Rapid Prototyping of Wireless Physical Layer Modules Using Flexible Software/Hardware Design Flow

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Software Defined Radio (SDR)

Characteristics

- Software implementation
- Hardware frontends

✚ Advantages

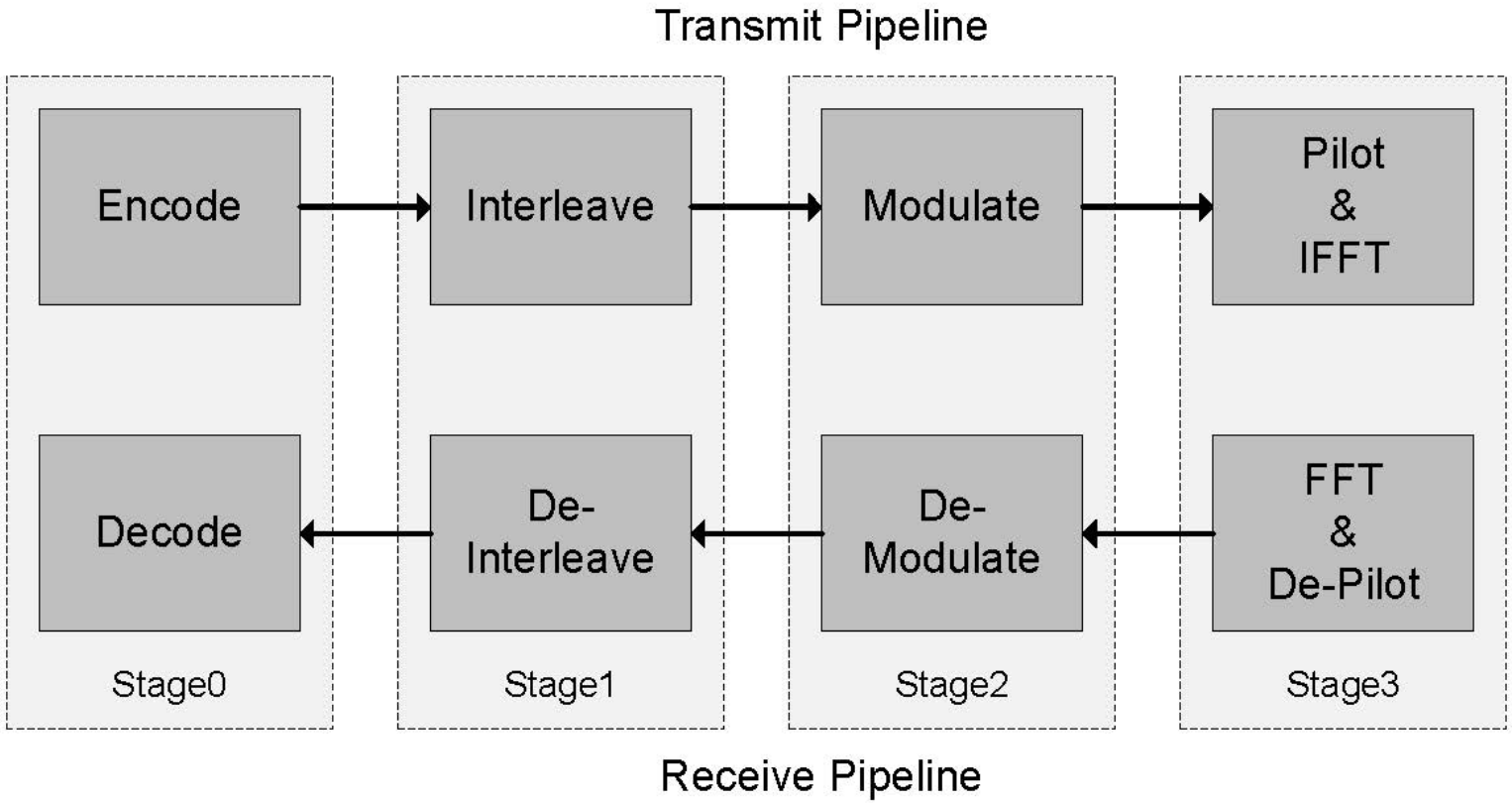
- Easily modified
- Faster time to market

