Chaotic Architectures for Secure Free-Space Optical Communication

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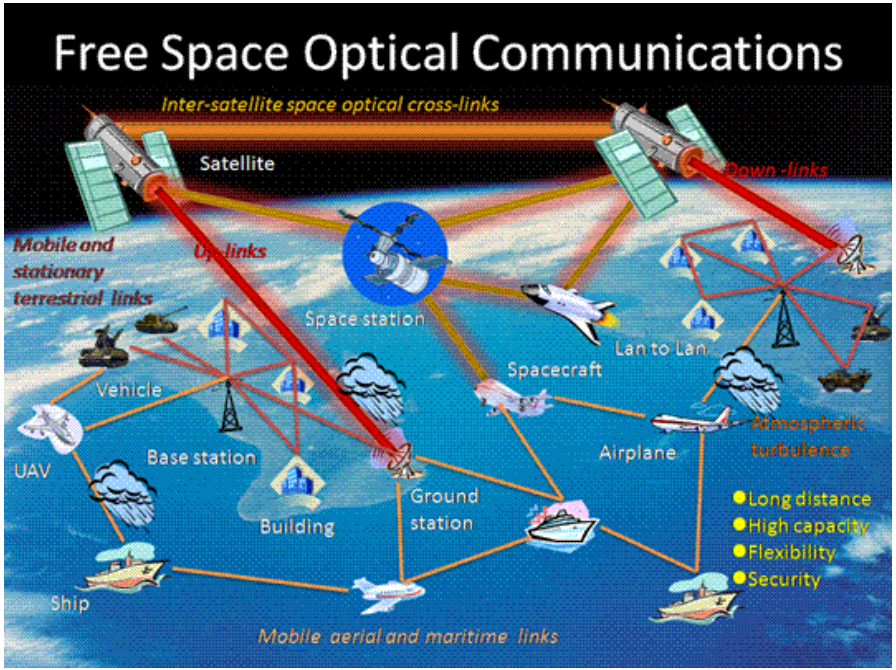
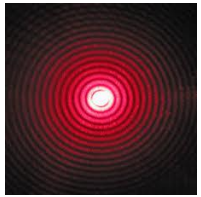
Outline

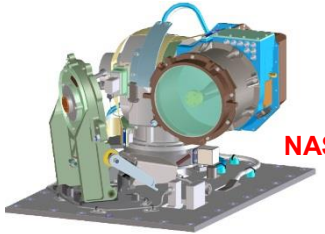
- Introduction and Motivation
- Approach
- Implementation Architecture
- Results and Future Work
- Summary and Conclusions

Introduction and Motivation

- **Free-Space Optical (FSO) vs. Free-Space Radio-Frequency (FSRF) communications**
  - Larger Bandwidth
  - Lower Cost, Power, Mass of implementation
  - Improved Security
- **Secure FSO communications**
  - Usually use laser N-slit-interferometers
    - Over relatively short propagation distances, particularly for deep-space communication
      - » Terrestrial applications → Several kilometers
      - » Space applications → Several thousand kilometers (2,000-10,000 km)
- **Security and Long-Range FSO communications**
  - Conflicting requirements







NASA's LLCD System

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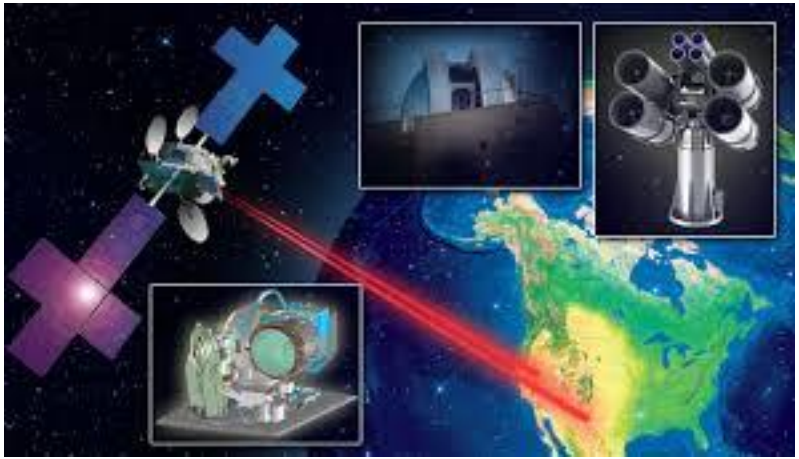
Approach

