Physical Layer Prototyping using WARPLab

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WARP Workshop
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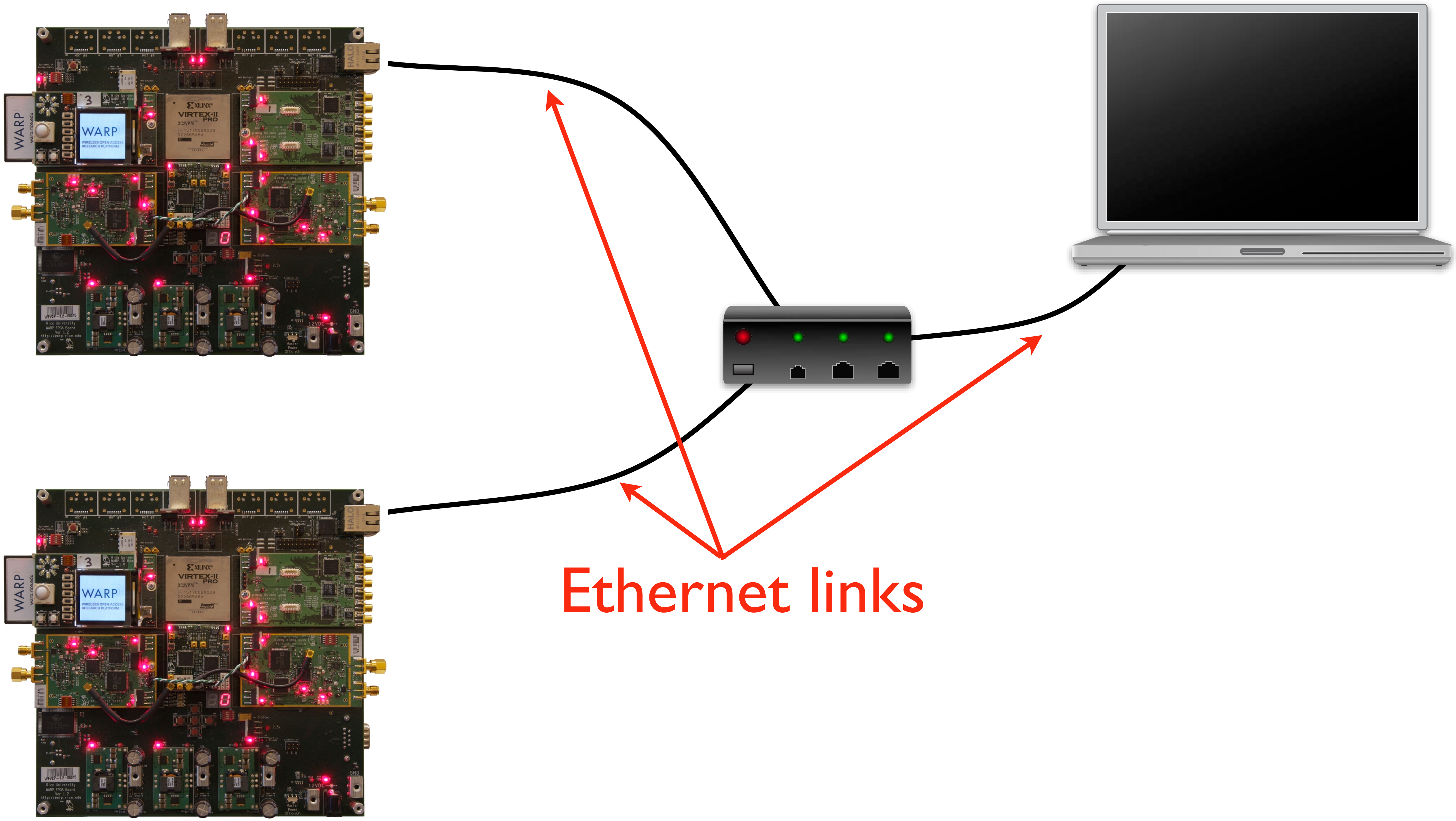
WARP

warp.rice.edu

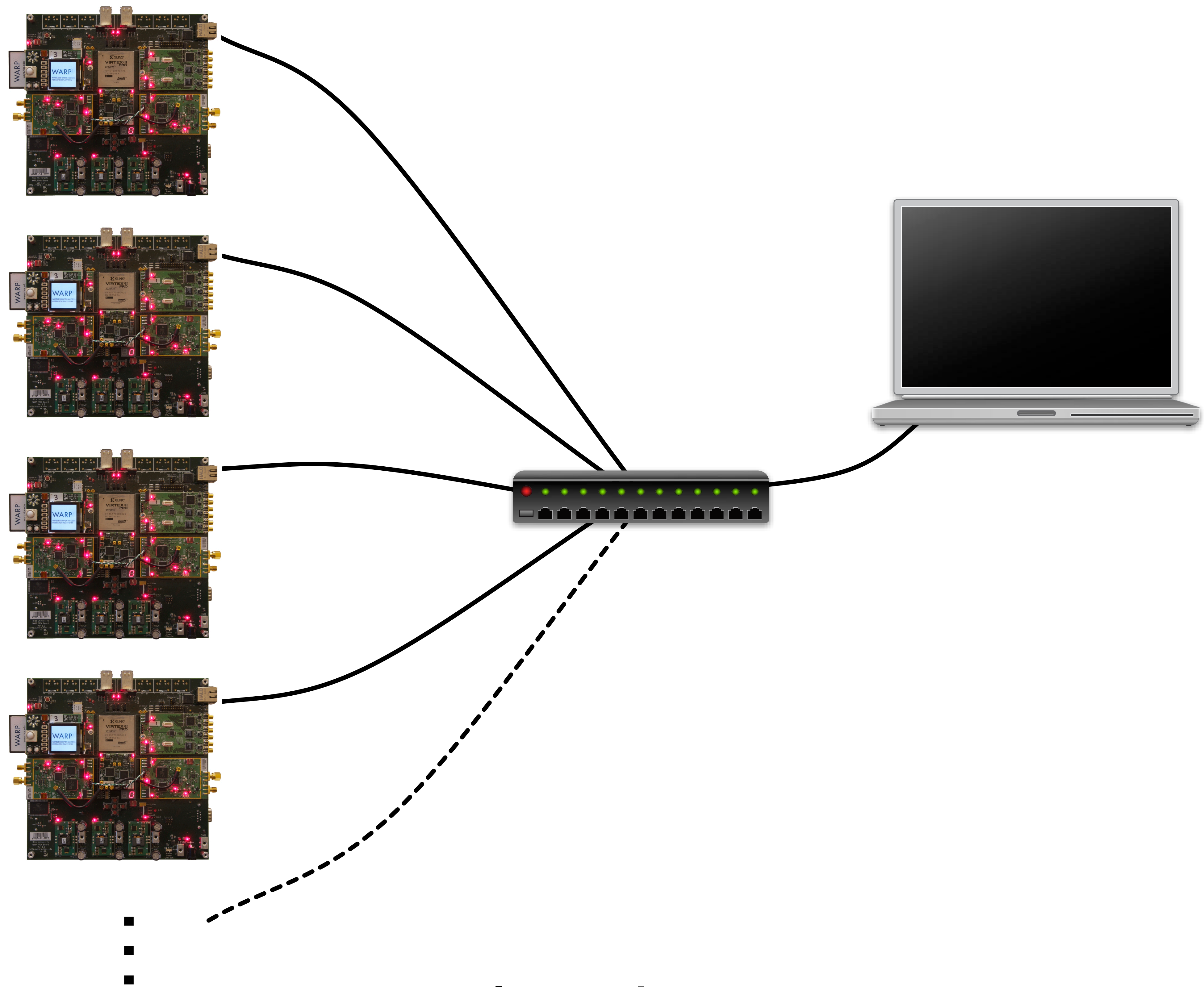
PHY Design Flows

- WARPLab
  - MATLAB↔WARP Link
  - Real-time Tx-Rx and offline processing
  - Very rapid prototyping of PHY algorithms
- Real-time PHY design
  - Low-level FPGA design using Sysgen
  - Putting it all together using XPS

