Physical Layer Prototyping using WARPLab

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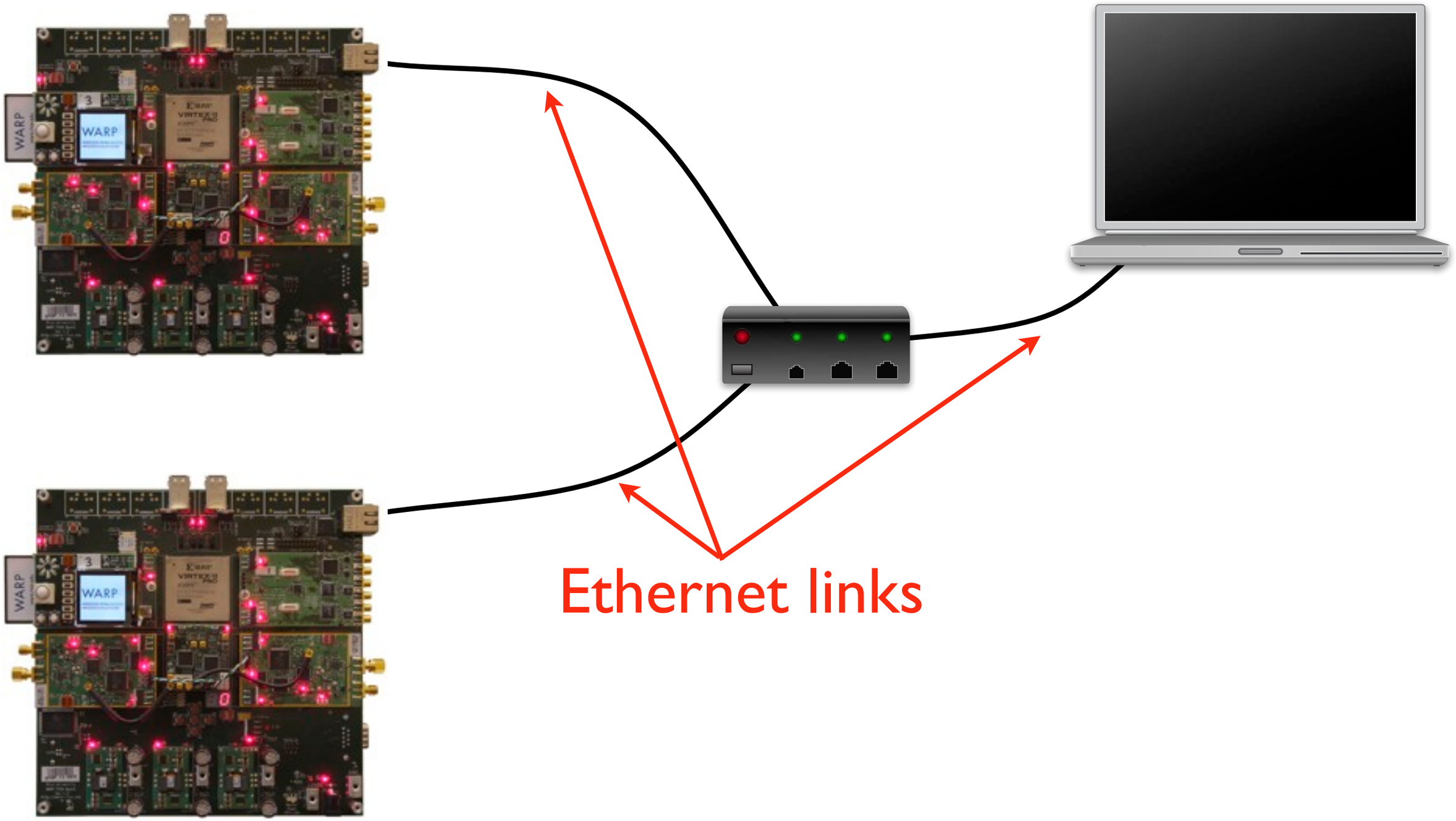
WARP Workshop
May 03, 2011

WARPLab Overview

- MATLAB ⟷ WARP Link
  - Interact with WARP nodes directly from the MATLAB workspace
- Very rapid prototyping of PHY algorithms
- Real-time Tx-Rx and offline processing

WARPLab Overview



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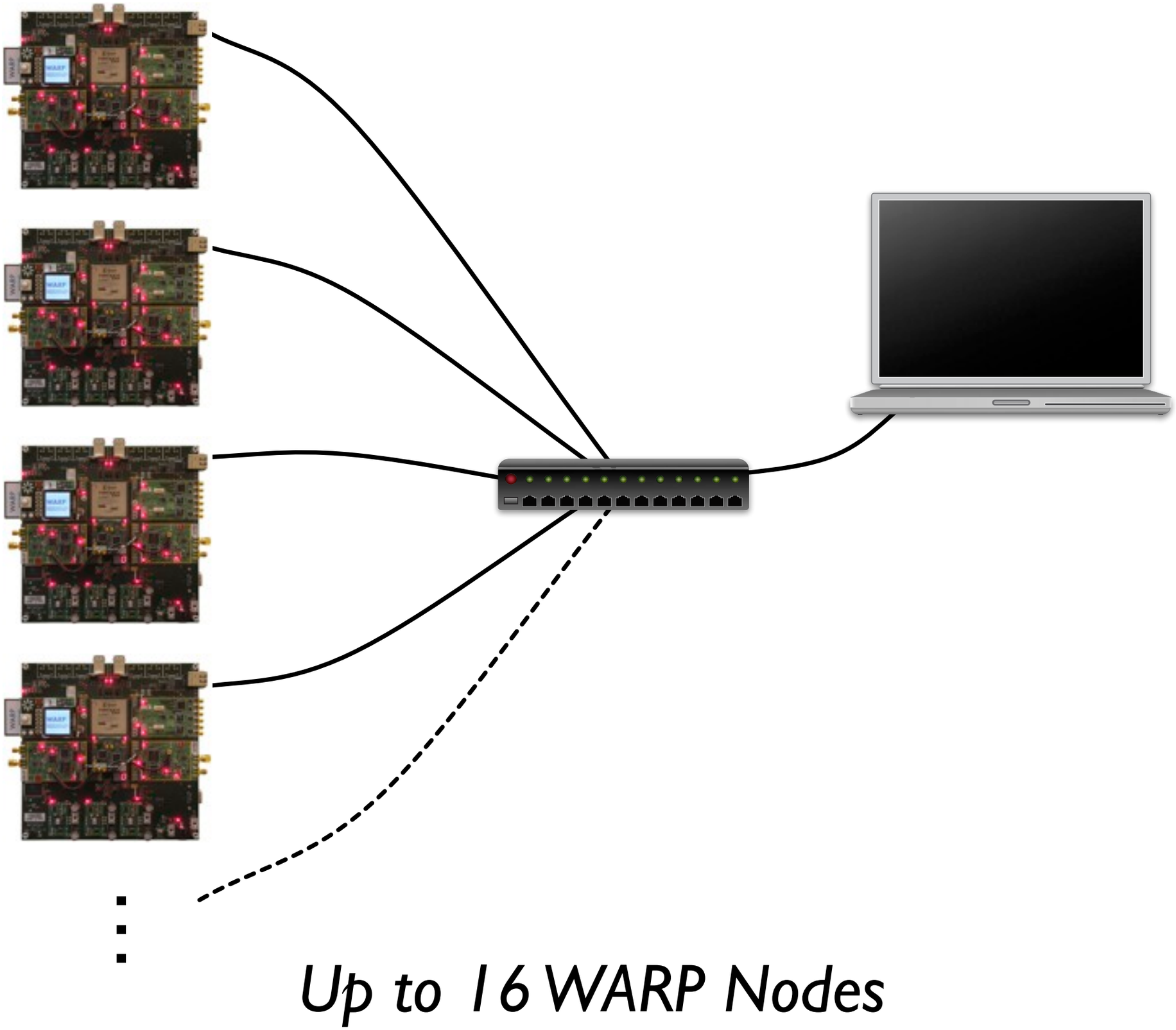
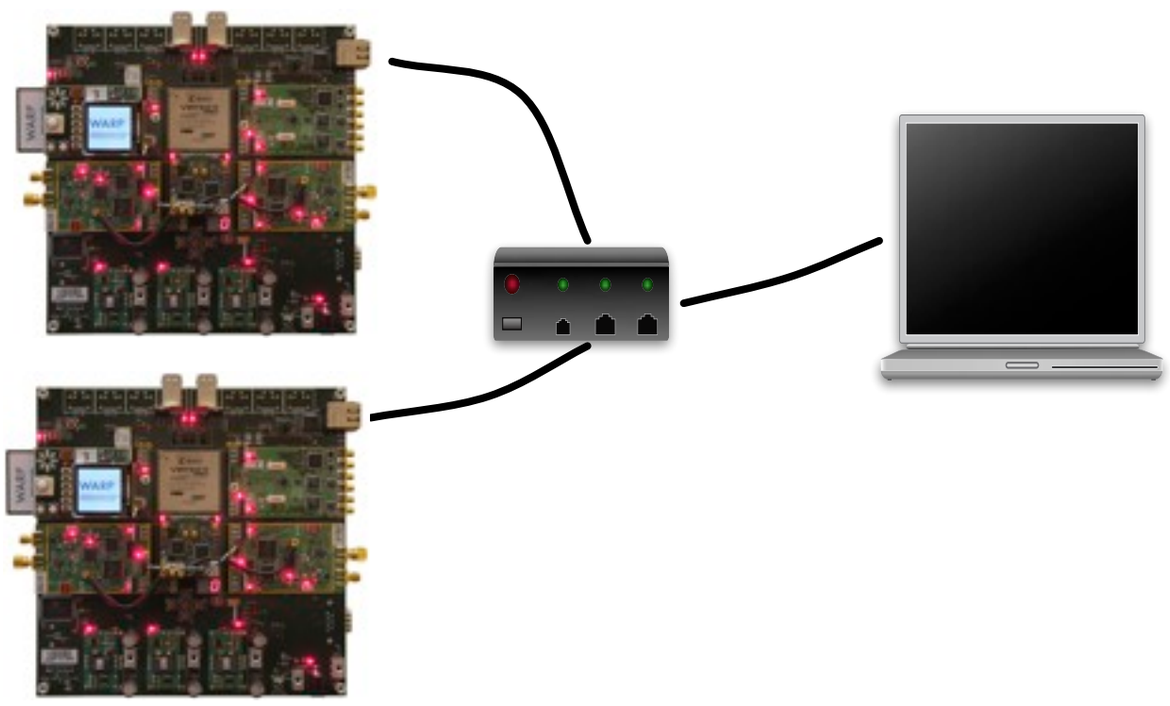