- **Chaotic Systems**
  - First presented by E. N. Lorenz in 1963
  - Display well defined, but extremely complex dynamic behaviors
    - Broadband noise-like signals similar to spread-spectrum signals
    - Multi-path fading resistance
    - Unpredictability
    - Sensitivity to initial conditions
  - Difficult for unintentional receivers to synchronize to the chaotic signal → Security
- **Pyramidal Filtering Structures**
  - Discrete Wavelet Transformation (DWT)
    - Minimize scintillation noise
      - » Usually found in space-to-ground, near-Earth, and terrestrial communications
- **FPGAs**
  - Stringent real-time requirements of FSO communications
    - Transmission Rates > 1 Gbps
    - Bit-Error-Ratios (BER) < 10^{-7}

NASA Goddard SPACE FLIGHT CENTER

Laser Communications Relay Demonstration (LCRD)



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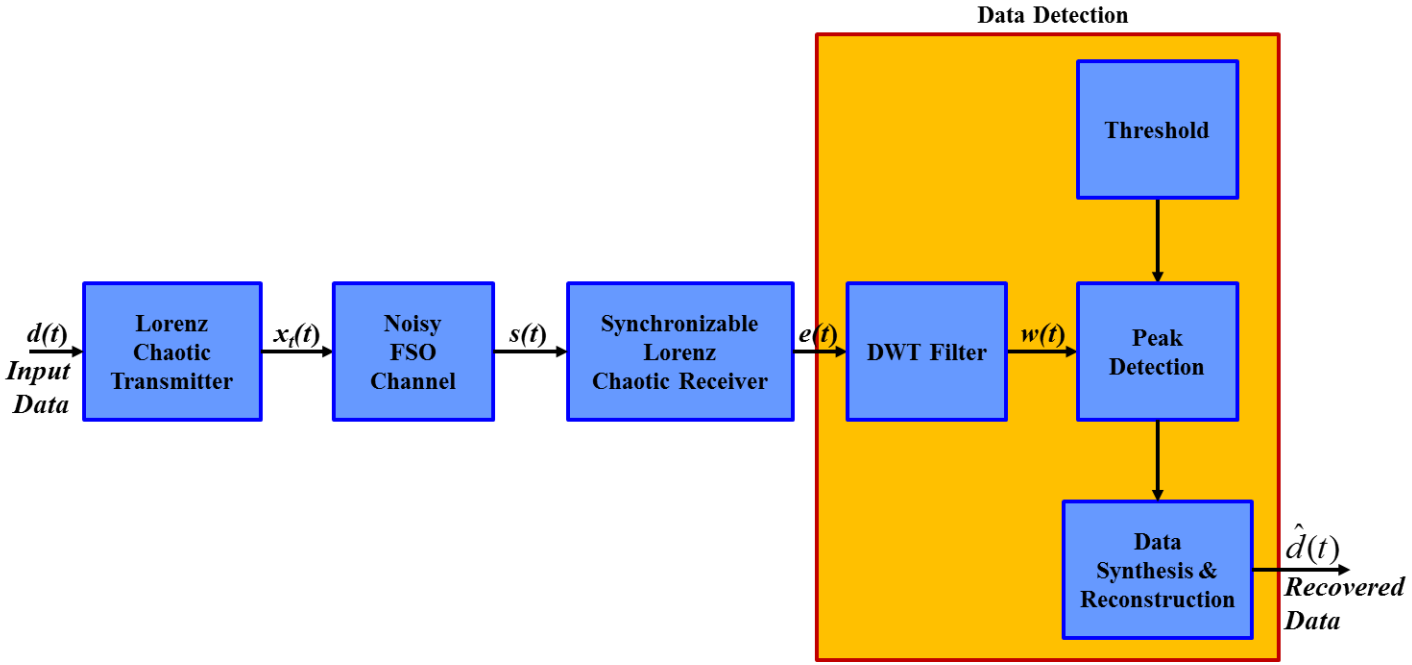
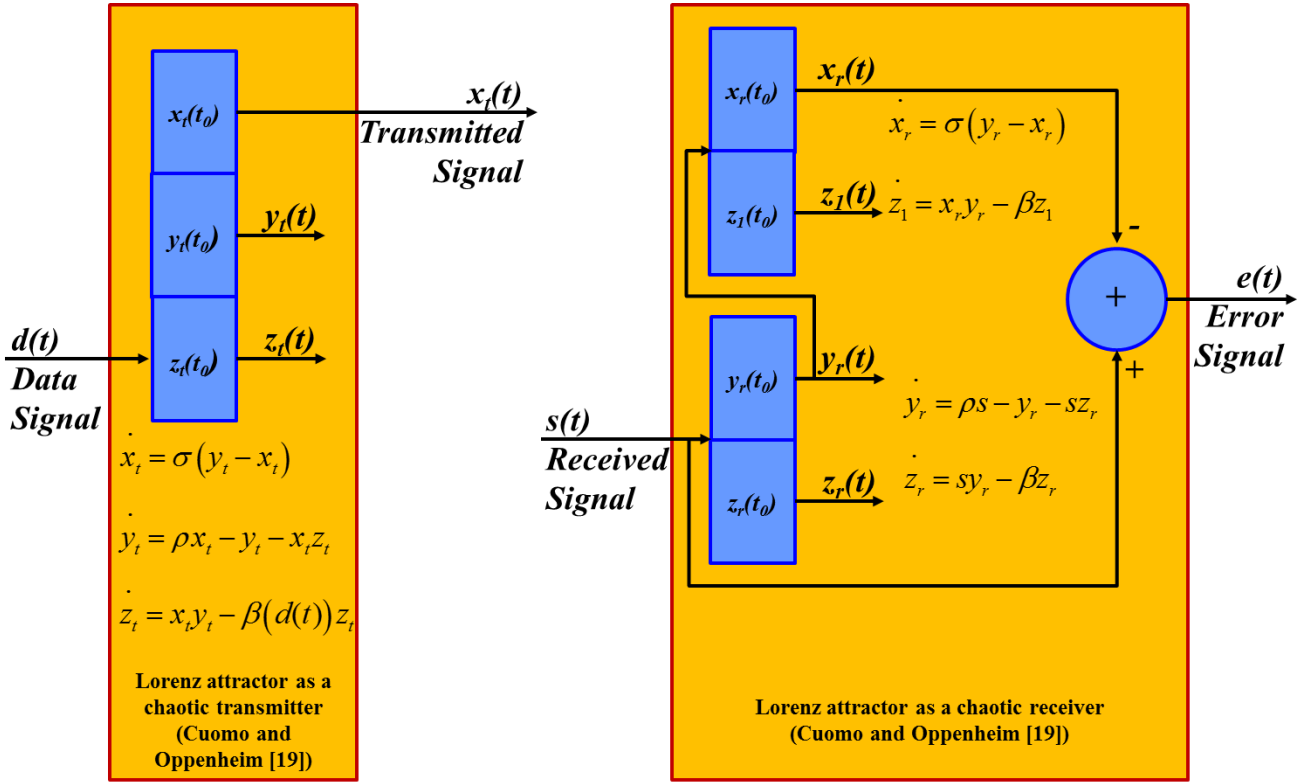
Proposed System Architecture