WARPLab Overview

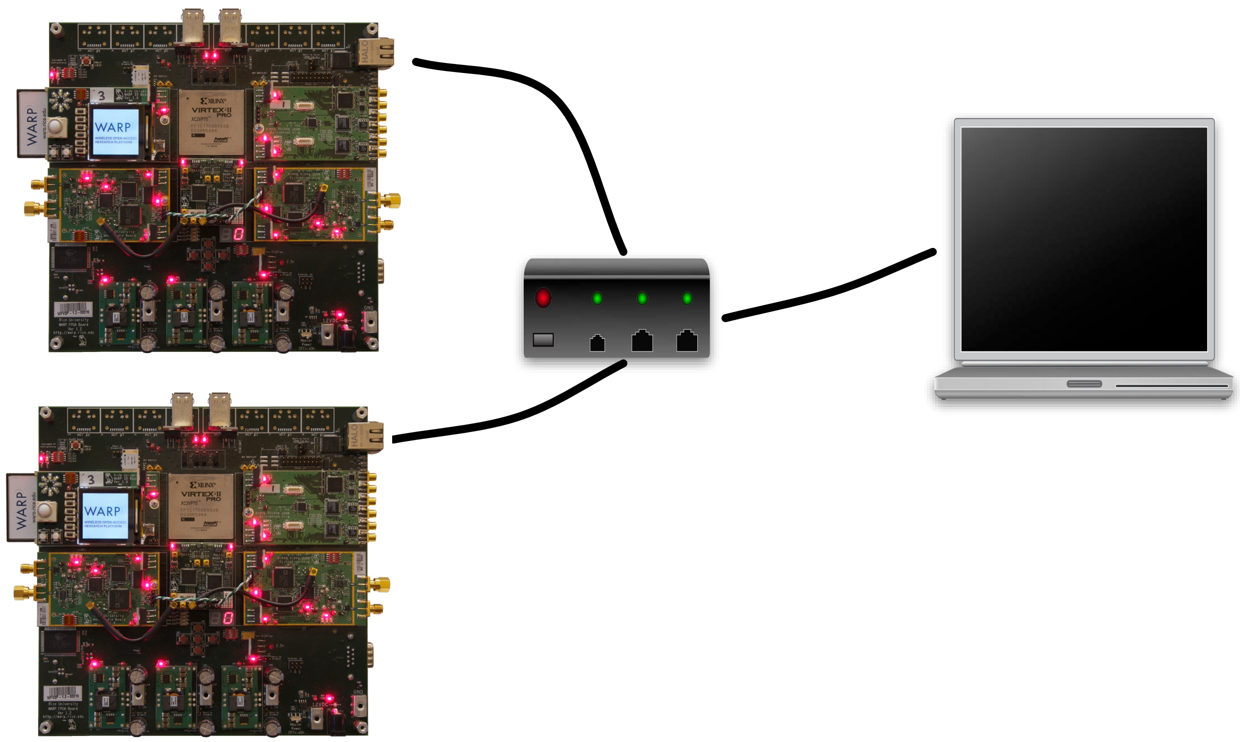


WARPLab Overview



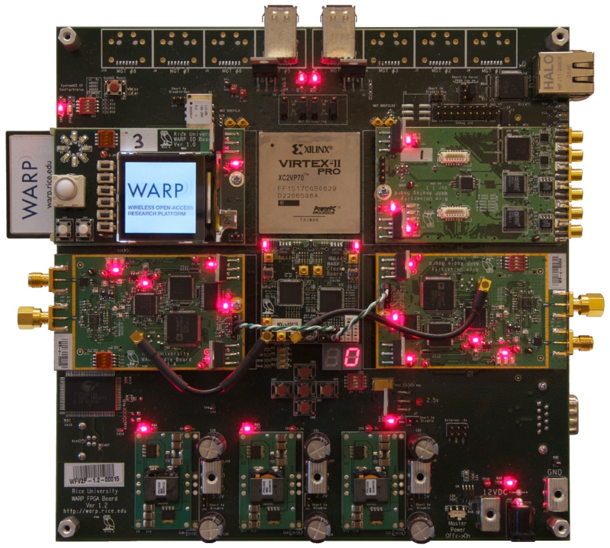
Up to 16 WARP Nodes

WARPLab Overview



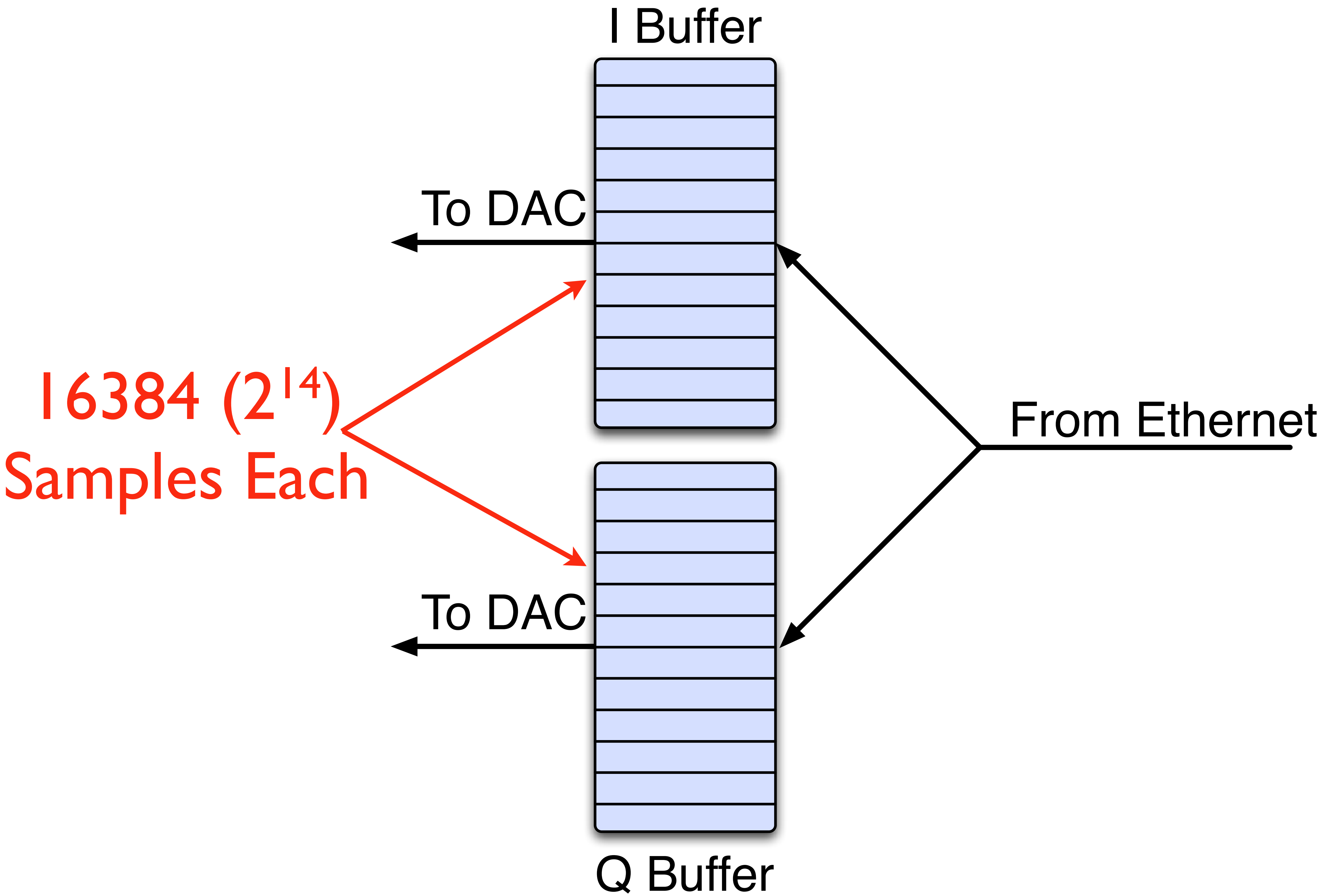
- One PC controls many WARP nodes
- MATLAB for signal processing
- Non-real-time processing
- WARP for wireless interfaces
- Real-time channel use

WARPLab Architecture



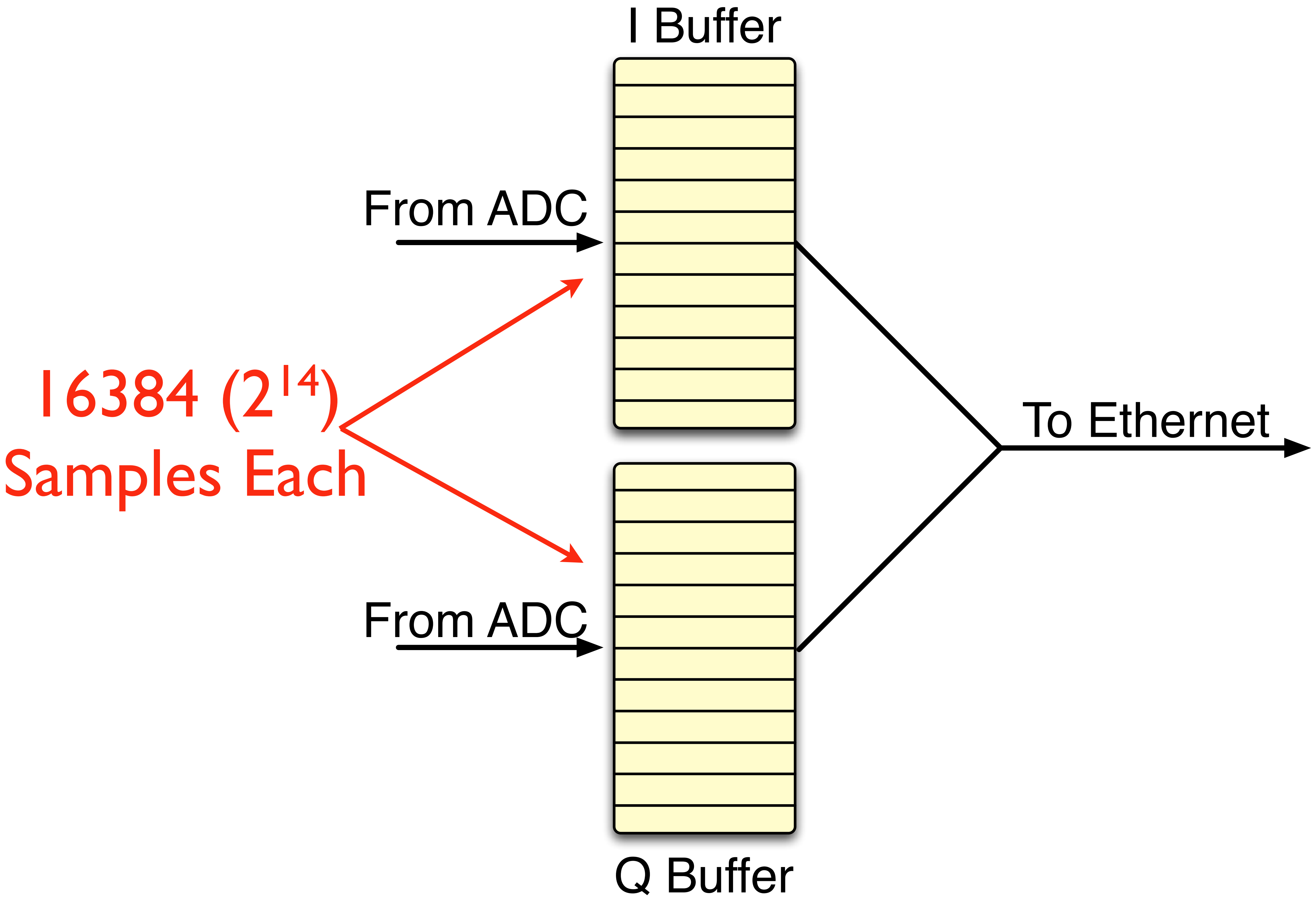
- Bitstream is provided
    - Reference design is provided
- Same bitstream for all nodes
    - Any node can be Tx or Rx
- MATLAB user interface
    - M-code functions provided facilitate interaction with boards
- All open-source