Up to 16 WARP Nodes

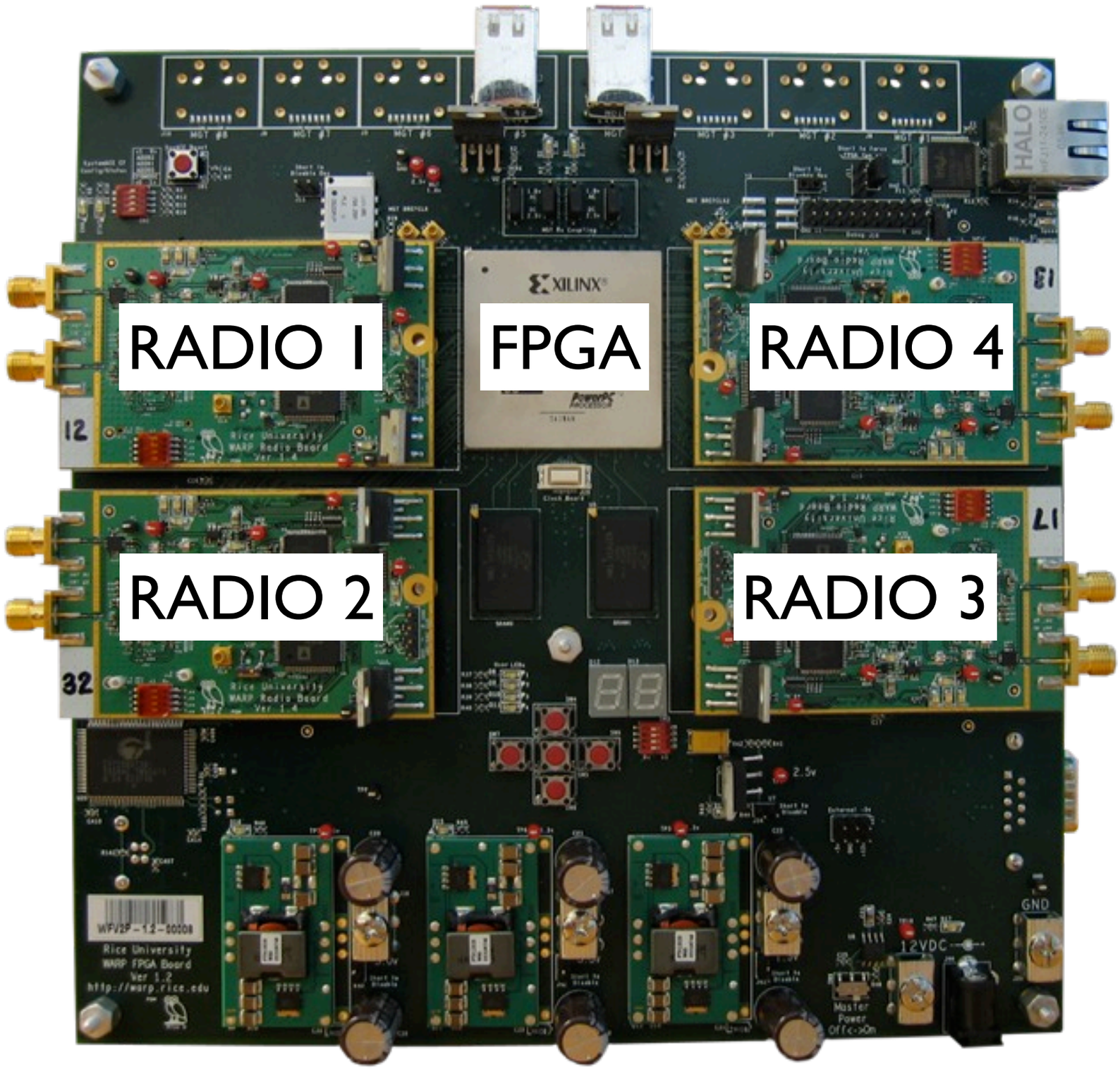
WARPLab Overview



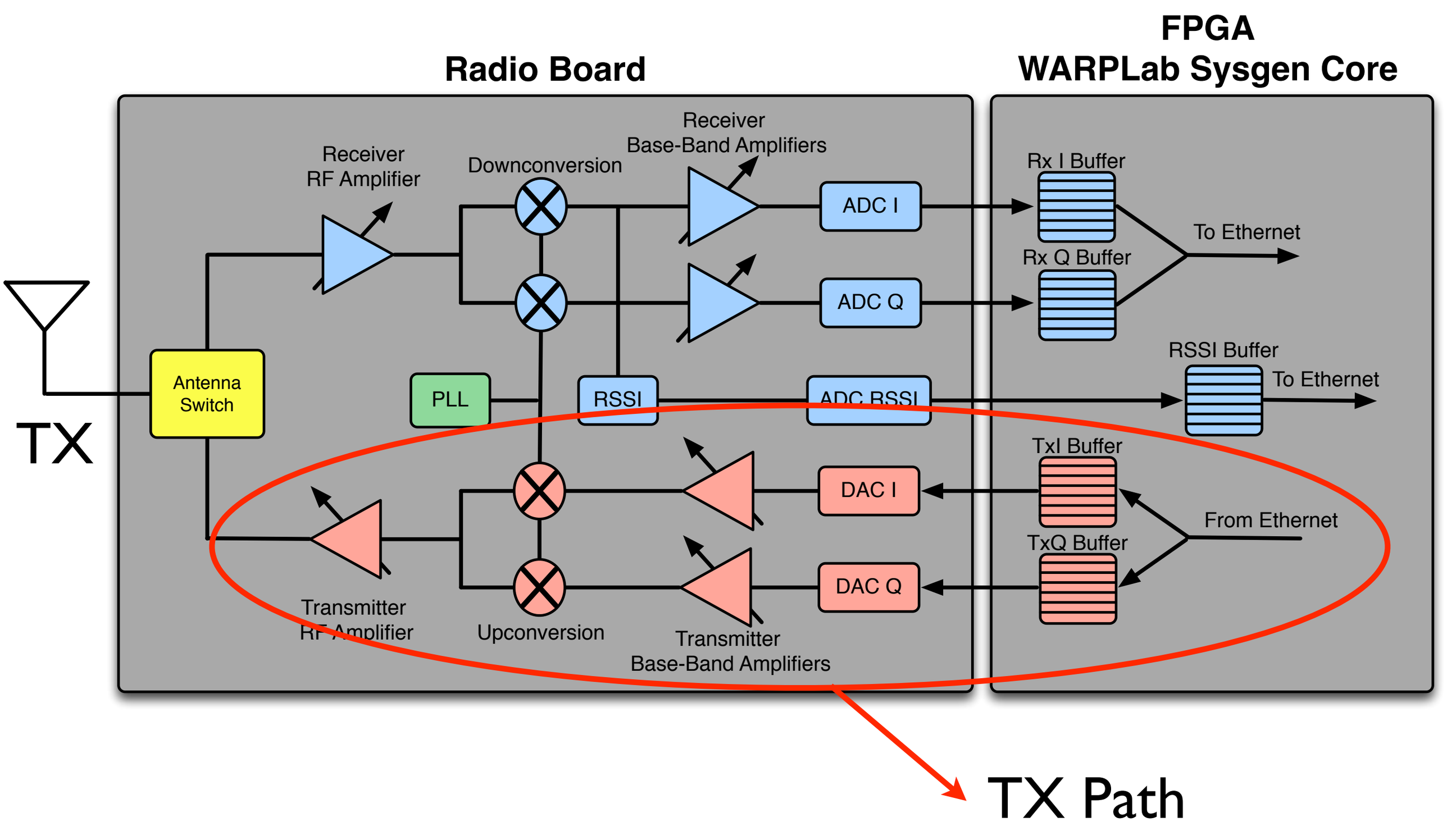
- One PC controls many WARP nodes
- MATLAB for signal processing
- Non-real-time processing

- WARP for wireless interfaces
- Real-time channel use

- Samples created in MATLAB are stored in the FPGA
- Samples in the FPGA are sent over-the-air using the radios



WARPLab Architecture



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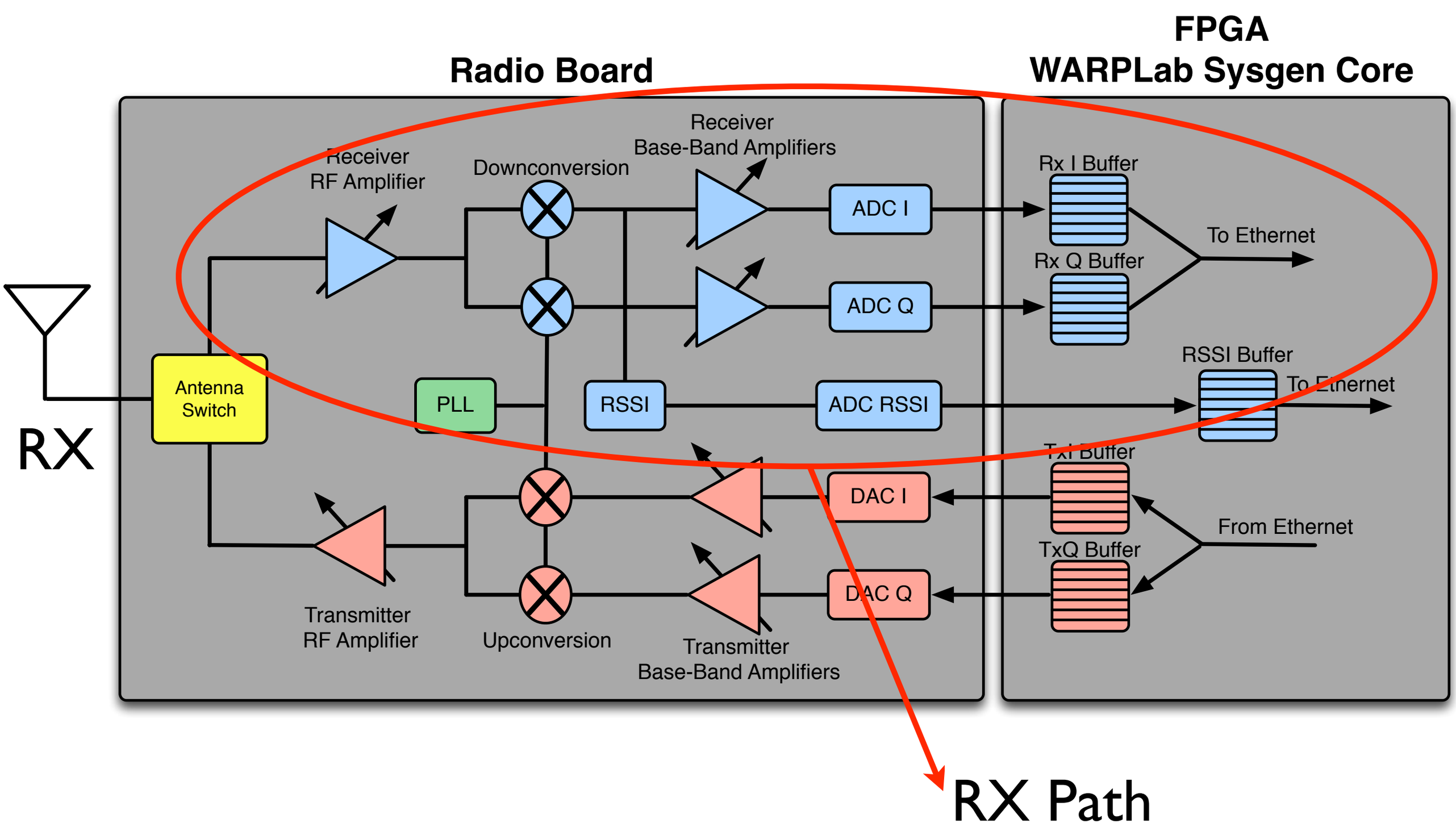

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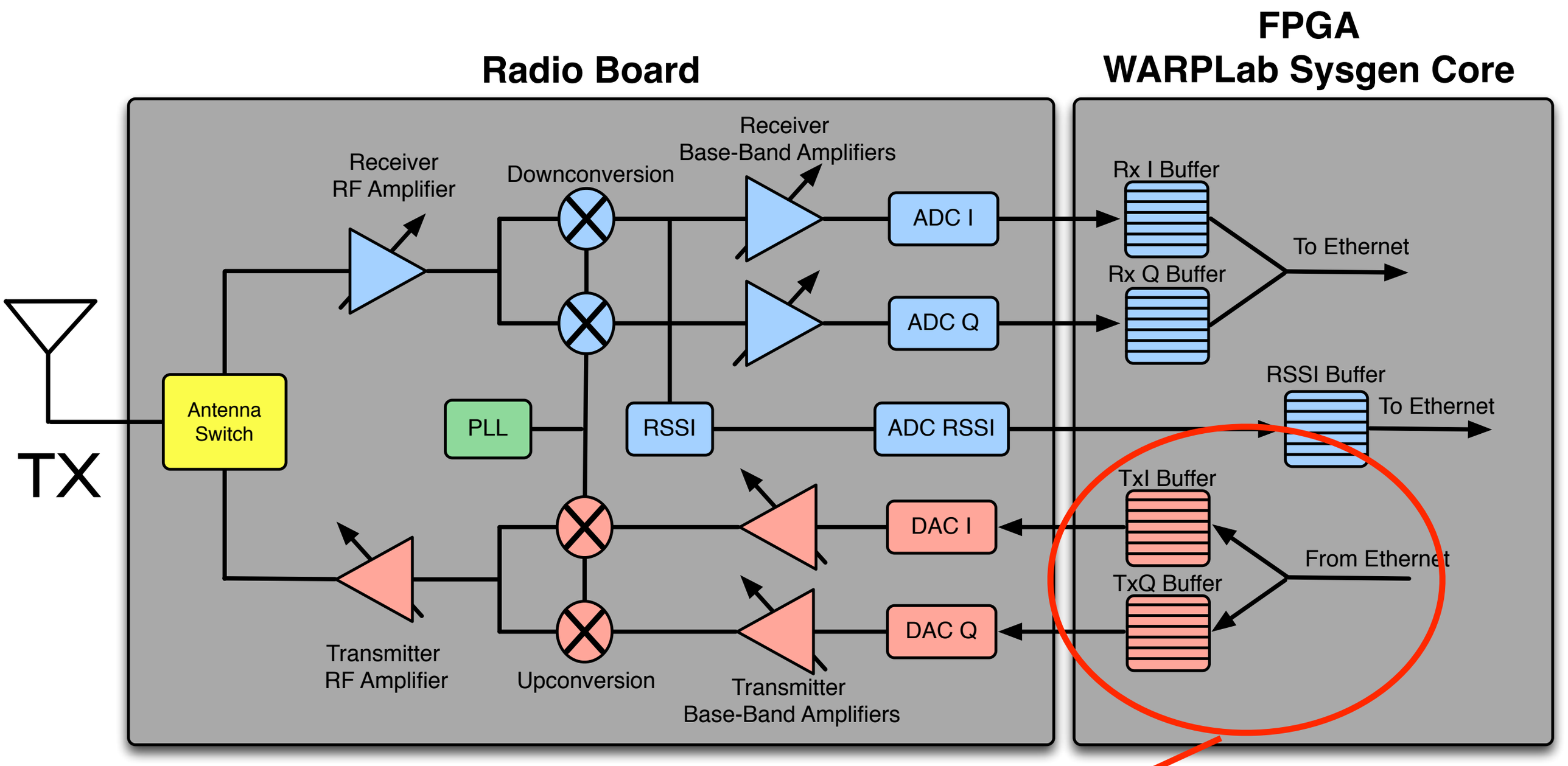
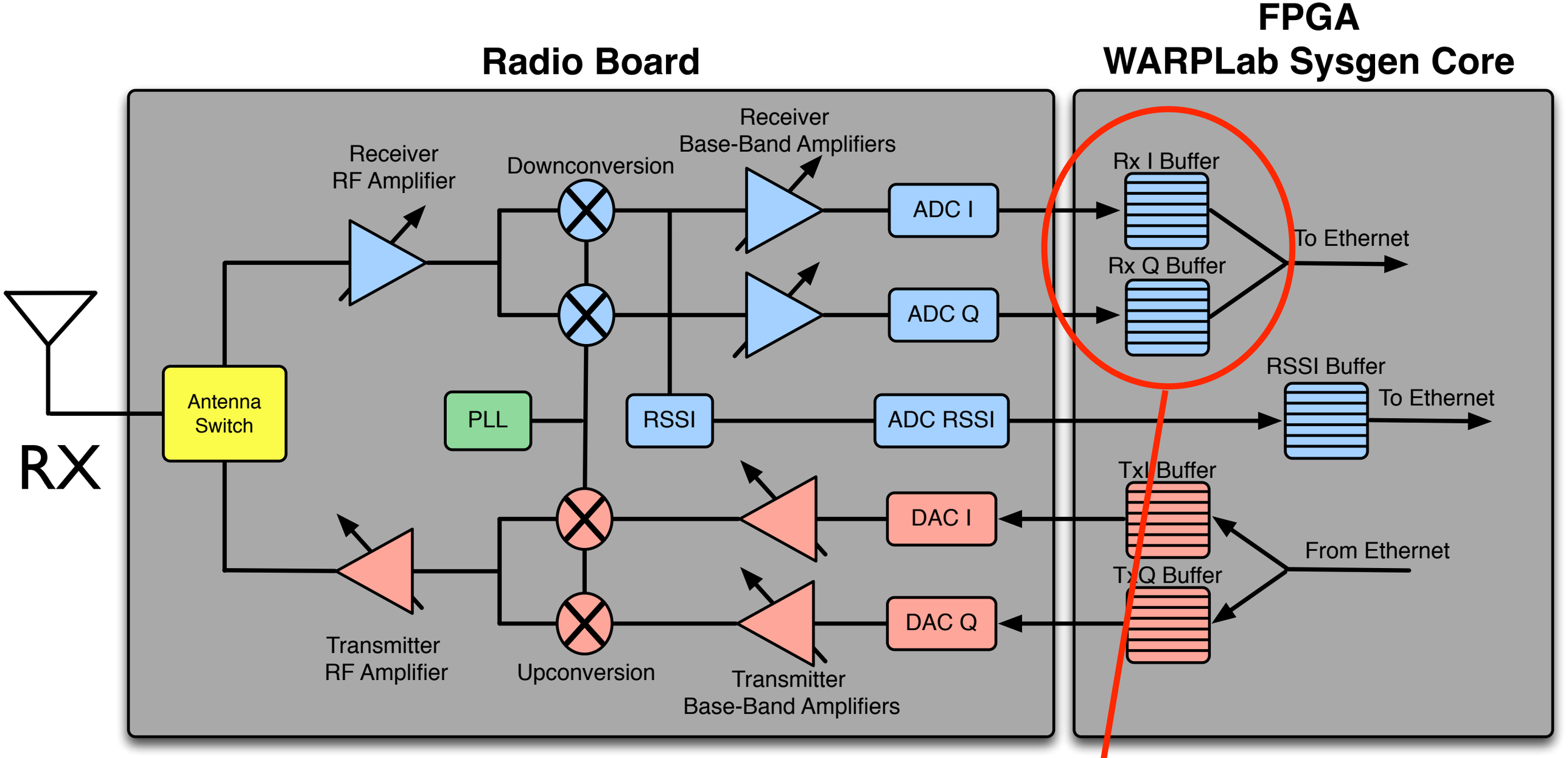


