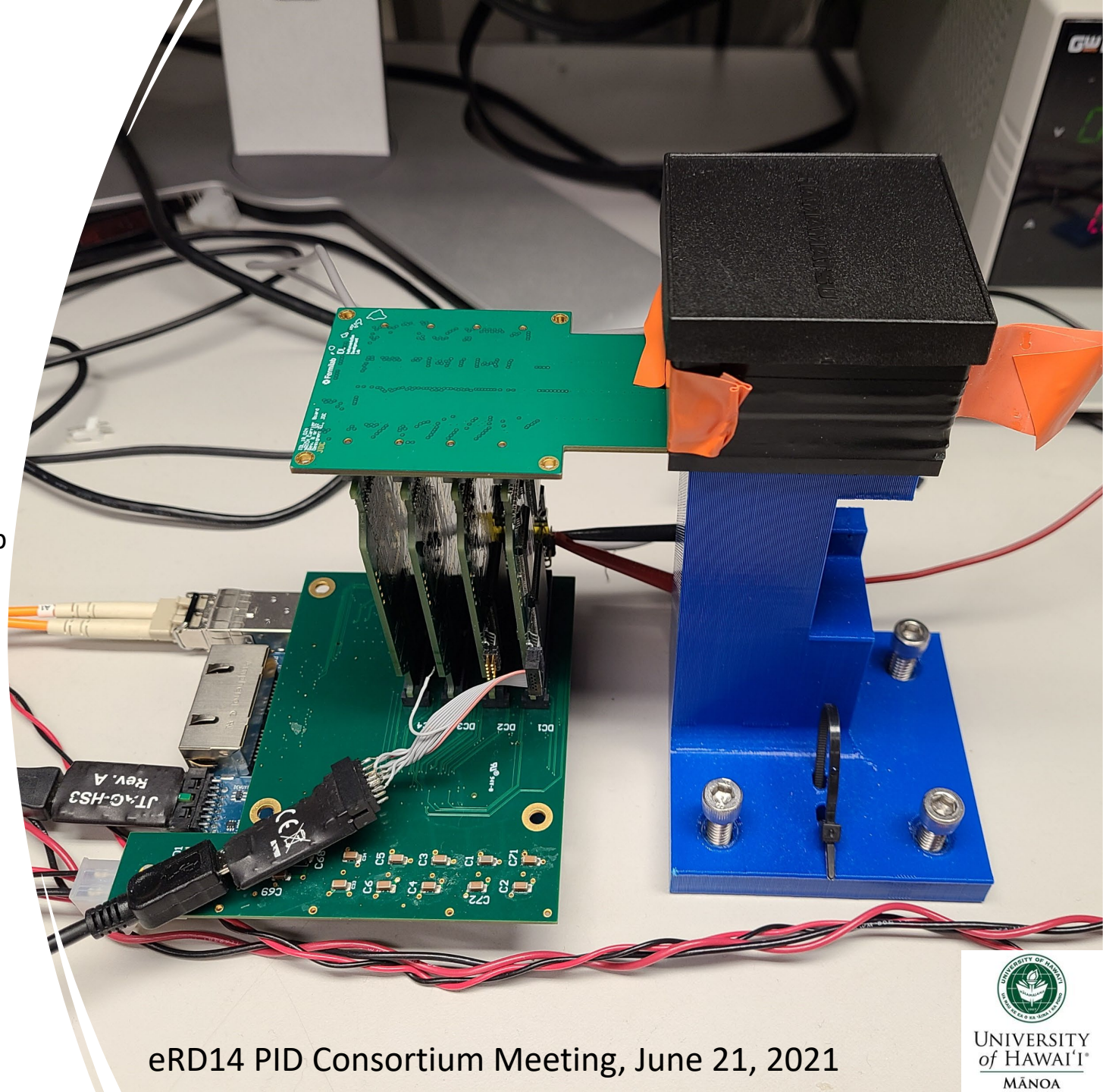


Development of the SiREAD based readout solution for the Particle Identification Detectors of the EIC

- Shivang Tripathi ^a, Gary Varner ^a
- Benjamin Rotter ^b, Isar Mostafanezhad ^b

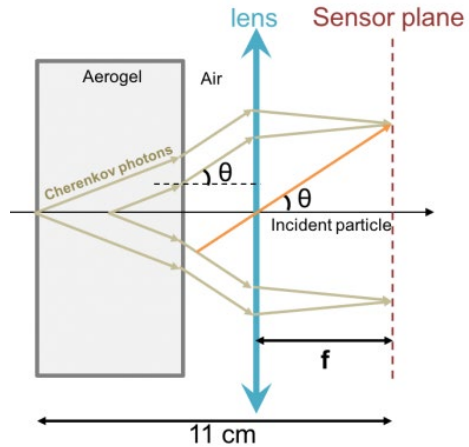
^a Instrumentation Development Lab,
University of Hawaii at Manoa

^b Nalu Scientific, Honolulu

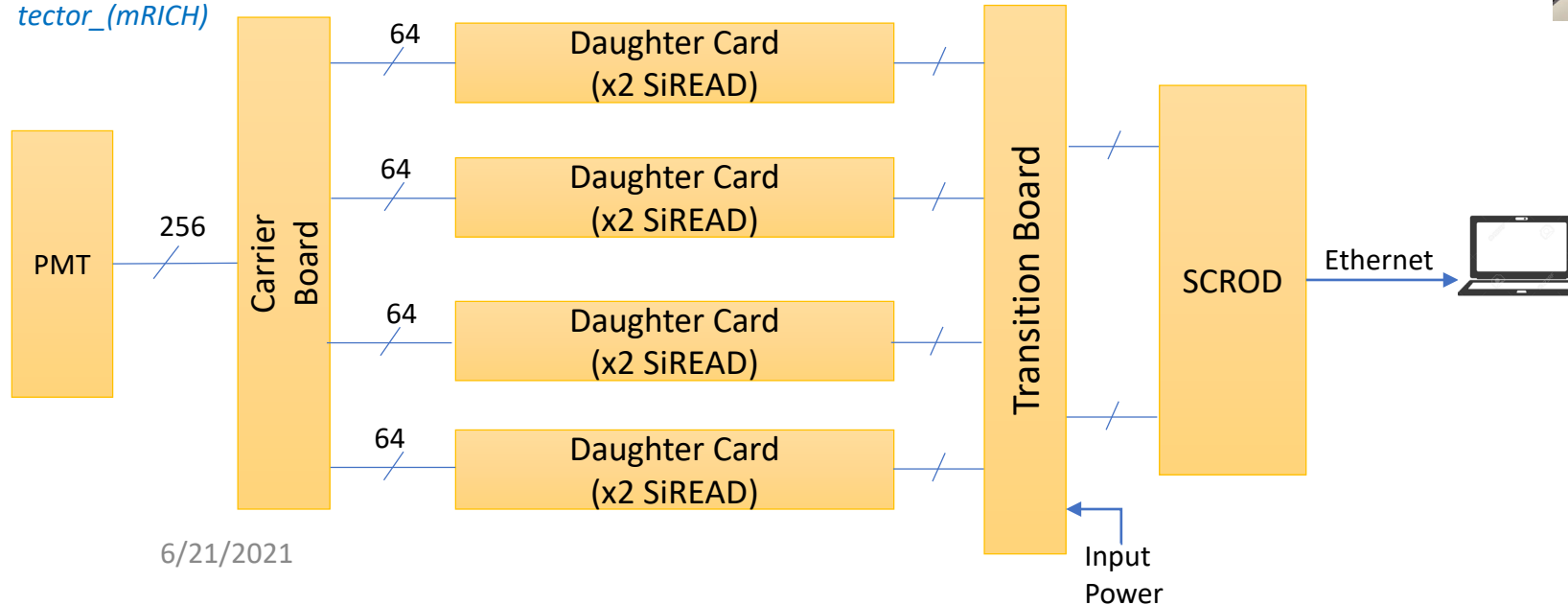
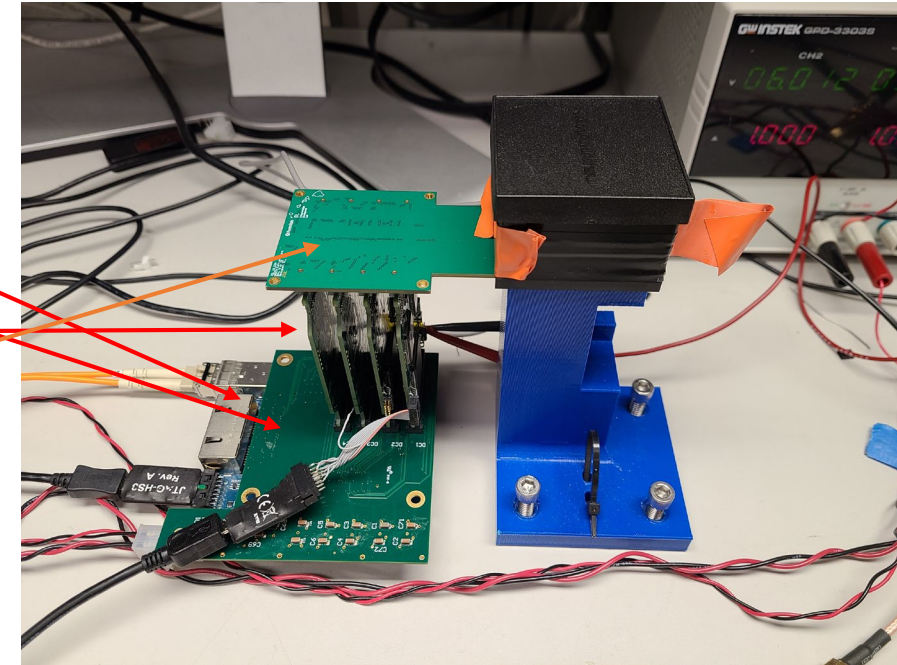
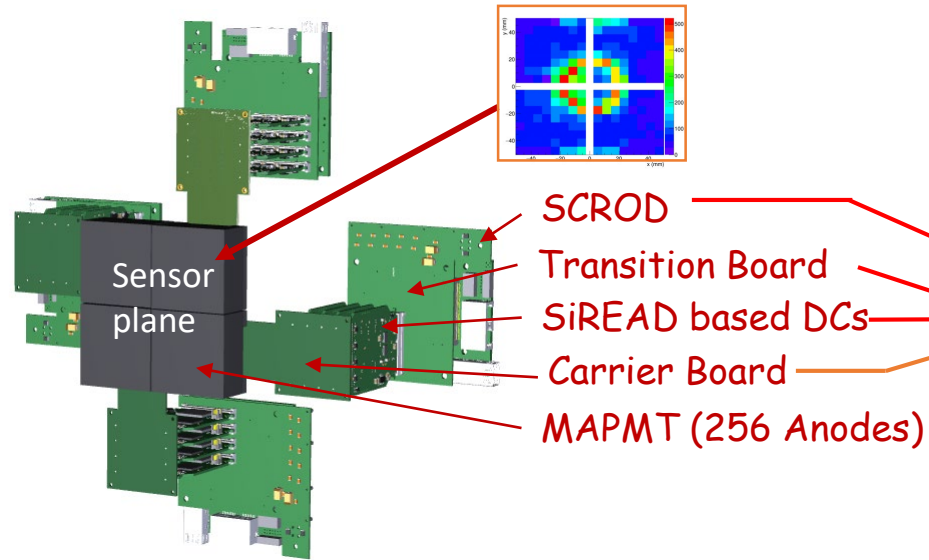


Readout Electronics for mRICH Detectors

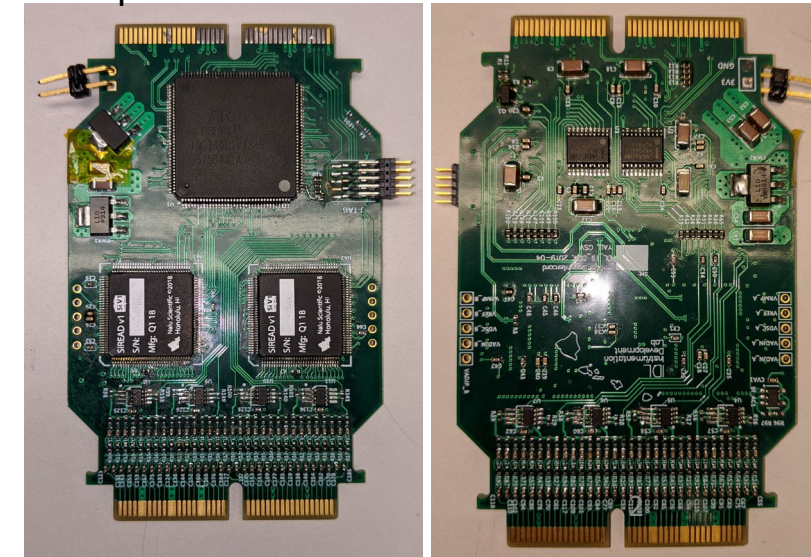
Modular RICH (mRICH)