WARPLab Architecture



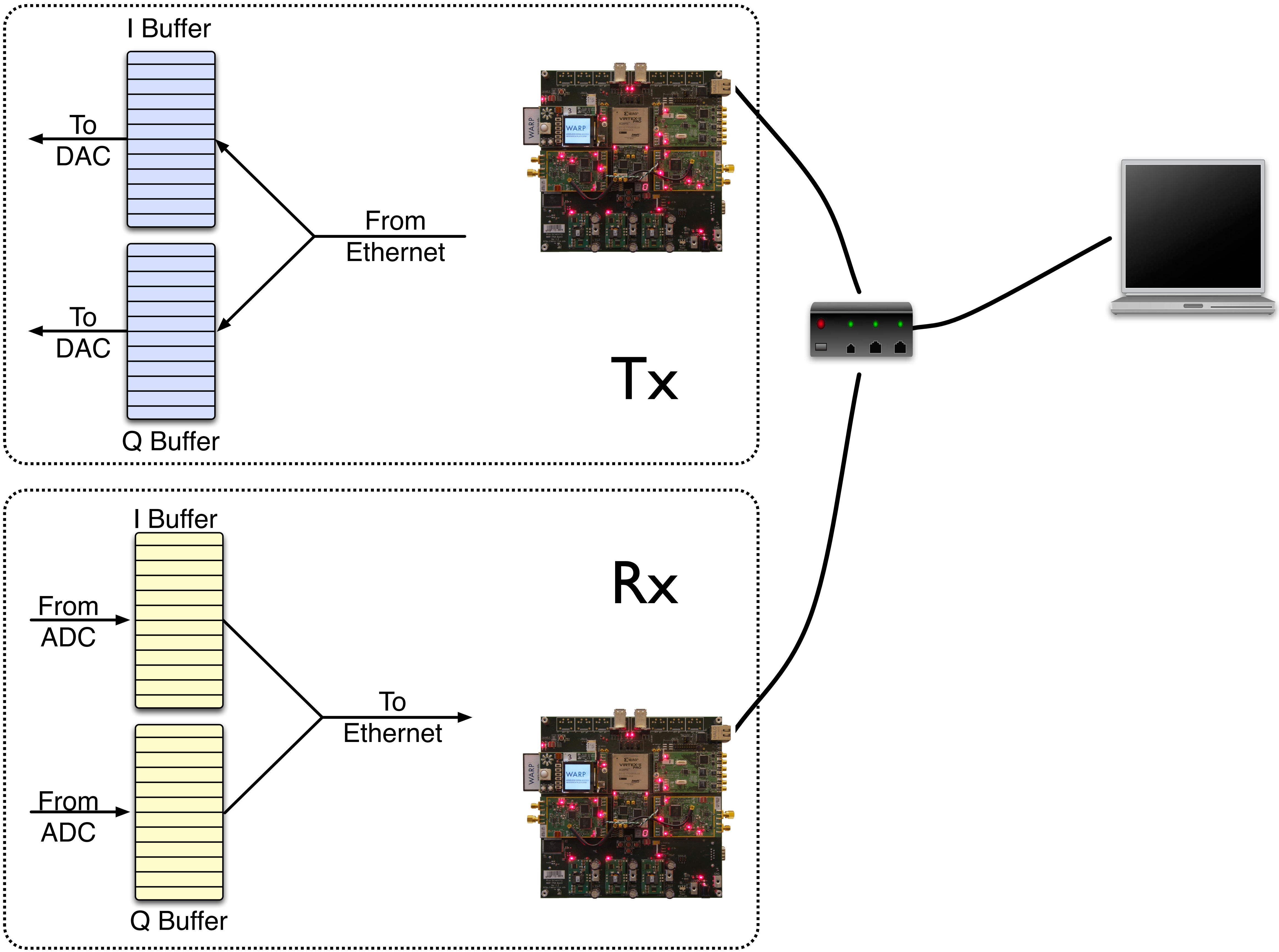
Transmit Path

WARPLab Architecture

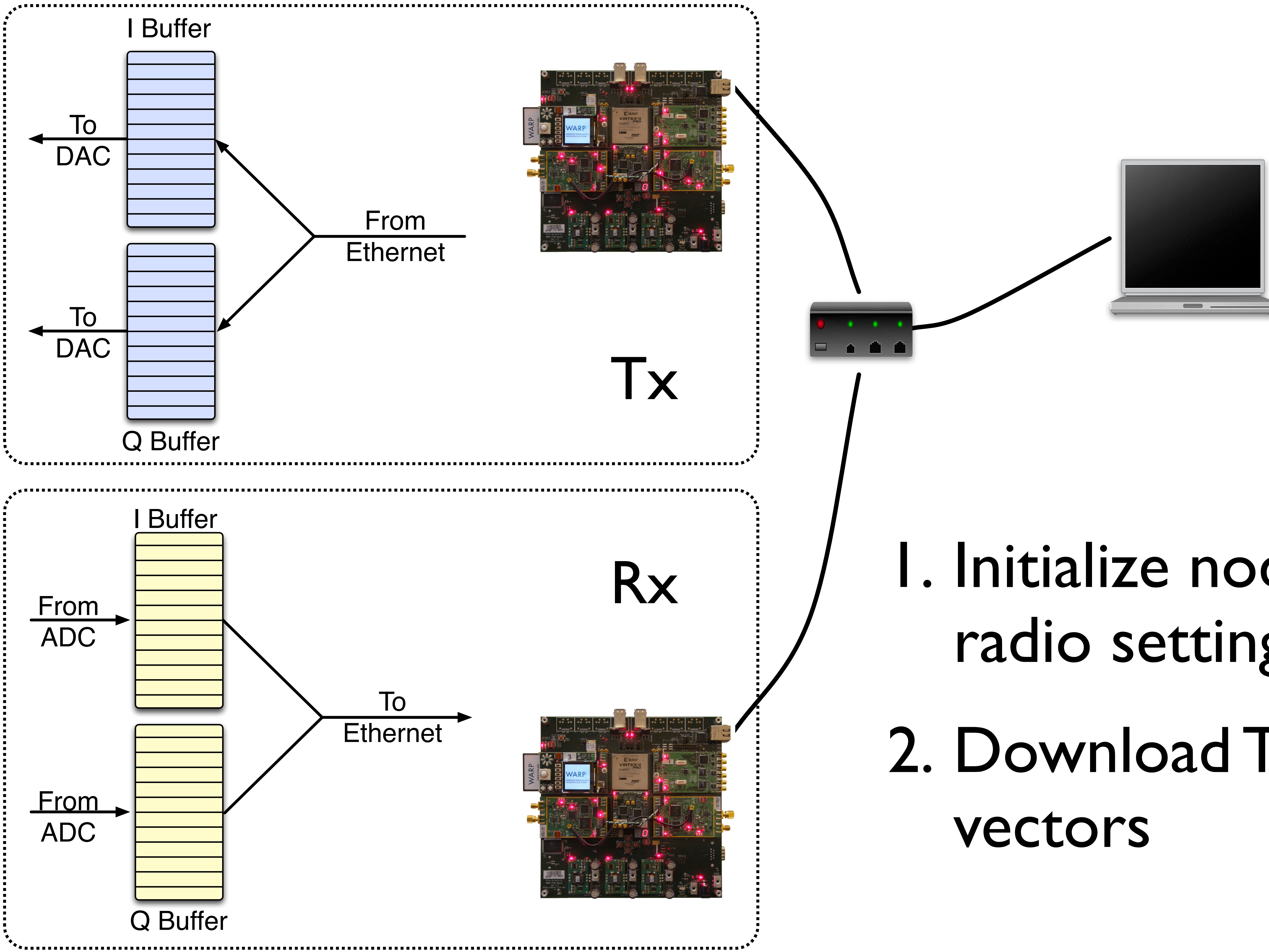


Receive Path

WARPLab Flow

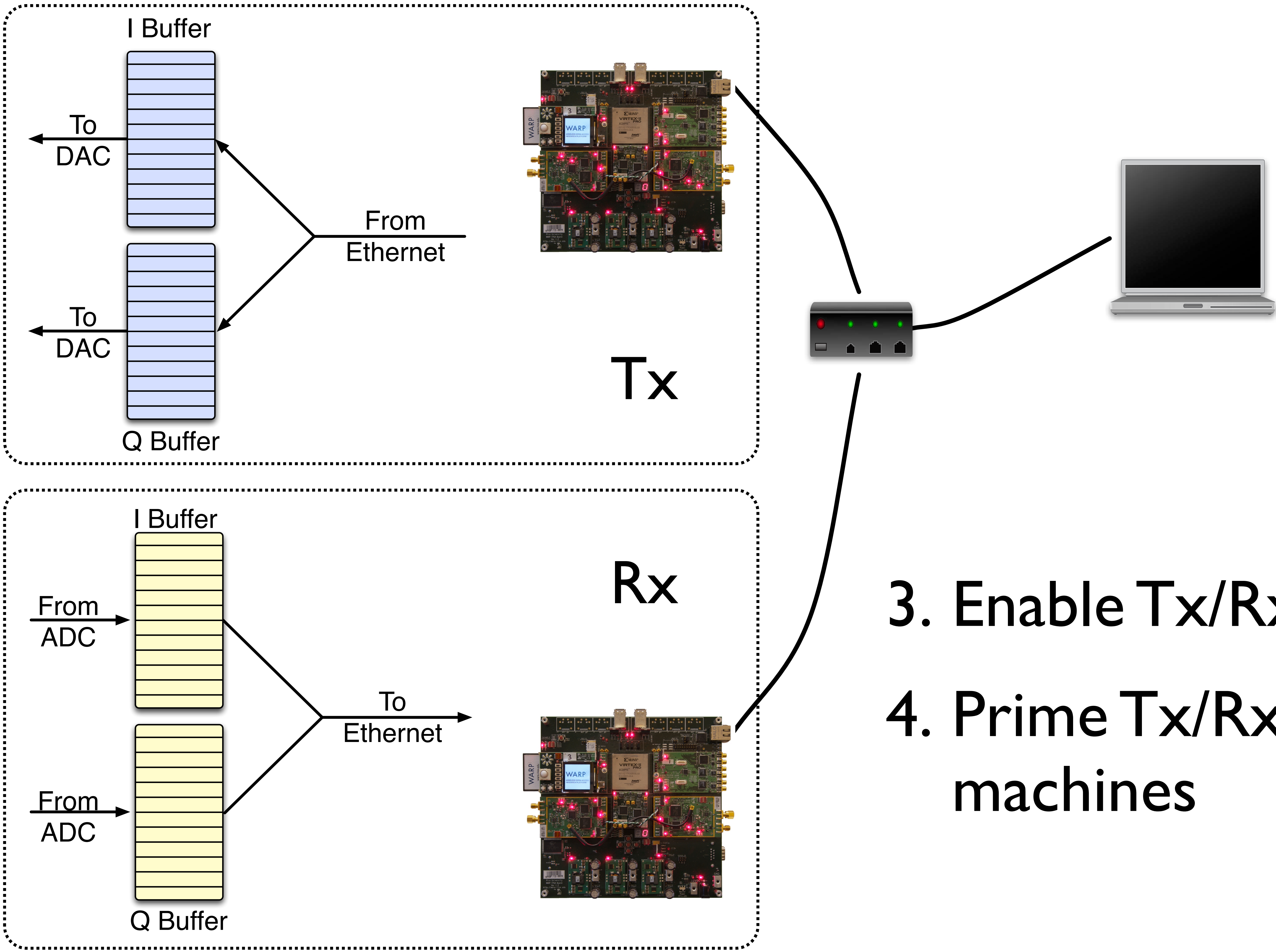


WARPLab Flow



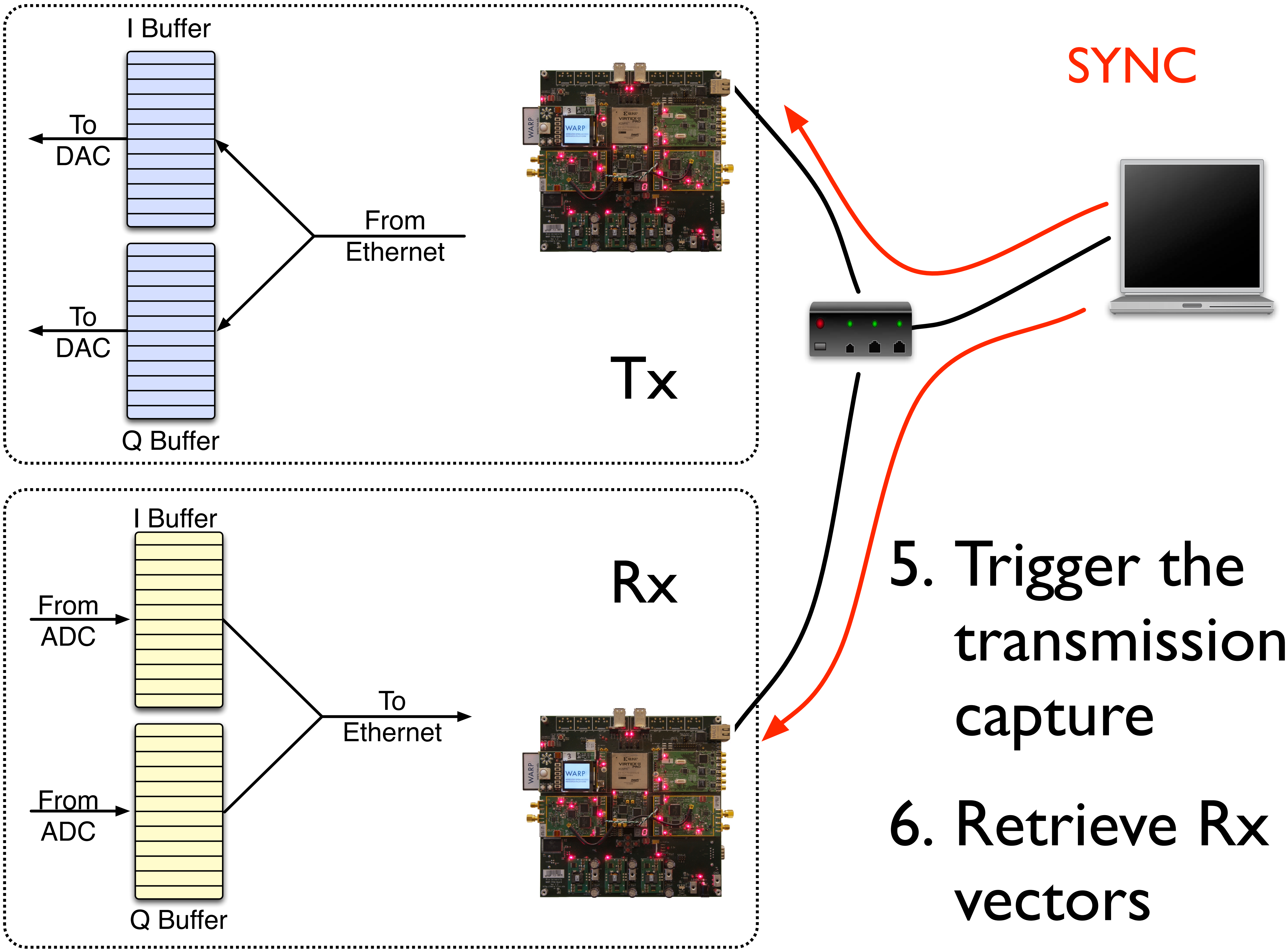
1. Initialize nodes & radio settings
2. Download Tx vectors