TX I/Q buffers
16384 (2^{14}) samples each

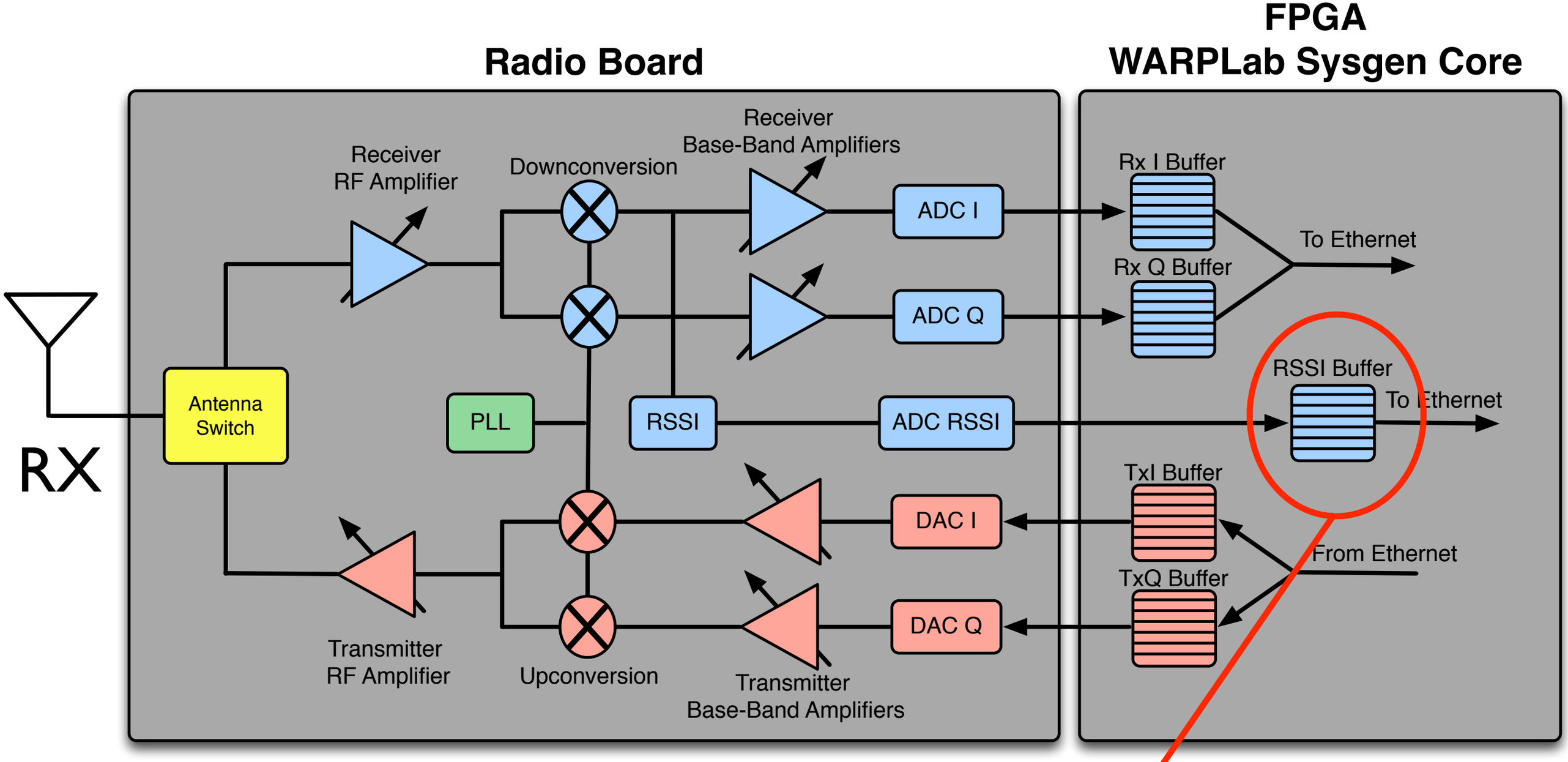
WARPLab Architecture



RX I/Q buffers

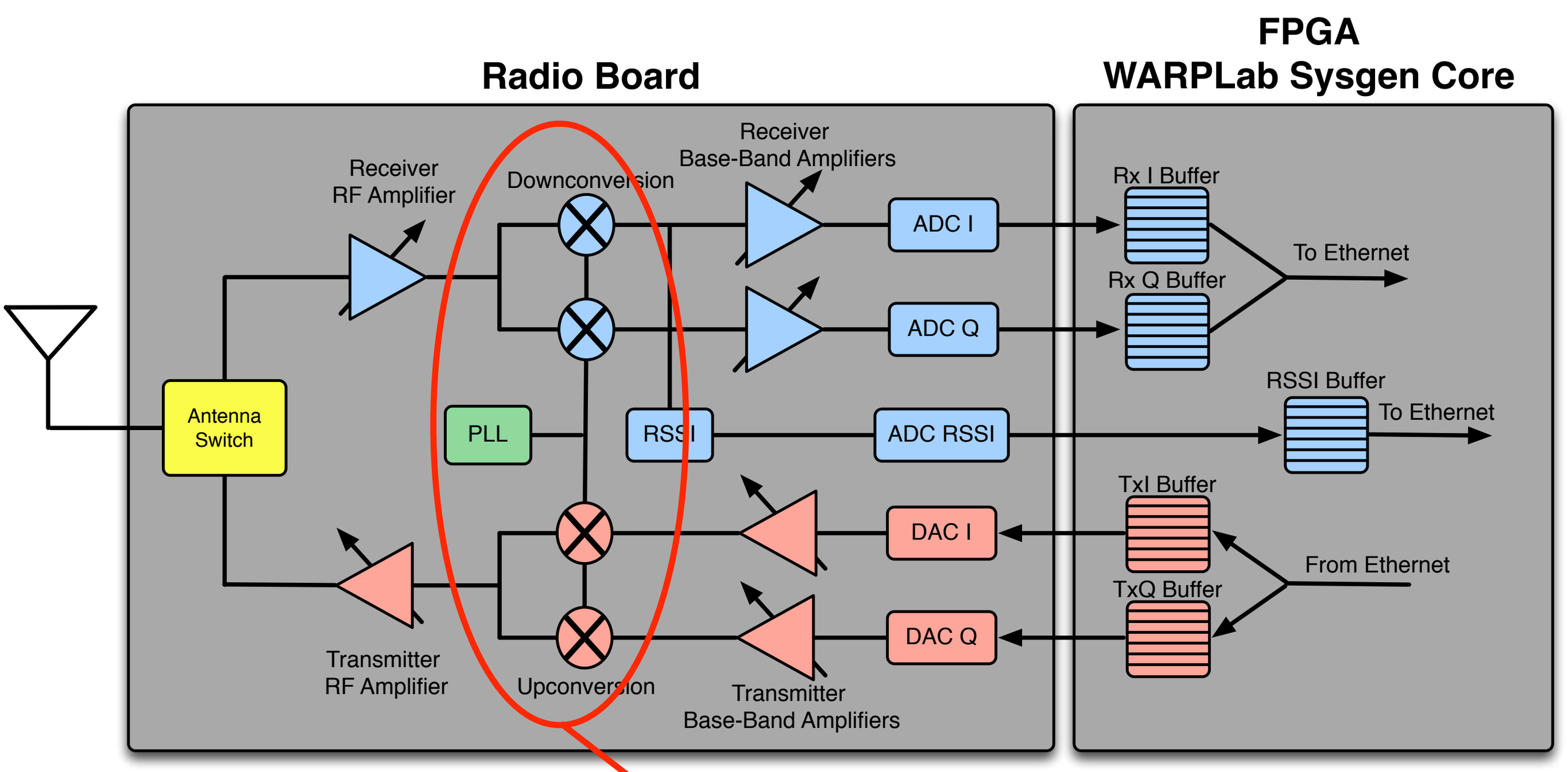
16384 (2^{14}) samples each

WARPLab Architecture



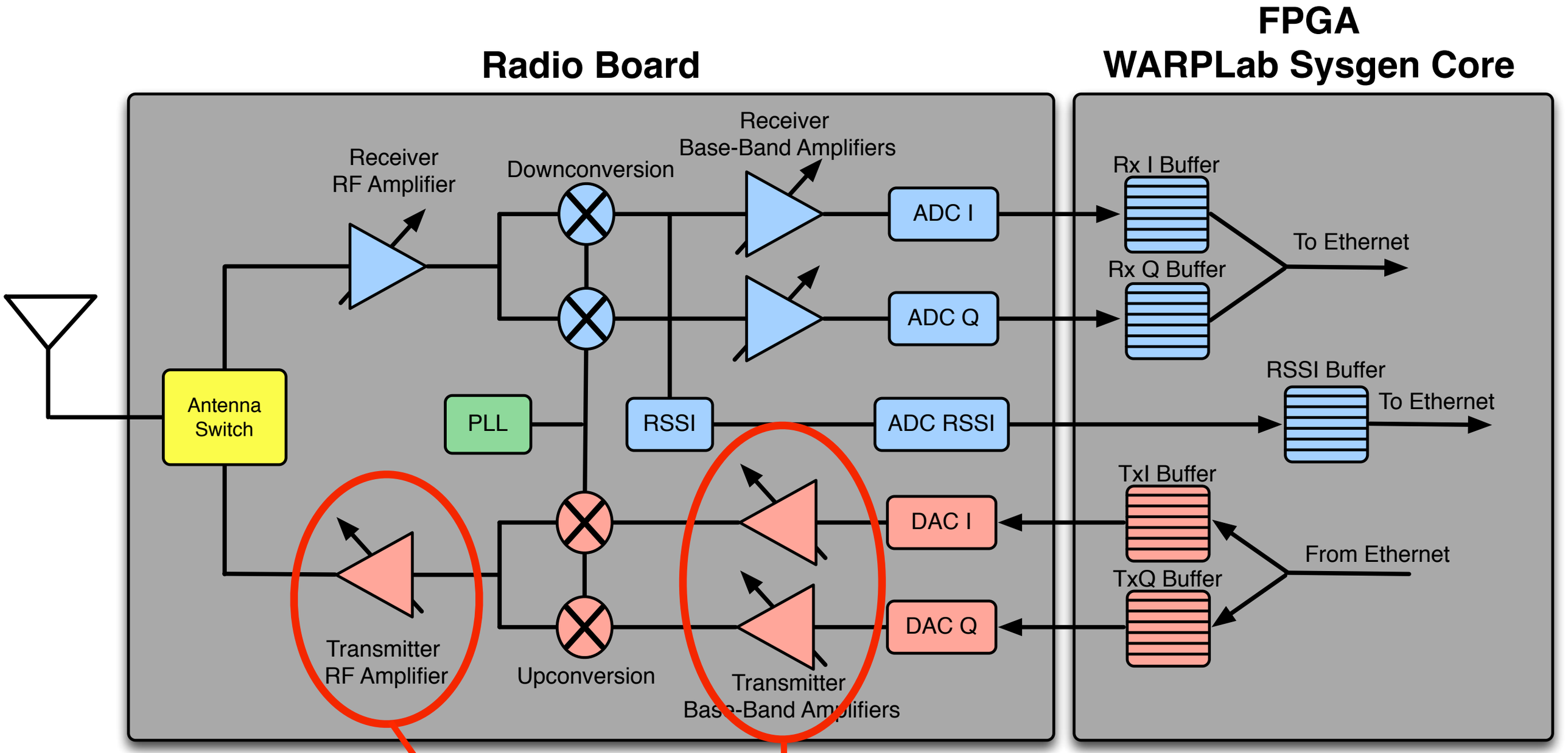
RSSI buffer
4096 (2^{12}) samples

WARPLab Architecture



Variable upconversion/downconversion carrier frequency
Value input from MATLAB

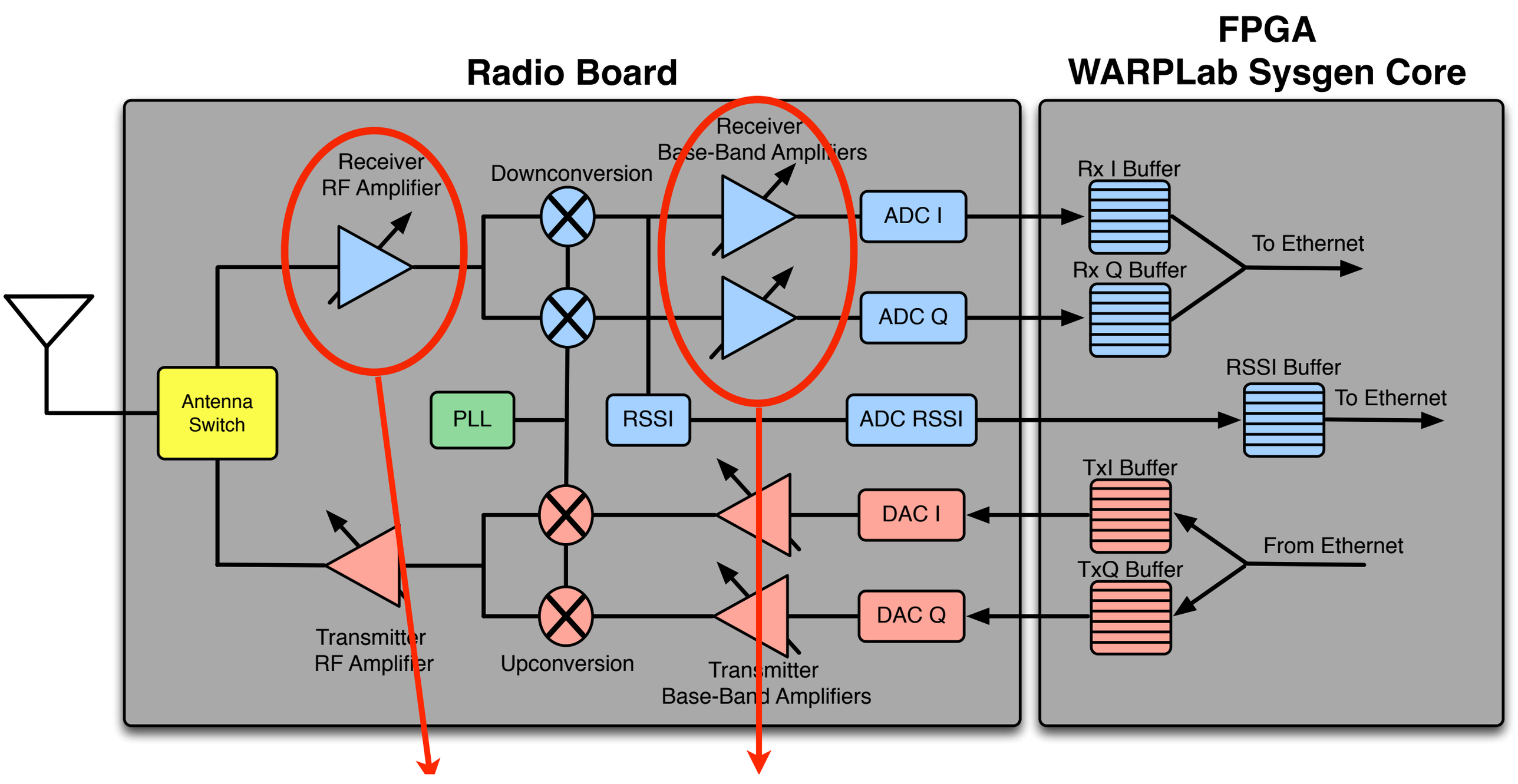
WARPLab Architecture



Variable gain Tx BB and RF amplifiers

Gain value input from MATLAB

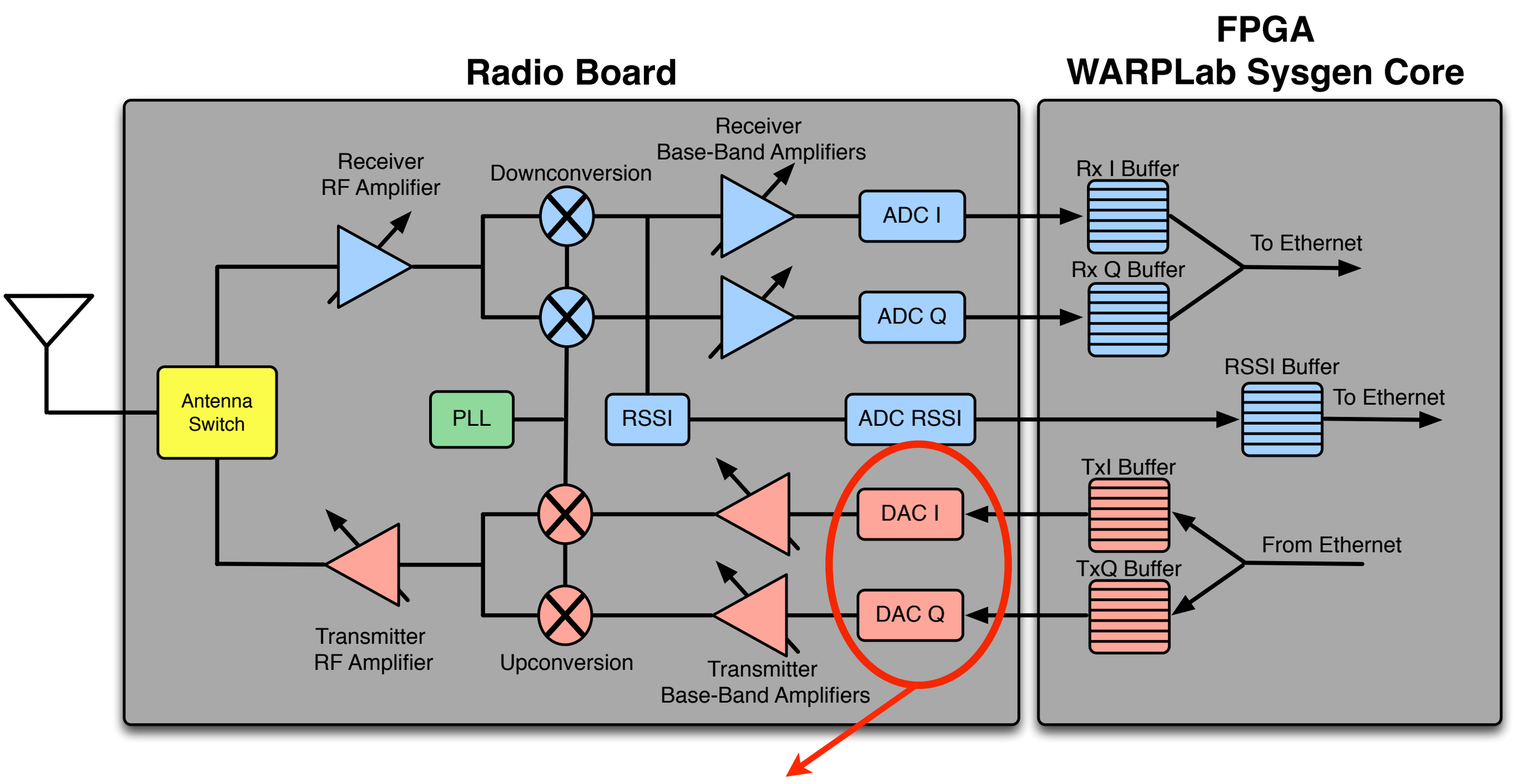
WARPLab Architecture