[http://phynp6.phyastr.gsu.edu/eRD14/index.php/Modular_Ring_Imaging_Chernkov_Detector_\(mRICH\)](http://phynp6.phyastr.gsu.edu/eRD14/index.php/Modular_Ring_Imaging_Chernkov_Detector_(mRICH))

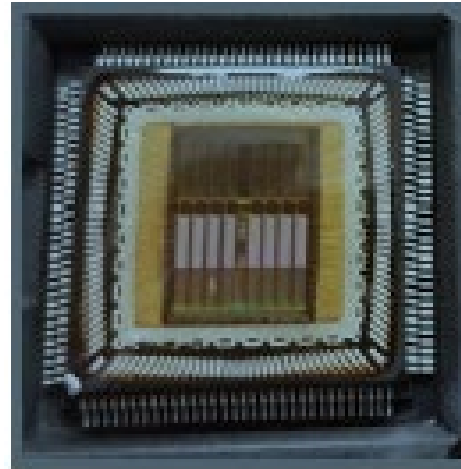


Top and bottom view of SiREAD-based DC



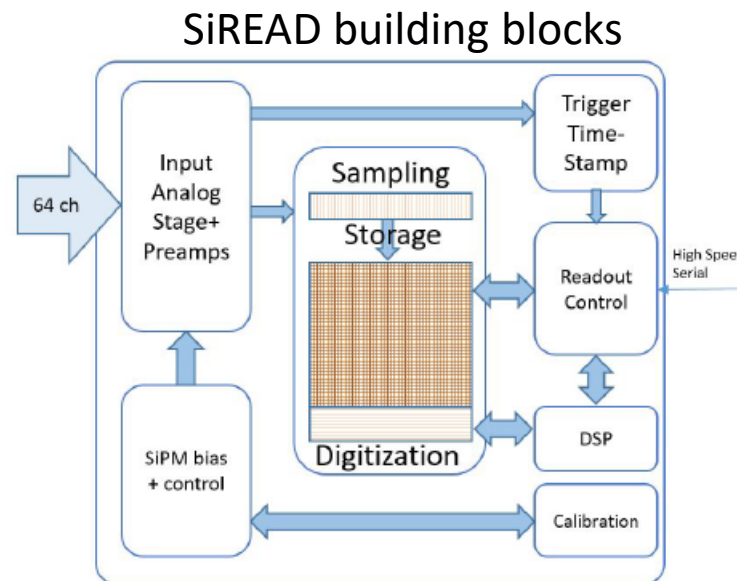
SiREAD ASIC

- ❑ 32- channel Waveform Sampling ASIC
- ❑ Up to 1 Giga-sample/sec
- ❑ System-on-Chip with built-in:
 - ✓ SiPM biasing
 - ✓ Calibration
 - ✓ Digitization control
 - ✓ DSP, etc.
- ❑ Triggering Mechanism
- ❑ Power optimized and high channel Switched Capacitor Array (SCA) based sampling
- ❑ Digitizing core similar to TARGET ASIC



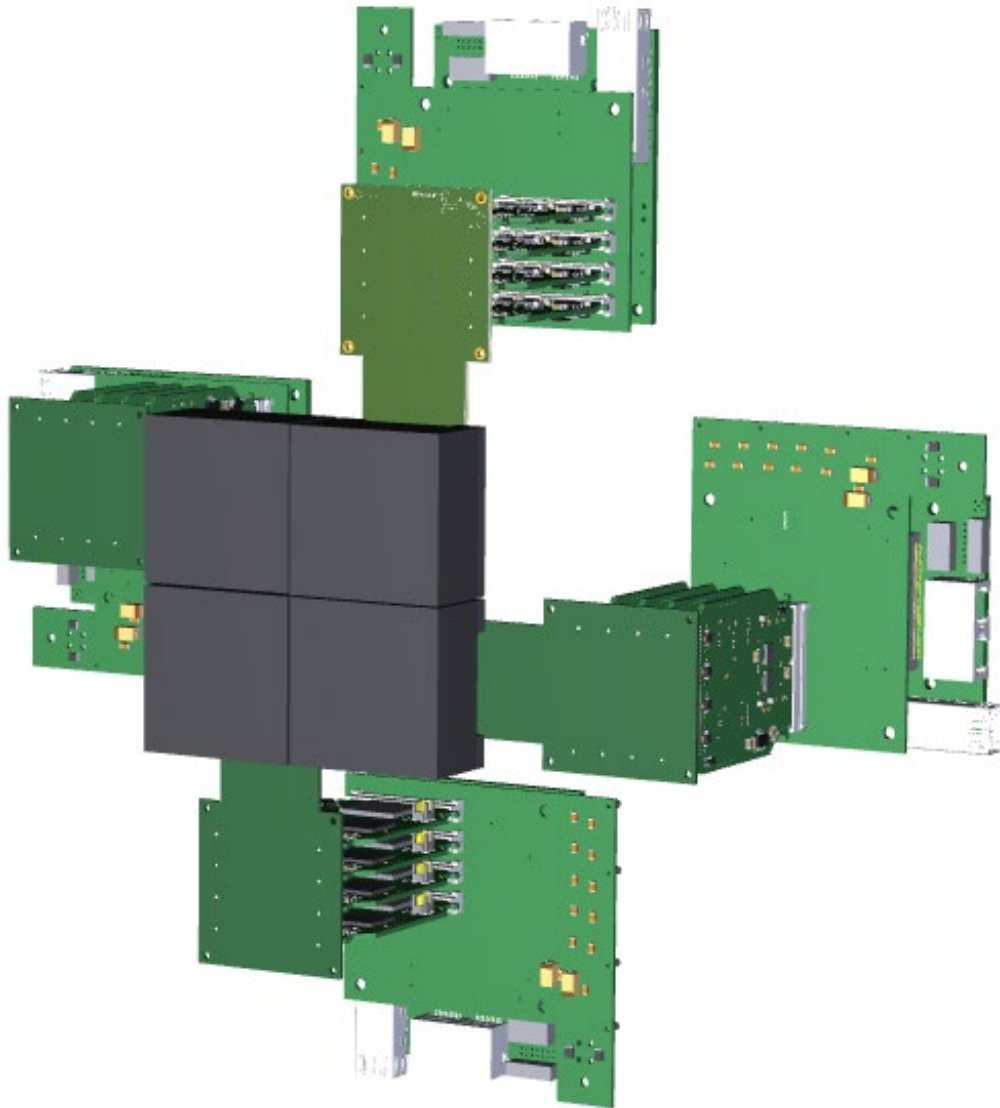
SiREAD prototype specifications

SiREAD Parameter	Specifications
Channels	32
Sampling rate	1 GSa/s
Storage samples/ch	4096
Est. Analog BW	0.7-1.1 GHz
RMS voltage noise	1.3 mV
Signal voltage range	2.1 V
ADC on chip	12 bits
Readout	Serial LVDS
Power consumption	20-40 mW/ch

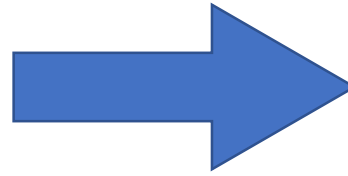


Isar Mostafanezhad, *et. al.*, "SiREAD: A 32 Channel 1 GSa/s Waveform Sampling and Readout System-on-Chip for High Density Detectors", IEEE NSS/MIC, 2018

Next version of the electronics

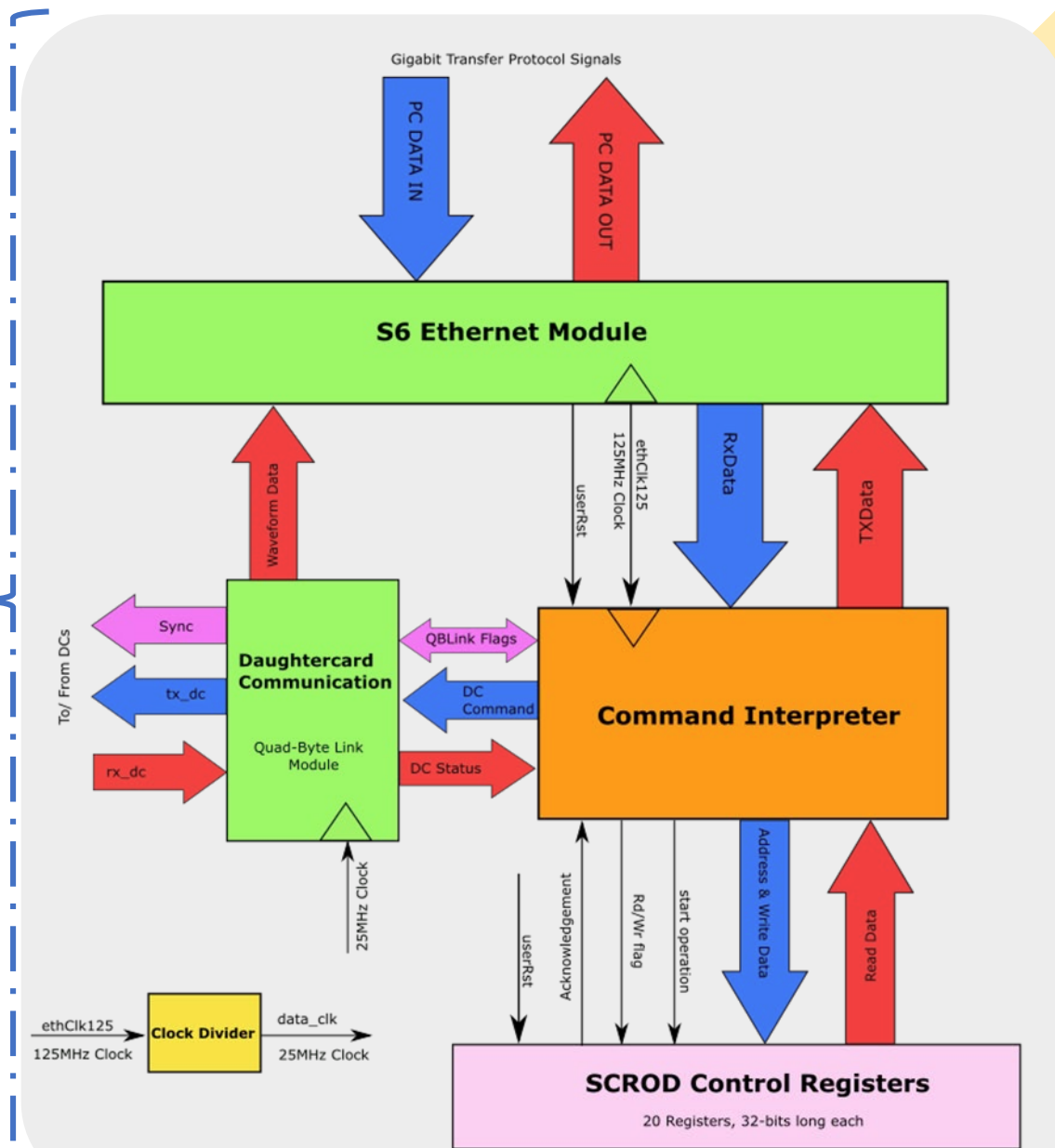
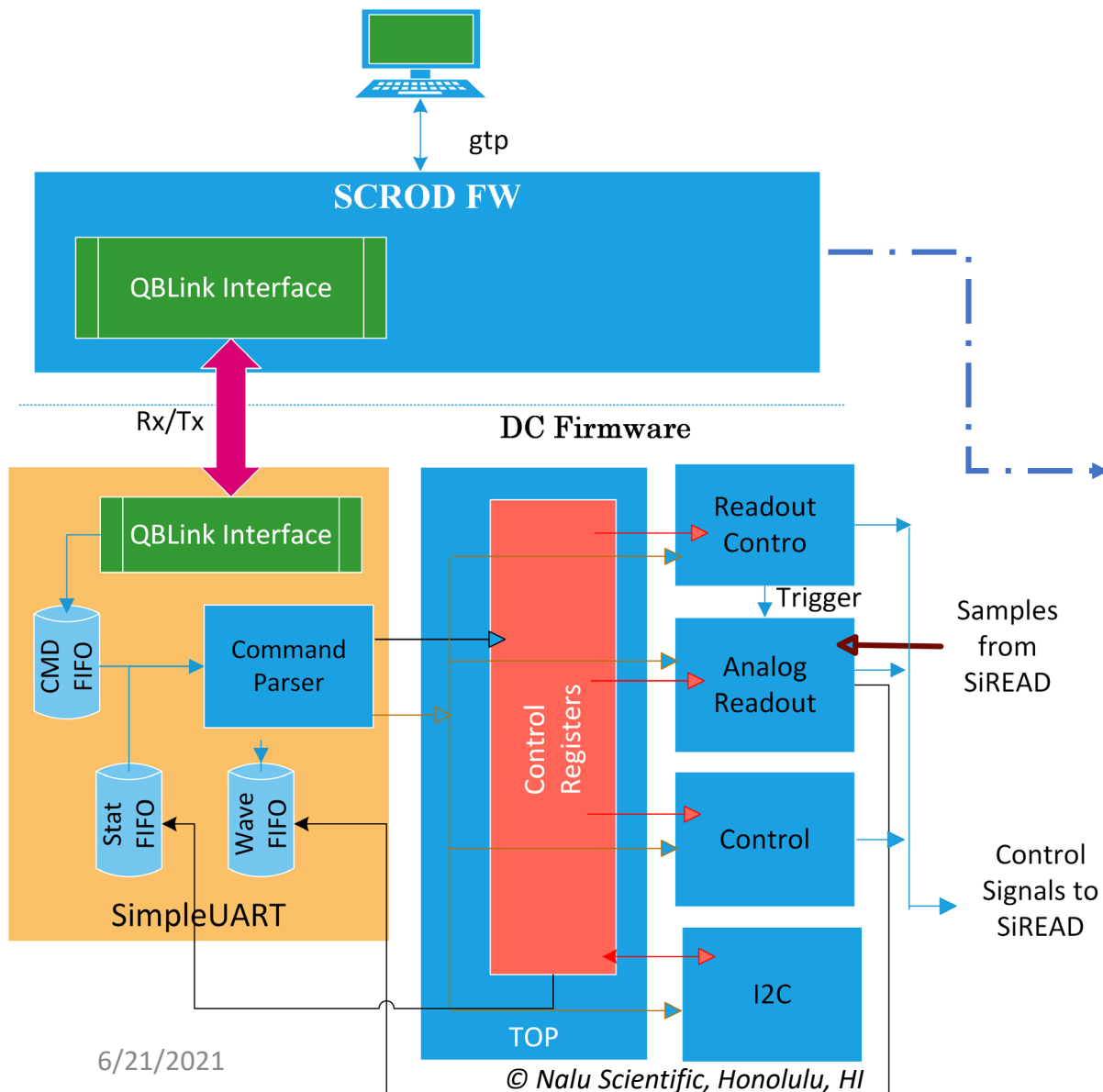