WARPLab Flow



3. Enable Tx/Rx paths
4. Prime Tx/Rx state machines

WARPLab Flow

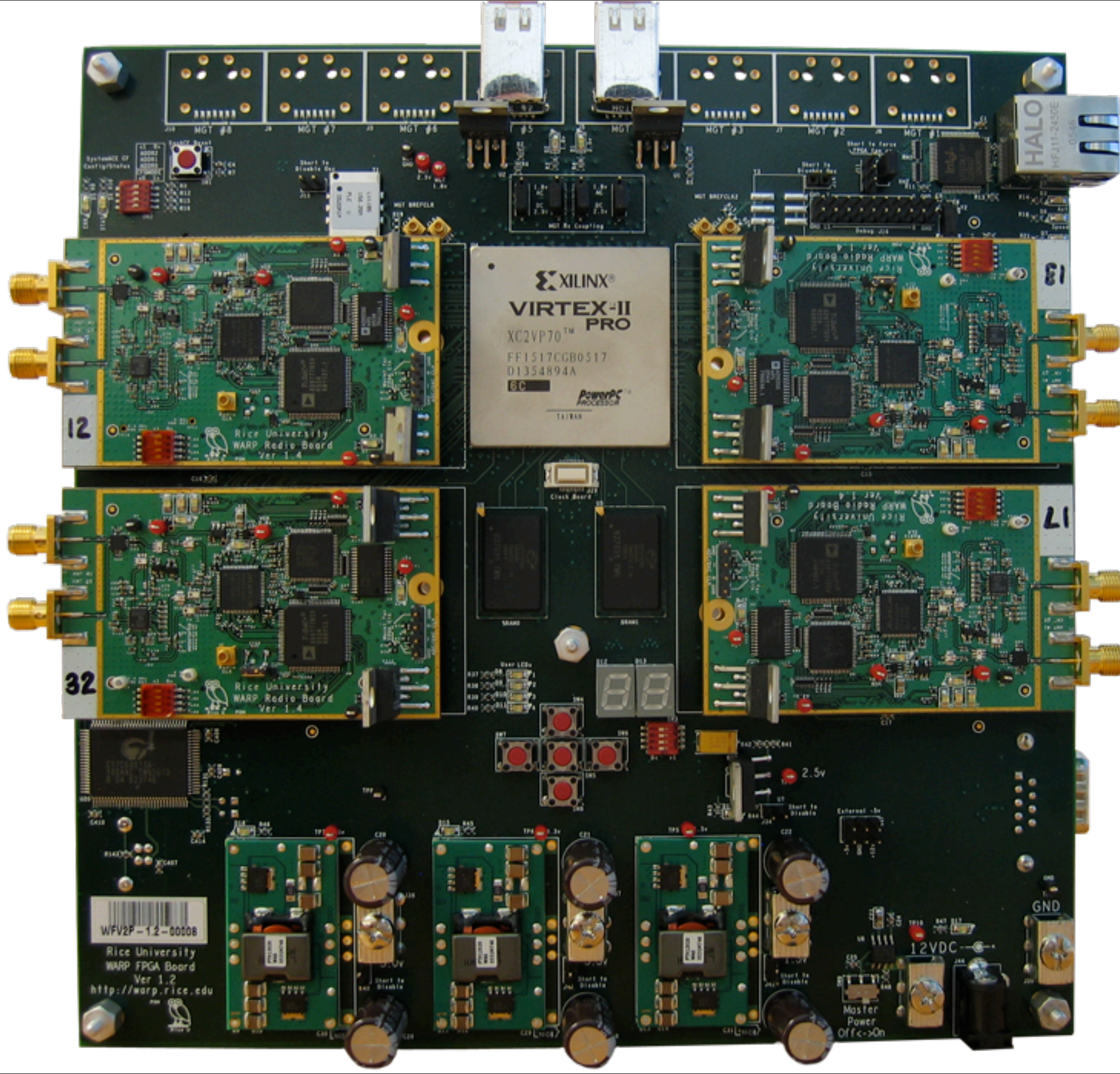


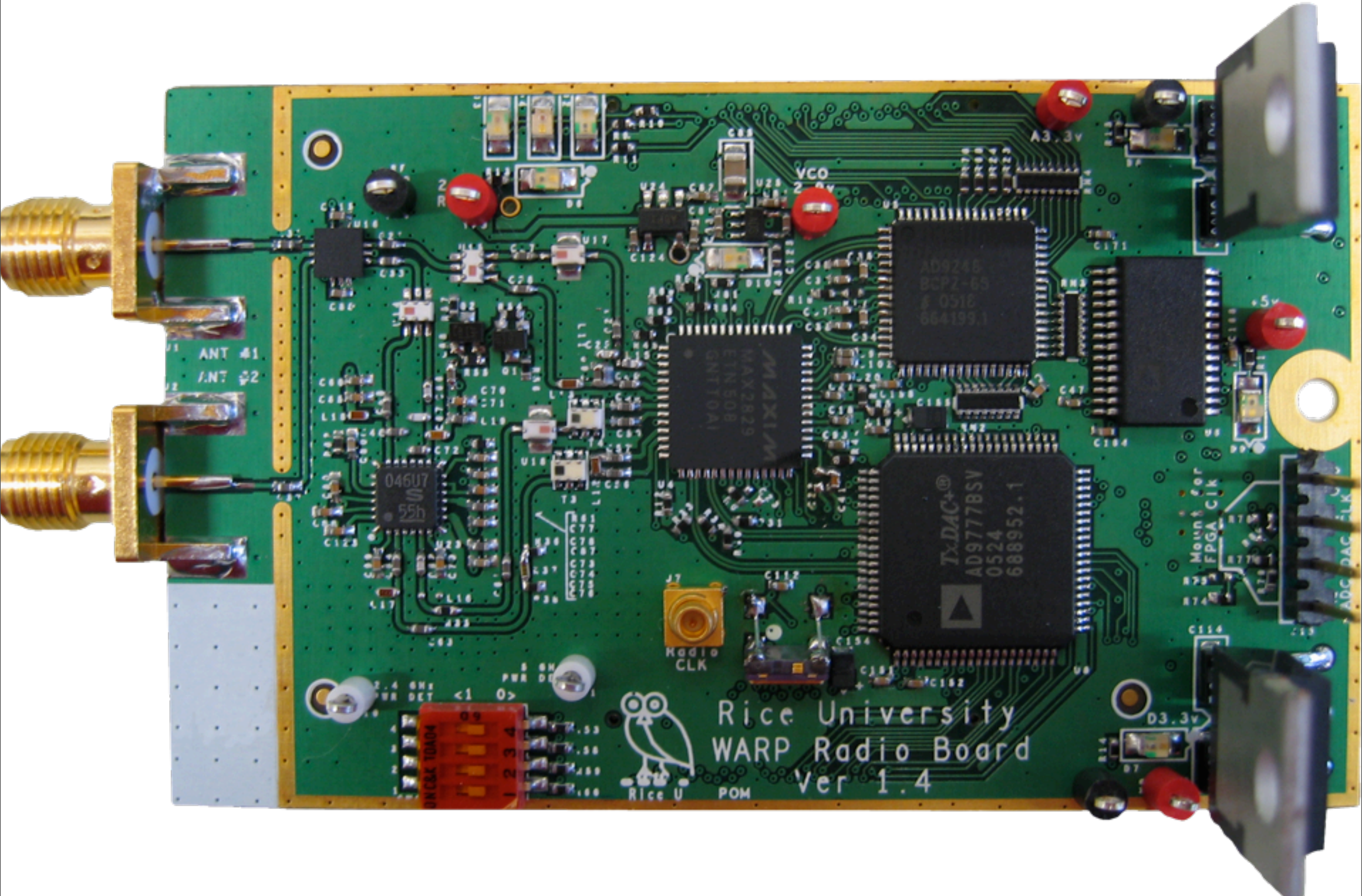
5. Trigger the transmission and capture

6. Retrieve Rx vectors

WARPLab Architecture

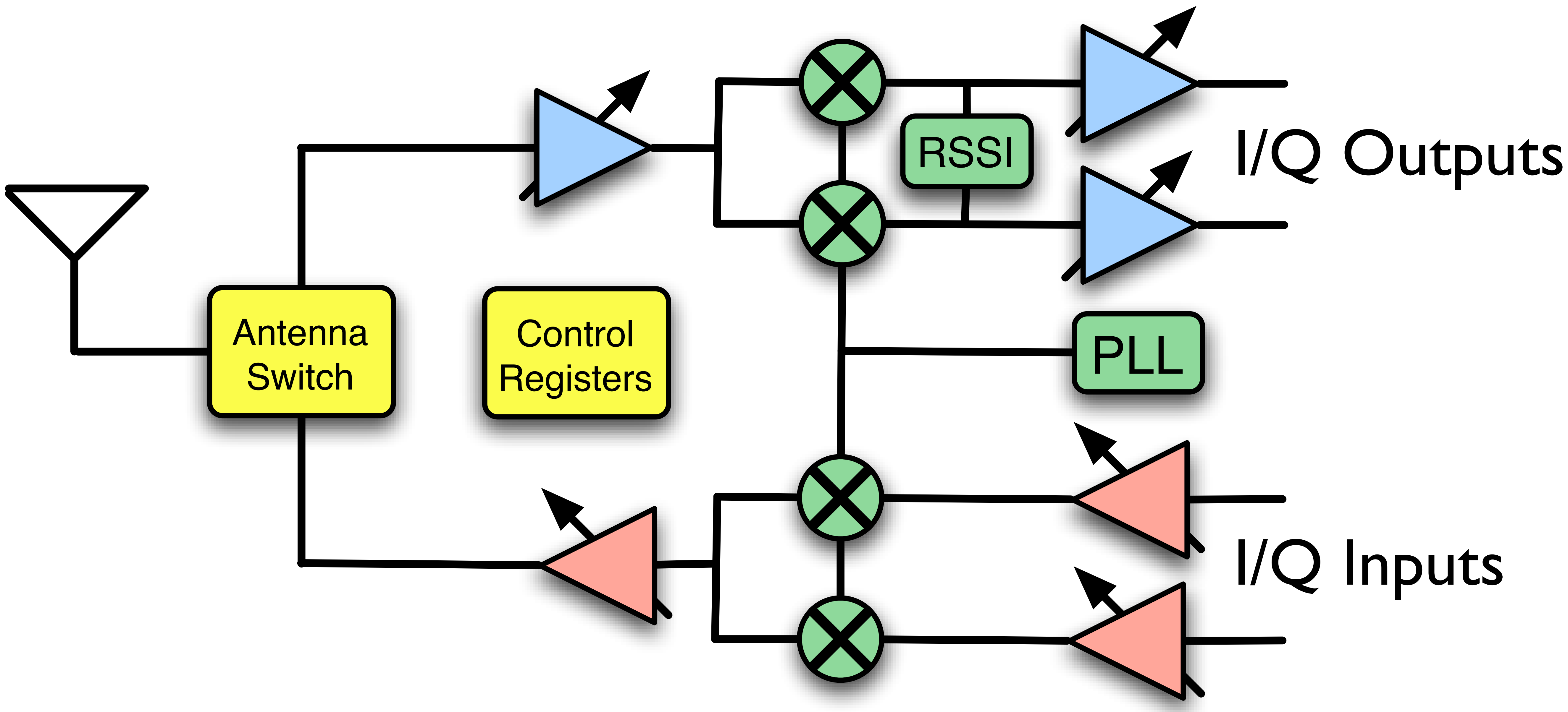
- Independent Tx/Rx buffers
  - Buffers persist between triggers
  - Rx path captures I/Q and RSSI
- Control and synchronization by Ethernet
- Low-level radio control
  - Tx/Rx gains
  - Center frequency


XILINX
VIRTEX-II PRO
XC2VP70
FF1517CGB0517
D1354894A
6C
PowerPC PROCESSOR
HALO
Rice University
WARP Radio Board
Ver 1.4
12
32
Rice University
WARP FPGA Board
Ver 1.2
http://warp.rice.edu
WFV2P-1.2-00008
2.5v
12VDC
GND
Master
Power
Off<->On



Rice University
WARP Radio Board
Ver 1.4
Rice U
POM
MAXIM
MAX2829
AD9248
BCPZ-65
TxDAC+
AD9777BSV
Radio
CLK
ANT #1
ANT #2
A3.3v
VCO
+5v
D3.3v
Mount for
FPGA Clk