Variable gain Rx BB and RF amplifiers

Gain value input from MATLAB

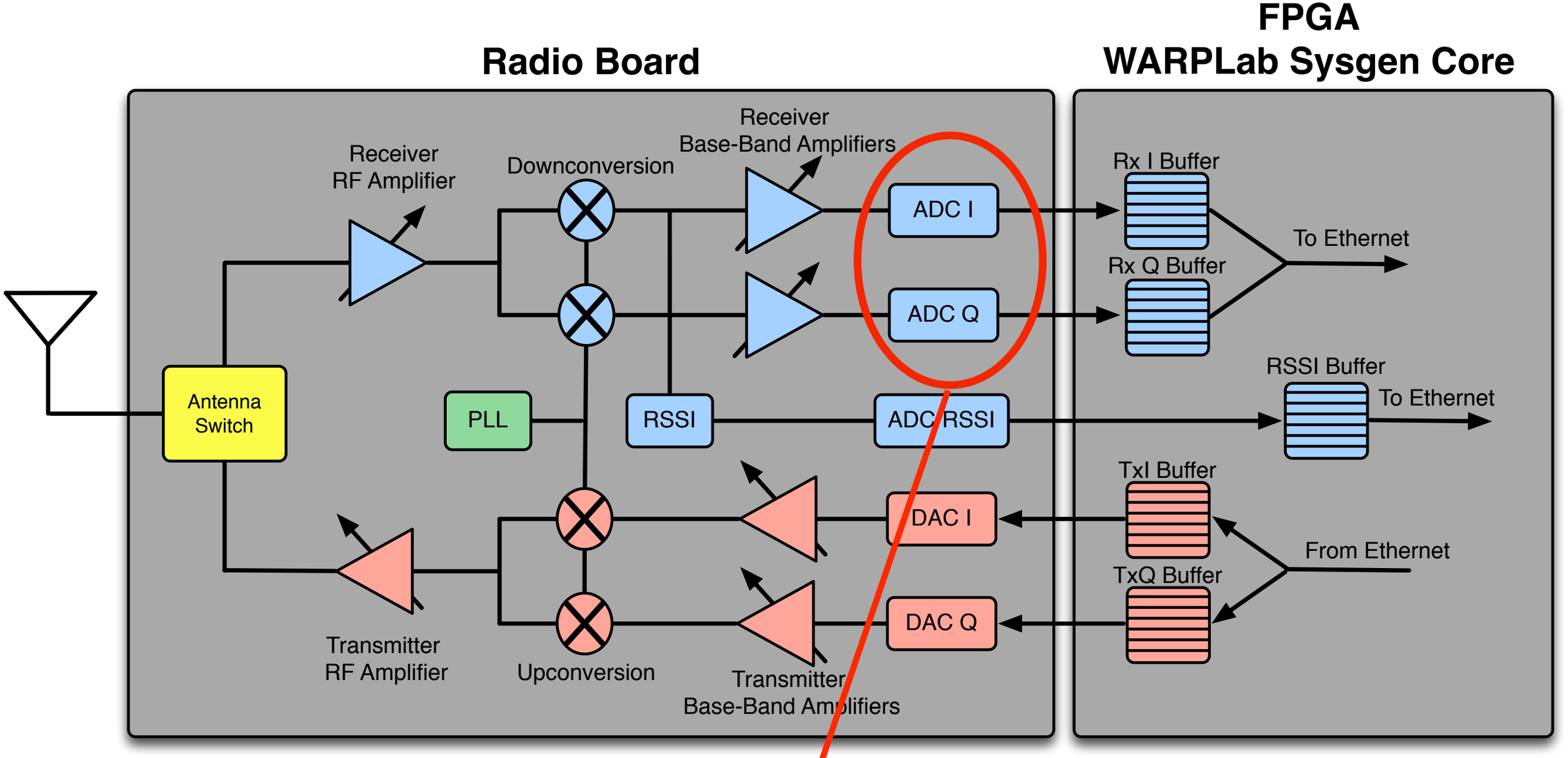
WARPLab Architecture



Fixed Point 16_15 I/Q DACs

Always clocked at 40 MHz

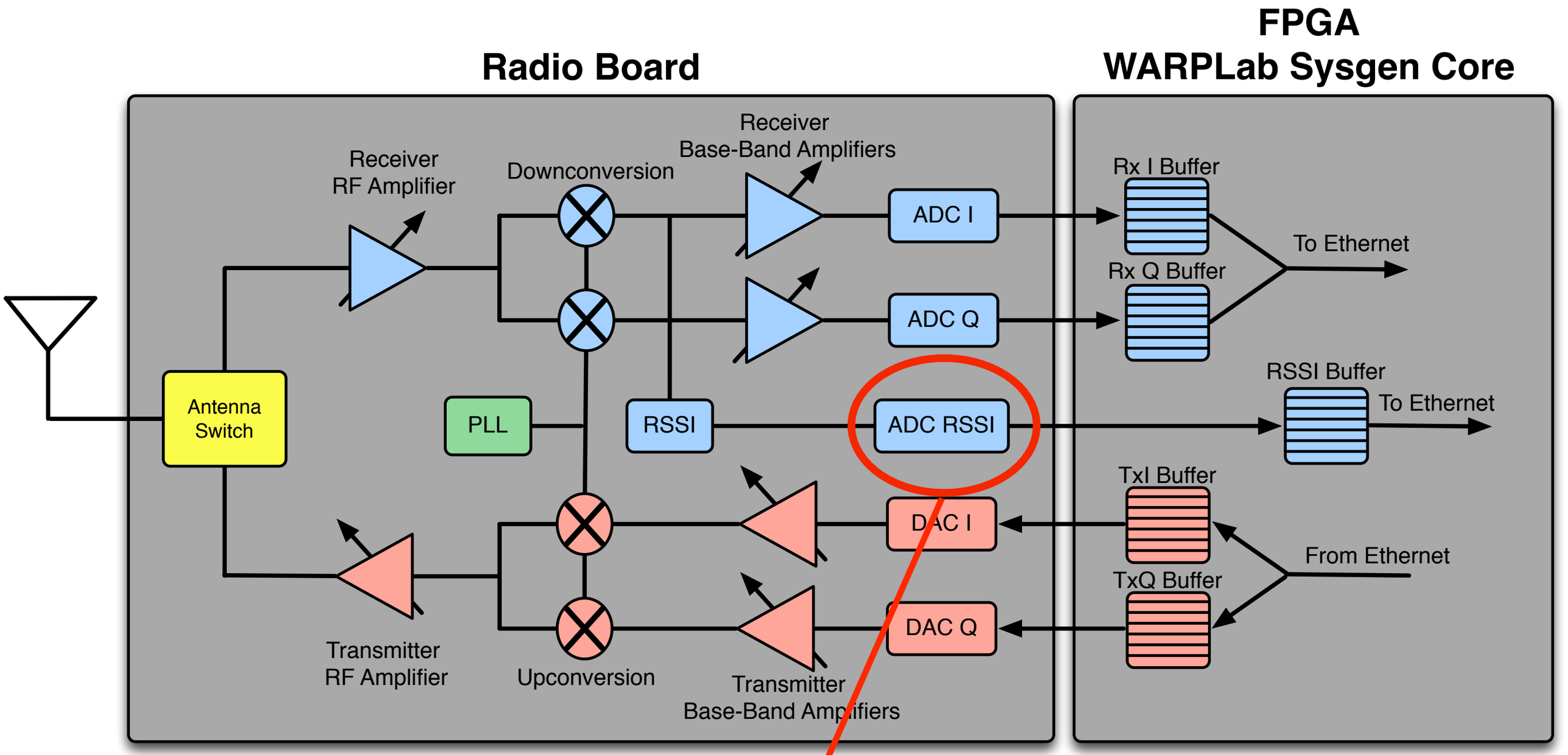
WARPLab Architecture



Fixed Point 14_13 I/Q ADCs

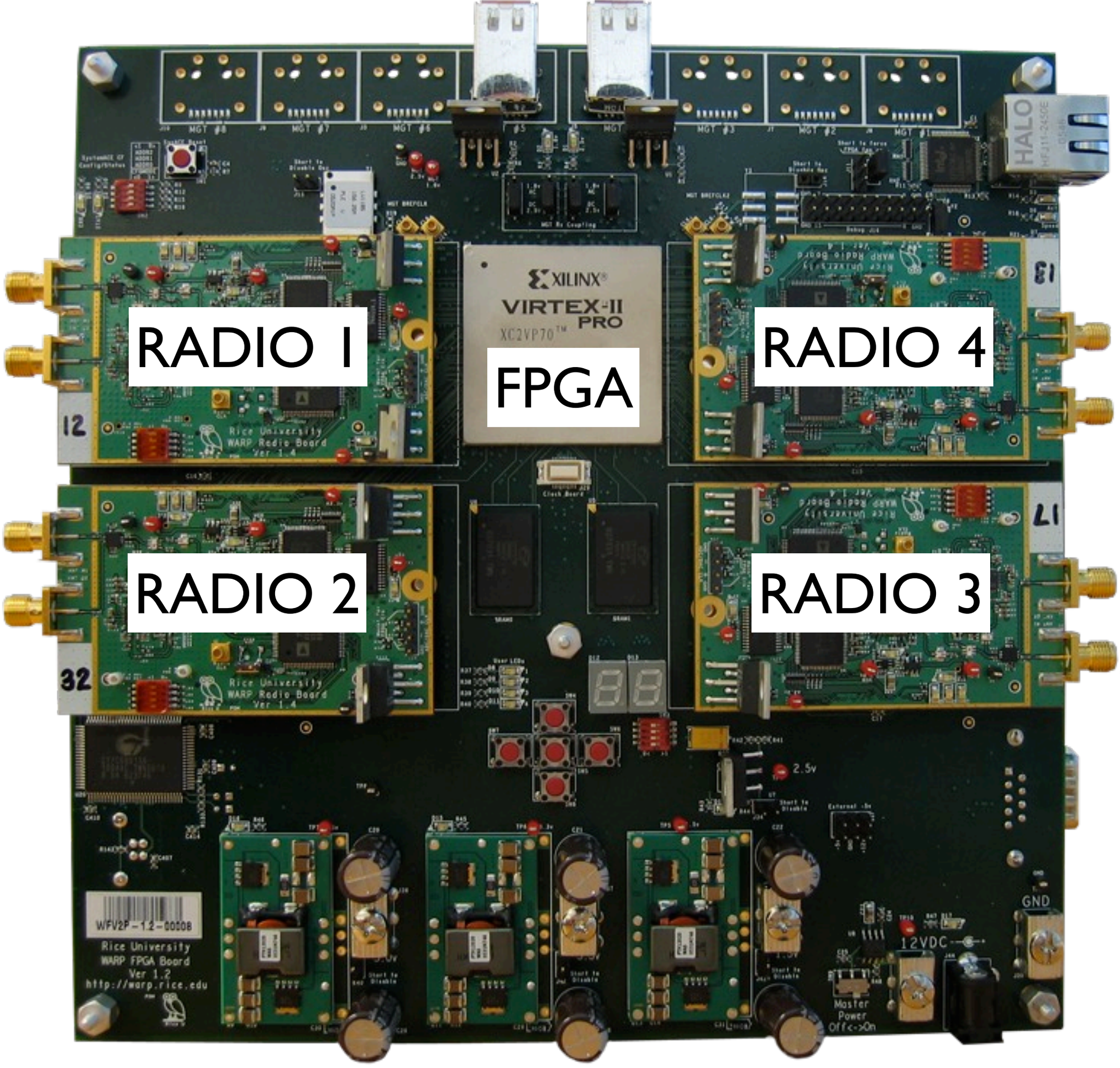
Always clocked at 40 MHz

WARPLab Architecture

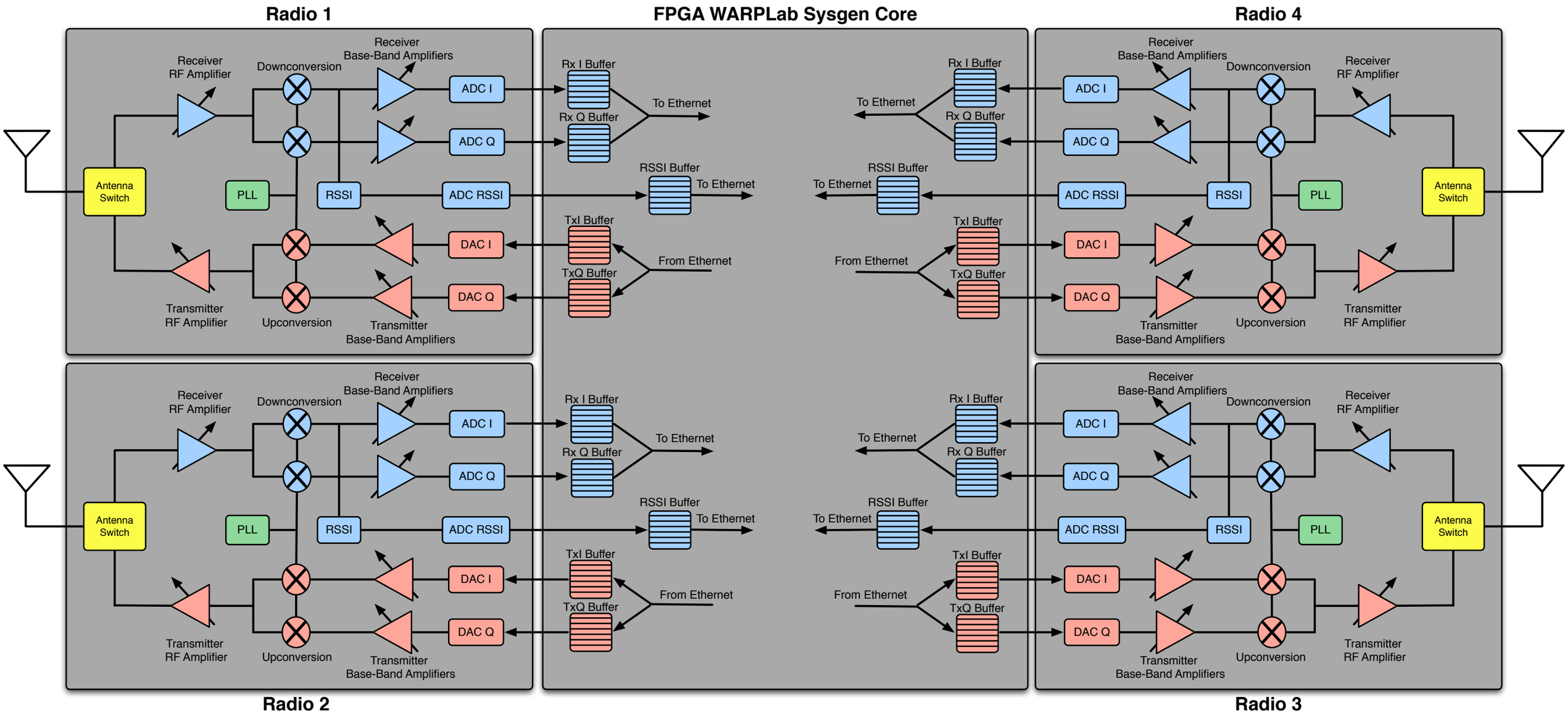


RSSI ADC always clocked at 10 MHz

10 bit number


RADIO 1
FPGA
RADIO 4
RADIO 2
RADIO 3
XILINX
VIRTEX-II PRO
XC2VP70
Rice University
WARP Radio Board
Ver 1.4
Rice University