Software
Defined
Communication
Testbed

− Disadvantages

- Slower speed compared to ASIC
- Hard to achieve real-time operations

Generic OFDM Baseband Pipeline



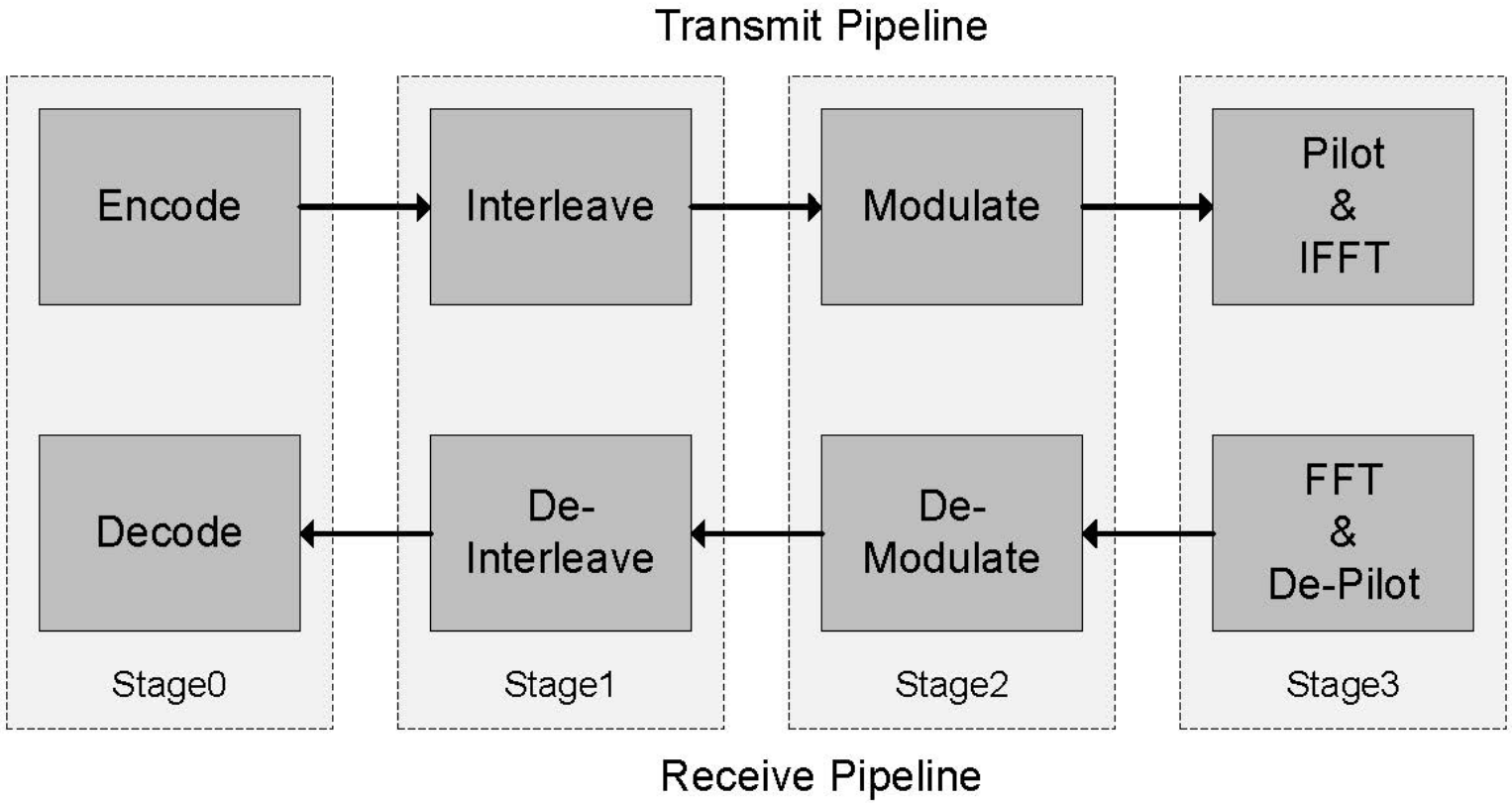
Configuration Parameters

[2,3,4]

Standard	Encoder Rates	Modulation Schemes	IFFT Size
802.16 WiMAX	1/2 , 2/3 , 3/4 , 5/6	BPSK, 4-QAM, 16-QAM, 64-QAM	128, 512, 1024, 2048
802.11n WLAN	1/2 , 2/3 , 3/4 , 5/6	BPSK, 4-QAM, 16-QAM, 64-QAM	64
802.11a WLAN	1/2 , 2/3 , 3/4	BPSK, 4-QAM, 16-QAM	64

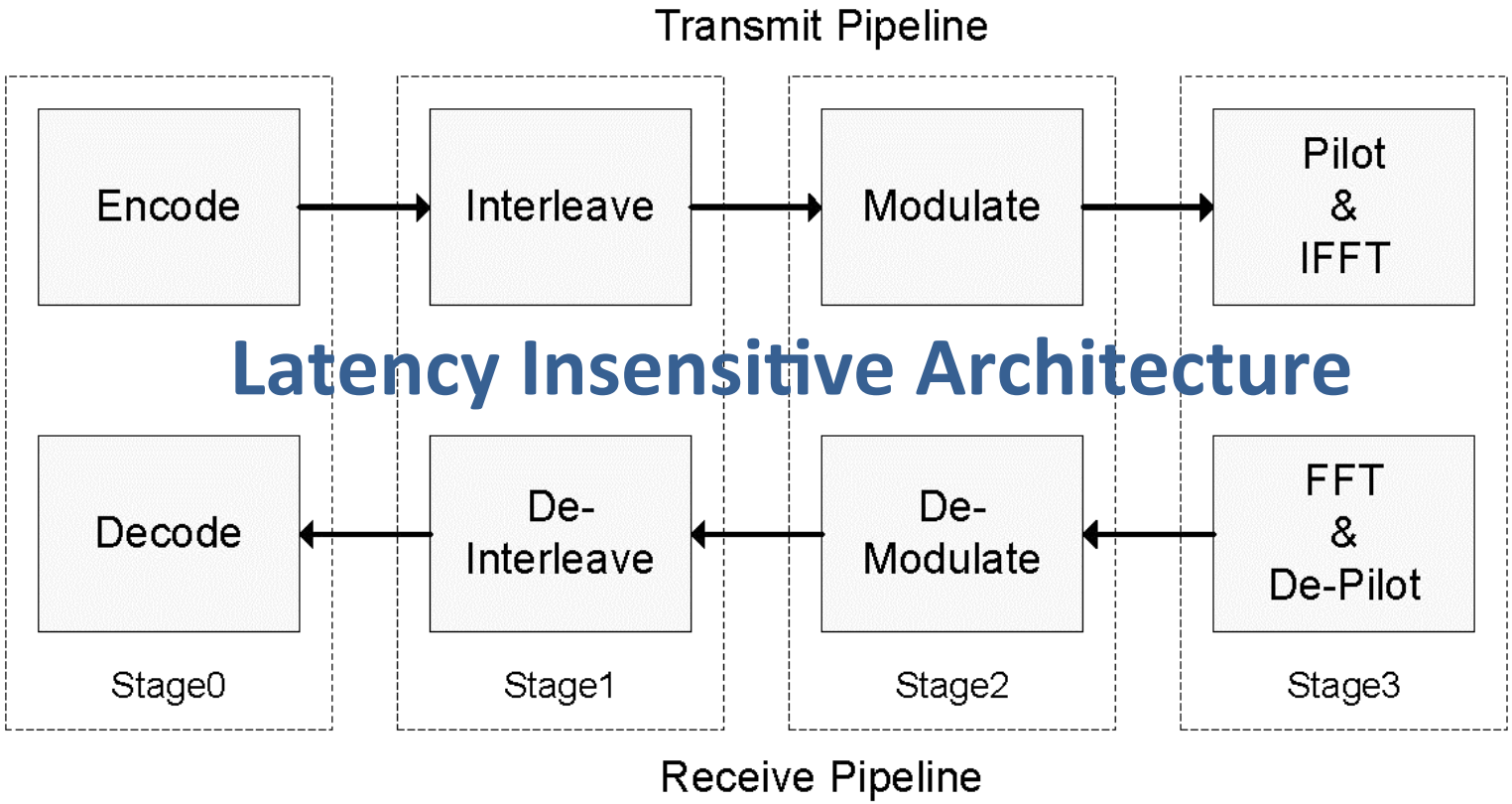
Pipeline Stage	Parameters
Encoder	Coding rate, Polynomial
Modulation	Modulation scheme, Data mapping value
Piloting	Pilot position, Pilot value, Symbol size
IFFT	Symbol size, Guard prefix

