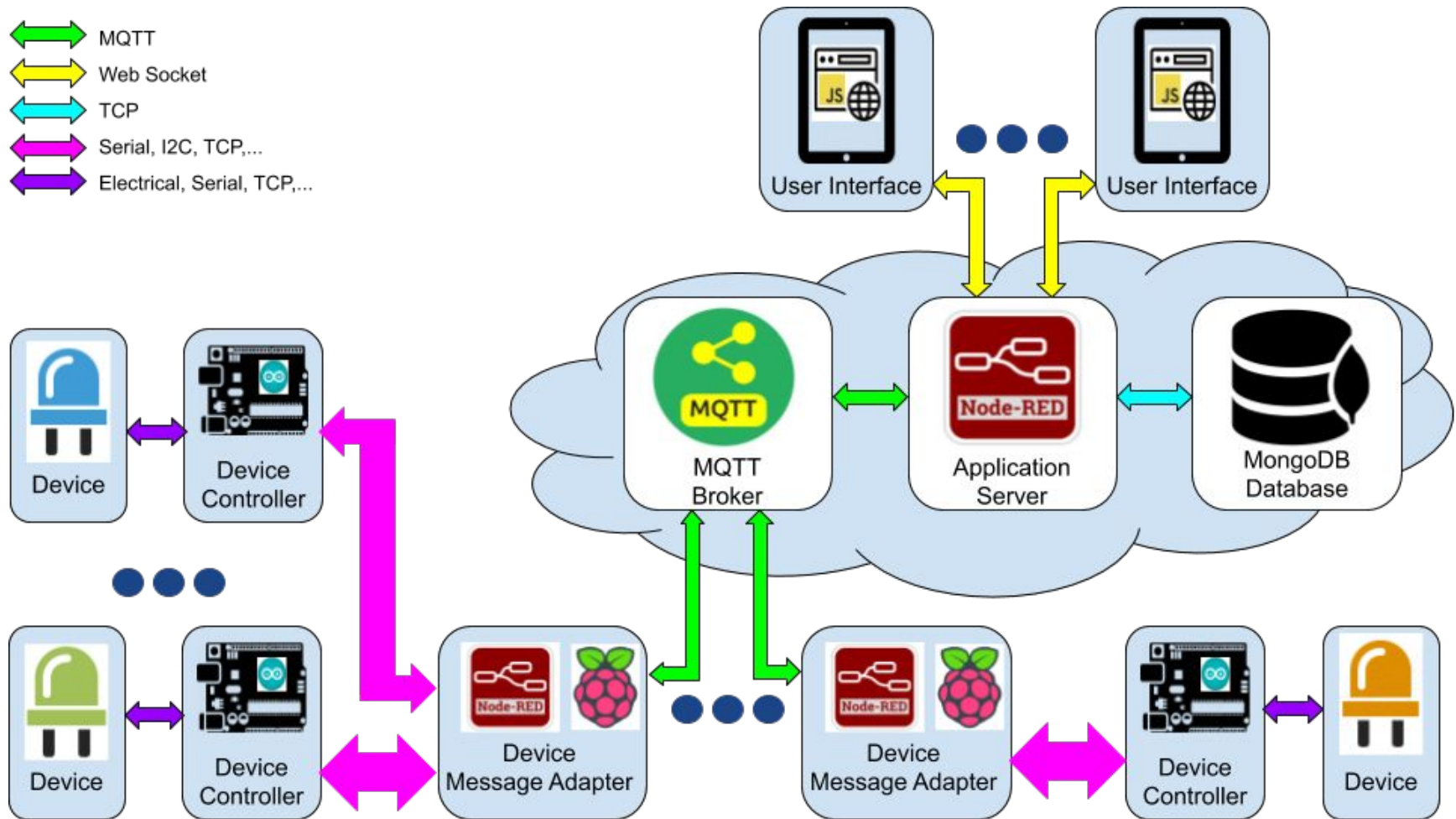
Could really use a skilled technician here

Oh no!
Teensy Microcontroller!


Oh no!
Raspberry Pi's!

System Architecture

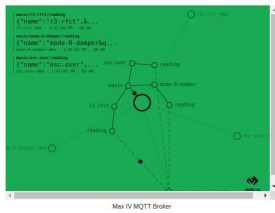
- MQTT
- Web Socket
- TCP
- Serial, I2C, TCP,...
- Electrical, Serial, TCP,...