WARP FPGA Board
Ver 1.2
http://warp.rice.edu
2.5v
12VDC
GND
Master Power Off<->On

WARPLab Architecture



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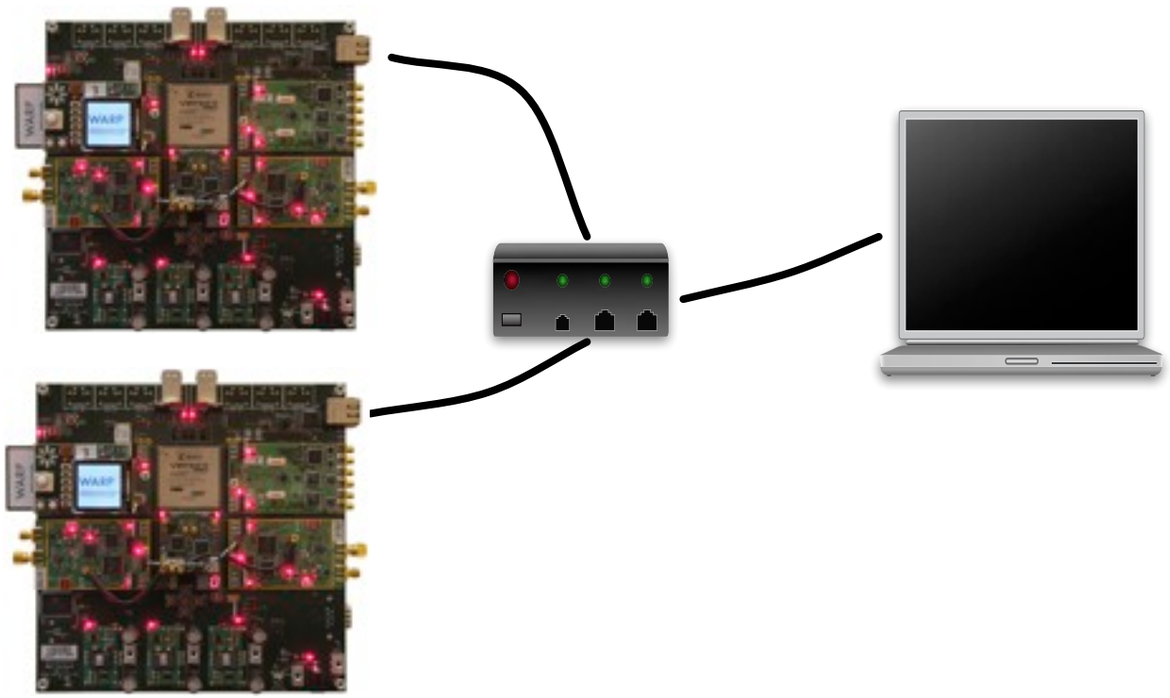

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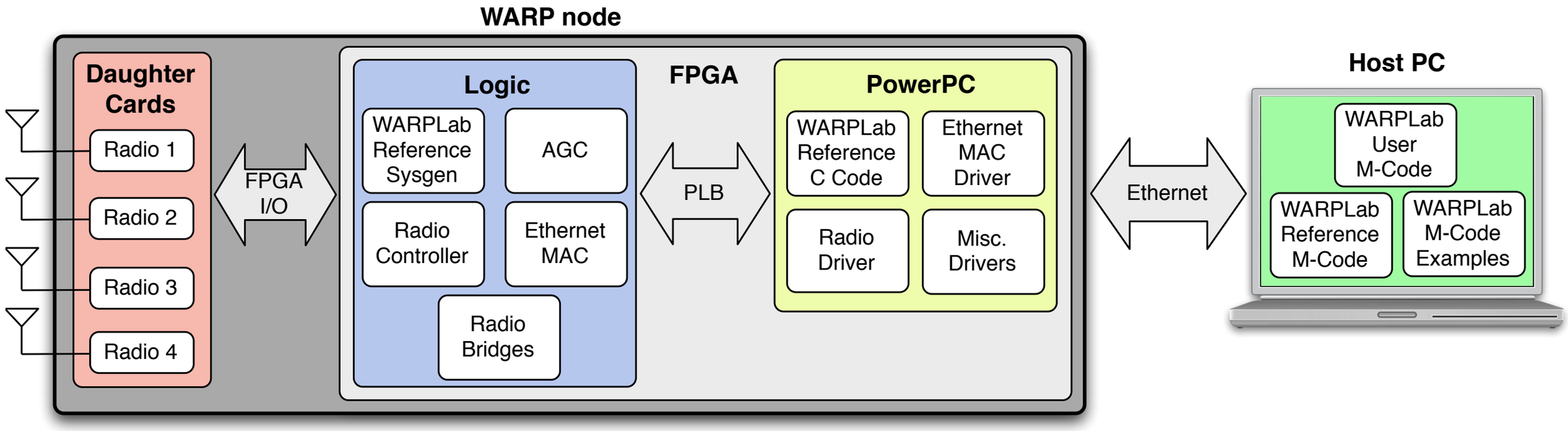

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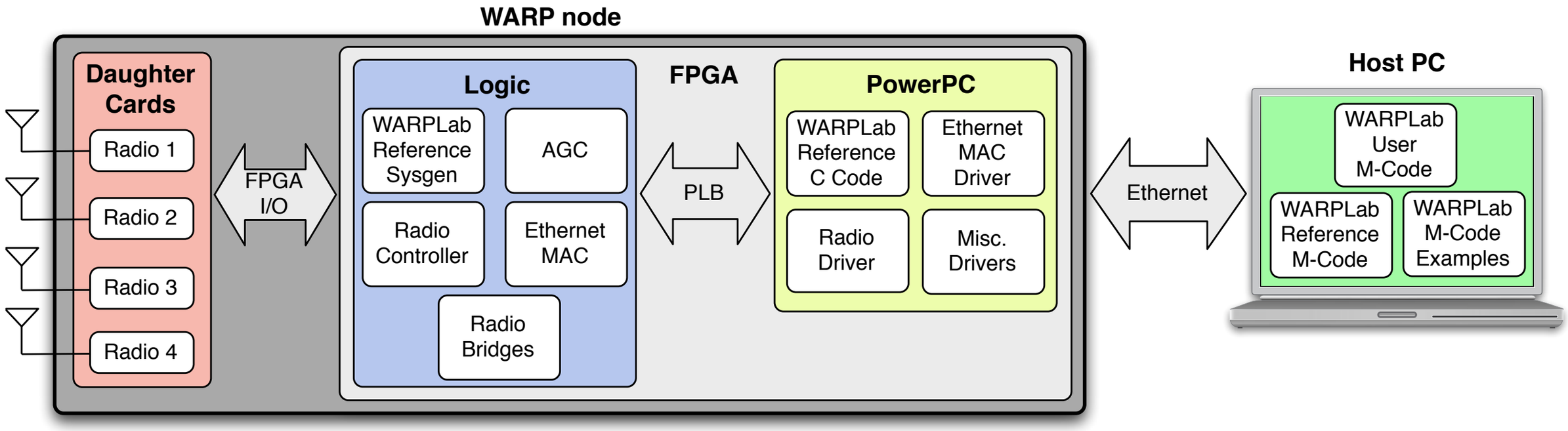

- The WARPLab framework provides the following
  - Reference design
  - Reference M-Code
  - M-Code Examples

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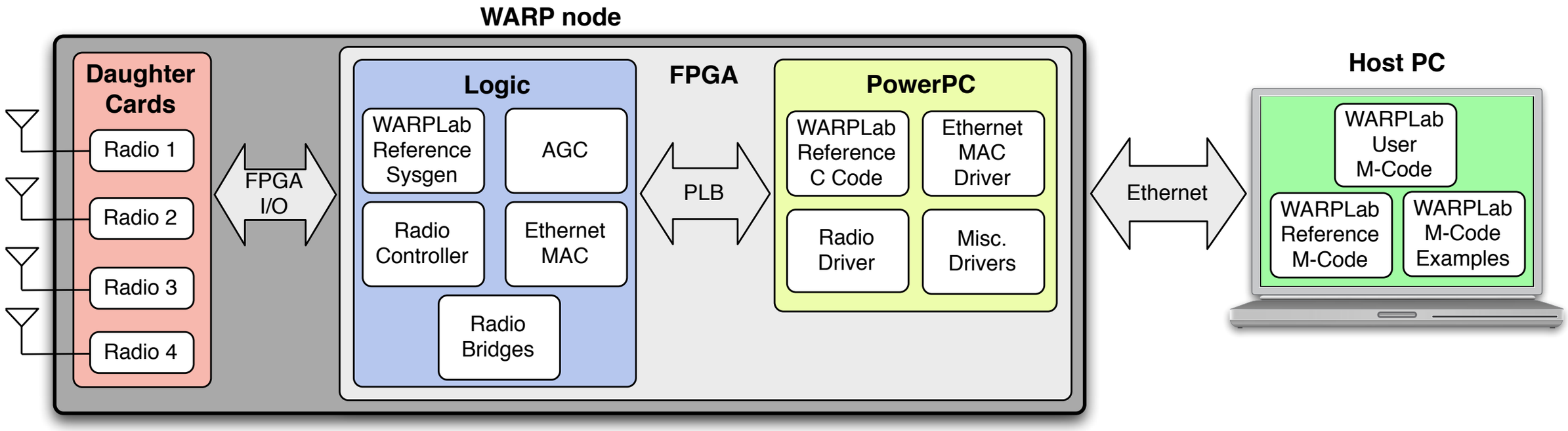