Radio Transceiver



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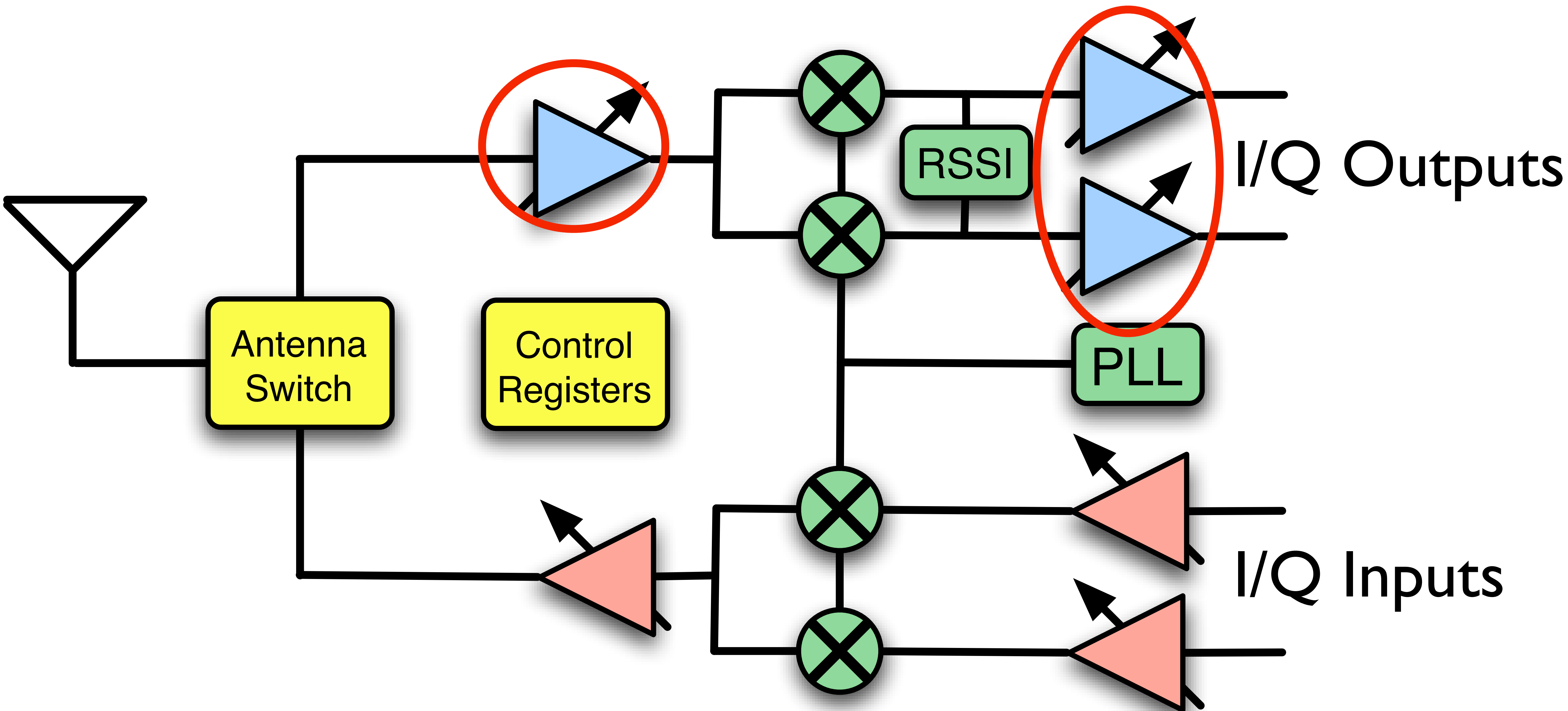
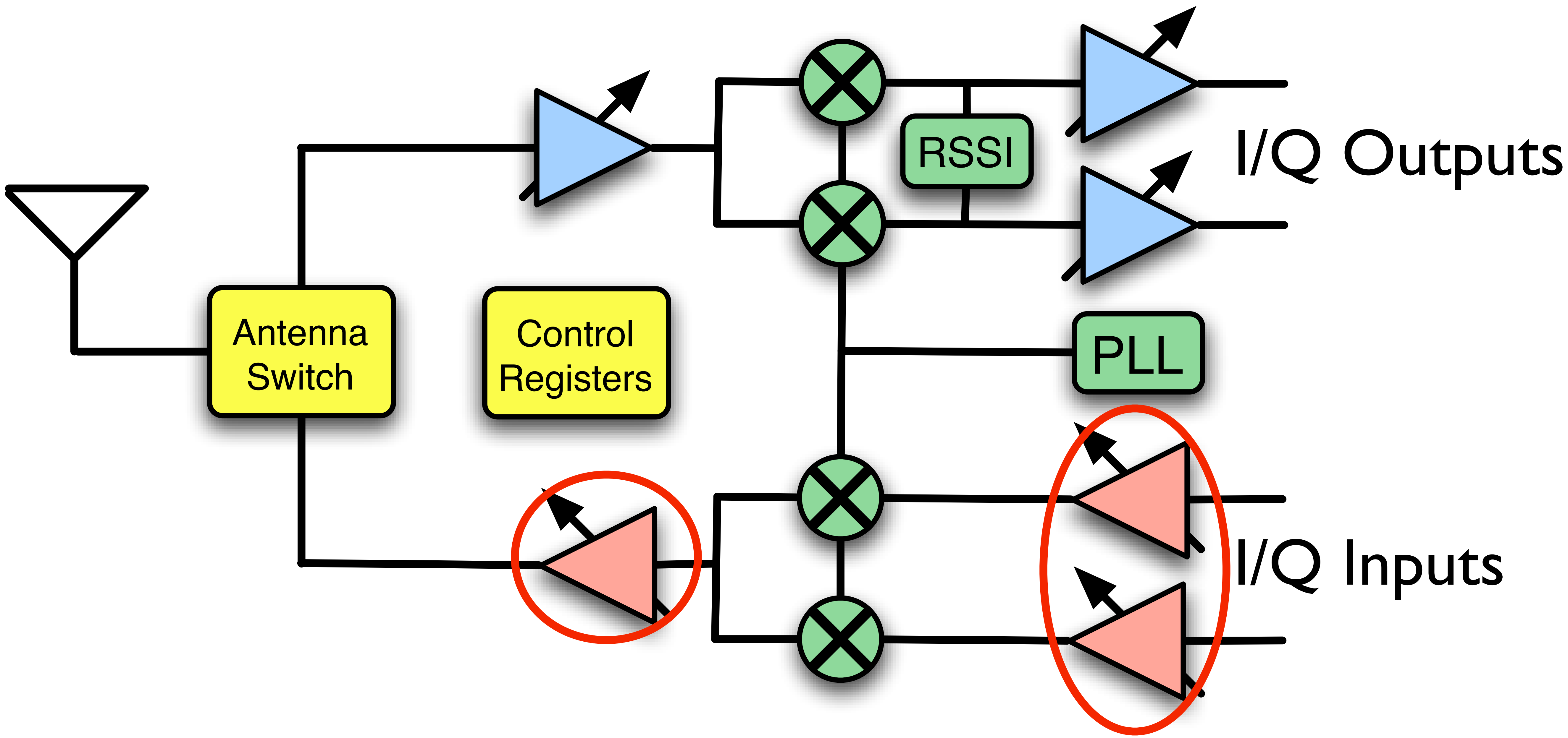


Variable Gain Rx Amplifiers
Gain value input from MATLAB

Radio Transceiver



Variable Gain Tx Amplifiers
Gain value input from MATLAB

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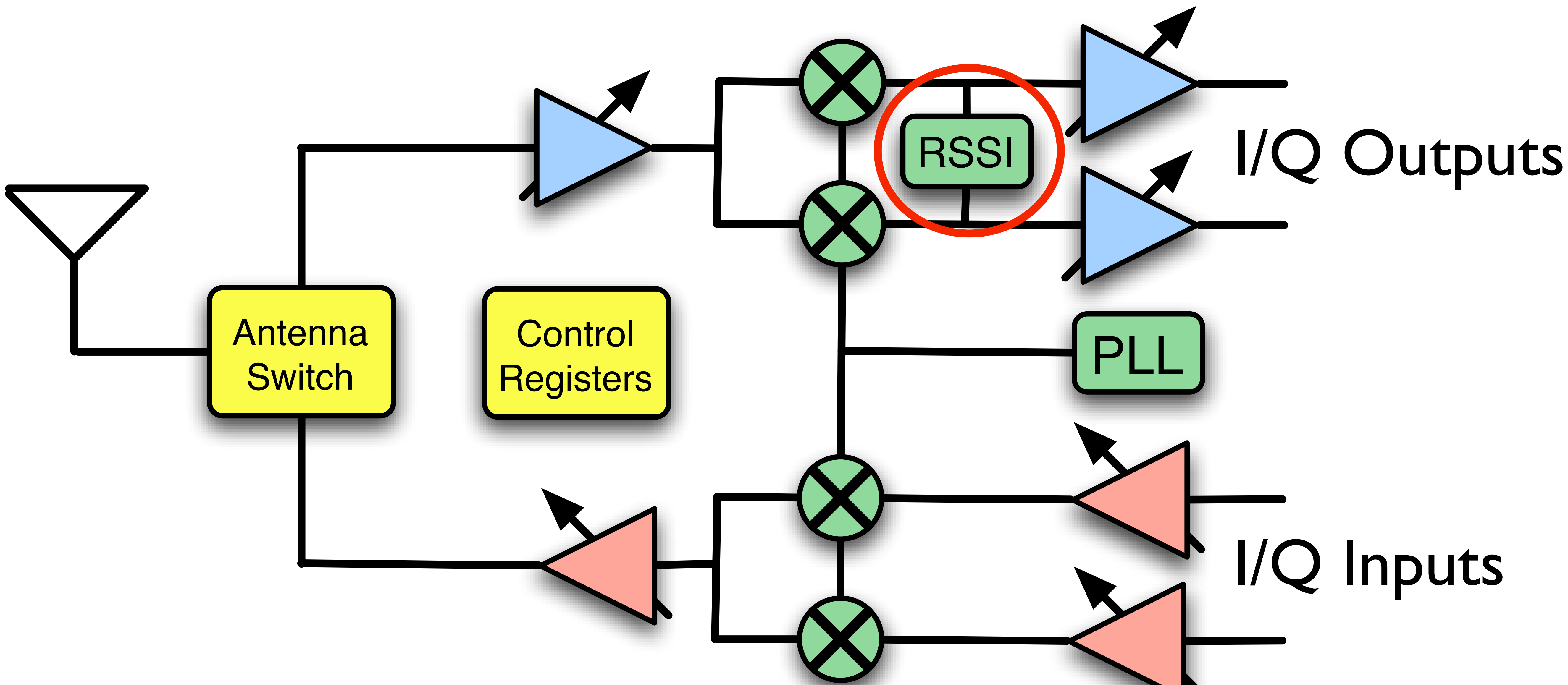
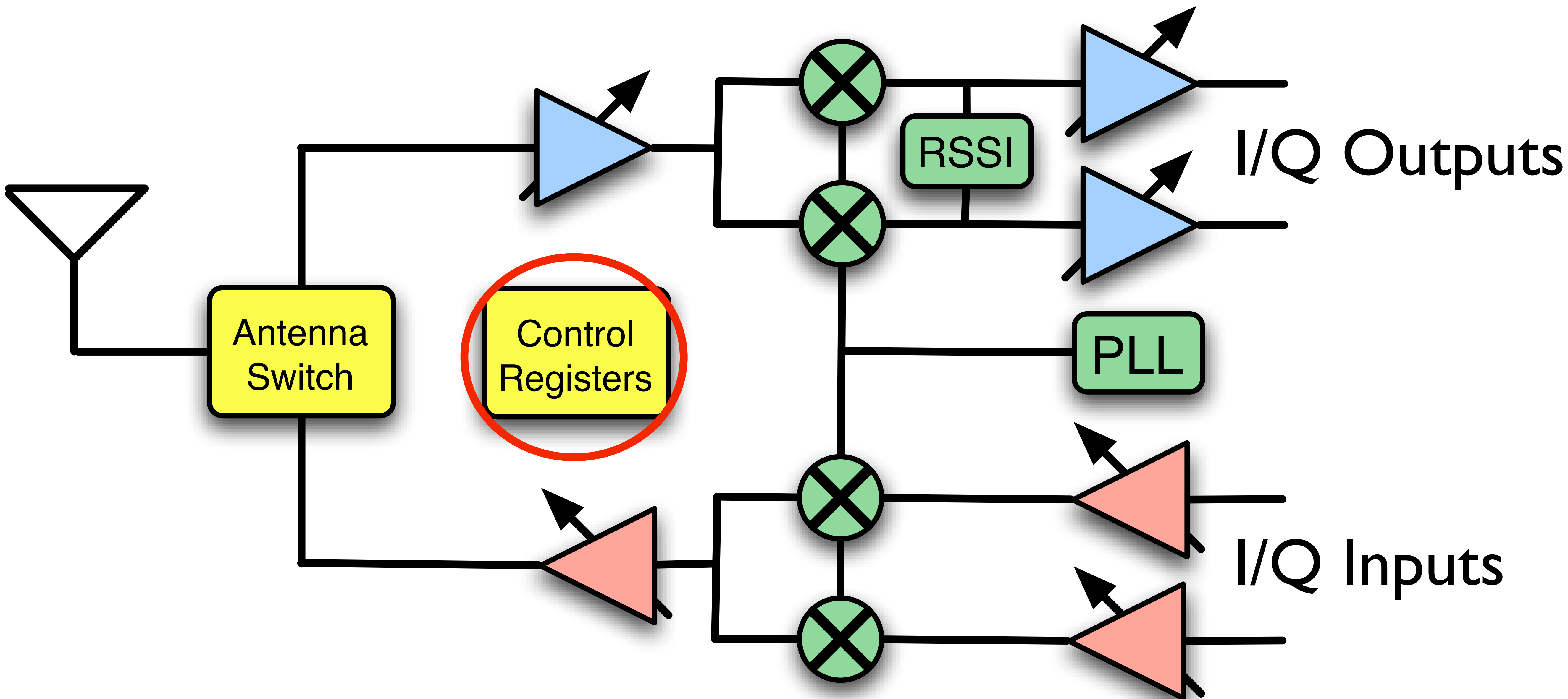