32-channel SiREAD Pin-wheel config Setup



64-channel HDSoc Setup

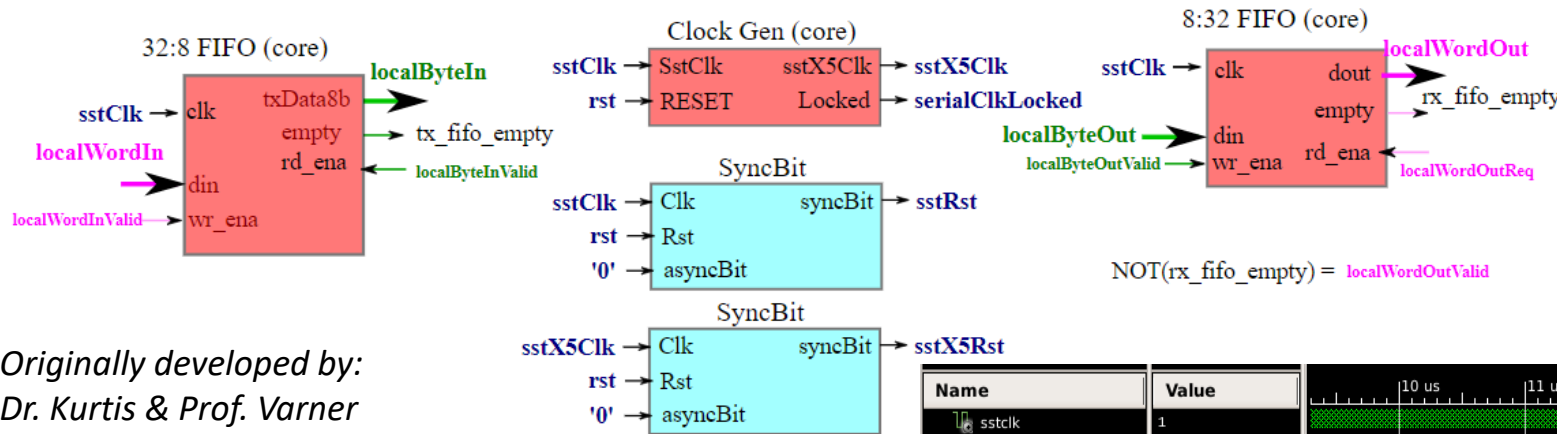
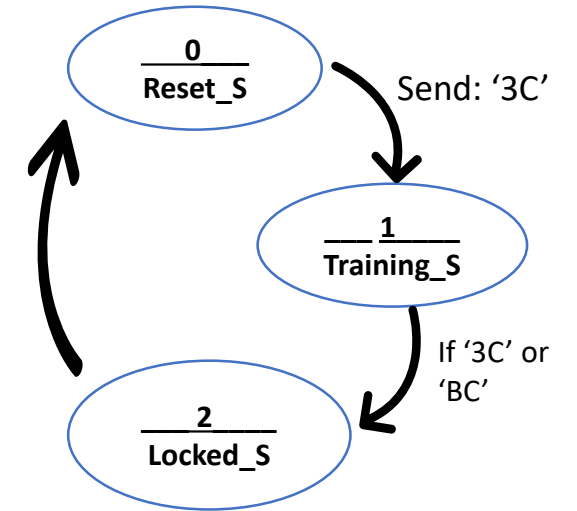
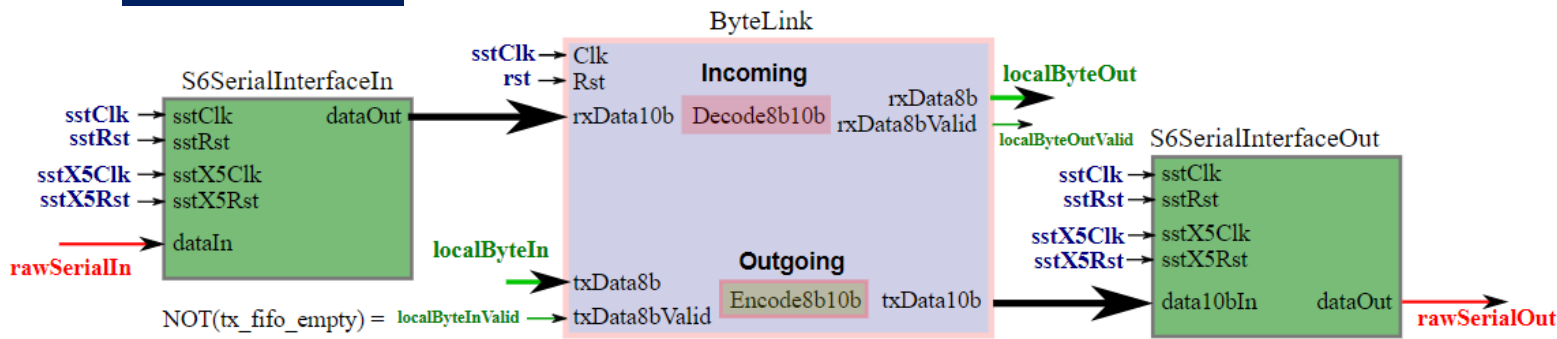
Firmware



QBLink

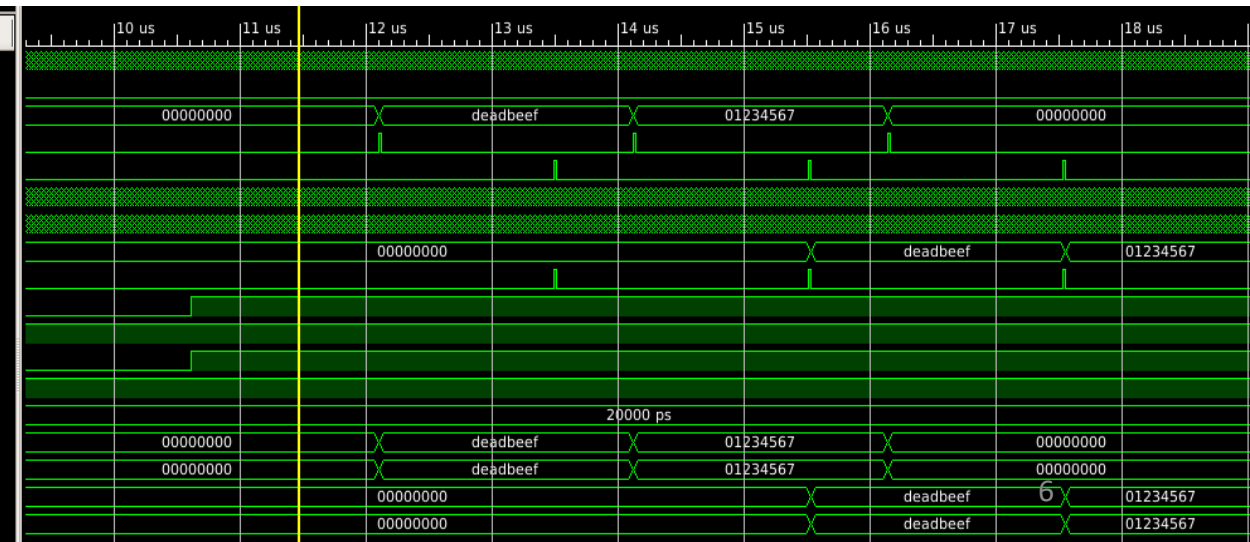
Quad Byte line (QBLink)