- Reference design
    - XPS project that contains all the FPGA code required to program the WARP nodes

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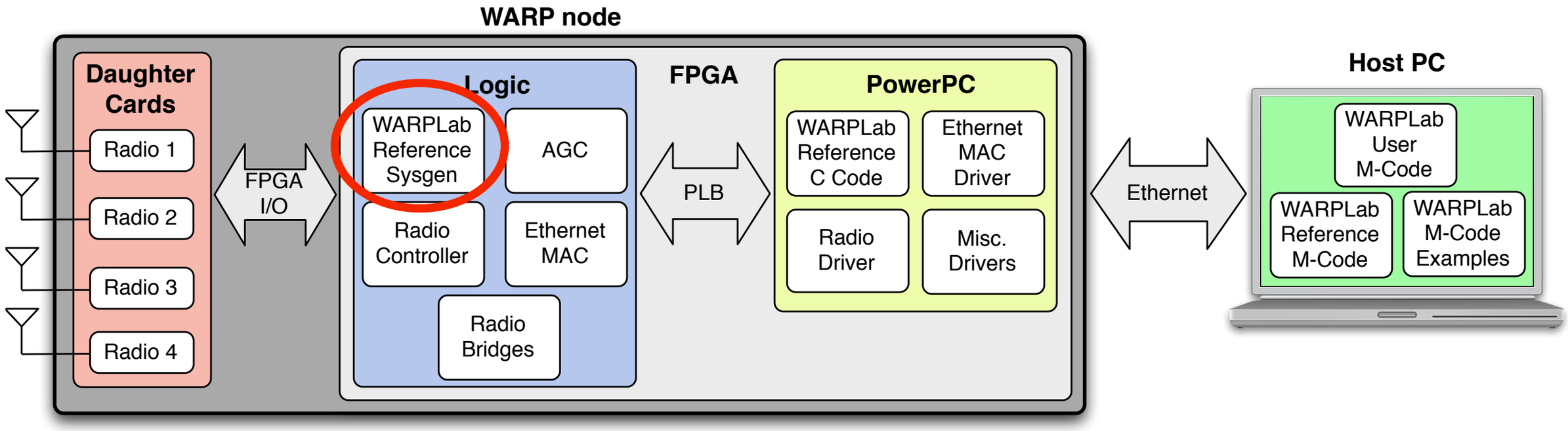

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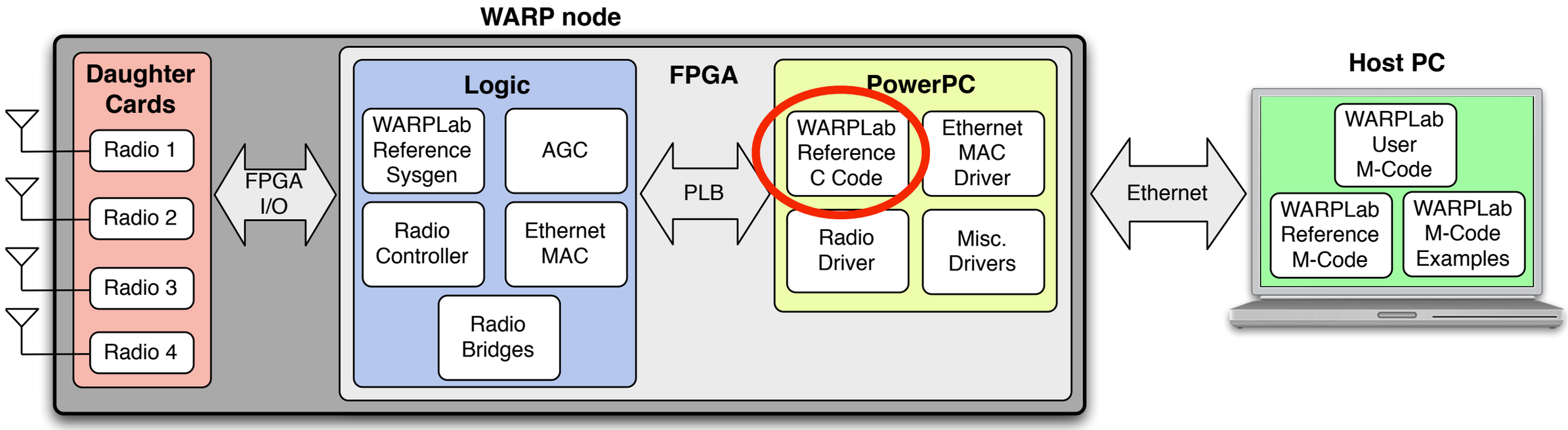
    - WARPLab Reference Sysgen - Ex: Buffers

WARPLab Architecture

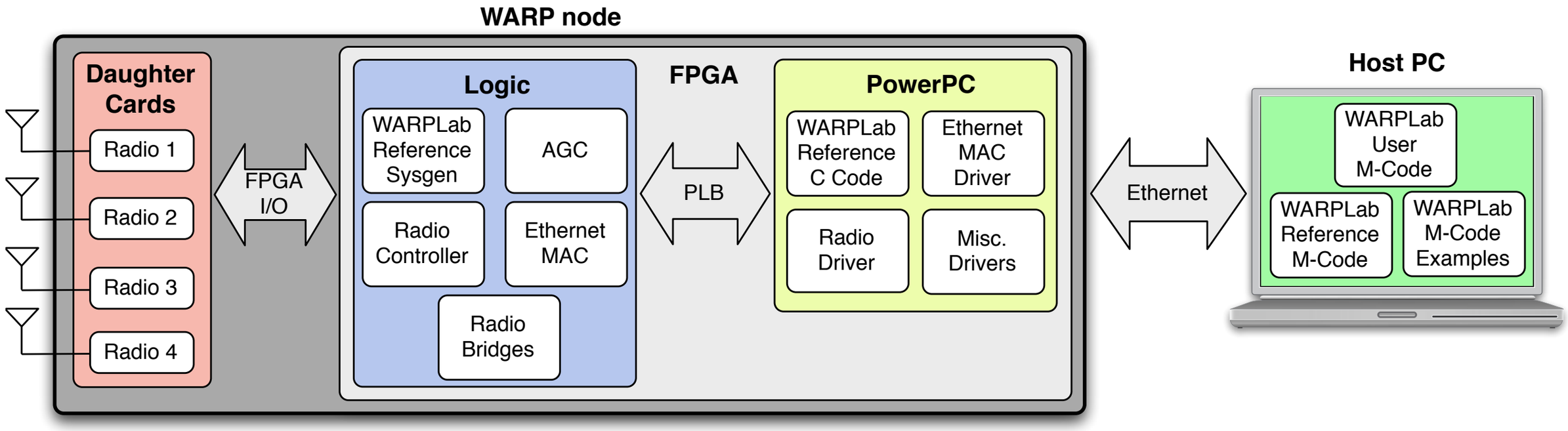


- Reference design
  - XPS project that contains all the FPGA code required to program the WARP nodes
  - WARPLab Reference Sysgen - Ex: Buffers
  - WARPLab Reference C Code - Ex: Ethernet

WARPLab Architecture

- Reference design
    - Bitsream (.bit) file to program the WARP nodes is provided
    - Same bitstream for all nodes.
        - Any node can be Tx or Rx
- All open source
    - All code required to generate bitstream is available online

WARPLab Architecture



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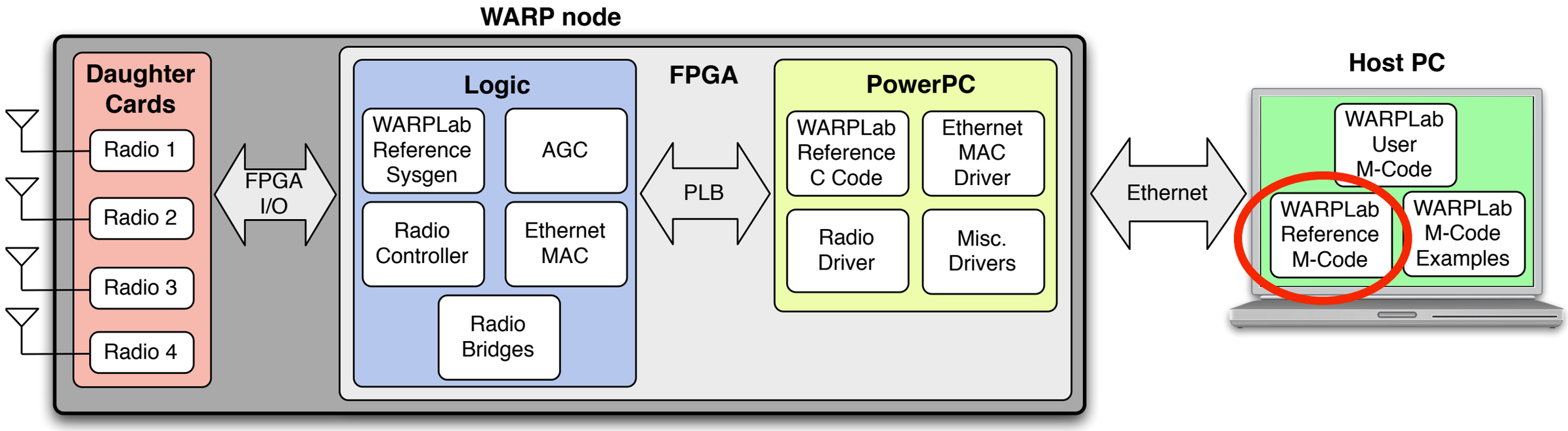
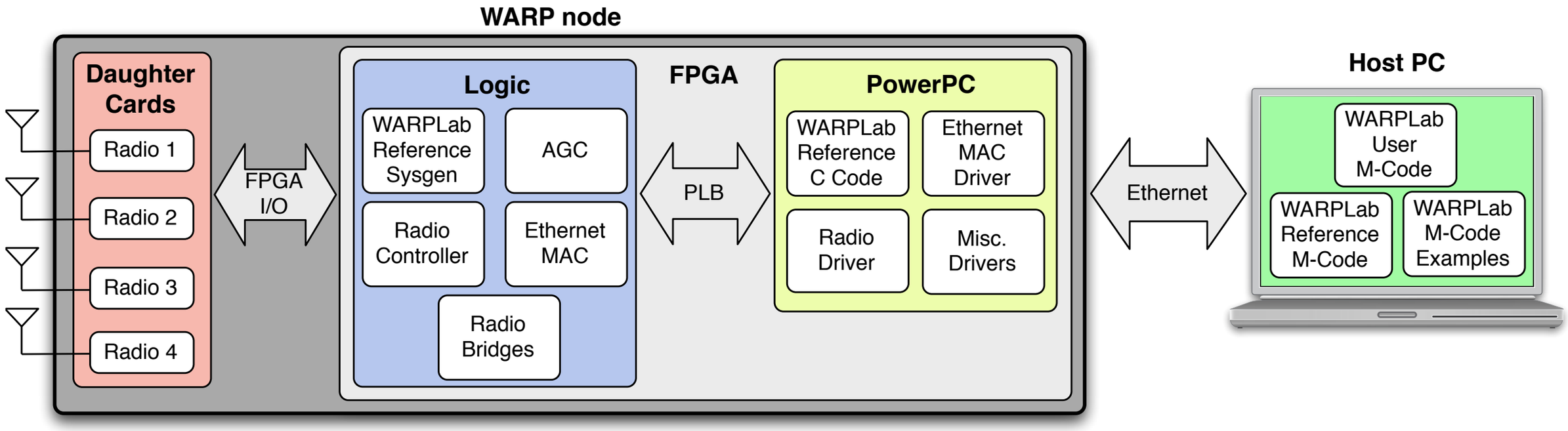


- Reference M-Code
  - MATLAB Code (M-Code) functions that allow interaction with WARP nodes
  - Ex:
    - warplab_writeSMWO(Node_ID,Buffer_ID,M_Vector)

WARPLab Architecture



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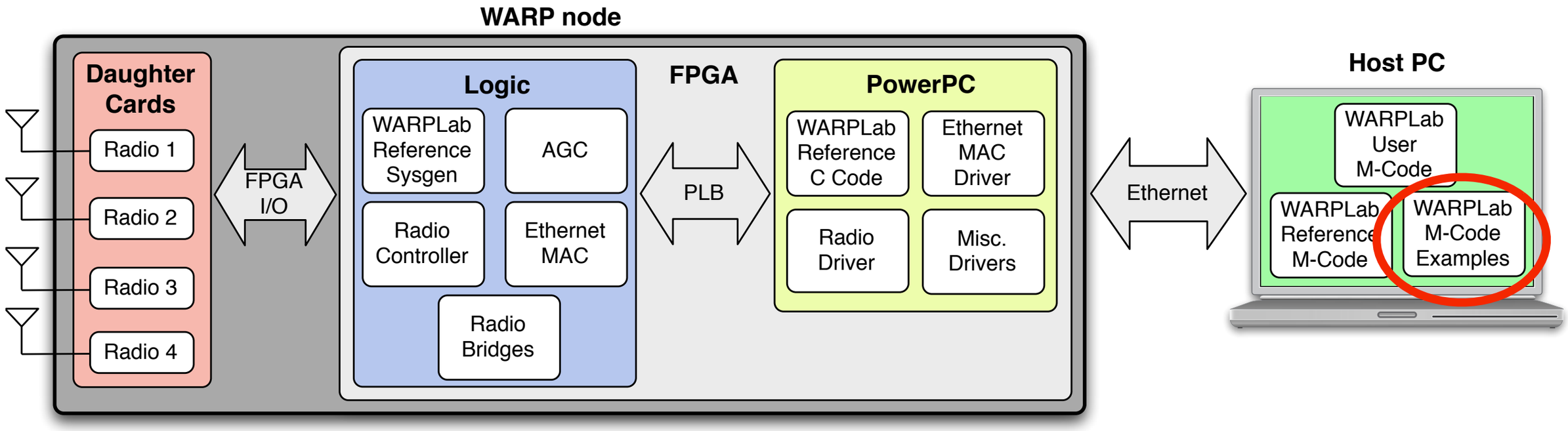
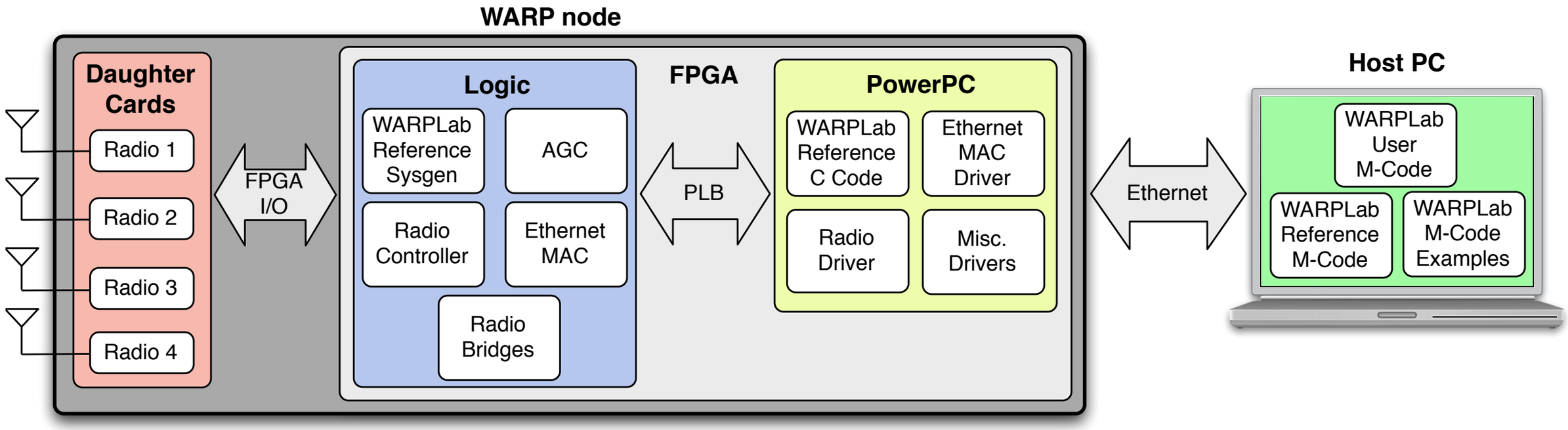