Chaotic Transmitter & Receiver



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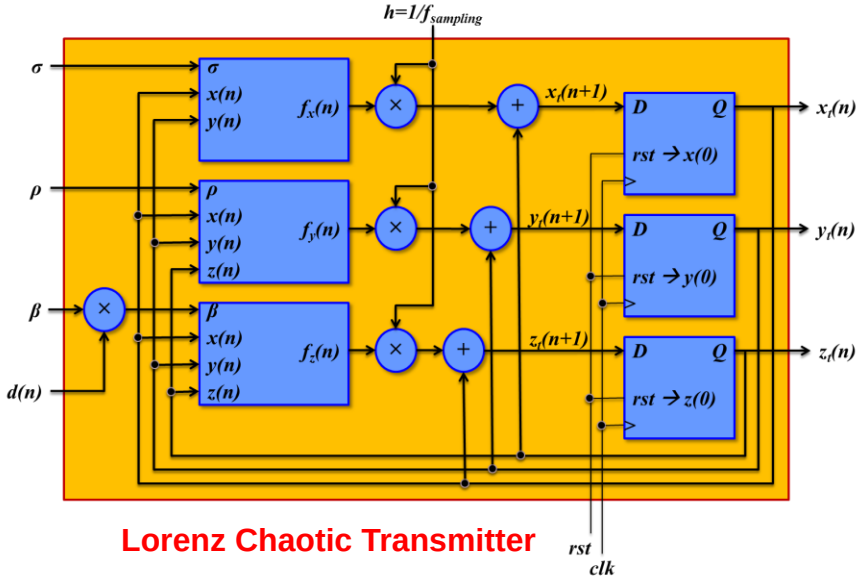
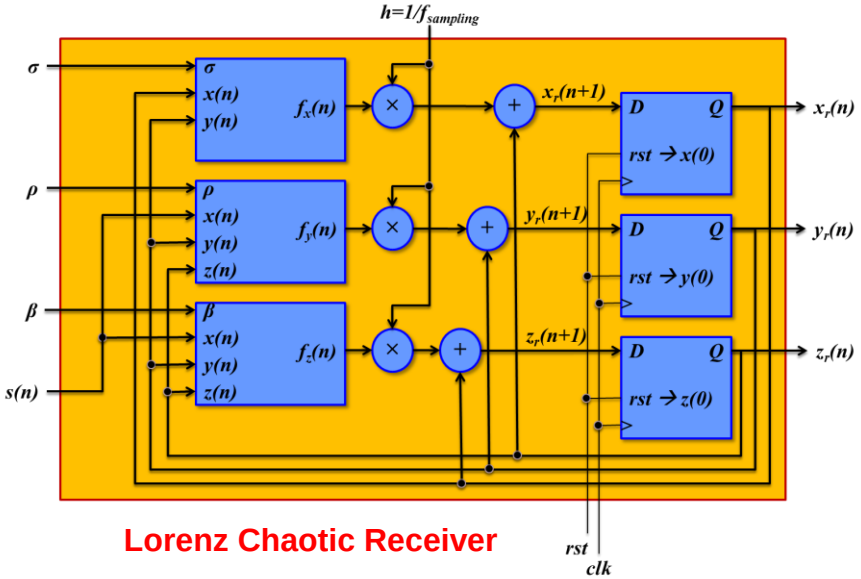
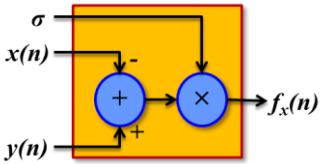
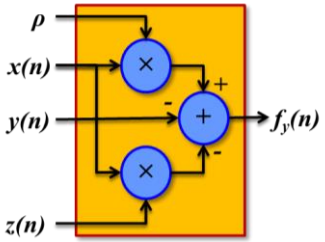