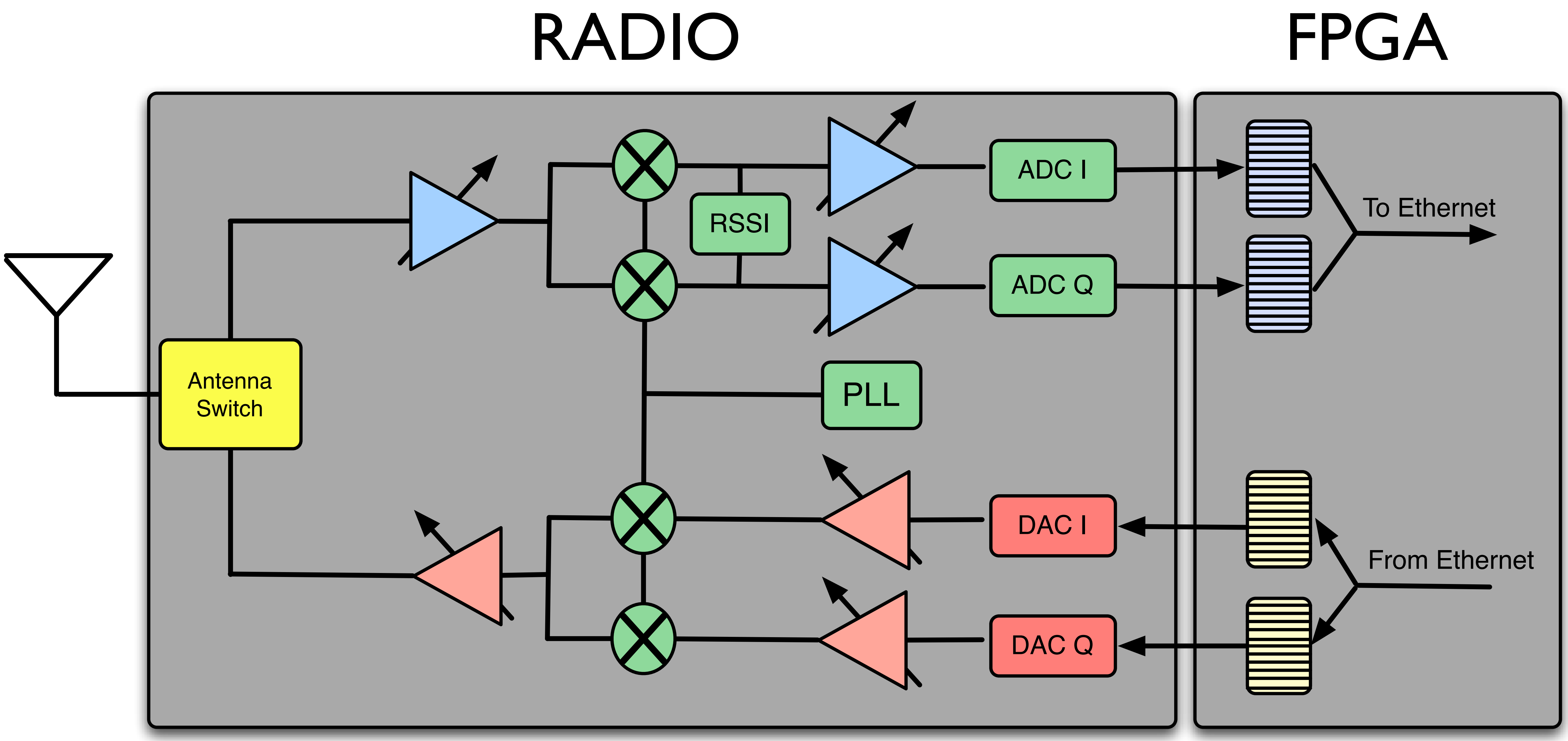
Received Signal Strength Indicator After RF Gain
Written in a buffer in the FPGA
Can be read from MATLAB

Radio Transceiver



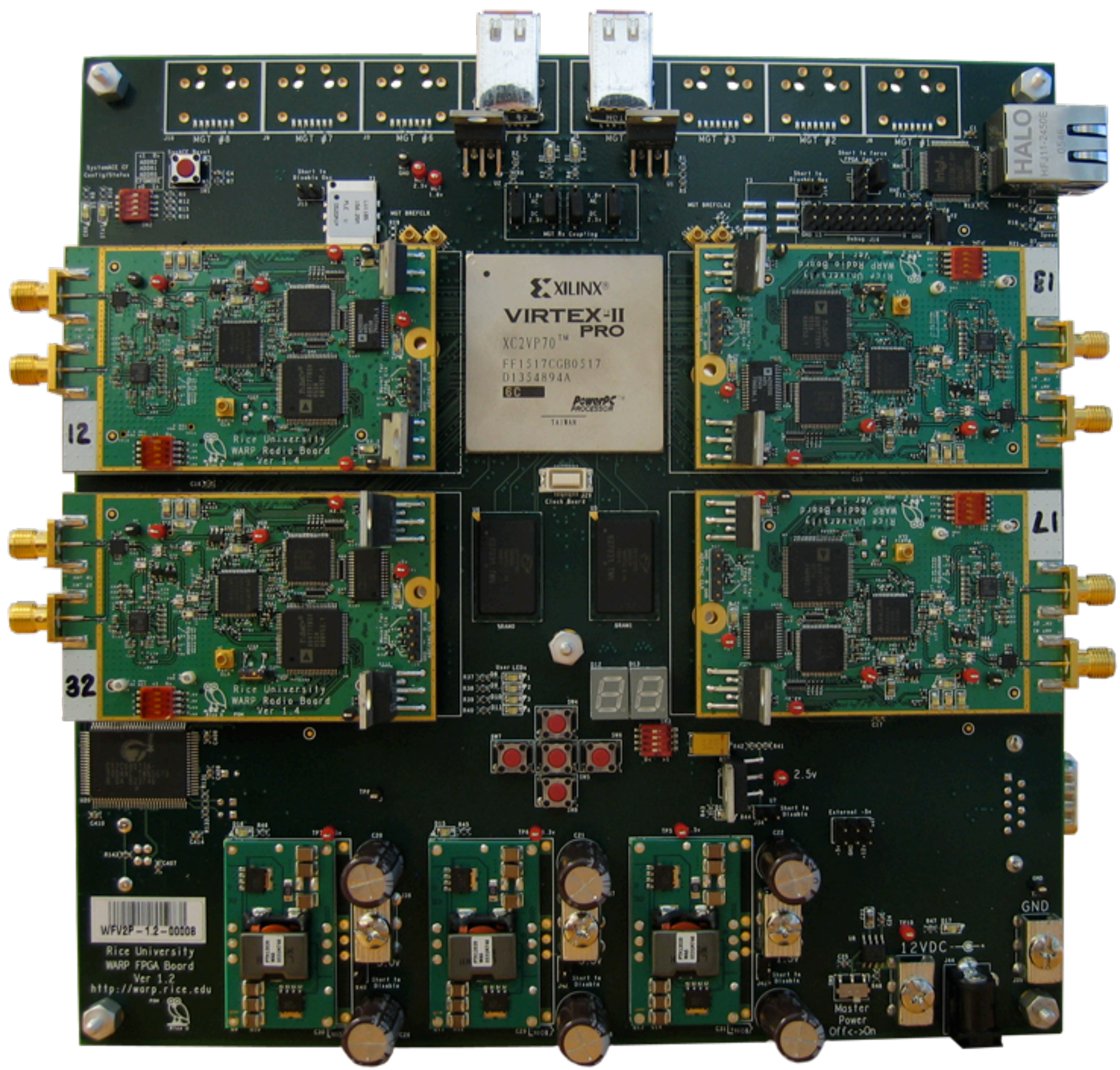
Register Bank
(controlled by SPI interface)