Generic OFDM Baseband Pipeline



- Fixed PHY implementation
- Fixed Configurations
- Fixed rates

~~Generic~~ Scalable OFDM Baseband Pipeline



- ~~Fixed~~ Scalable PHY implementation
- ~~Fixed~~ Scalable Configurations
- ~~Fixed~~ Scalable rates

Software Defined Communication Testbed[1]

- Software interface driven flexible hardware implementation
  - Software flexibility
  - Hardware speeds
- Rapid prototyping
  - OFDM based comm. standards
  - Variations within comm. standards
- Runtime adaptable

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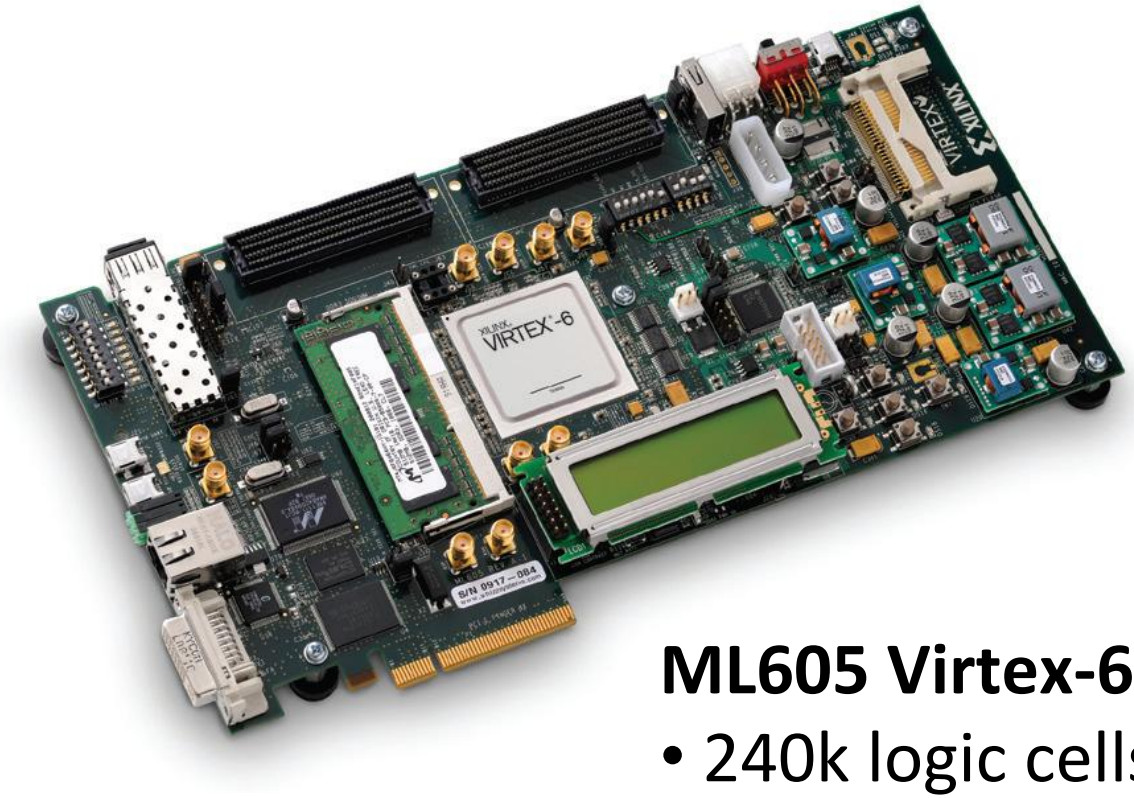
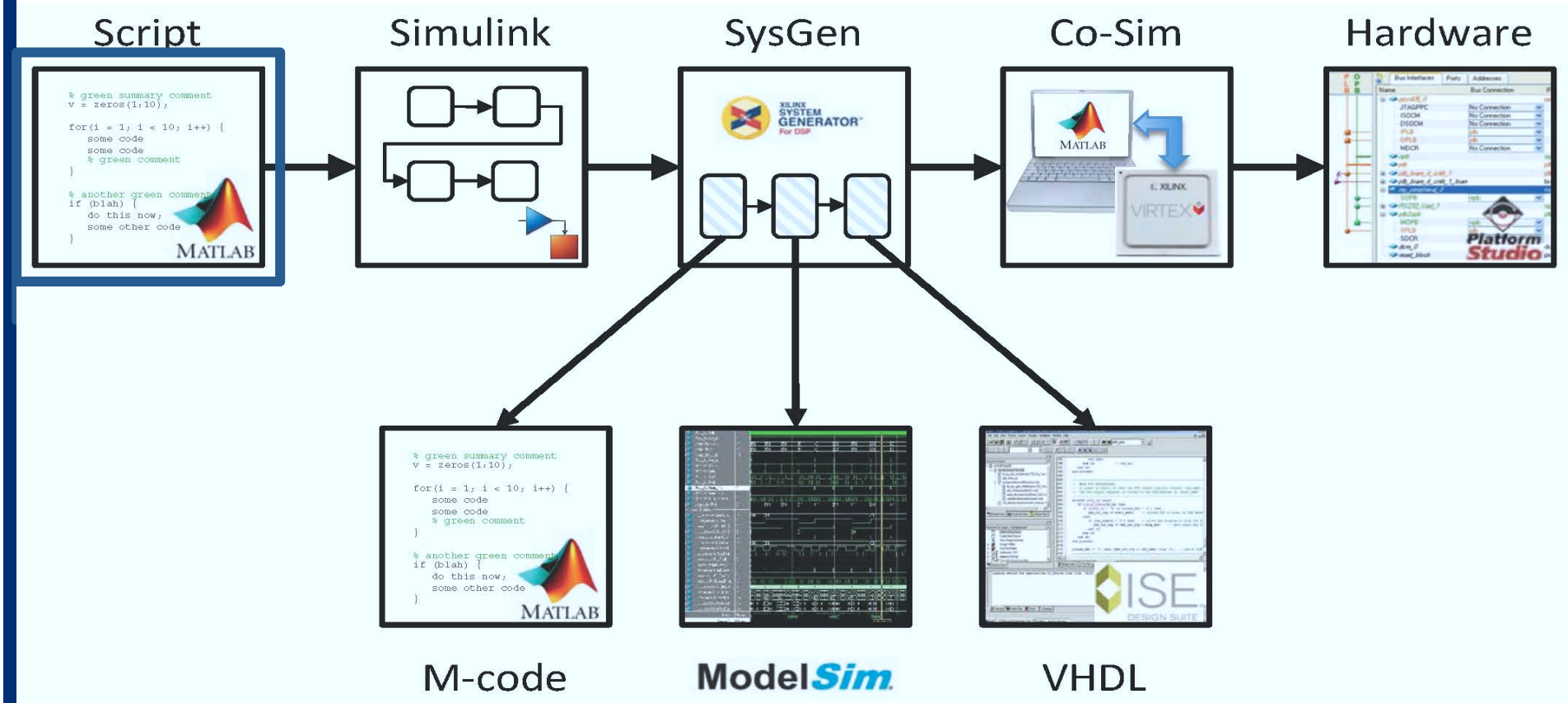
Hardware Platform