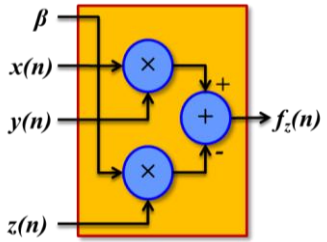
Lorenz Chaotic Transmitter



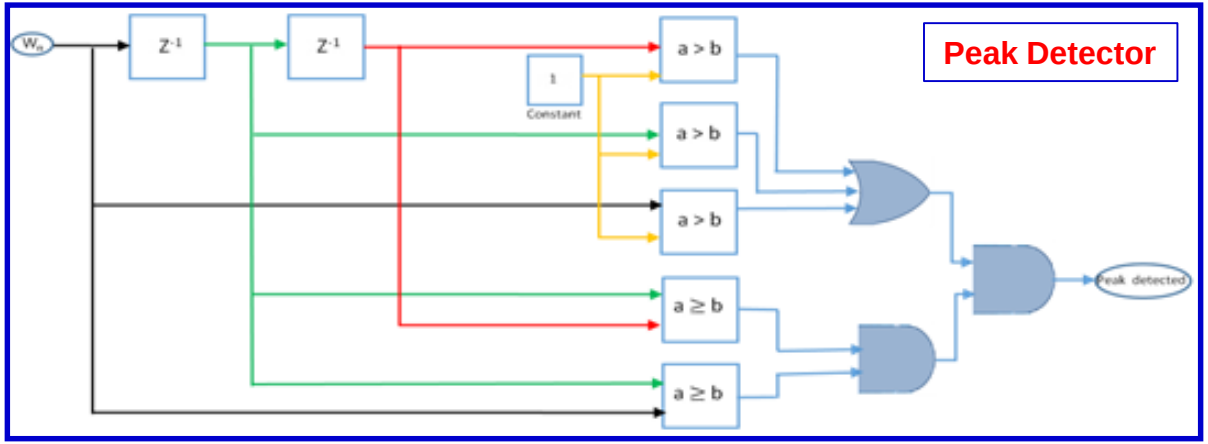
Lorenz Chaotic Receiver

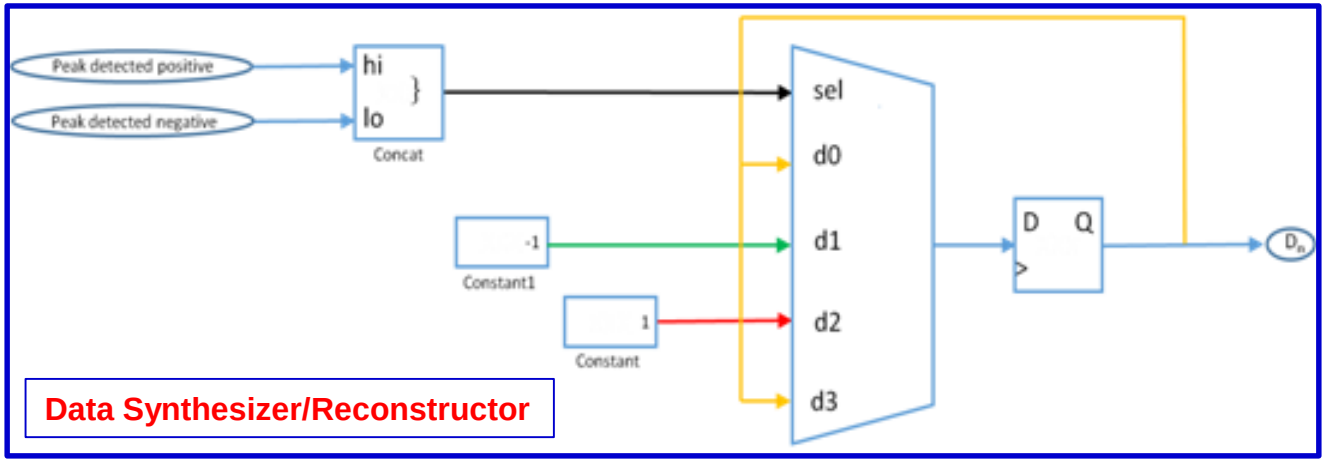