WARPLab Architecture



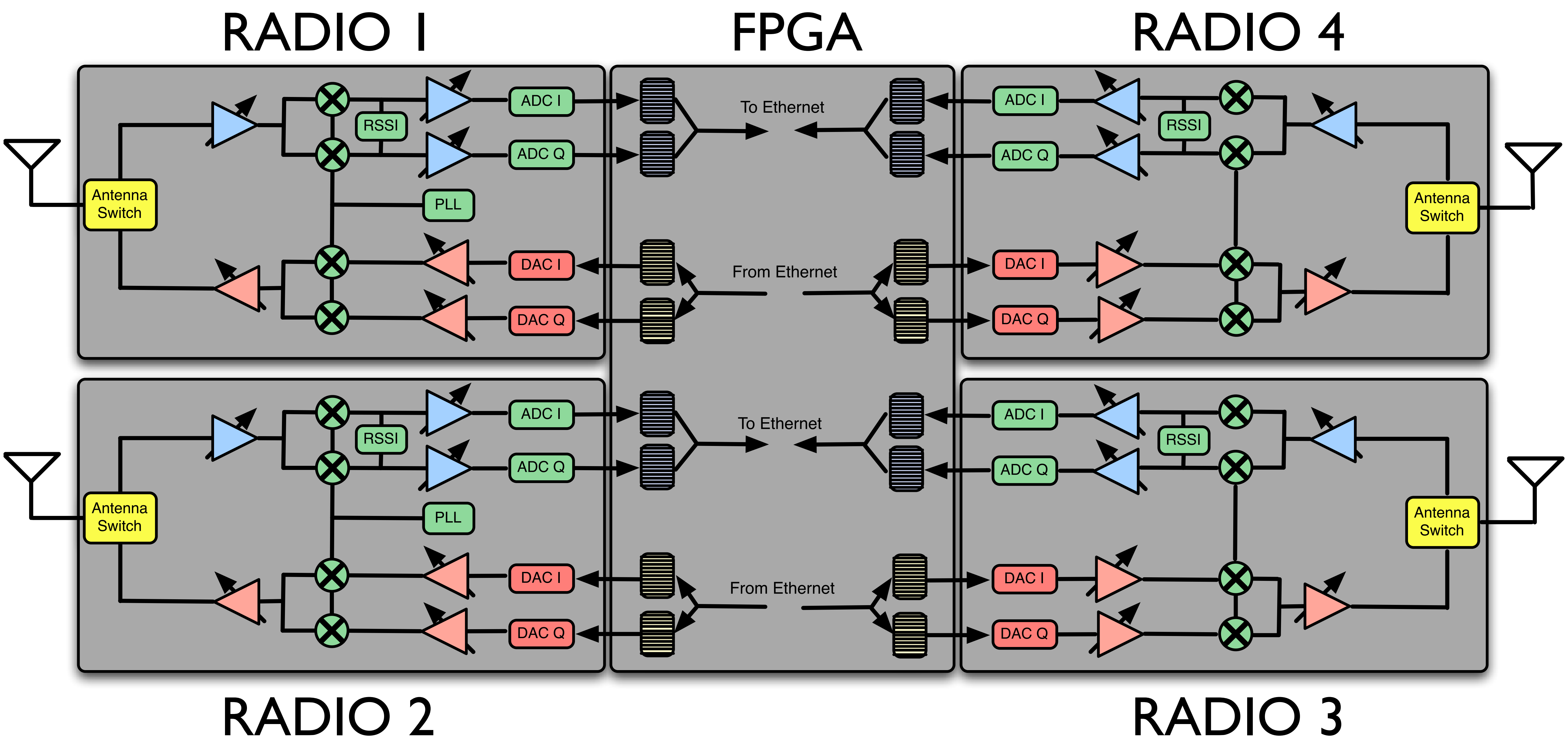
WARPLab Architecture

4x4 node



WARPLab Architecture

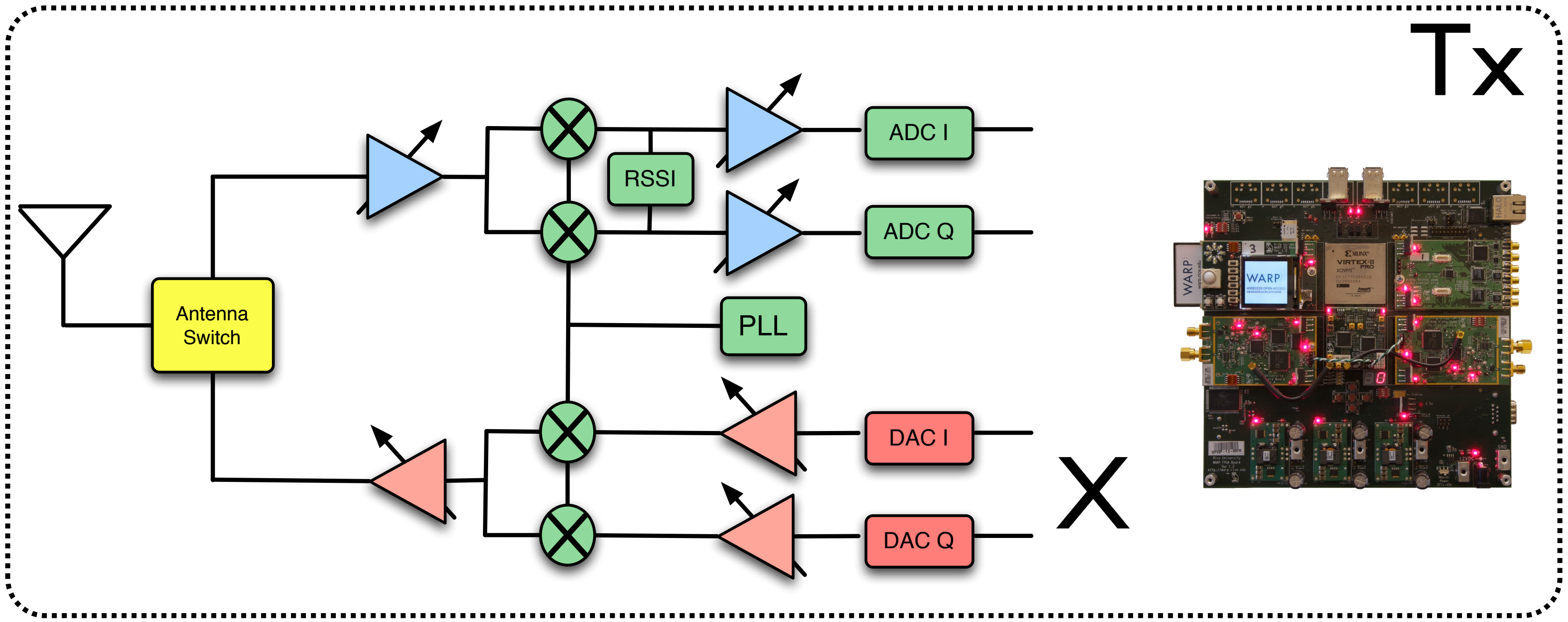
4x4 node



Tx Signal Requirements

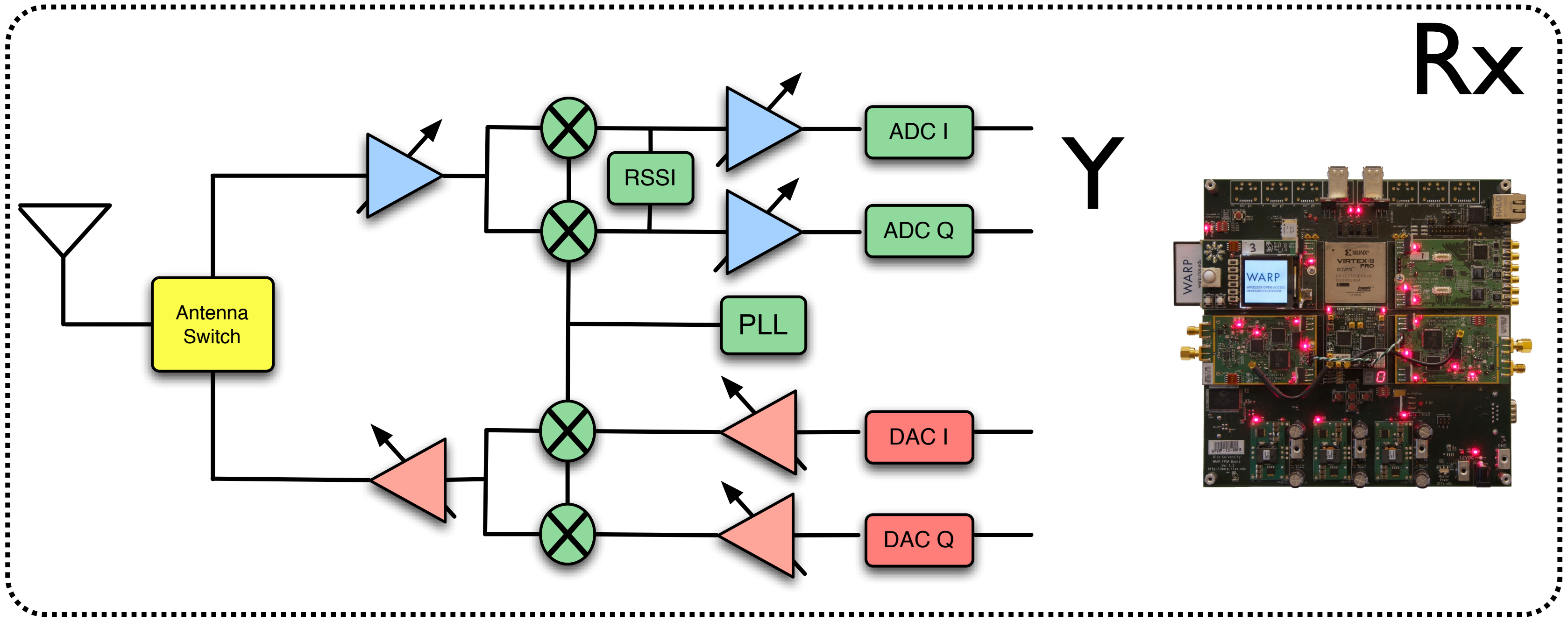
- Amplitude of real part in [-1,1]
- Amplitude of imaginary part in [-1,1]
- Highest frequency 9.5 MHz (19 MHz BW)
- Lowest frequency 30 KHz
- 40 MHz sampling

Tx to Rx path



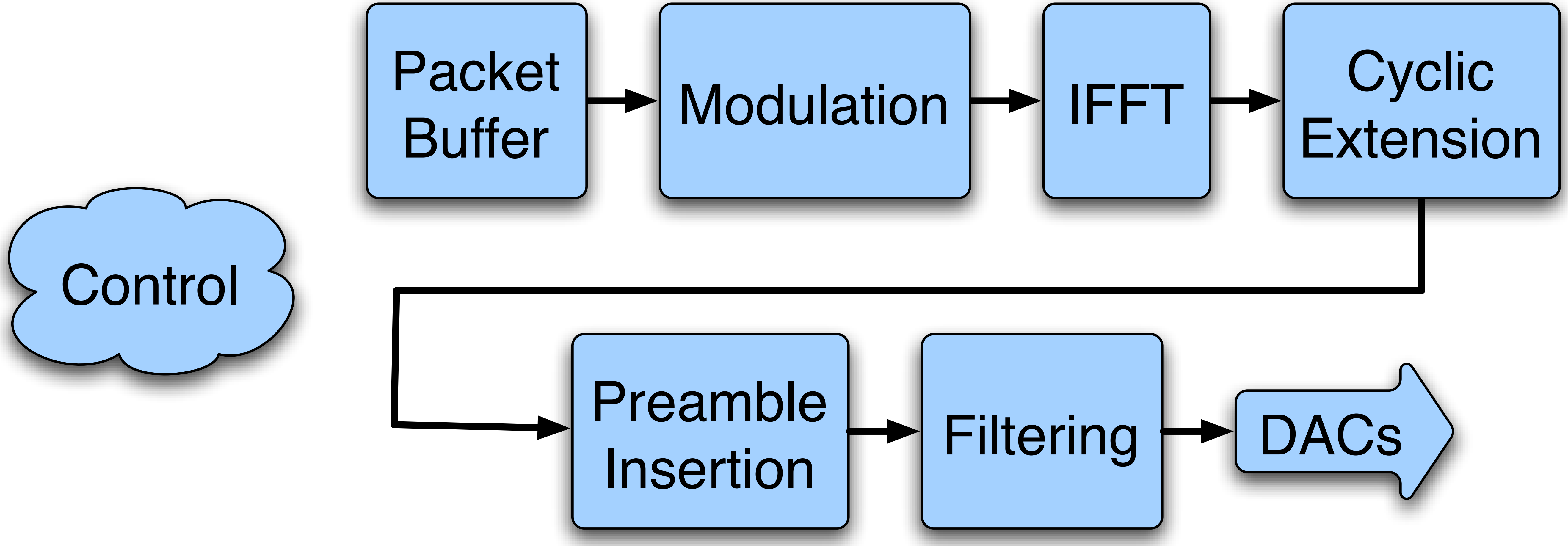
$Y = |H| \, G_{RXBB} \, G_{RXRF} \, G_{TXPA} \, G_{TXRF} \, G_{TXBB} \, X$

|H| : Wireless channel magnitude



PHY Example: OFDM Tx

WARPLab offline vs. Sysgen real-time



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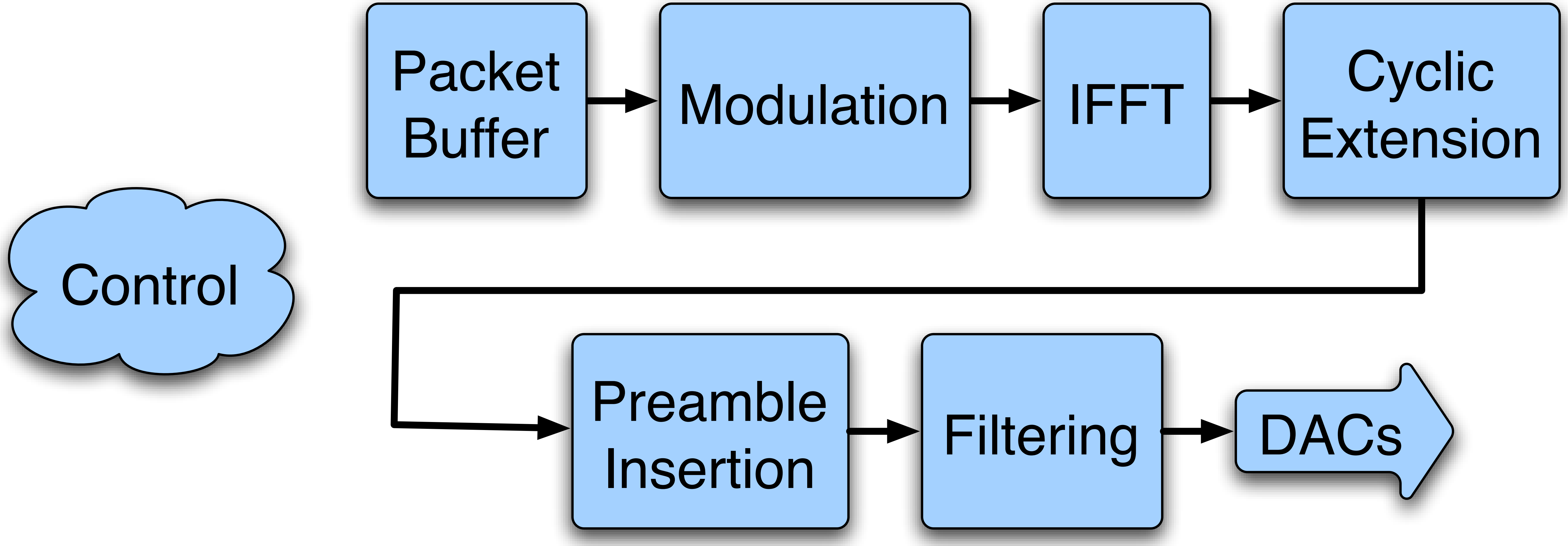
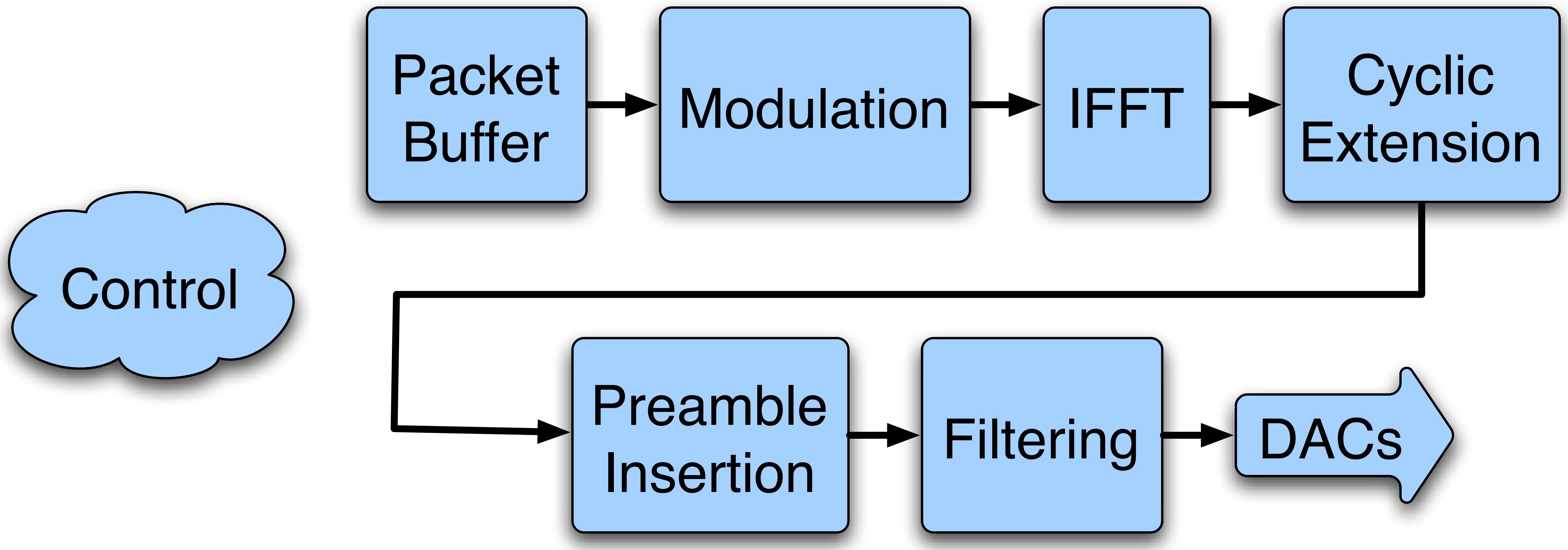


- Offline Matlab processing
- Download samples to board
- Real-time Tx/Rx

PHY Example: OFDM Tx

WARPLab offline vs. Sysgen real-time



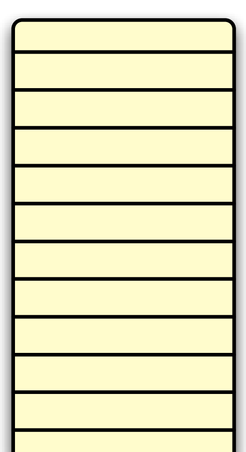
- Each sample to DACs is generated in real-time
- Real-time Tx/Rx