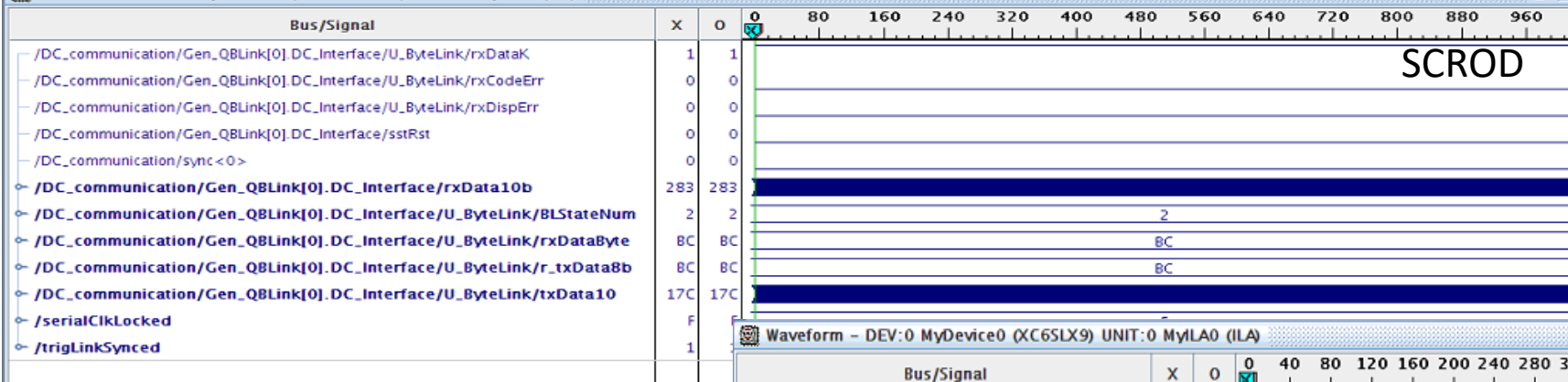
ByteLink State Machine



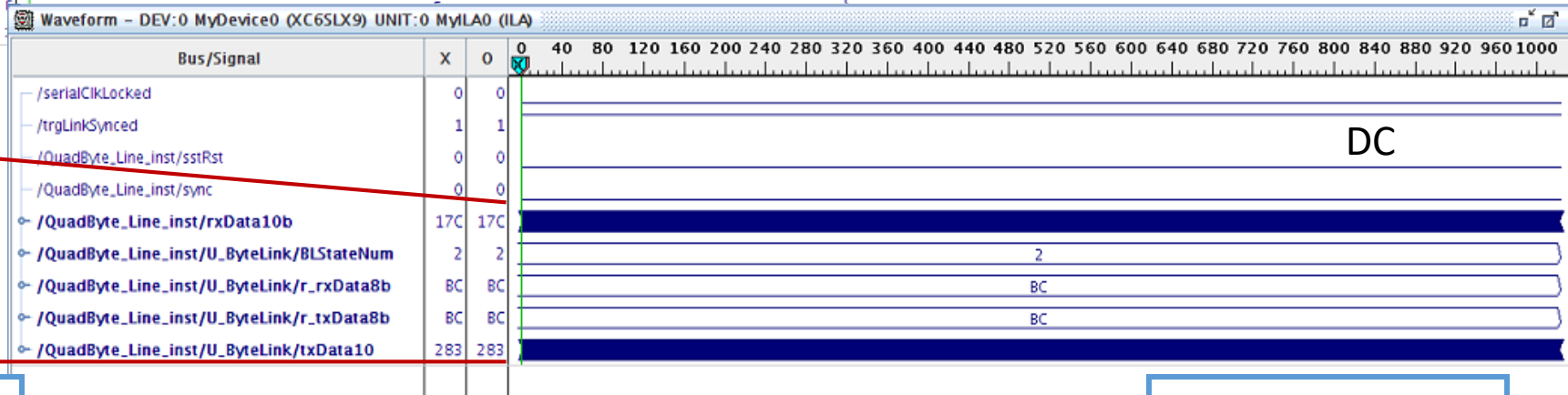
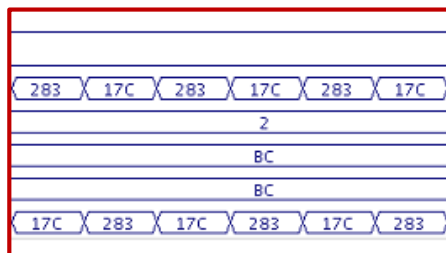
NOT(rx_fifo_empty) = localWordOutValid

Name	Value
sstclk	1
rst	0
wordin[31:0]	00000000
wordinena	0
wordoutreq	0
rawserialout	0
rawserialin	0
wordout[31:0]	00000000
wordoutvalid	0
trglknsynced1	1
serialclklocked1	1
trglknsynced2	1
serialclklocked2	1
sstclk_period	20000 ps
localwordin[31:0]	00000000
din[31:0]	00000000
localwordout[31:0]	00000000
dout[31:0]	00000000



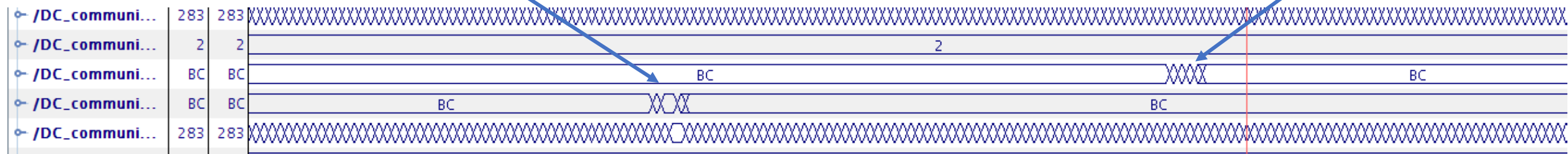


QBLink



Command going out
from SCROD to DC

Response coming
from DC



/rxData10b	17C	17C	0B9
/U_ByteLink...	2	2	2
/U_ByteLink...	BC	BC	AD05123400FACE
/U_ByteLink...	BC	BC	BC
/U_ByteLink...	17C	17C	

Command Interpreter

Structure of Command Packet

Word	High Bytes		Low Bytes		Description
	31:25	24:16	15:8	7:0	
0	0x00BE11E2				Header word
1	packet size				Number of remaining words except packet checksum: 6
2	0x646f6974				Labels packet as a Register Command
3	0x00	Device label		Device #	Device labels: (SCROD) 0x00A5, (DC) 0x00DC Device #: 0x00 (SCROD), 0x01 through 0x08 (DC #)
4	verbosity (31:24)	Command ID(23:0)			Verb(7): suppresses command response. Command ID: unique ID to each command
5	command type				Ping: 0x70696e67, read: 0x72656164, write: 0x72697465
6	Register Value (0x0000 for read operations)		register address		Command data
7	command checksum				sum words 4 through 6
8	packet checksum				sum of entire words 0 to 7

Error Response

Word	Bytes
0	x"00BE11E2"
1	x"00000005"
2	WORD_ERR_C = x"7768613f"
3	wordScrodRevC = x"0000A500"
4	00 & commandId
5	errFlags
6	Checksum

Error Flags

Error Constants (errFlags)
Packet size error: ERR_BIT_SIZE_C = x"00000001"
Packet type error: ERR_BIT_TYPE_C = x"00000002"
Invalid command target: ERR_BIT_DEST_C = x"00000004"
Invalid command type: ERR_BIT_COMM_TY_C = x"00000008"
Command checksum error: ERR_BIT_COMM_CS_C = x"00000010"
Packet checksum error: ERR_BIT_CS_C = x"00000020"
Timeout Error: ERR_BIT_TIMEOUT_C = x"00000040"
connection to DC failed: QBLINK_FAILURE_C: x"00000500"

PING Response

Word	Bytes
0	x"00BE11E2"
1	x"00000005"
2	WORD_ERR_C = 0x7768613f or WORD_ACK_C = 0x6F6B6179
3	wordScrodRevC = x"0000A500"
4	00 & commandID
5	WORD_PING_C = 0x70696e67
6	Checksum

WRITE Response

Word	Bytes
0	x"00BE11E2"
1	x"00000006"
2	WORD_ERR_C = 0x7768613f or WORD_ACK_C = 0x6F6B6179
3	wordScrodRevC = x"0000A500"
4	00 & commandID
5	WORD_WRITE_C = 0x72697465
6	r.regWrData & r.regAddr
7	Checksum

READ Response

Word	Bytes
0	x"00BE11E2"
1	x"00000006"
2	WORD_ERR_C = 0x7768613f or WORD_ACK_C = 0x6F6B6179
3	wordScrodRevC = x"0000A500"
4	00 & commandID
5	WORD_READ_C = x"72656164"
6	r.regWrData & r.regAddr
7	Checksum

Raw Data Formats for the Imaging Time-of-Propagation (iTOP) Electronics

https://www.phys.hawaii.edu/~kurtisn/doku.php?id=itop:documentation:data_format

Command Interpreter

Table 10. Register Write Response

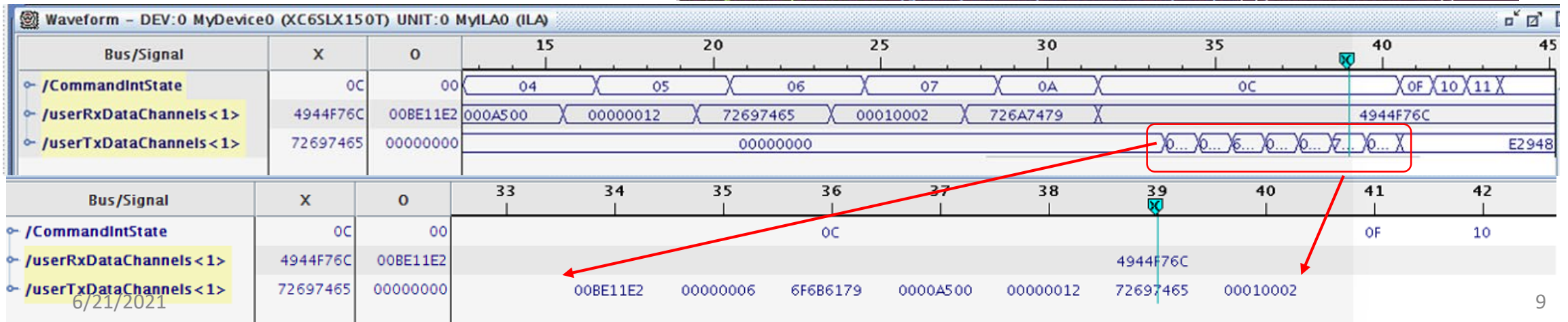
Word	Bytes
0	x"00BE11E2"
1	x"00000006"
2	WORD_ERR_C = 0x7768613f or WORD_ACK_C = 0x6F6B6179
3	wordScrodRevC = x"0000A500"
4	00 & commandID
5	WORD_WRITE_C = 0x72697465
6	r.regWrData & r.regAddr
7	Checksum

```

mrlich@mrlich-OptiPlex-390: ~/github/mRICH-FW/EIC-Beamtest-FW/scripts
0xe09386d9
mrlich@mrlich-OptiPlex-390:~/github/mRICH-FW/EIC-Beamtest-FW/scripts$ python3 UDP_Client_NP.py
command checksum is: 0x726a7479
proto_message is: [12456418, 6, 1685023092, 42240, 18, 1919513701, 65538, 1919579257, 1229256556]
0xbe11e2
0x6
0x646f6974
0xa500
0x12
0x72697465
0x10002
0x726a7479
0x4944f76c
UDP Target Address: 192.168.1.33
UDP Target Port: 2001
Sent message...
0xbe11e2
0x6
0x646f6974
0xa500
0x12
0x72697465
0x10002
0x726a7479
0x4944f76c

recv message...
0xbe11e2
0x6
0x6f6b6179
0xa500
0x12
0x72697465
0x10002
0xe2948cda
mrlich@mrlich-OptiPlex-390:~/github/mRICH-FW/EIC-Beamtest-FW/scripts$ python3 UDP_Client_NP.py