ML605 Virtex-6 FPGA Baseband

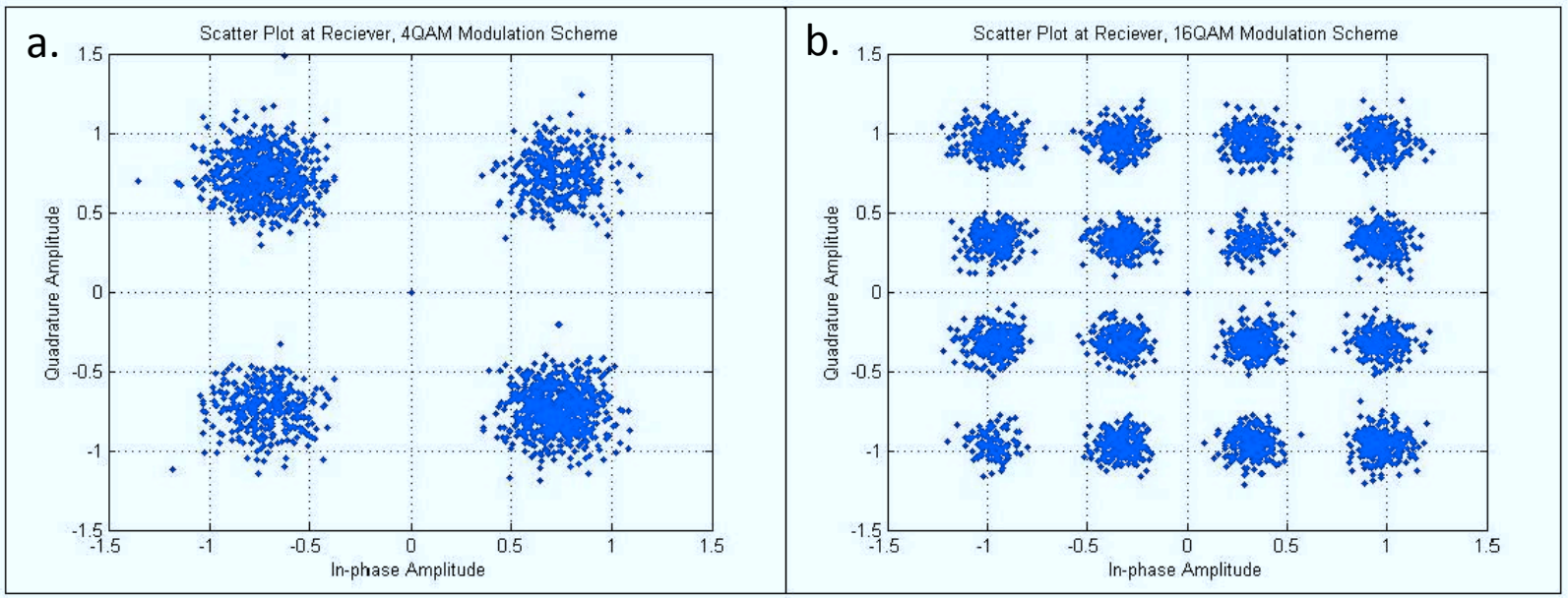
- 240k logic cells, 700 DSP slices, 400 BRAMs
- Gigabit Ethernet
- FPGA Mezzanine Connector (FMC)

Software/Hardware Design Flow



- Hardware Implementation
  - Microblaze driven experiments
  - On-board data generation and validation

Two Configurations of Coding and QAM

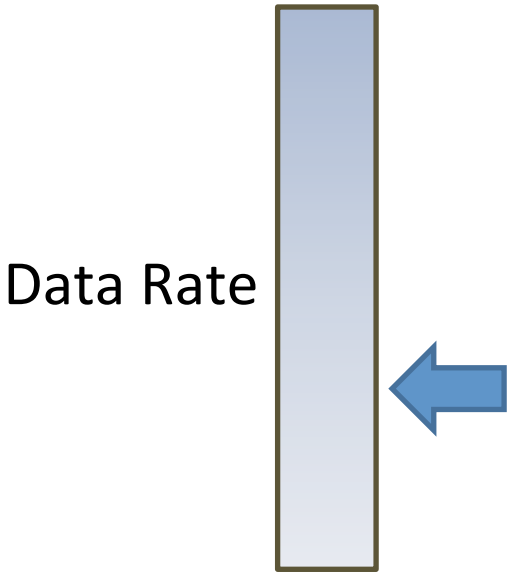


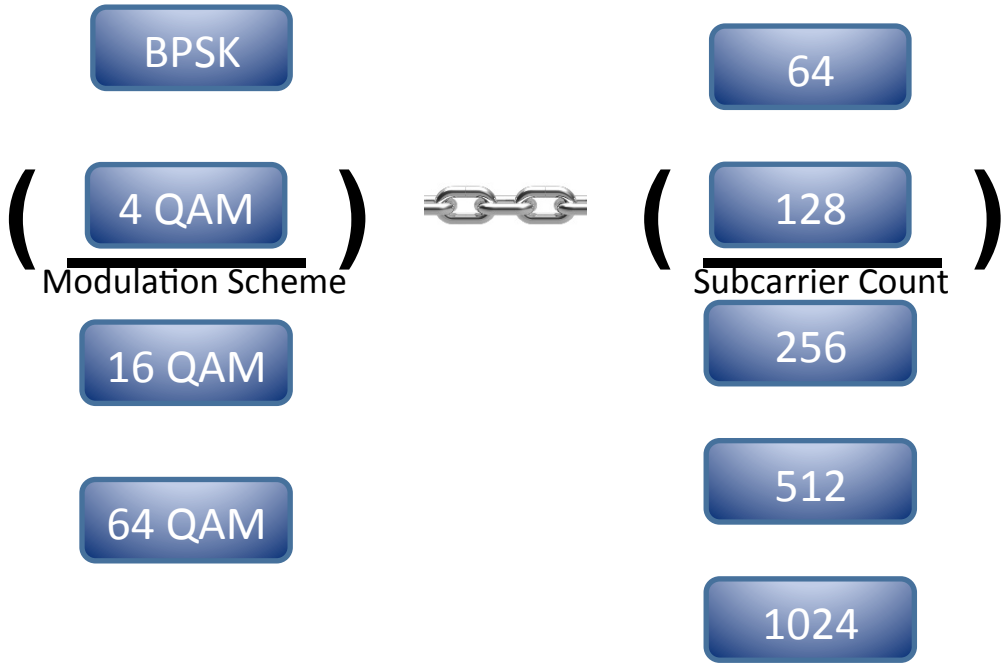
- AWGN channel
- Constellation mapping for:
  a. 4QAM mod 1/2 coding rate, SNR=15dB
  b. 16QAM mod 3/4 coding rate, SNR=20dB