Mode 0 Web Software

Max IV Applications 

- OO Display
- OO Spectrogram
- Mode 0 Damper
- R3 RFCT
- Blinky-Lite Core




OO Display 

Summary

Beam current (mA)	193.54
RMS Phase (pS)	48.17
Max Mode	59
Mode Amp (pS)	29.72
Avg Phase (pS)	2.09
Phase Shifter (mV)	-11.4

Mode Spectrum

Mode 0 Damper 


Dipole


On (0 - 1)	1
Sign (-1 - +1)	1
Gain (-4 - +4)	2
Filter Tap (1 - 20)	18
Max AC	50
Offset	555

Quadrupole

On (0 - 1)	0
Sign (-1 - +1)	-1
Gain (-4 - +4)	1
Filter Tap (1 - 20)	9
Max AC	20
Offset	455

WiFi Connection

Device Update 


OO Spectrogram 

Summary

Beam current (mA)	194.81
RMS Phase (pS)	65.46
Max Mode	59
Mode Amp (pS)	42.49
Avg Phase (pS)	3.66
Phase Shifter (mV)	6.5

Mode Spectrum

Start Time: 9/29/2019, 1:35:48 PM
Stop Time: 9/29/2019, 1:37:27 PM


MAX IV R3 Fill Pattern 

Beam current (mA) 248.89

Mode Spectrum

Phase

Bunch Intensity

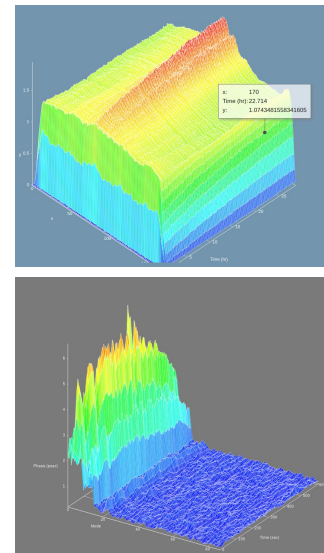
MAX IV R3 Fill Pattern 


Beam current (mA) 248.61

Mode Spectrum

Phase

Bunch Intensity



R3 RFCT 

Dashboard

Beam Current (mA) 215.8 [Edit](#)

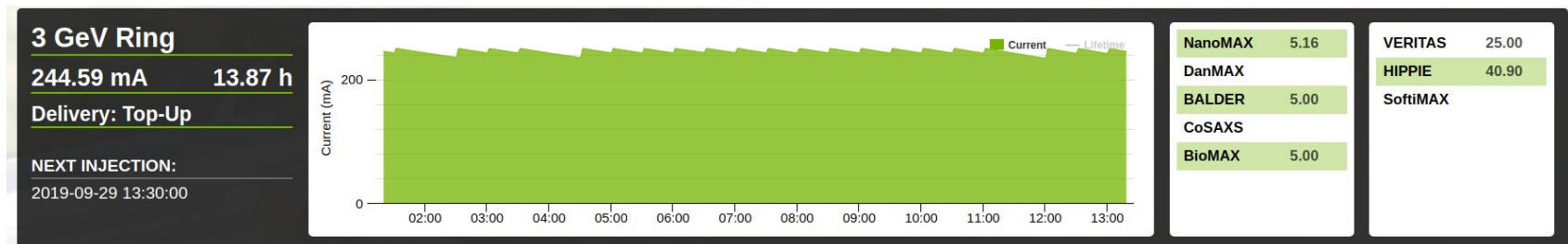
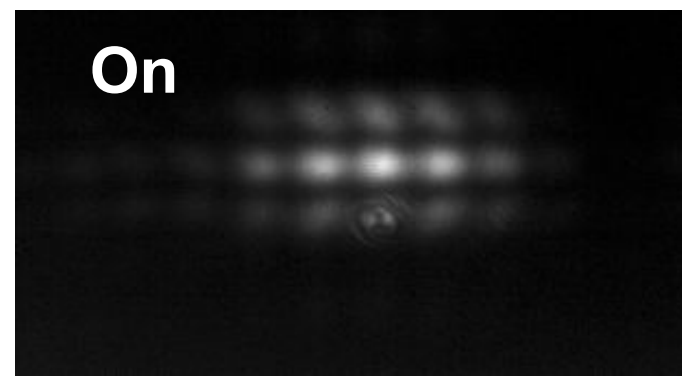
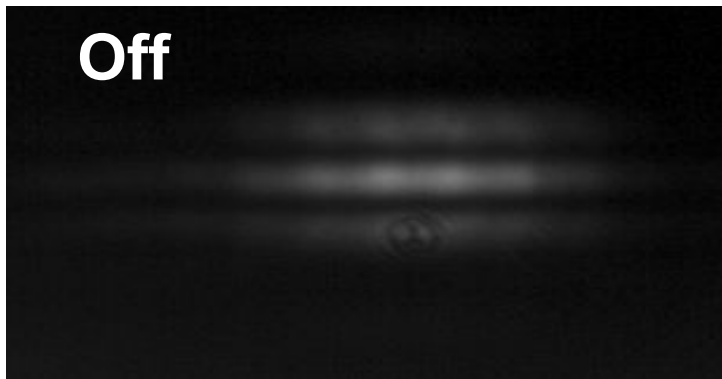
History