- M-Code Examples
  - Illustrate how to use the functions in the WARPLab Reference M-Code
  - Today's Lab 1

WARPLab Architecture



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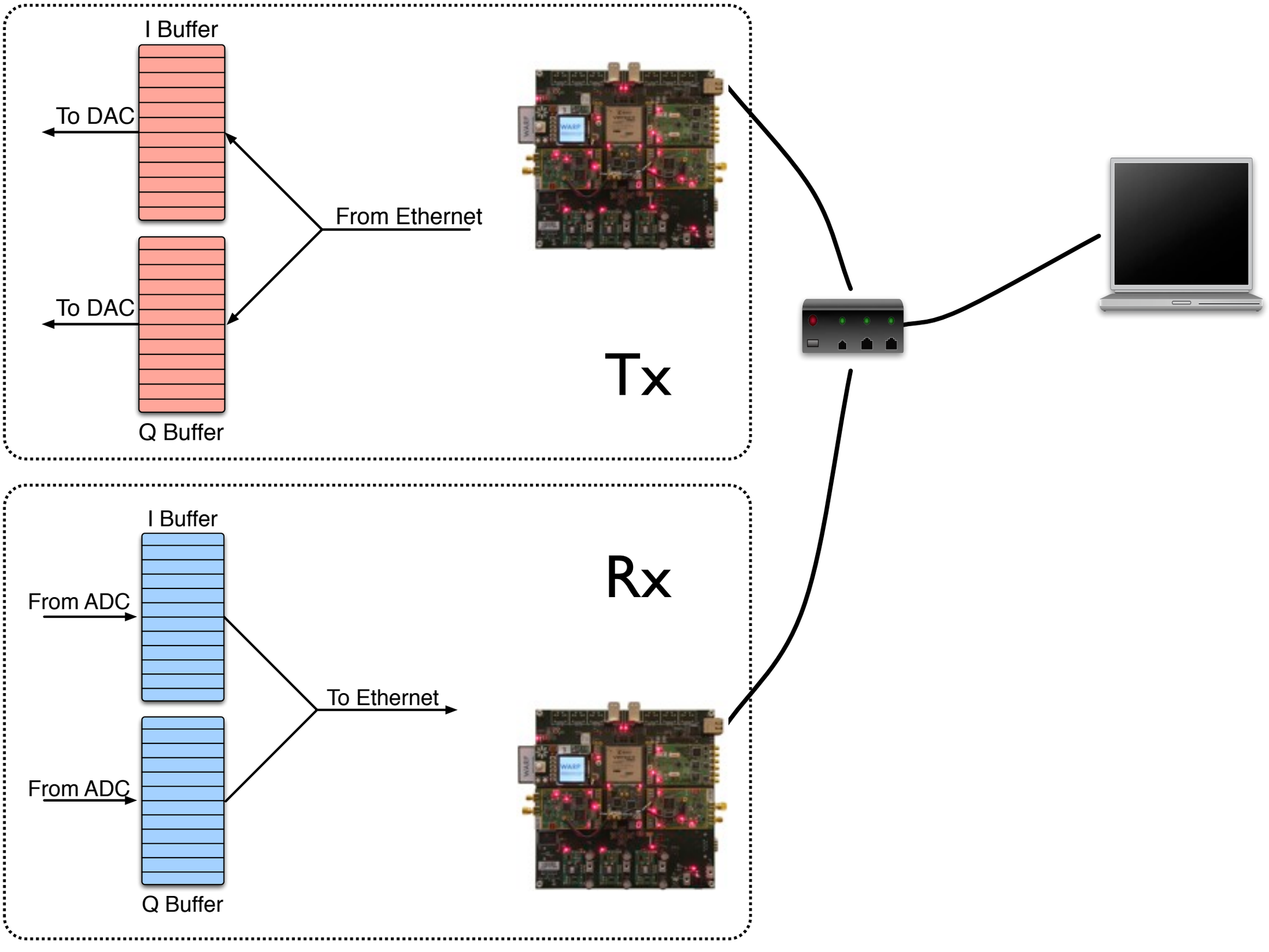
All open source

WARPLab Flow



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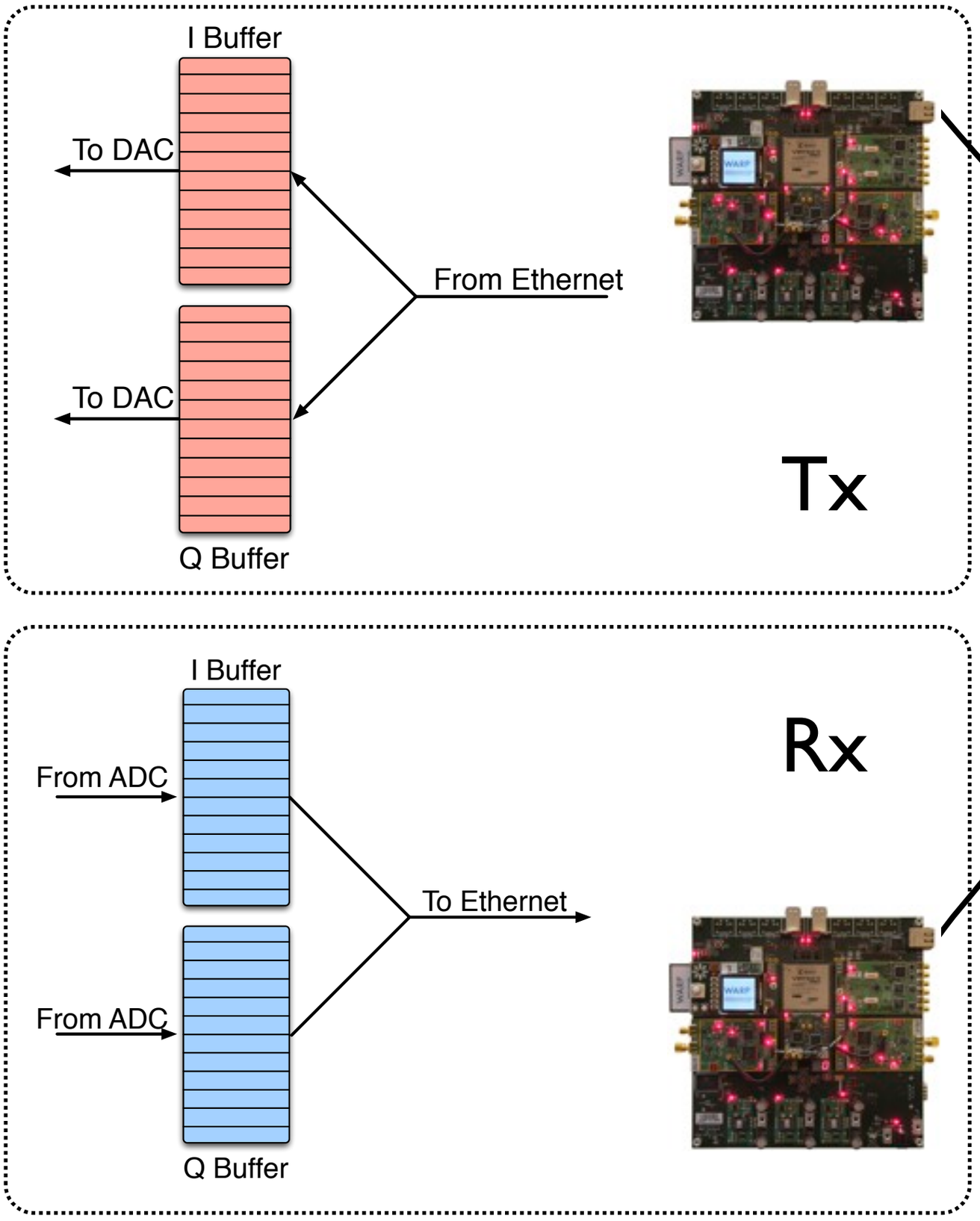
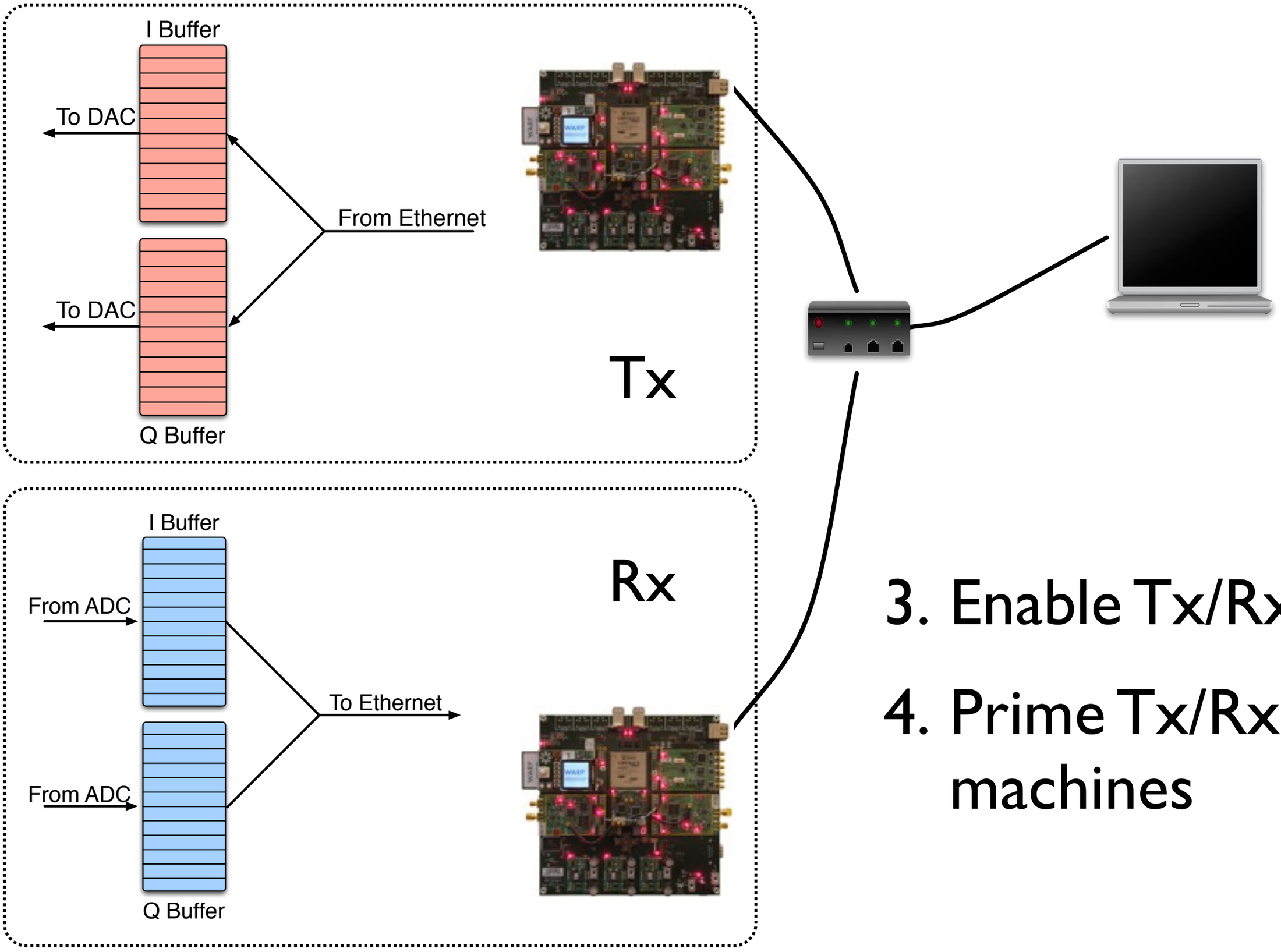