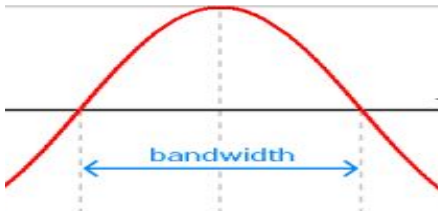
What's the data rate?

Based of

- Communication standard
- Rates implemented







Bandwidth

Conclusion

- Built Software Defined Communication Testbed (SDC)
- Described SDC's step by step design approach realizing PHY software implementation into hardware
- SDC provides flexibility and real-time speeds with its software interfaced hardware implementation

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Questions?

References

- [1] Chacko, James; Sahin, Cem; Nguyen, Danh; Pfeil, Doug; Kandasamy, Nagarajan; Dandekar, Kapil, "FPGA-based latency-insensitive OFDM pipeline for wireless research," High Performance Extreme Computing Conference (HPEC), 2014 IEEE , vol., no., pp.1,6, 9-11 Sept. 2014
- [2] ECMA-368: Standard:High rate ultra wideband PHY and MAC standard
- [3] IEEE 802.16: 2009 standard for local & metropolitan area networks part 16: Air interface for broadband wireless access systems.
- [4] IEEE 802.11: standard for wireless lan medium access control (mac) & physical layer (phy) specifications, 2012.

OFDM Physical / Baseband layer

- Filter stage
  - Enforcing BW limitations
- Modem stage
  - Signal conditioning
  - Most diverse
- Codec stage
  - Frame/symbol conditioning
  - Heavy computation

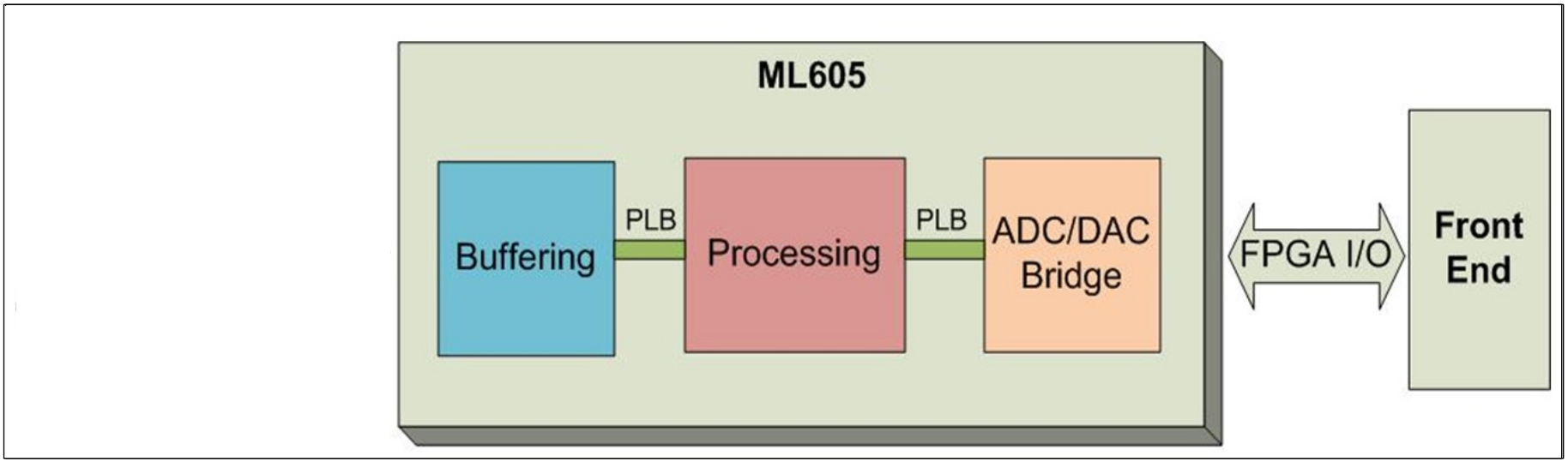
PCIe Connection

Gen 1 x8 PCIe connection provides the fastest data link

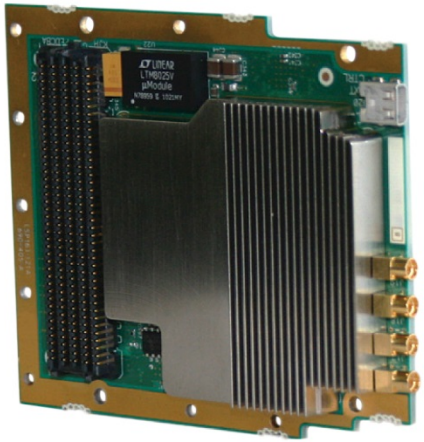
- Based on Microsoft's Speedy PCI Express design
- Provides DMA into FPGA RAM
- Measured write max BW: ~1.425 GB/s
- Measured read max BW: ~1.2 GB/s
- Still in development: Currently being integrated with other components of our system

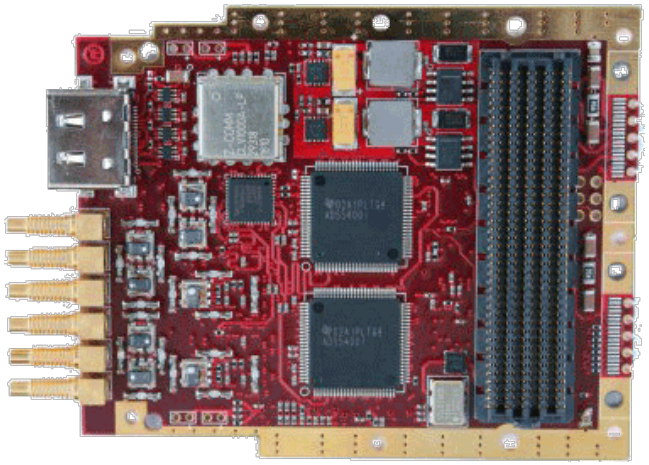
Data Flow

On-Board prototyping
Xilinx SDK/EDK+ ML605 HW + Radio frontend



Hardware Platform





Nutaq Radio420x

- Frequency agility
- 300 MHz – 3 GHz
- 20 MHz BW signals
- Programmable center frequency