Archive

2 4 8 24 72 168 Hours

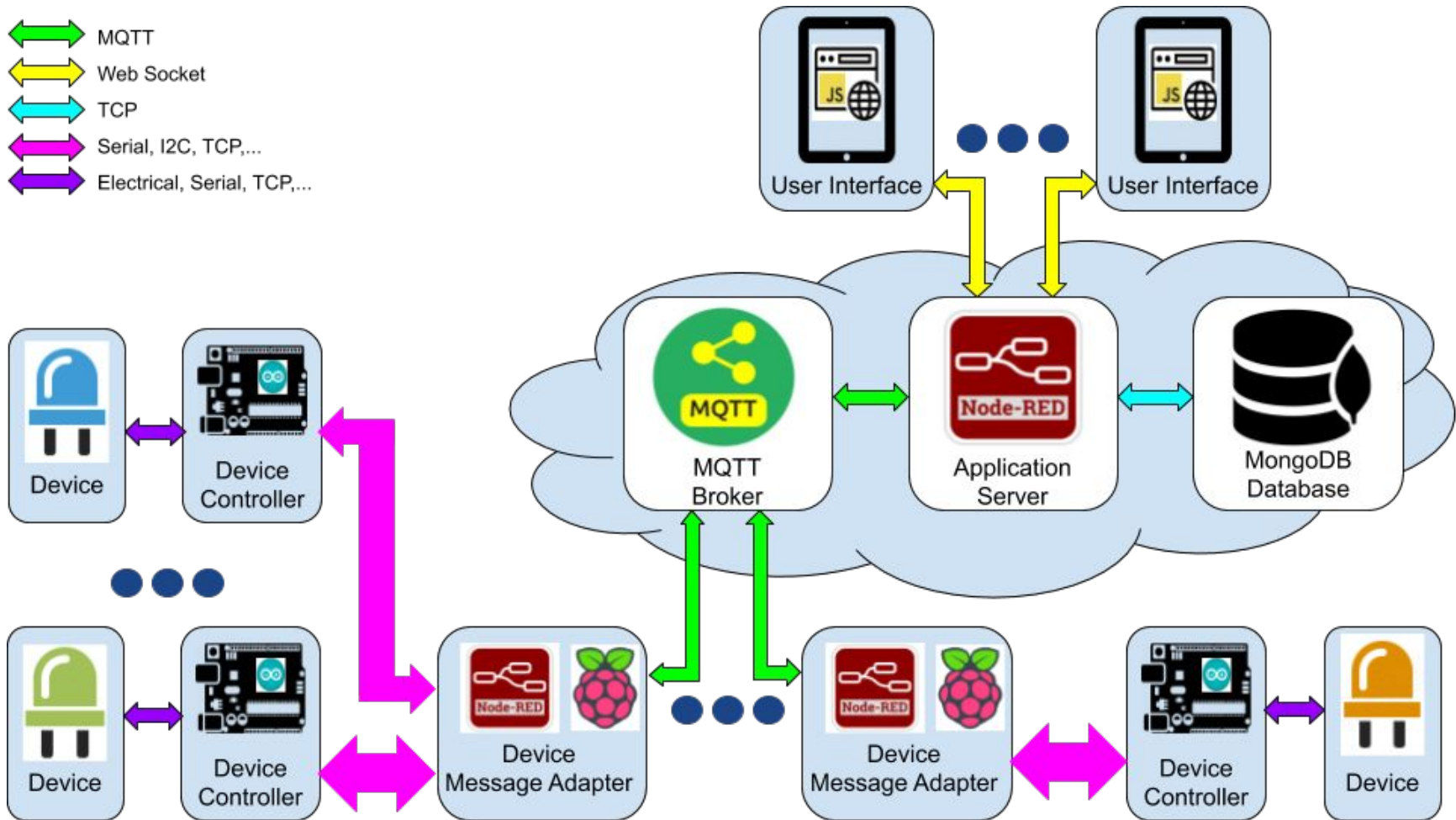
The Results

- 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



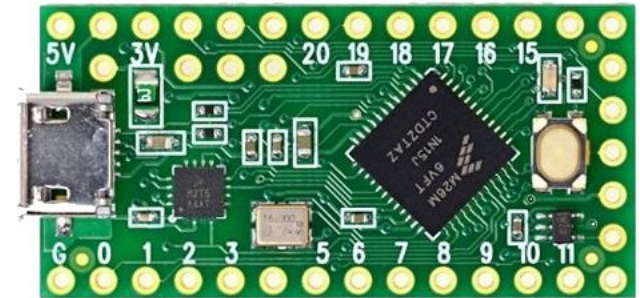
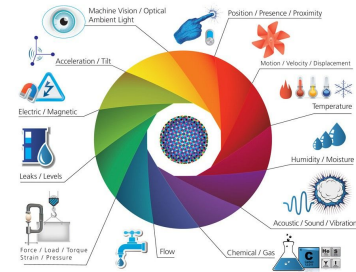
My IoT Architecture

- MQTT
- Web Socket
- TCP
- Serial, I2C, TCP,...