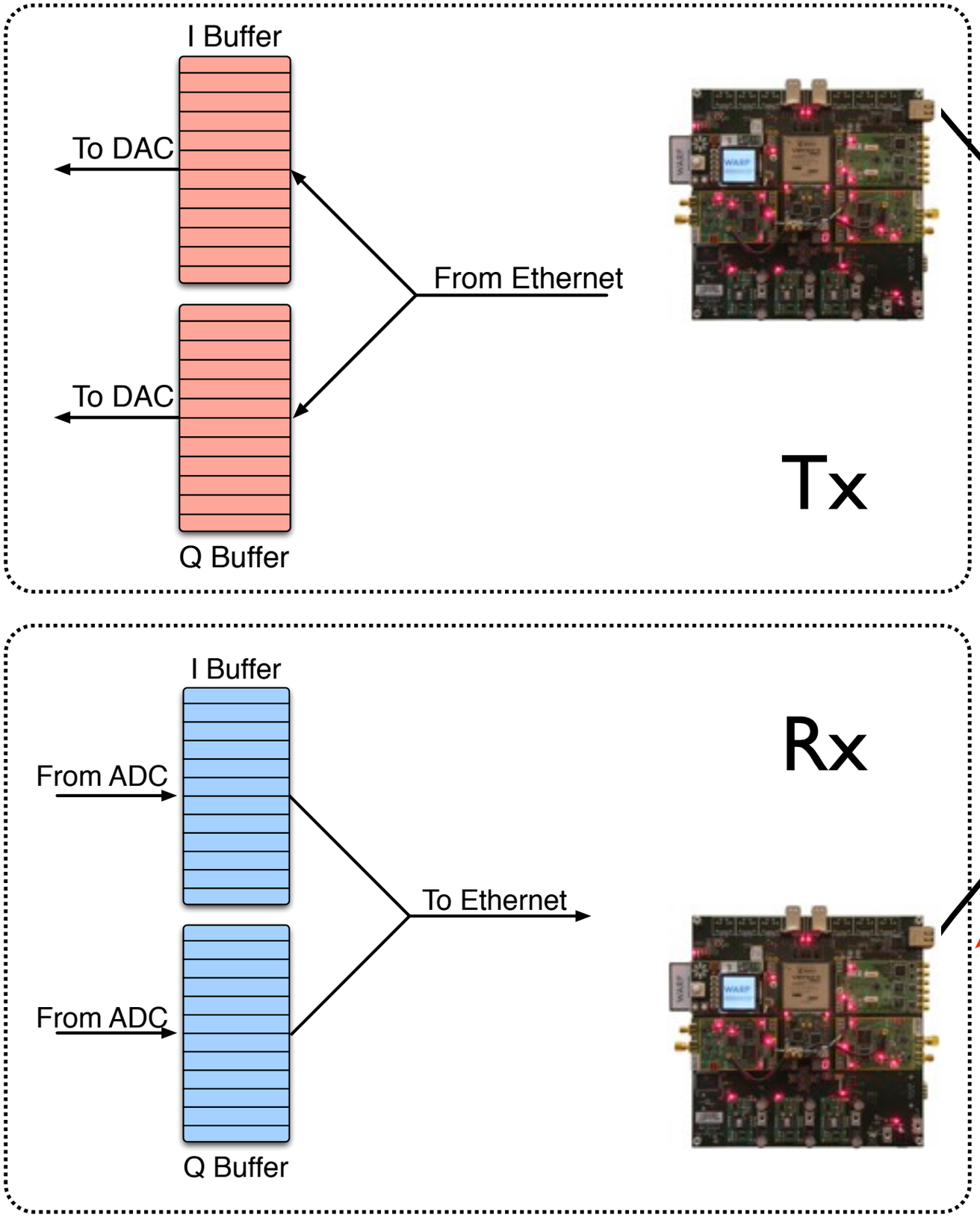
1. Initialize nodes & radio settings
2. Download Tx vectors

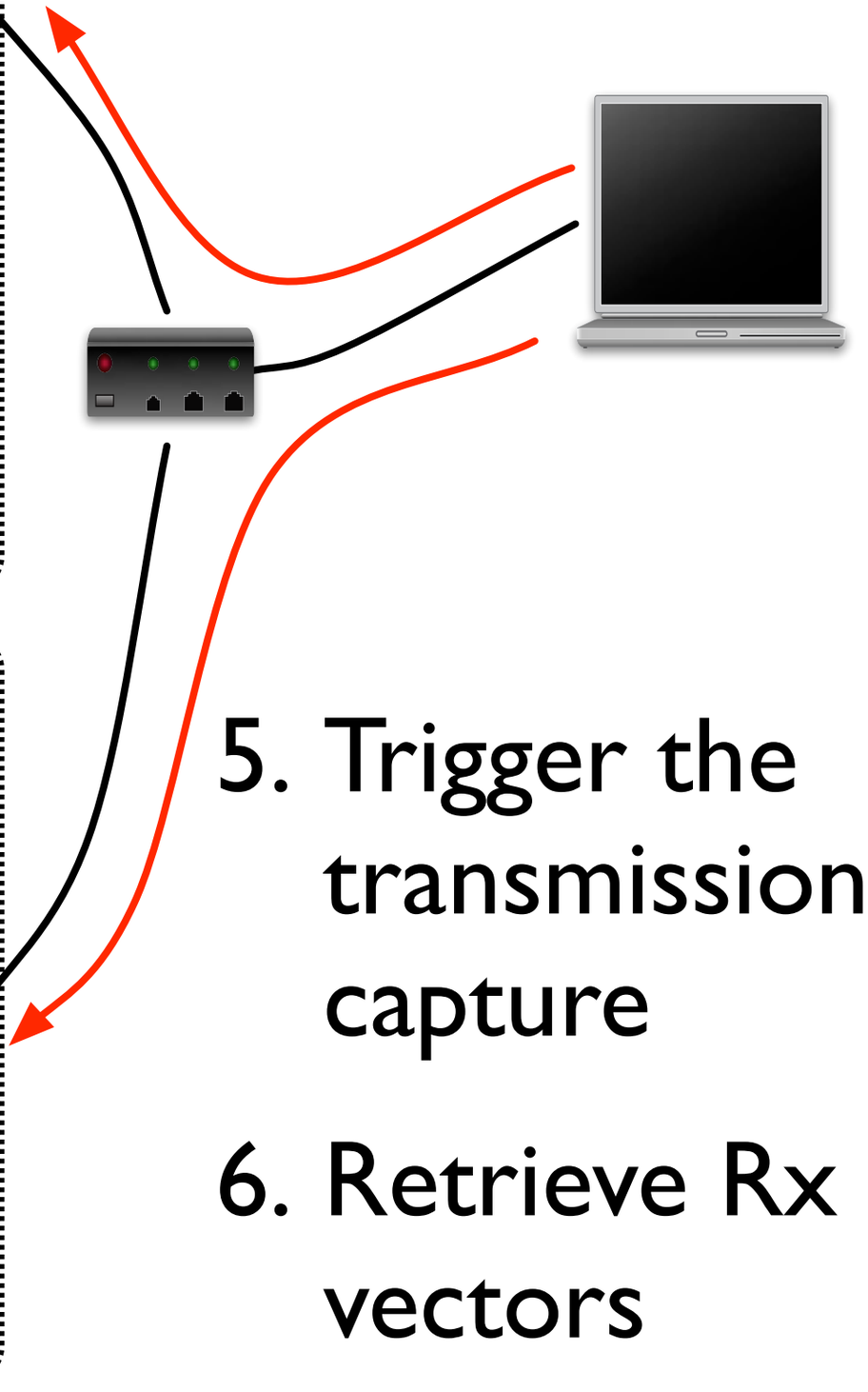
WARPLab Flow



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

WARPLab Flow



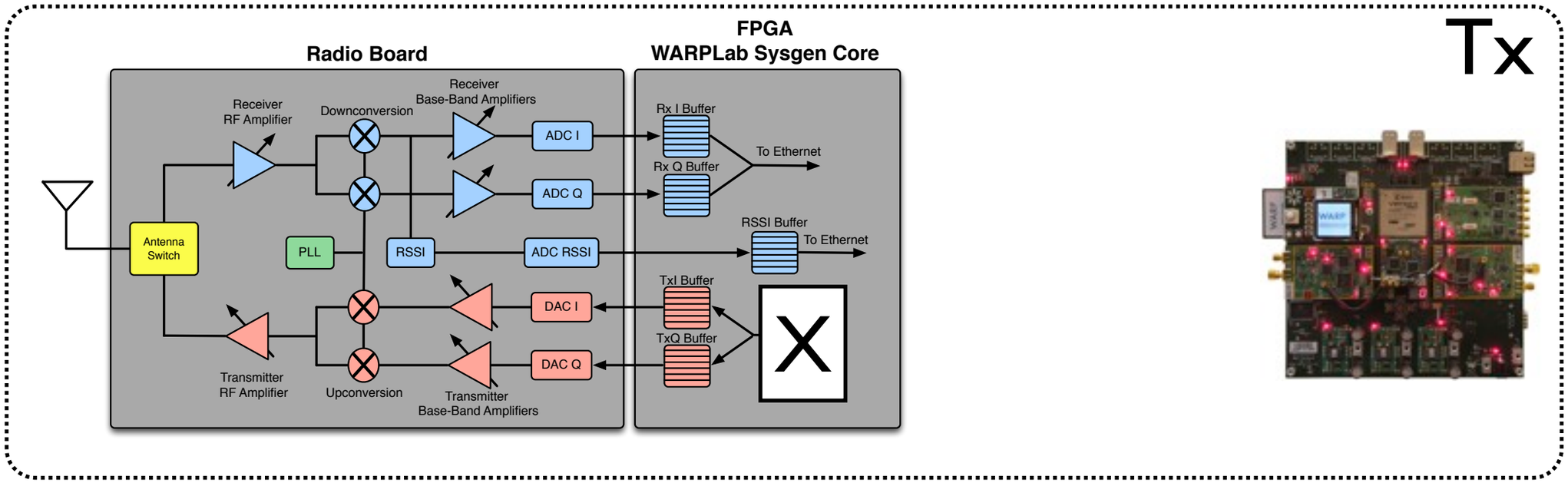


5. Trigger the transmission and capture
6. Retrieve Rx vectors

Tx BB Signal Requirements

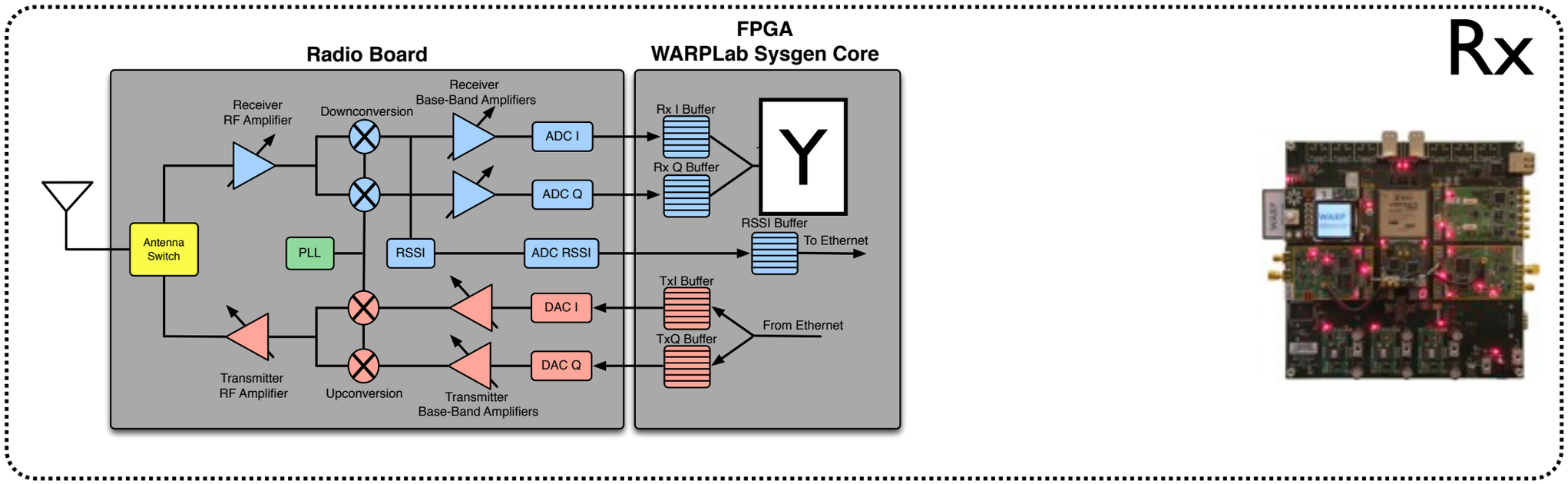
- Amplitude of real part in [-1,1]
- Amplitude of imaginary part in [-1,1]
- Highest frequency 9.5 MHz (19 MHz BW)
- Lowest frequency 30 KHz
- 40 MHz sampling
- Note: Buffers persist between triggers

Tx to Rx path



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

$|H|$:Wireless channel magnitude



Research using WARPLab

- **Beamforming**
  - Duarte, Sabharwal, Dick Rao. *Beamforming in MISO Systems: Empirical Results and EVM-based analysis*. IEEE Transactions on Wireless Communications, 2010.
  - Aryafar, Anand, Salonidis, Knightly. *Design and Experimental Evaluation of Multi-User Beamforming in Wireless LANs*. Mobicom 2010.
- **Collision Resolution**
  - Liu, Kountouriotis, Petropulu, Dadenkar. *ALOHA with Collision Resolution (ALOHA-CR): Theory and Software Defined Radio Implementation*. IEEE Transactions on Signal Proc. 2010.
- **Sphere detection, MIMO Relays**
  - Amiri, Wu, Duarte, Cavallaro. *Physical Layer Algorithm and Hardware Verification of MIMO Relays Using Cooperative Partial Detection*. IEEE ICASSP 2010.
- **Full-Duplex**
  - Duarte, Sabharwal. *Full-Duplex Wireless Communications Using Off-The-Shelf Radios: Feasibility and First Results*. Asilomar 2010

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- http://warp.rice.edu/trac/wiki/PapersandPresentations
  - Liu, Kountouriotis, Petropulu, Dadenkar. *ALOHA with Collision Resolution (ALOHA-CR): Theory and Software Defined Radio Implementation*. IEEE Transactions on Signal Proc. 2010.

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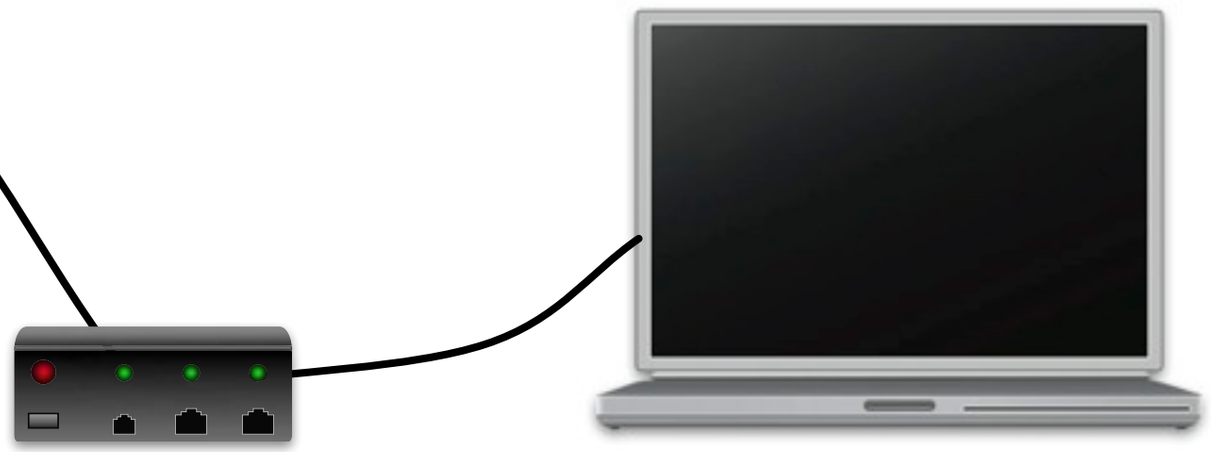
Lab 1: WARPLab

- Exercise 1:
  - Spectrum sensing using WARPLab
- Optional Exercises:
  - Continuous transmitter
  - Building a real bits-to-RF transmitter

Today's setup

WARP node

MATLAB on computer



Ethernet switch