Peak Detector & Data Synthesizer/Reconstructor





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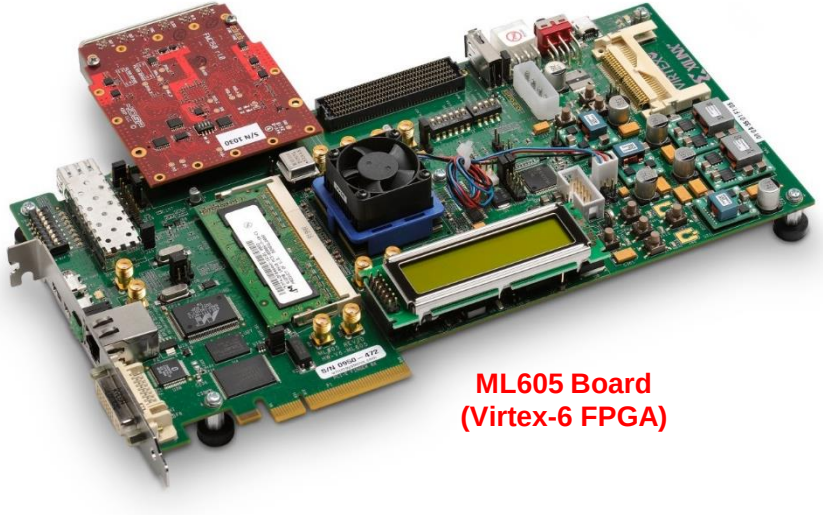
Results

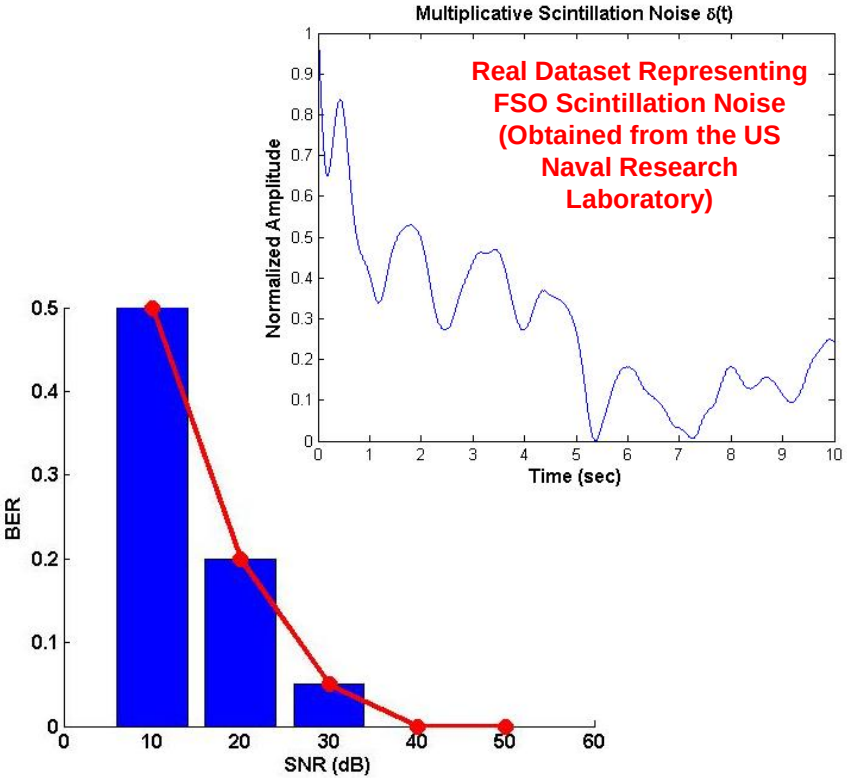


ML605 Board
(Virtex-6 FPGA)