- Electrical, Serial, TCP,...

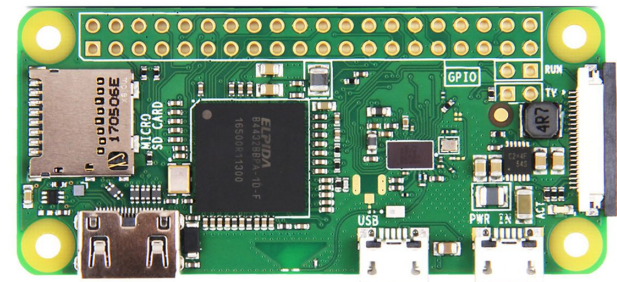


IoT Components

- 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



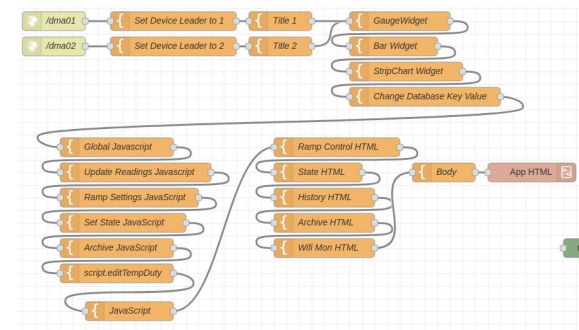
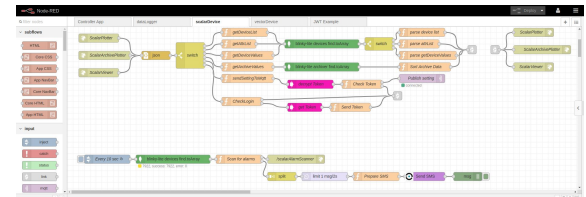
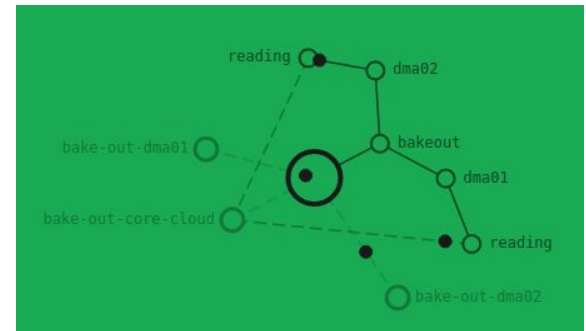
Teensy LC Device Controller