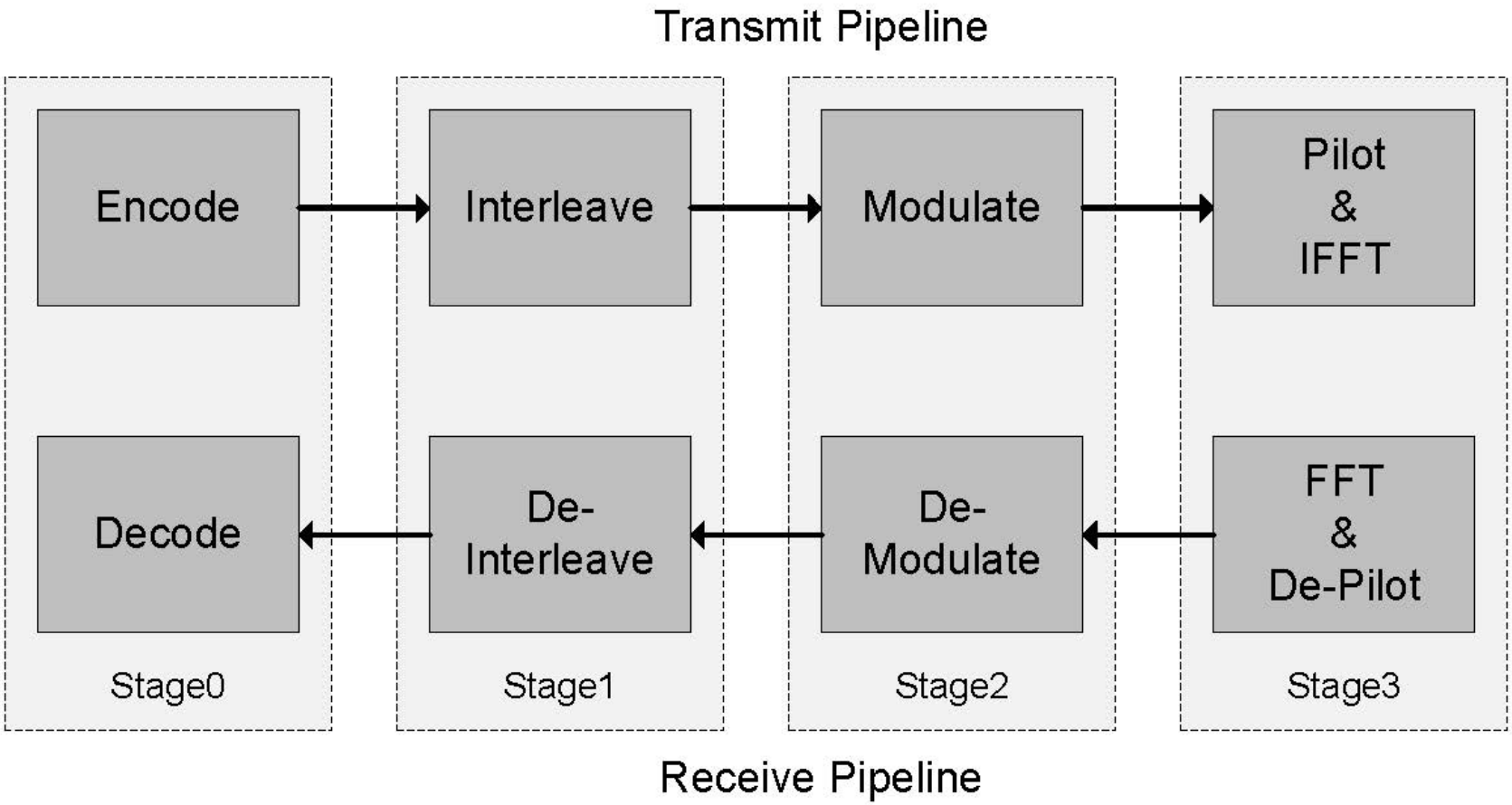
4DSP FMC110

- Fast DAC / ADC 1Gsps
- 250 MHz BW signals
- UWB applications

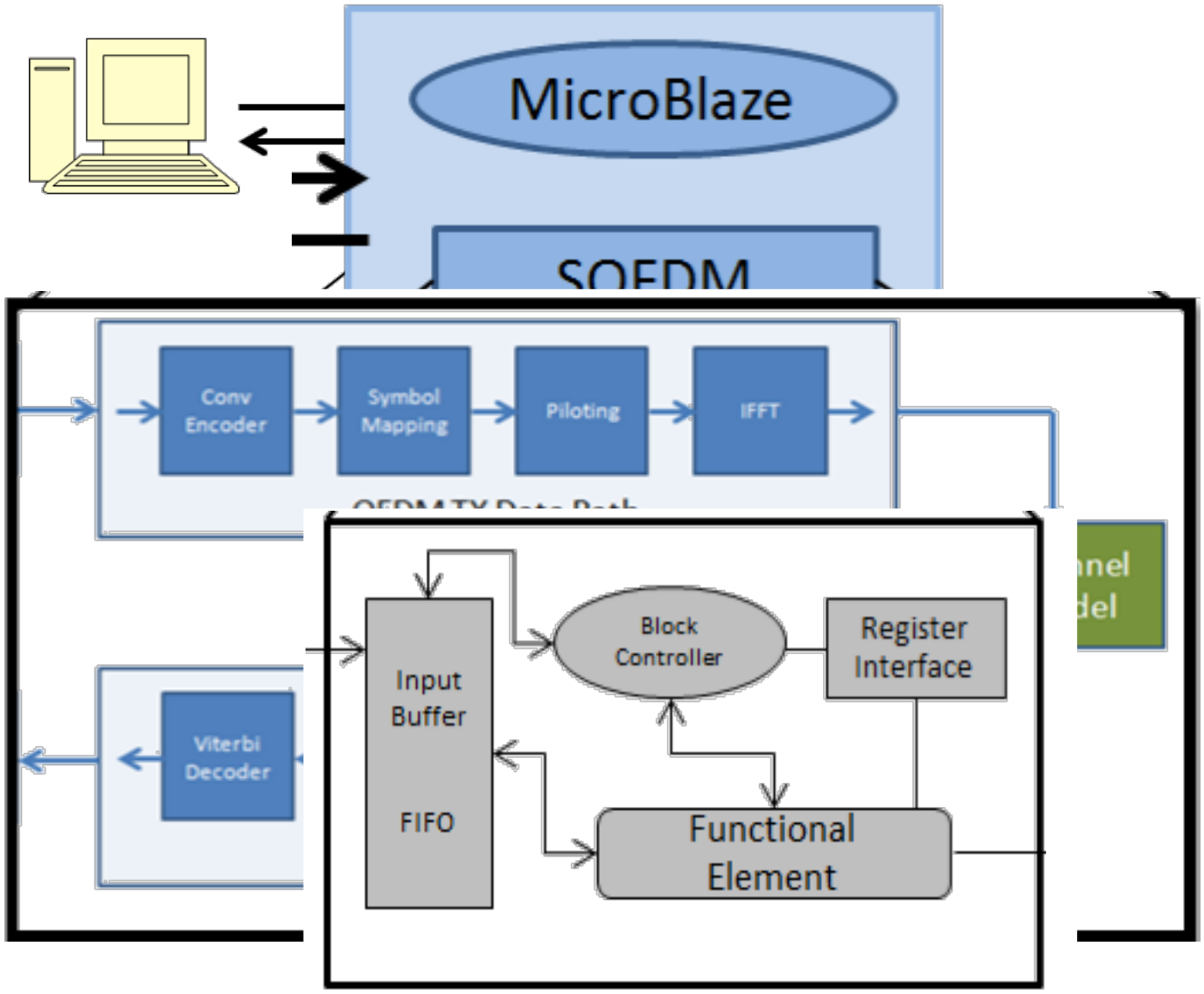
Orthogonal Frequency Division Multiplexing (OFDM)