PHY Example: OFDM Tx

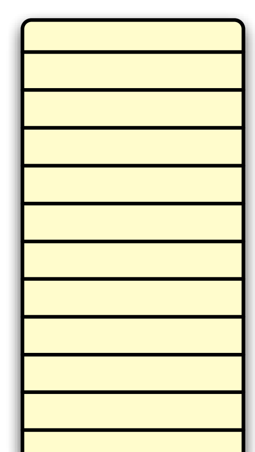
WARPLab offline vs. Sysgen real-time

```
trainingSym_freq = [0 -1 1 -1 1 -1 1 -1 1 -1 -1 -1 -1 1 1 -1 1 1 1 1 1 -1 -1 1 1 -1 -1 0 0 0...
 0 0 0 0 0 0 0 0 1 -1 1 1 1 -1 -1 -1 -1 1 1 -1 1 -1 1 1 -1 1 1 1 -1 -1 -1 -1 -1 -1];
trainingSyms_time = ifft(trainingSym_freq, 64);
numBytes = 240;
numOFDMSyms = 20;
fftWindowOffset = 6;
numTrainingSyms = 4;
pilotTonesTx = (randint(numOFDMSyms, 4, 2) .* 2) - 1;

dataTx_qpsk = randint(1, numBytes*4, 4);
mod_qpsk = qammod([0:3], 4, 0, 'gray');
modnorm_qpsk = modnorm(mod_qpsk, 'avpow', 1);
symsTx_qpsk = repmat([zeros(1,47) 1], 1, 20);%qammod(dataTx_qpsk, 4, 0, 'gray') .* modnorm_qpsk;
symsTx_qpsk = qammod(dataTx_qpsk, 4, 0, 'gray') .* modnorm_qpsk;
symsTx_mat = reshape(symsTx_qpsk, 48, numOFDMSyms).'; %20x48
ifftInTx = zeros(20, 64);

%Start filling in the FFT input matrix, leaving zeros where needed
% Columns: 1->DC, 32->max +freq, 33->max -freq, 64->min -freq
% Leave zeros in columns([1 8 22 28:32 33:38 44 58])
ifftInTx(:, [2:7 9:21 23:27 39:43 45:57 59:64]) = symsTx_mat; %20x64
ifftInTx(:, [8 22 44 58]) = pilotTonesTx;
ifftInTx = [repmat(trainingSym_freq, numTrainingSyms, 1); ifftInTx];
ifftOutTx = ifft(ifftInTx.', 64).';

cycExtTx = [ifftOutTx(:,49:64) ifftOutTx];
TxVec = reshape(cycExtTx.', 1, prod(size(cycExtTx)));

TxVec_air = [zeros(1,250) interp(TxVec, 4) zeros(1,2^14 - length(TxVec)*4 - 250)];
```

Final Output to DACs



I Buffer



Q Buffer

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WARPLab offline vs. Sysgen real-time

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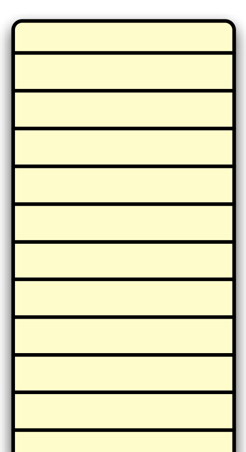
Packet generation and modulation

Final Output to DACs



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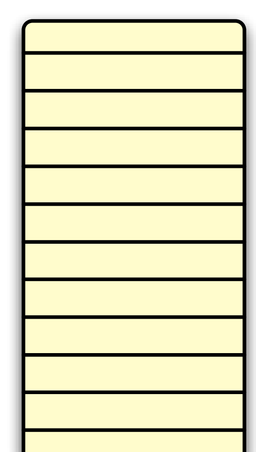

Q Buffer

PHY Example: OFDM Tx

WARPLab offline vs. Sysgen real-time

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IFFT

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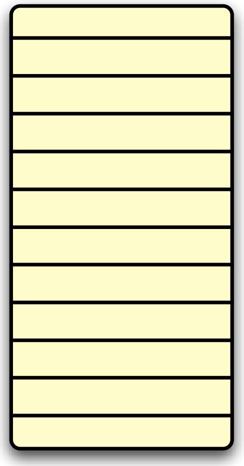

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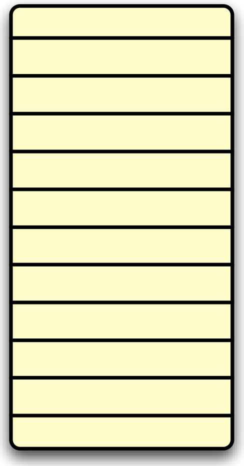

Q Buffer

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WARPLab offline vs. Sysgen real-time

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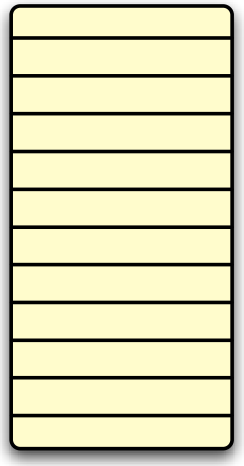
Cyclic extension

Final Output to DACs



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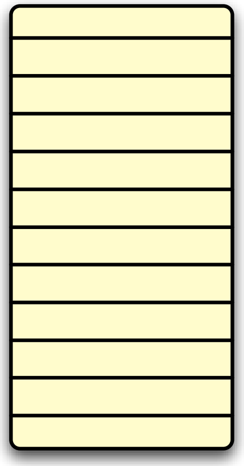

Q Buffer

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WARPLab offline vs. Sysgen real-time

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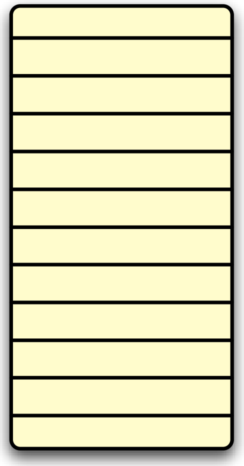
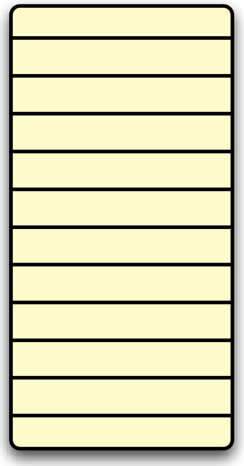
Filtering

Final Output to DACs



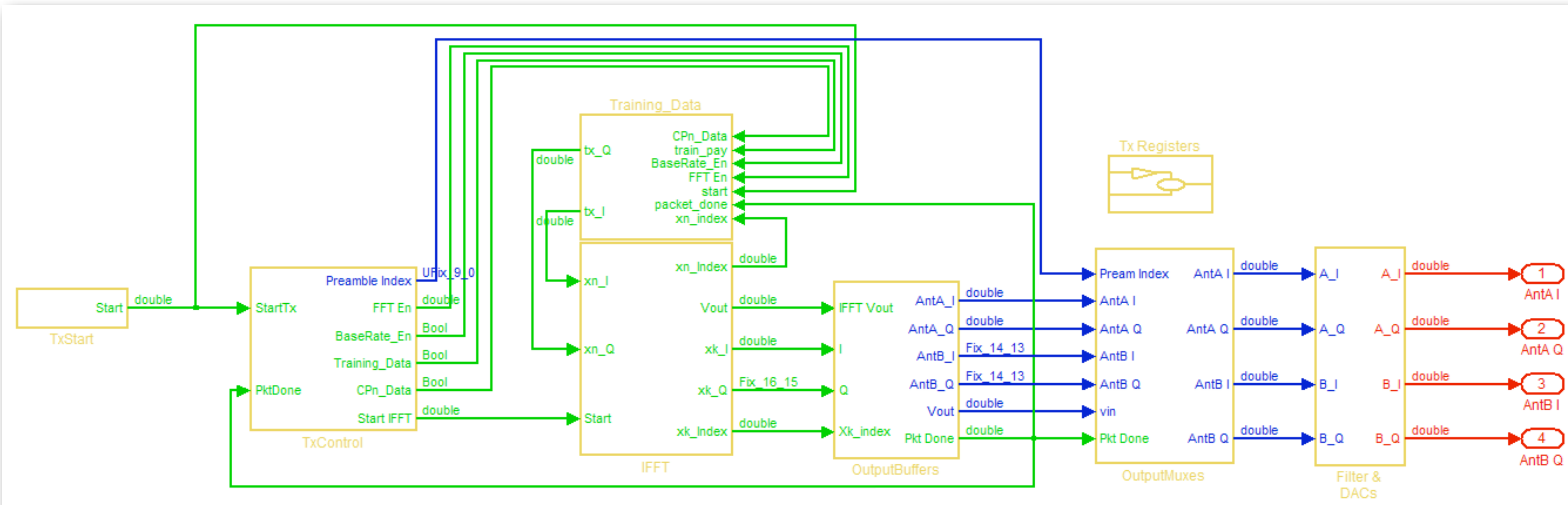
I Buffer



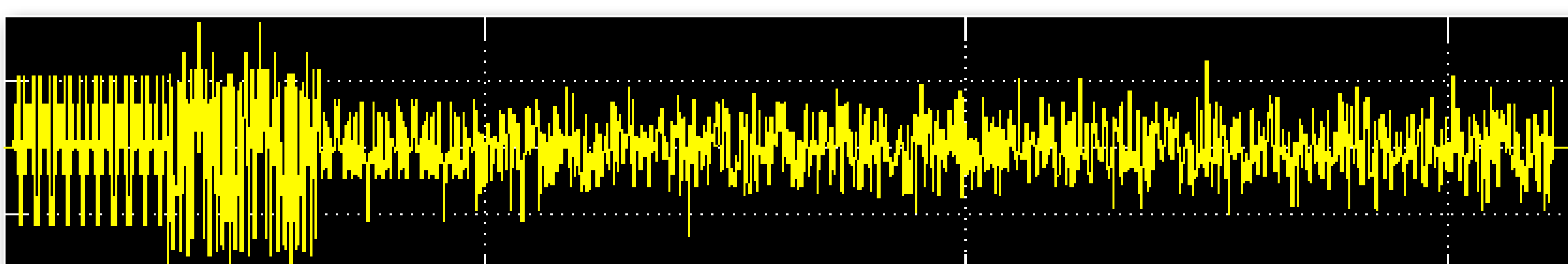
Q Buffer

PHY Example: OFDM Tx

WARPLab offline vs. Sysgen real-time

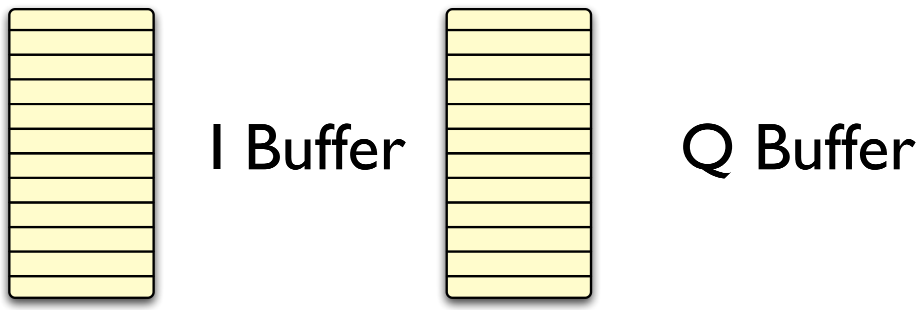


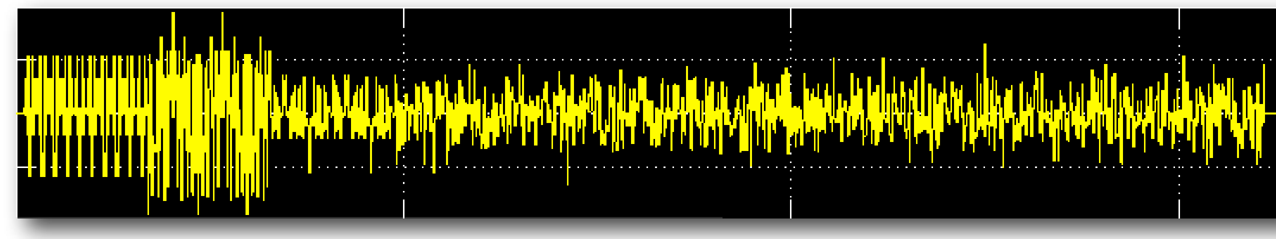
Final Output to DACs



PHY Example: OFDM Tx

WARPLab offline vs. Sysgen real-time





Same final output to DACs

- Signal processing offline MATLAB
- SYNC signal
- Limited buffer length
- PHY algorithm test

- Cost of generating each sample in real time
- Control, Pkt Detection
- Allows a real time system
- Network test

WARPLab Examples

- Hardware characterization
- Channel measurement
- Sphere detection
- Cooperative communications
- Beamforming

Lab 1: WARPLab

- WARPLab graphical interface
- SISO communication
- Measuring the wireless channel
- Building a real bits-to-RF transmitter
- Continuous transmitter mode
- Two-way communication
- 2x2 MIMO communication

WARPLab Overview