```

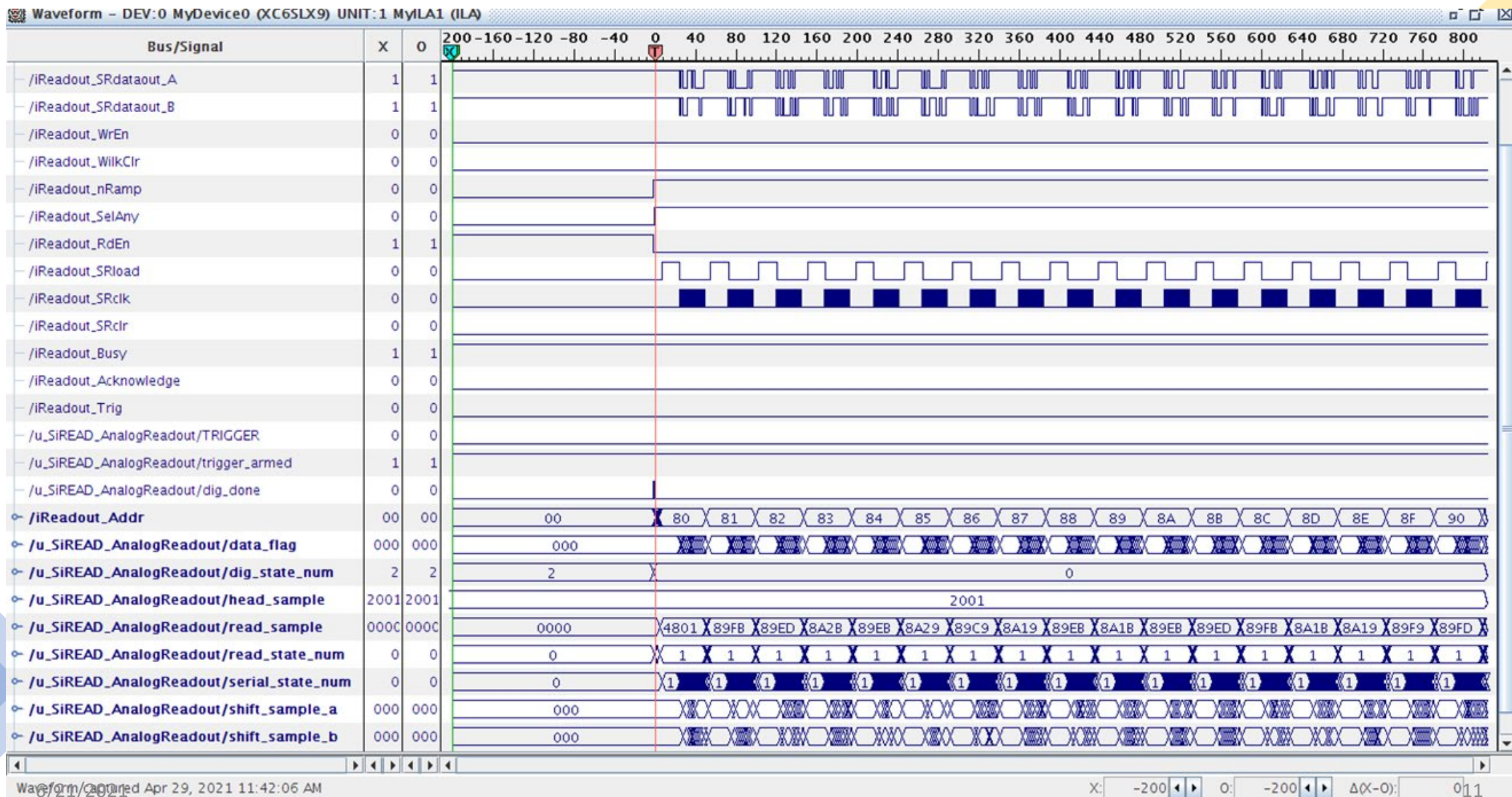


DC Control Reg Map

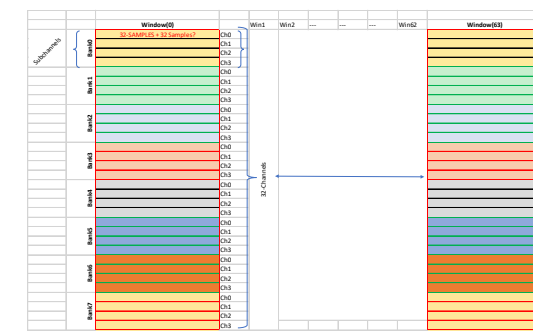
Reg no	Value	Reg(Hex)	Valu(Hex)	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	Remarks		32-bit Command
				32768	16384	8192	4096	2048	1024	512	256	128	64	32	16	8	4	2	1			
3	0 03		0000																0	Read same wind	AF	AF030000
4	2052 04		0804					1	0	0	0	0	0	0	0	0	1	0	0	RegClr, Clk_OE,	AF	AF040804
5	1 05		0001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	runevs	AF	AF050001
6	1500 06		05DC					0	1	0	1	1	1	0	1	1	1	0	0	ramp	AF	AF0605DC
7	3008 07		0BC0		0	0	0	1	0	1	1	1	1						0	writeaftertrig, loa	AF	AF070BC0
8	10 08		000A				0	0	0	0	0	0	0	0	0	1	0	1	0	numwinds, lookb	AF	AF08000A
9	16384 09		4000		1														0	i2c_en	AF	AF094000
10	15 0A		000F	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	chansela	AF	AF0A000F
11	61441 0B		F001	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	chanselb	AF	AF0BF001
12	0 0C		0000															0	0	digrst,sysrst	AF	AF0C0000
14	0 0E		0000									0	0	0	0	0	0	0	0	syncloc	AF	AF0E0000
15	0 0F		0000	0					0	0	0	0	0	0	0	0	0	0	0	i2c_words, i2c_a	AF	AF0F0000
16	0 10		0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	i2c_data0	AF	AF100000
17	0 11		0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	i2c_data1	AF	AF110000
18	0 12		0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		AF	AF120000
19	0 13		0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		AF	AF130000
20	0 14		0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		AF	AF140000

- Configure SiREAD using Control (AFRRVVVV) and Analog Registers (BWMAAVVV)
- Python script to configure and send commands to DC
- Read Register values using ADDR XXXX command

SiREAD: Software Trigger (C0XXXXXX)



SiREAD: *Data format*



16-bit Word: HHH, D DDDD, DDDD, DDD 1 [3-bit Header & 12-bit Data & 1]

HHH: 001 (1) => Event Header
 010 (2) => Window header
 100 (4) => Data
 111 (7) => End

	A	B	C	D	E	F
1	37 25		2325	8997	1	402
2	35 23			0	0	0
3	125 7D		3C7D	15485	1	3646
4	60 3C			0	0	0
5	21 15		2015	8213	1	10
6	32 20			0	0	0
7	1 01		4001	16385	2	0
8	64 40			0	0	0
9	157 9D		899D	35229	4	1230
10	137 89			0	0	0
11	143 8F		898F	35215	4	1223

Event Header 3 times:

1st: 001, 12-bit TriggerTimeNs, 1 (001 000110010010 1)

2nd: 001, 12-bit TriggerTimeNs, 1 (001 111000111110 1)

3rd: 001, 12-bit Event Number, 1 (001 000000001010 1)

Window Header:

010 5-bit Curr_chan, 6-bit Curr Wind, 1 (0100 0000 0000 000 1) => Ch0 W0

Data: 100 0 1001 1001 110 1 (Actual Data: 0 1001 1001 110 =1230)

Total 64 such data words (32 for each SiREAD, Alternatively)

After 64 data samples:

135	177 B1		89B1	35249	4	1240
136	137 89			0	0	0
137	1 01		4801	18433	2	1024
138	72 48			0	0	0
139	105 69		8969	35177	4	1204

0100 1000 0000 0001 => Ch16 W0

Ch0 W0 > Ch16 W0 > Ch1 W0 > Ch2 W0 > Ch3 W0 >

Ch0 W1 > Ch16 W1 > Ch1 W1 > Ch2 W1 > Ch3 W1

1305	39 27		8A27	35367	4	1299
1306	138 8A			0	0	0
1307	206 CE		FACE	64206	7	3431
1308	250 FA					

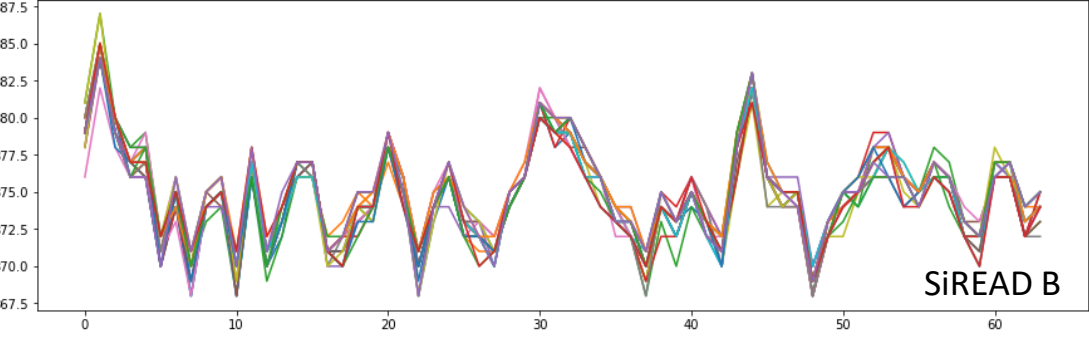
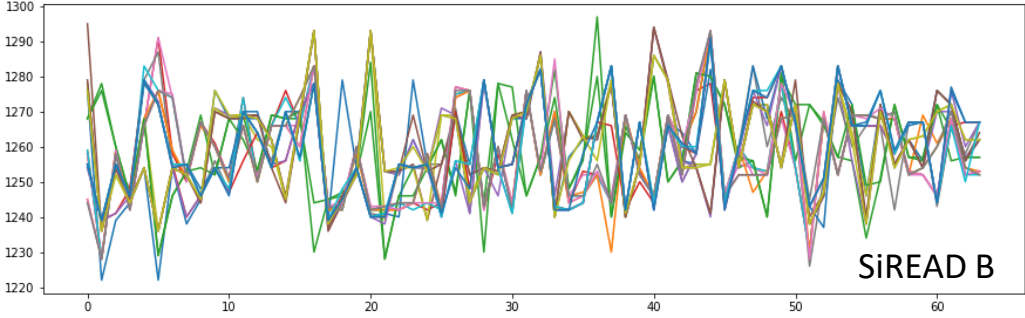
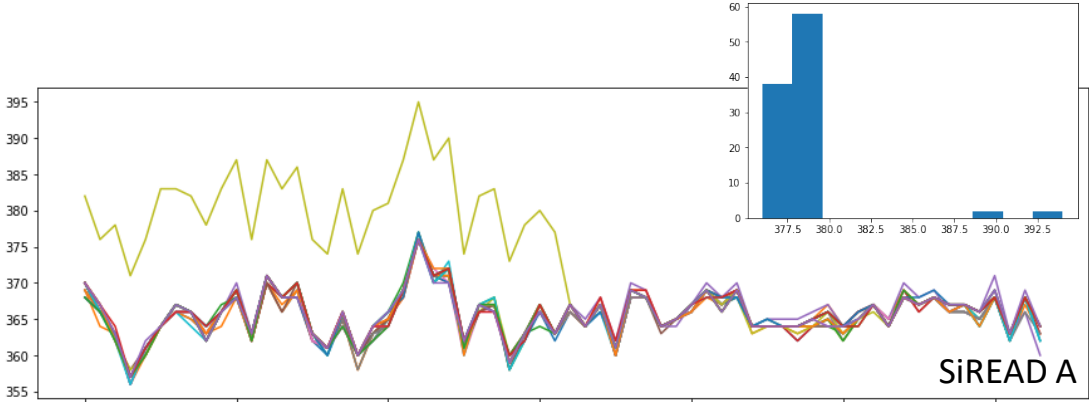
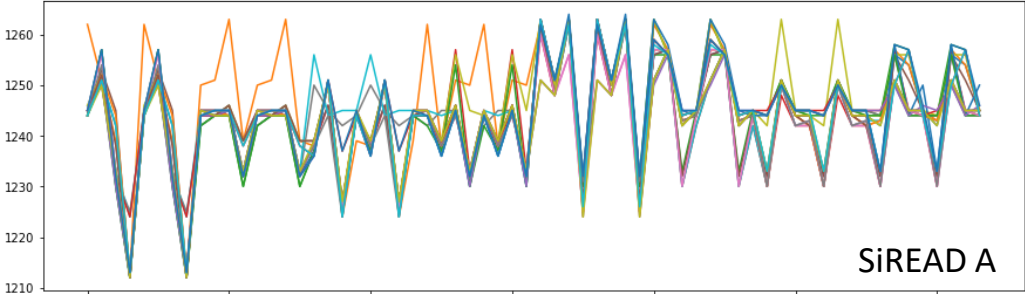
End: 1111 1010 1100 1110 (FACE)

Cmd to select Channels:

From ASIC A: AF0A 000F

From ASIC B: AF0B 0001

Parsing and debugging of first set of data:



Sample by sample comparison of data on ILA and parsed data

```
In [87]: thing = all_data[0][0]["data"][0]
for value in thing:
    print("{0:d} {0:012b} {0:02x}".format(value))
```

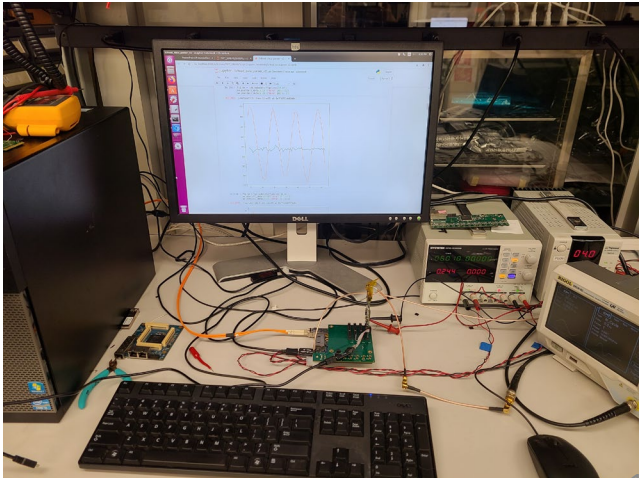
368 000101110000 170
379 000101111011 17b