- Encodes digital data unto multiple subcarrier frequencies
- Advantageous against inter symbol interference & frequency selective fading
- More sensitive to frequency and timing offset
- Simpler frequency equalization techniques compared to time domain
- Can increase performance through spatial diversity
  - This area will be revisited later
- Baseband/Physical layer consists of components that works at different rates based on standard being implemented

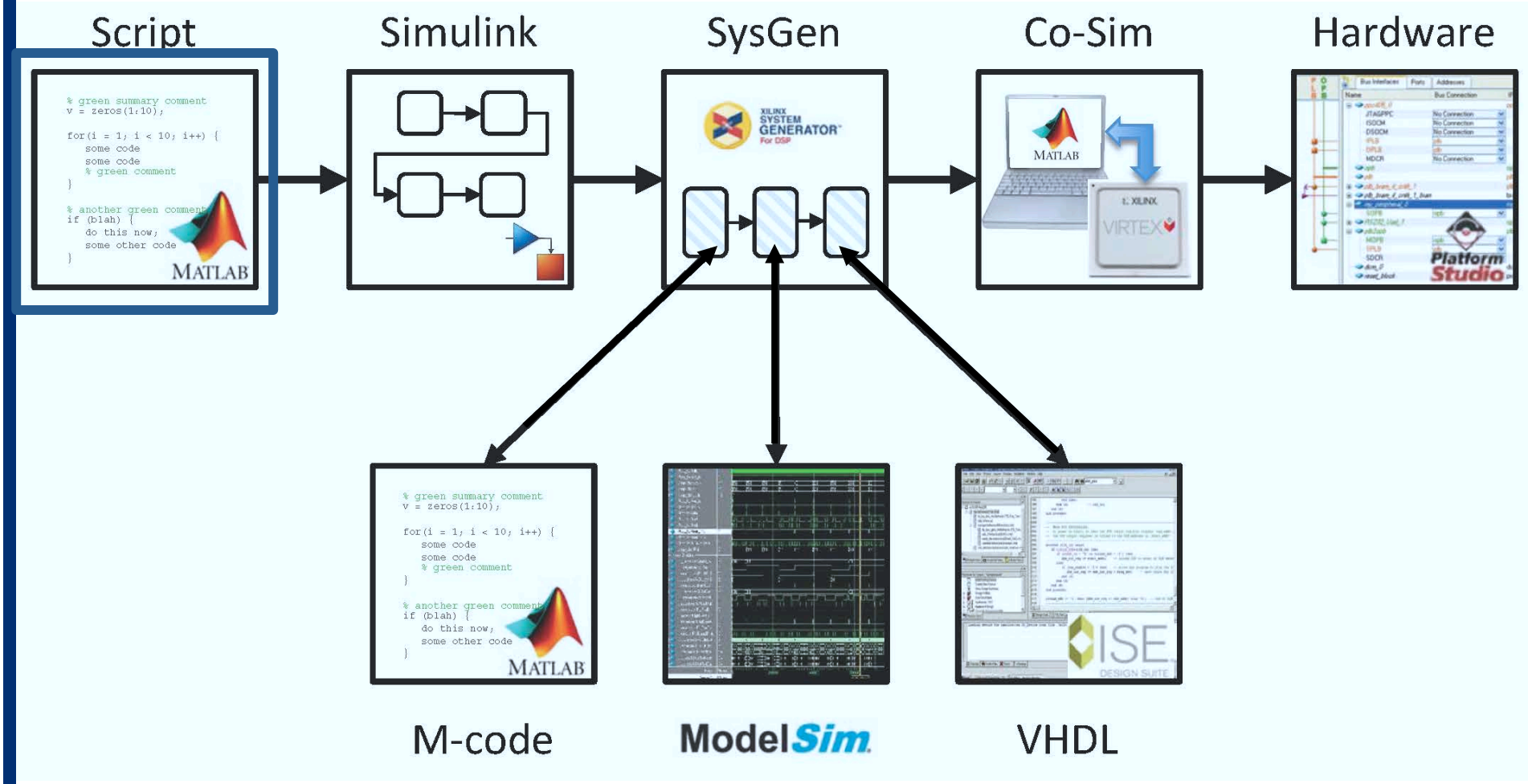