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

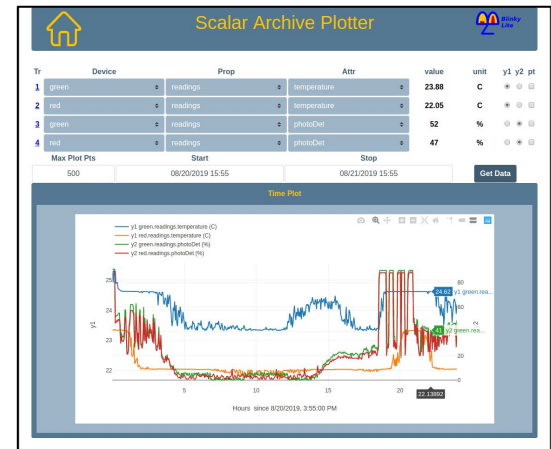


System Features

- 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

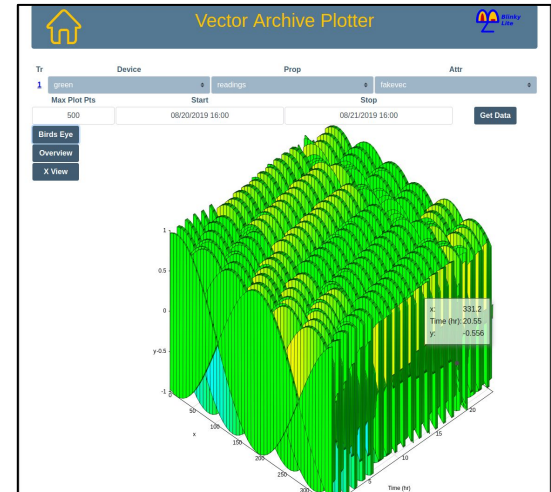
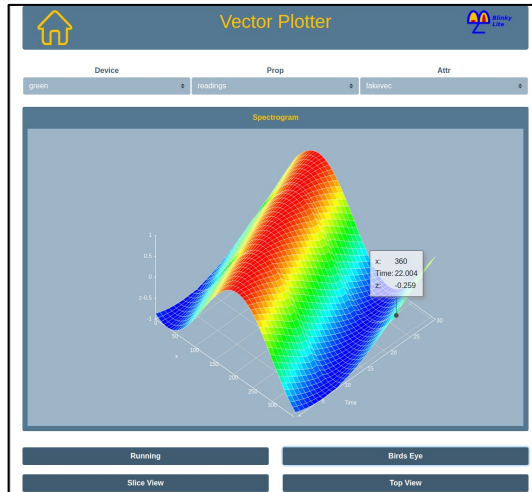
System Features

Eight web-based core applications



Alarm Scanner

Alarm	Device	Property	Attribute	Value	Unit	Type
<input type="radio"/>	green	readings	ultraDist	258	cm	HHH
<input type="radio"/>	red	readings	ultraDist	250	cm	HHH



Access Log

Start Date: 08/18/2019 08:39 | Stop Date: 08/19/2019 08:39 |

url	ip	country	region	city	rds	isp	timezone	datetime
/	83.254.136.245	undefined	undefined	Lund	483-254-136-245.linband.com.hk.as	Com Hem AB	Europe/Stockholm	2019-09-19 08:38:49
/	83.254.136.245	undefined	undefined	Lund	483-254-136-245.linband.com.hk.as	Com Hem AB	Europe/Stockholm	2019-09-19 08:38:56
/node-0-dumper	78.72.135.23	undefined	undefined	Lund	78-72-135-23-red8.boc.wika.com	Telia Company AB	Europe/Stockholm	2019-09-19 07:38:54
/	78.72.135.23	undefined	undefined	Lund	78-72-135-23-red8.boc.wika.com	Telia Company AB	Europe/Stockholm	2019-09-19 07:38:45
/settings-kg	78.72.135.23	undefined	undefined	Lund	78-72-135-23-red8.boc.wika.com	Telia Company AB	Europe/Stockholm	2019-09-19 07:38:27
/access-kg	78.72.135.23	undefined	undefined	Lund	78-72-135-23-red8.boc.wika.com	Telia Company AB	Europe/Stockholm	2019-09-19 07:37:46
/settings-kg	130.235.58.234	undefined	undefined	Lund	www012.ark.lu.se	Lund University	Europe/Stockholm	2019-09-19 06:48:19
/access-kg	130.235.58.234	undefined	undefined	Lund	www012.ark.lu.se	Lund University	Europe/Stockholm	2019-09-19 06:44:59
/	130.235.58.234	undefined	undefined	Lund	www012.ark.lu.se	Lund University	Europe/Stockholm	2019-09-19 06:21:18
/	188.150.74.104	undefined	undefined	Lund	188.150.74.104	Com Hem AB	Europe/Stockholm	2019-09-18 22:22:27

Settings Log

Start Date: 08/18/2019 08:40 | Stop Date: 08/19/2019 08:40 |

url	device	ip	country	region	city	rds	isp	timezone	datetime
/r/rlt	<input type="text" value="rlt"/>	<input type="text" value="83.254.136.245"/>	undefined	undefined	Lund	483-254-136-245.linband.com.hk.as	Com Hem AB	Europe/Stockholm	2019-09-18 12:03:00

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