/u_SiREAD_AnalogReadout/serial_state_num

/u_SiREAD_AnalogReadout/shift_sample_a

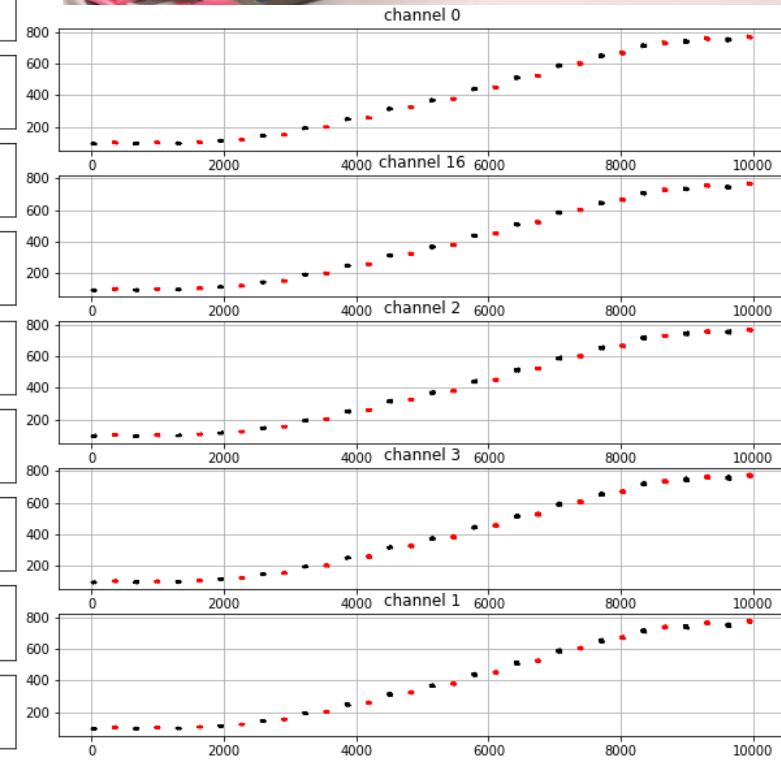
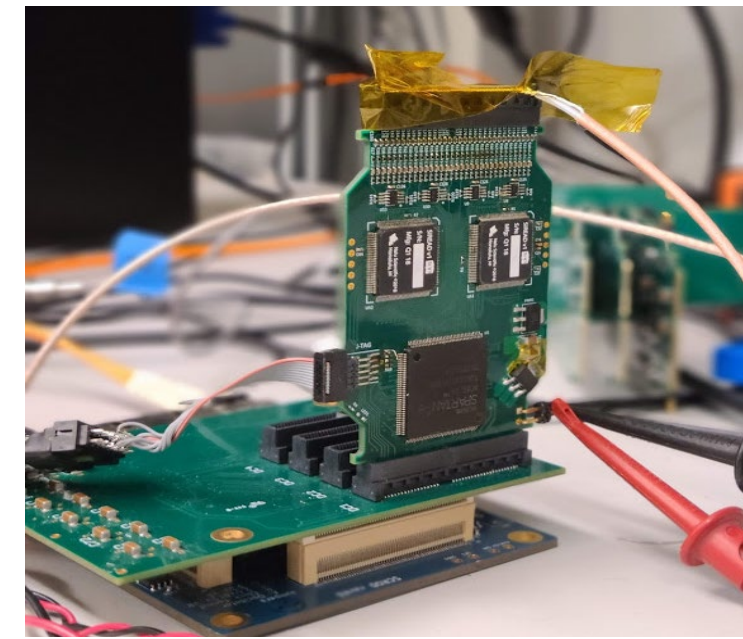
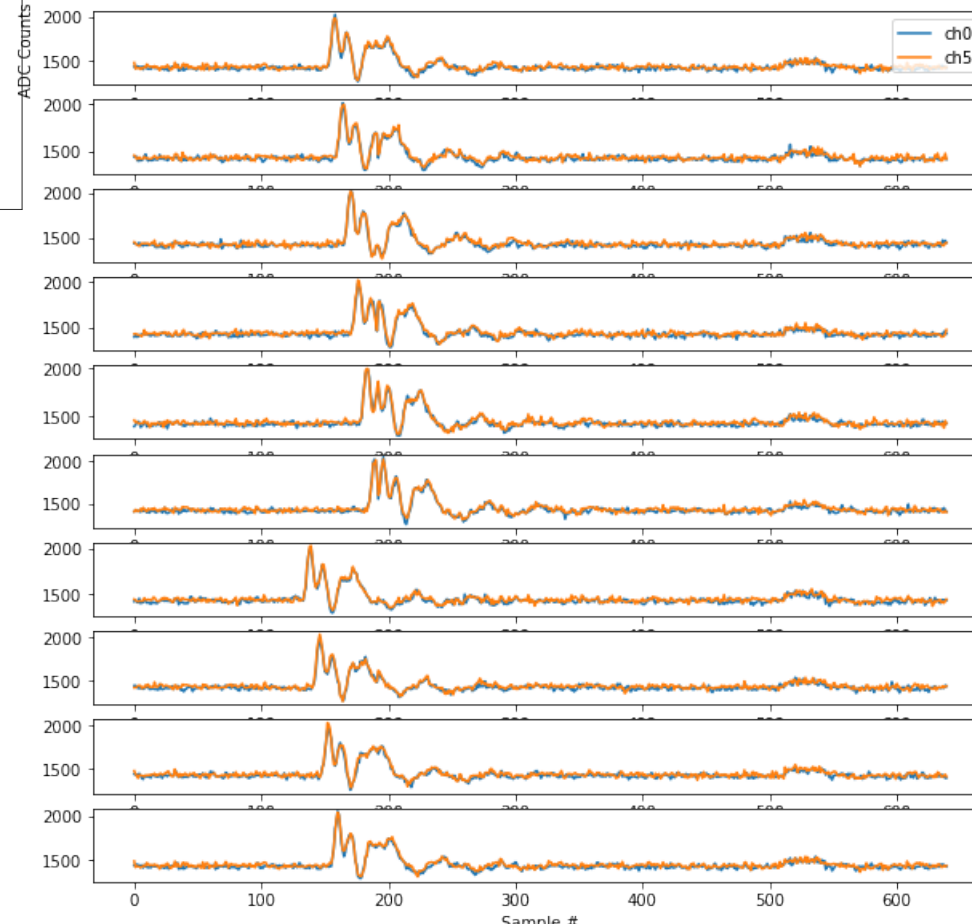
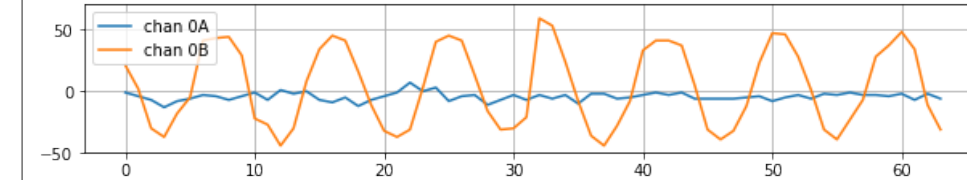
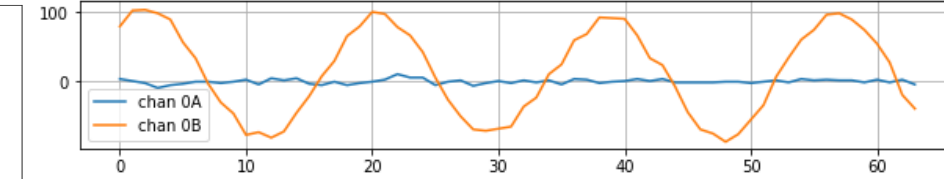
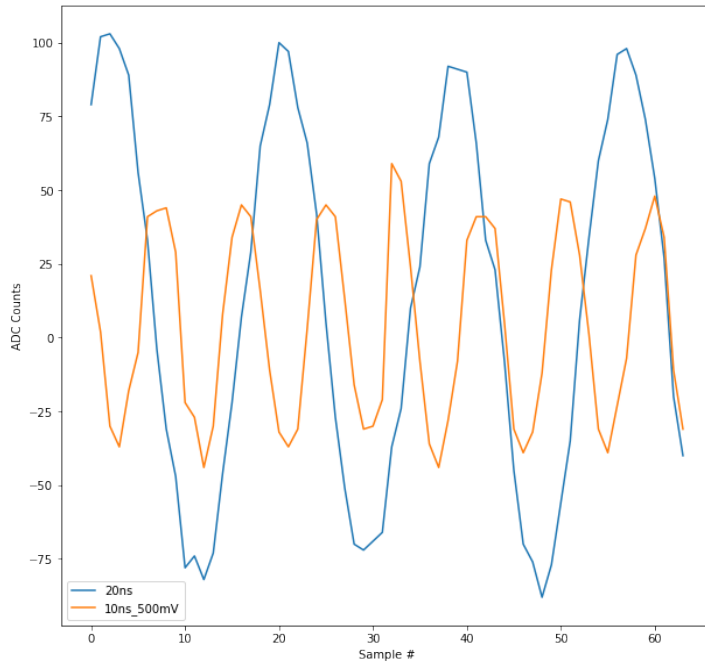
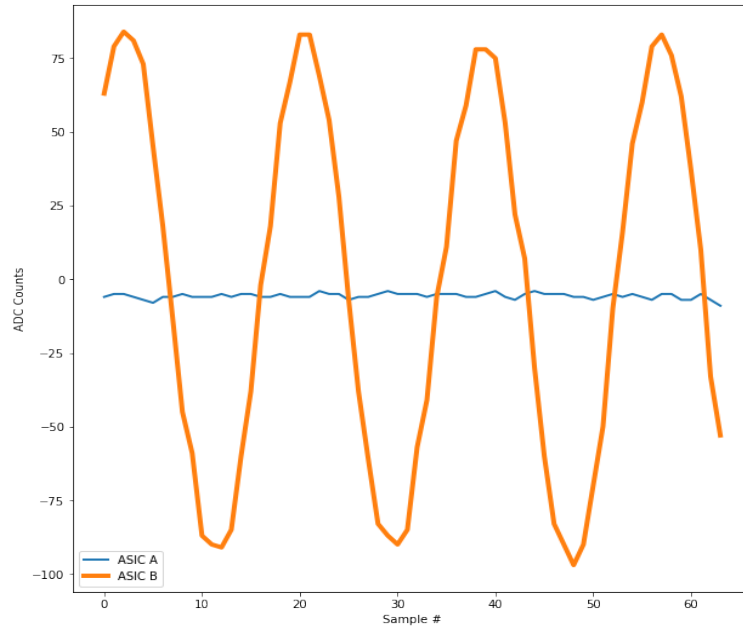
/u_SiREAD_AnalogReadout/shift_sample_b

5	0	3	5
170	000	170	
178	000	17B	

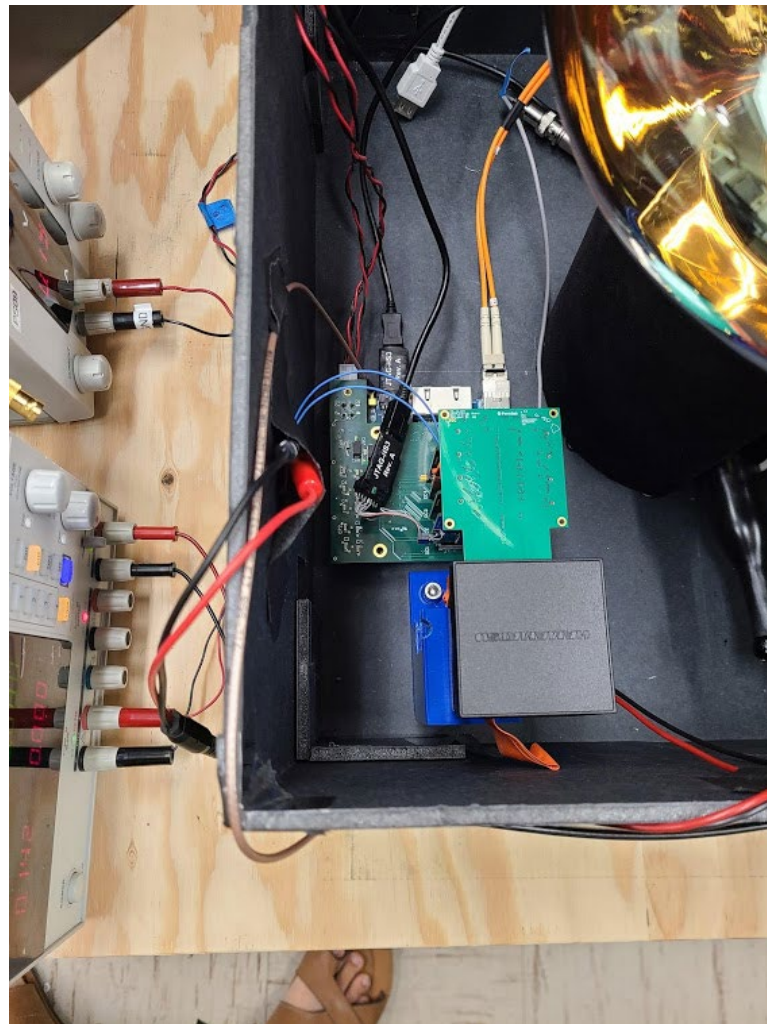
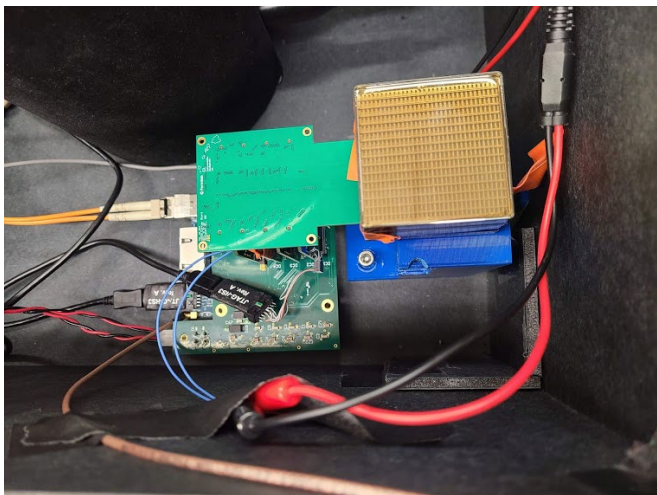