Generic OFDM Baseband Pipeline



System Layout

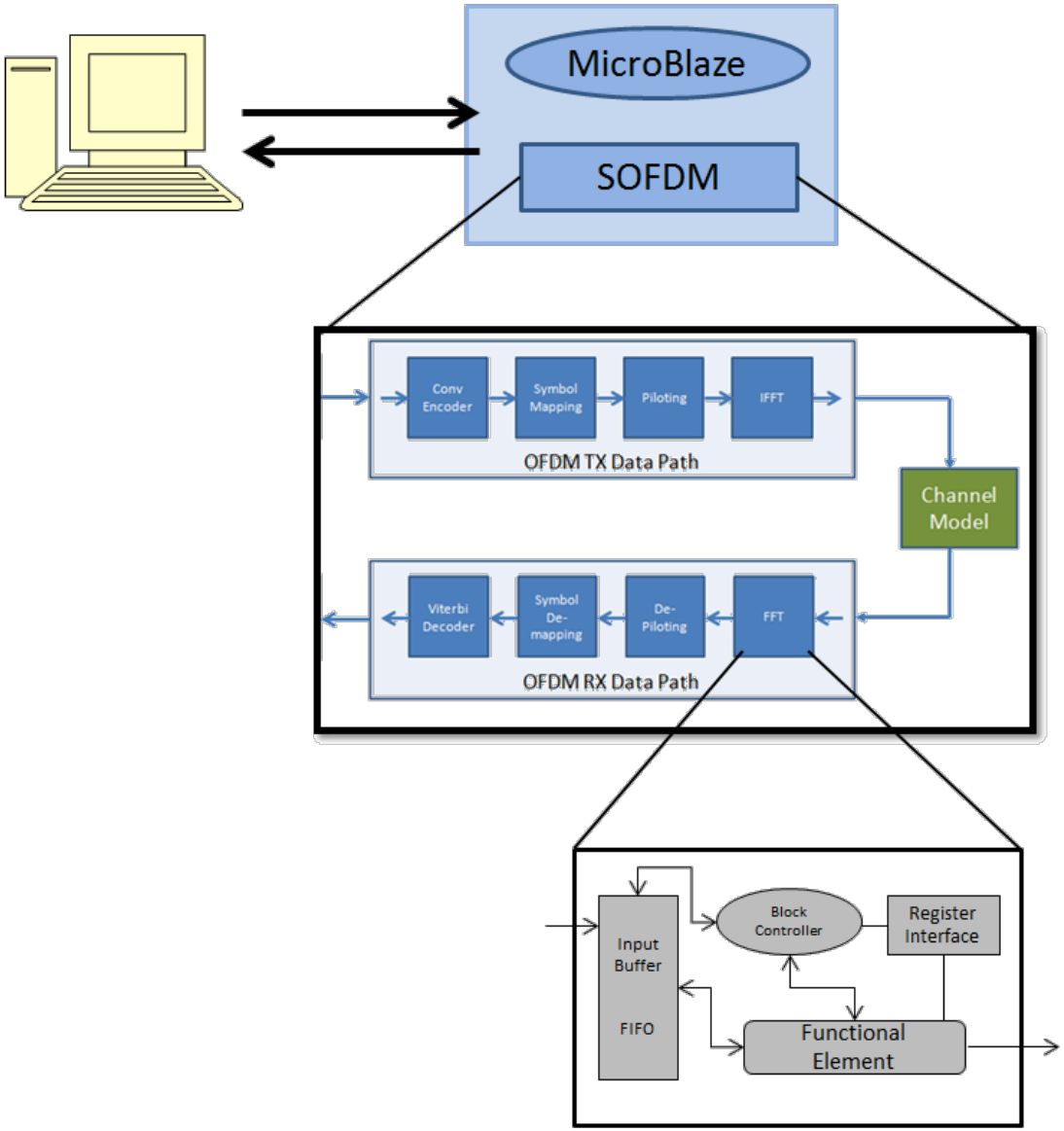


Software/Hardware Design Flow

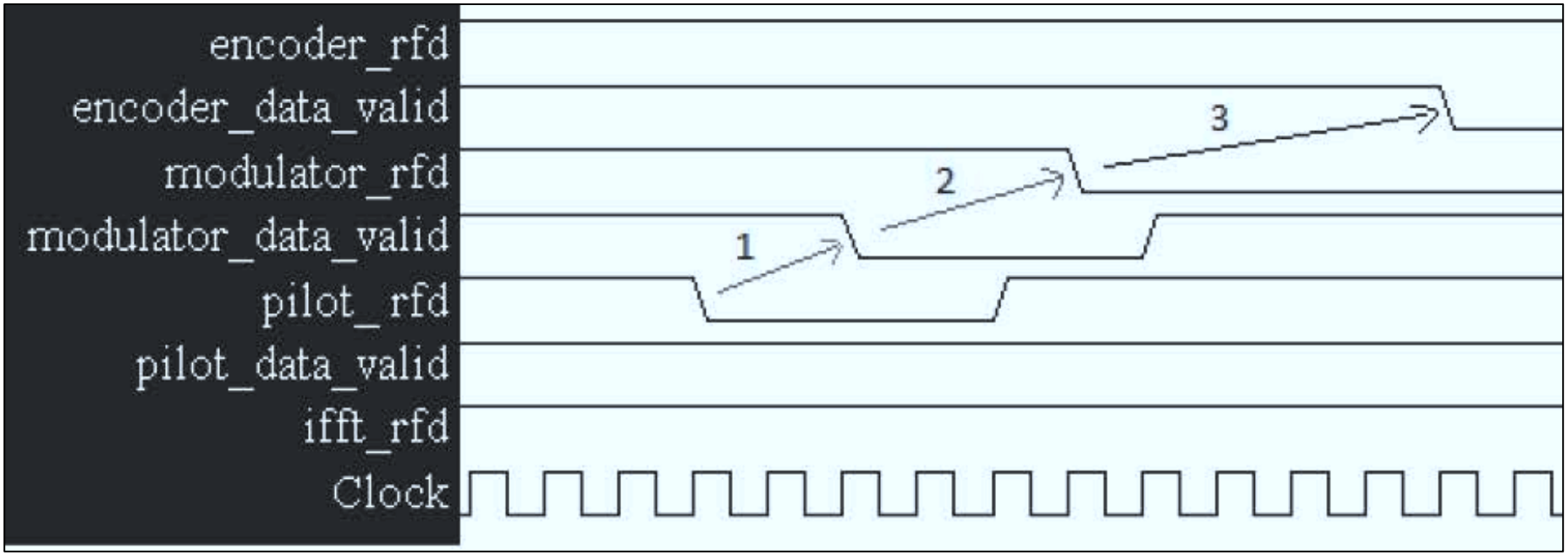


- Hardware Simulation

System Layout



Stall Propagation



Stall caused by piloting block propagating backwards

Software Defined Radio (SDR)

- Traditional radios are largely hardware based
  - Physical components
  - More difficult to modify
  - Minimal flexibility
- SDRs can be defined as some or a lot of traditional hardware layers implemented through software