SiREAD's First Light

Sine waves



PMT Test Setup:



Summary

- SCROD FW
- DC FW
- Software is evolving
- Testing PMT

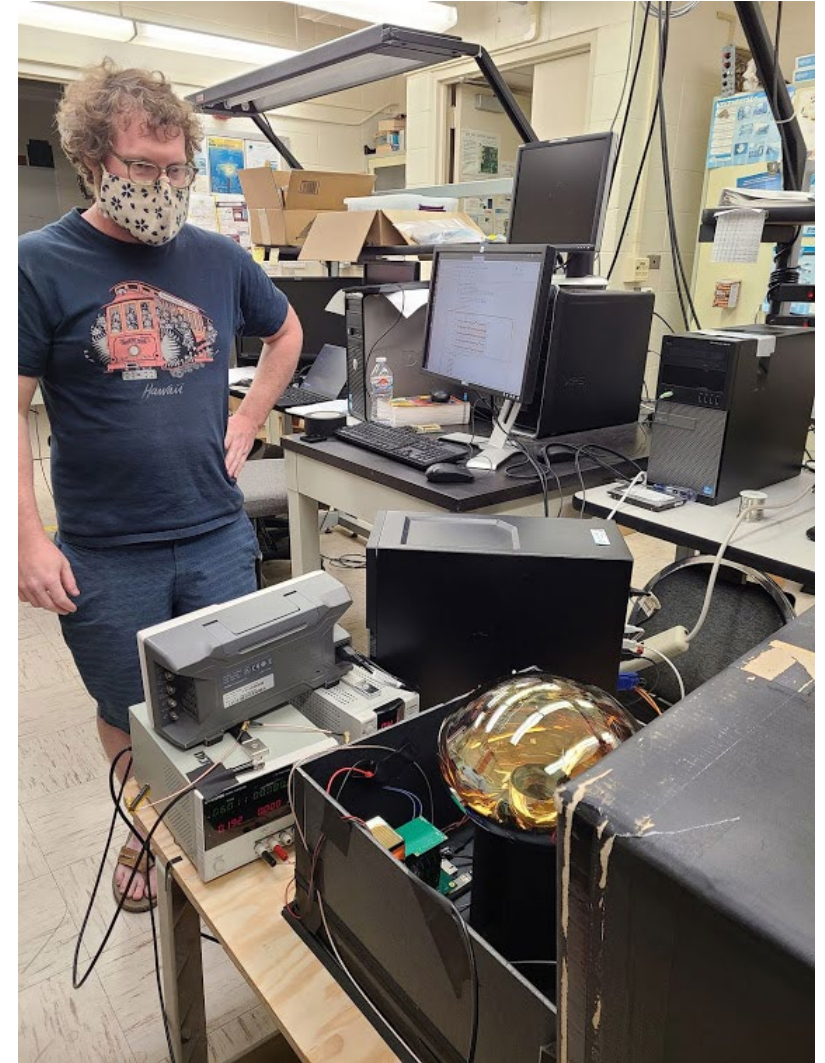


Future Activities

- More work on PMT, if available !!
 - SiREAD application in aRICH
- HDSoc based readout

Acknowledgment

- SiREAD Designers & Developers (Nalu Scientific)
 - Board Designers
 - SiREAD DC (Yasir Ali, G. Varner)
 - Transition Board (TL, G. Varner)
 - SCROD Rev5 (MZA +)
 - Carrier Board 9 (JDC,TL,EL)
- Dr. Kurtis, Nathan (QBLink)
- IDLAB Members
- Funding Agencies
- eRD14 Consortium



Backup

QBLink Debugging...

DC TxData10b:

283, 17C, 283, 17C, 283, 17C,.....

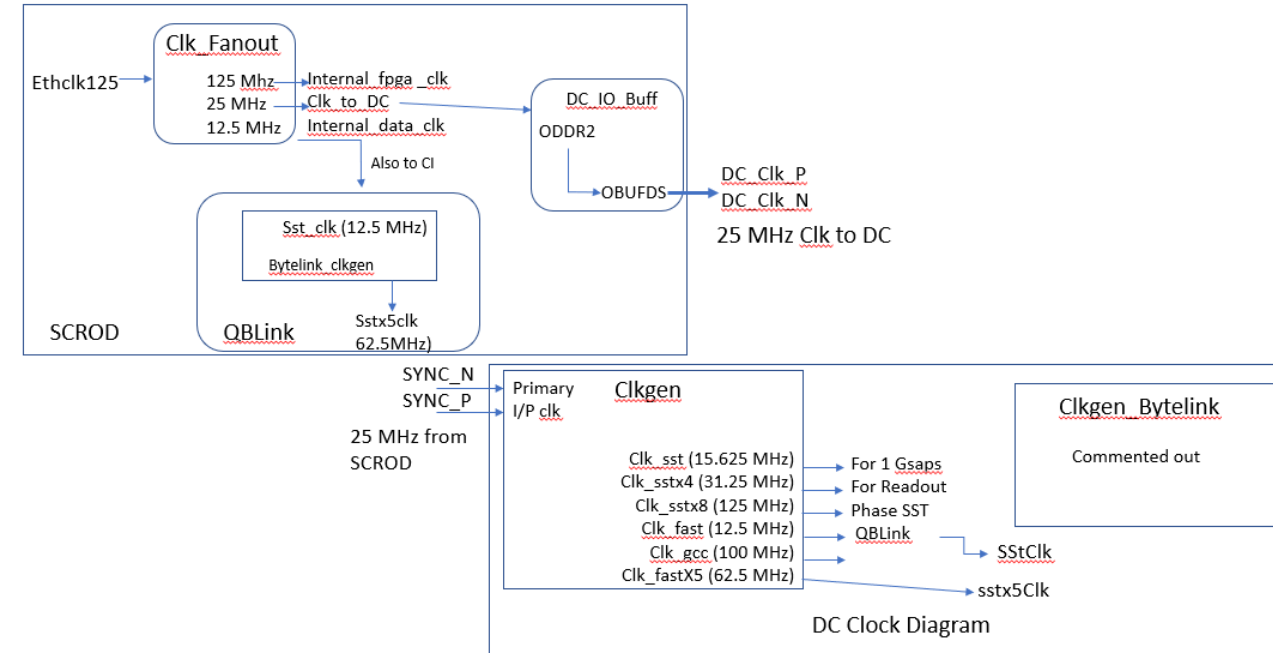
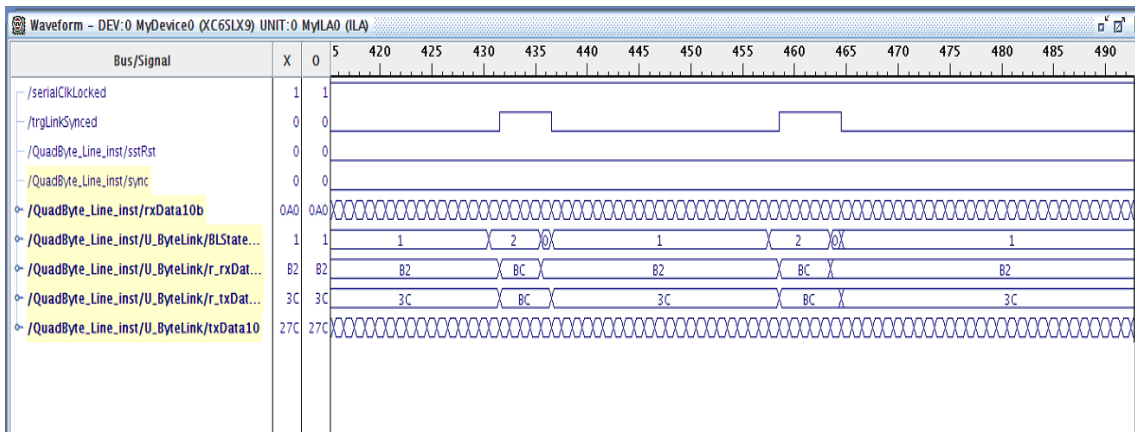
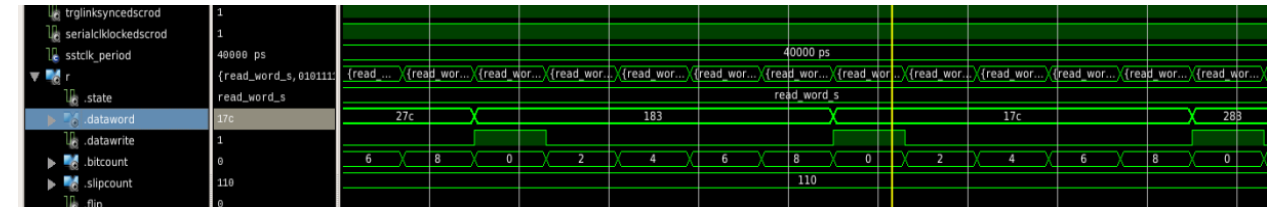
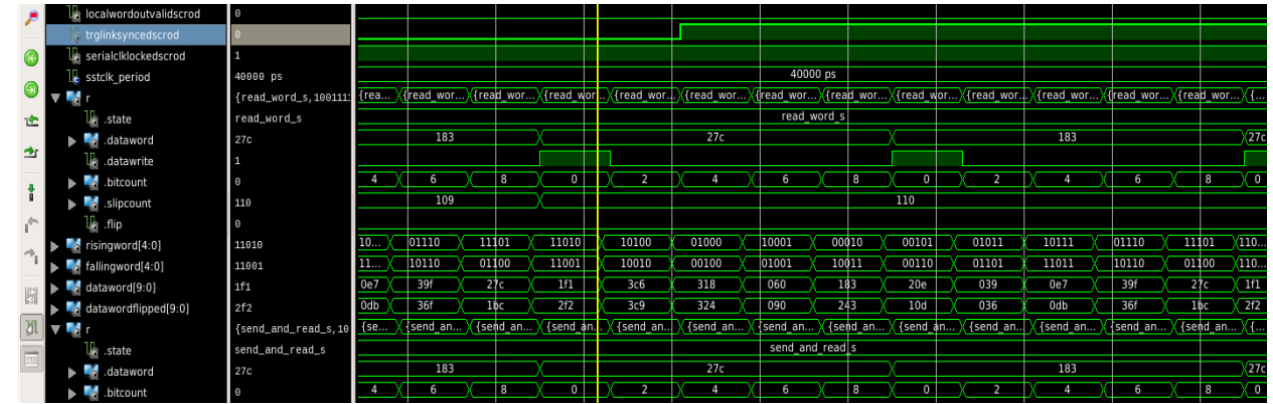
10 1000 0011 01 0111 1100 10 1000 0011 01 0111 1100...

SCROD rxData10b:

250,1AF, 250, 1AF, ... , 097,368,... 3E5,01A...

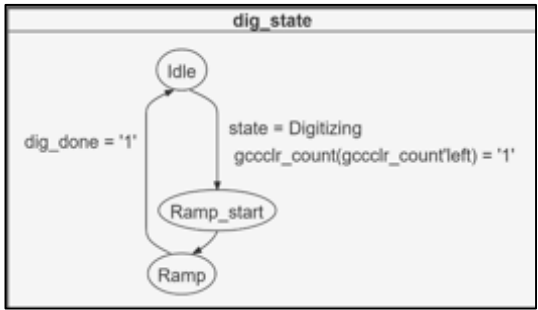
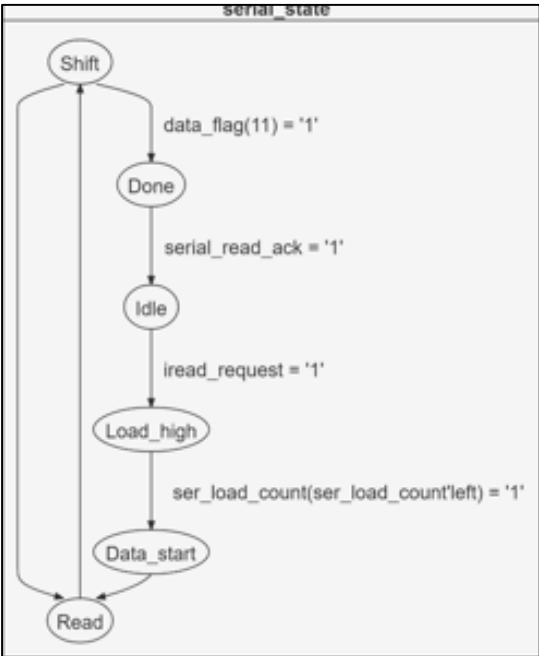
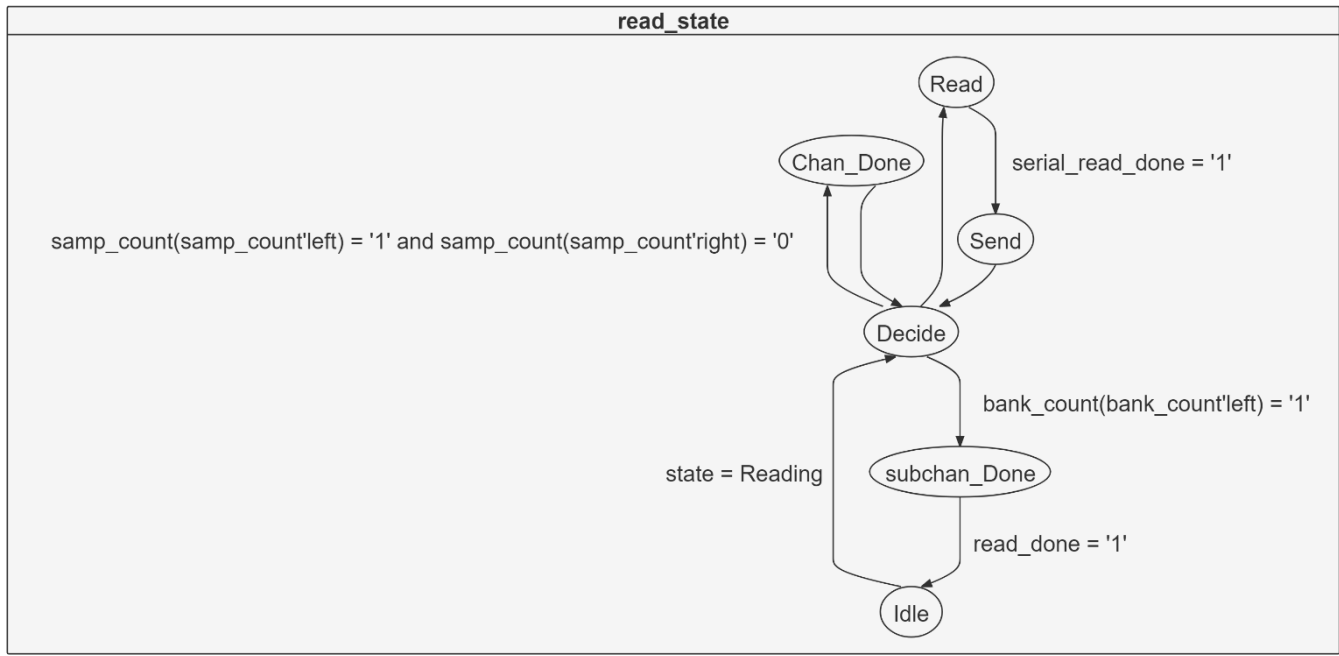
1001010000,0111010111,1,1001010000,0111010111,1,0010010111,1101101000,
2 8 3 1 7 C 2 8 3 1 7 pattern broken

{ falling_edge & risingedge }{rising_edge&falling edge}
0001101011,1110010100
1 7 C 2 8 ...

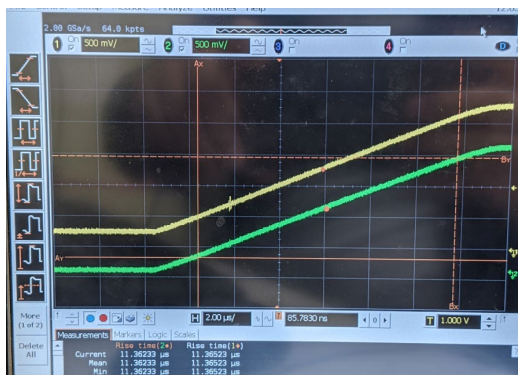
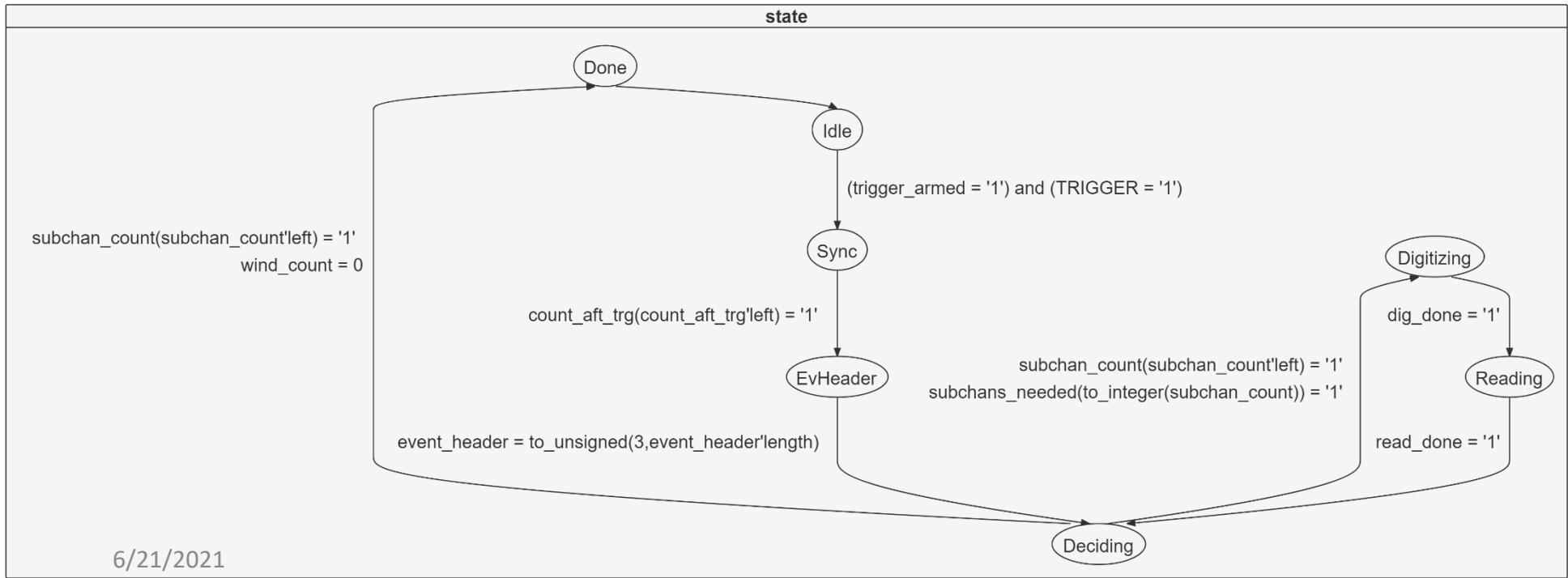


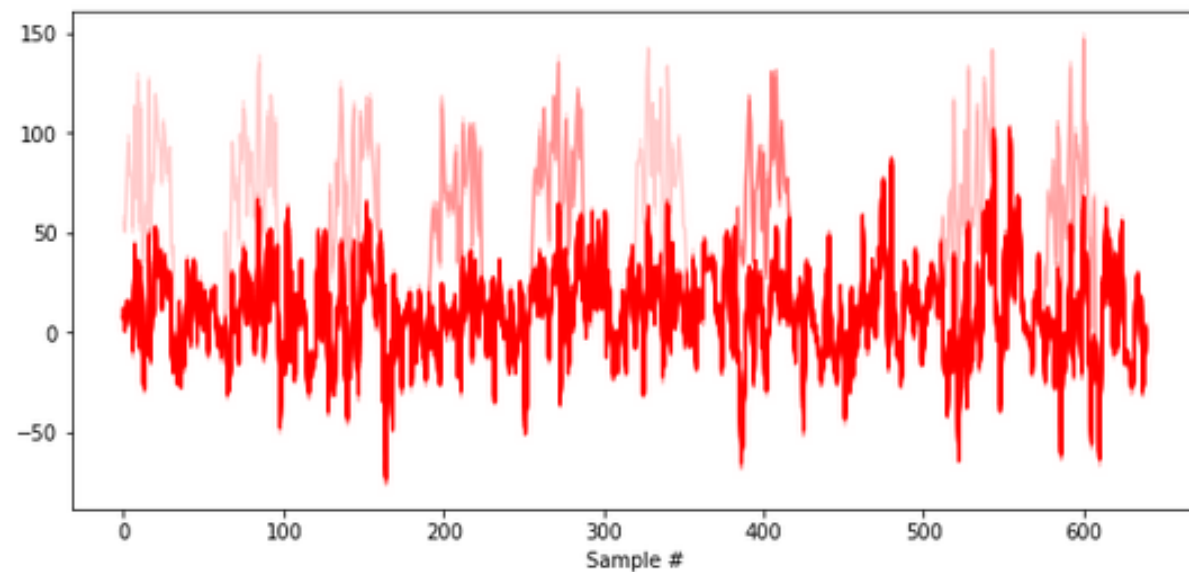
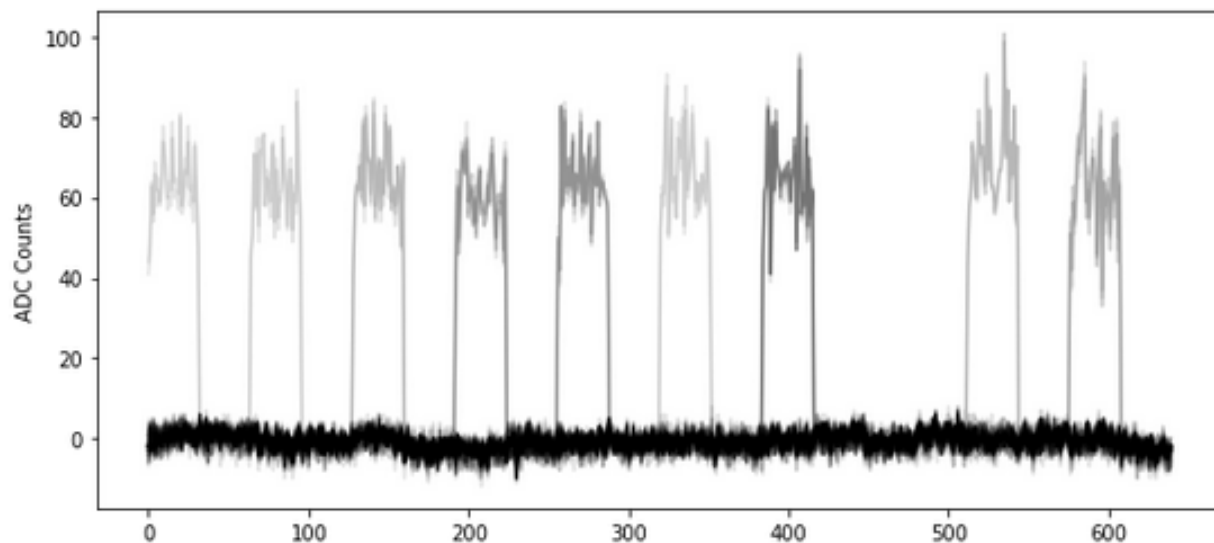
Troubleshooting

Issues	Probable Solution
No Ethernet Connection	- Check if all Ethernet module files are from the Ethernet repo folder (Especially Syncbit.vhd file) - Check power: 6V & 4V
Power	Transition Board(TB) should get 6V & 4V Currently TB-to SCROD Connector's few pins have been taped to avoid TB sending extra Voltage to SCROD
Wrong output response on Terminal	- Check Synthesize Properties - If using cdc ILA, check if all signals are under correct clock domain
QbLink not syncing	- Modify the clocking module
Any other thing not behaving as expected	Check for the ucf file for any incorrect pin connections



SiREAD AnalogReadout State Machine





```
try:
    ax[0].plot(np.array(ev["data"])[0][1::2]) - peds[0][1::2], color=
    #ax[1].plot(np.array(ev["data"])[1][1::2]) - np.mean(peds[1][1::2],
    ax[1].plot(np.array(ev["data"])[1][1::2]) - peds[1][1::2], color=

    except Exception as e:
        print(e)
ax[-1].set_xlabel('Sample #')
ax[0].set_ylabel('ADC Counts')
#ax[0].legend()
```

```
l: Text(0, 0.5, 'ADC Counts')
```