Performance and FPGA Resource Utilization of a Single-Engine Prototype

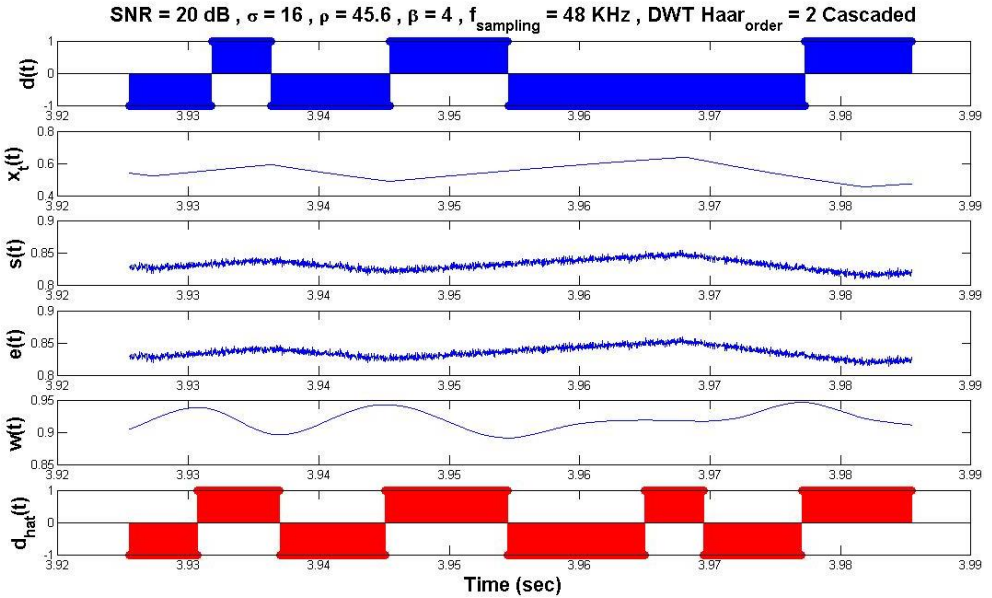
FPGA Device: xc6vlx240t Package: ff1156 Speed Grade: -1			
FPGA Resource	**Used**	**Available**	**Utilization (%)**
Slice Registers	630	301,440	1
Slice LUTs	958	150,720	1
Occupied Slices	368	37,680	1
RAMB36E1	6	416	1
DSP48E1	24	768	3
Bonded IOBs	51	600	8
Detection Precision (bits)	28		
Clock Frequency (MHz)	200		
Throughput (Gbps)	5.6		

Results



Real Dataset Representing FSO Scintillation Noise (Obtained from the US Naval Research Laboratory)

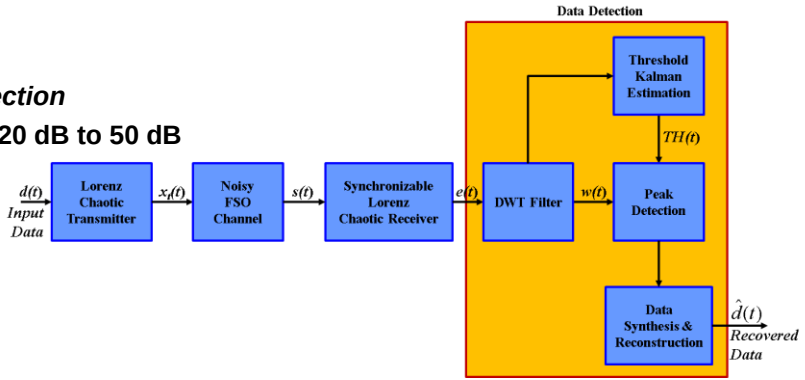
Bit-Error-Ratio (BER) at Different Noise Levels



Aperiodic NRZ Data Transmitted Over a Noisy FSO Channel (SNR = 20dB)

Summary and Conclusions

- **FSO and Chaotic systems combined**
  - Longer-range communication
  - Inherent security in chaotic systems
  - Targeting both space and terrestrial applications
- **Haar DWT employed**
  - Attenuate the undesired effects of FSO channels
  - Relative success based on static thresholding
- **Bit-Error-Ratio (BER) measured**
  - Different levels of noise of different types, such as scintillations and additive white Gaussian noise (AWGN) with zero-mean
- **FPGAs proposed**
  - Could comfortably accommodate the stringent real-time requirements of FSO
  - Prototyped utilizing Xilinx Virtex-6 ML605 board
- **Future work**
  - Improving BER using *adaptive thresholding* and *optimized peak detection*
  - Increasing the dynamic range of the system, e.g. SNR ranging from -20 dB to 50 dB
  - Investigating Doppler effects
  - Investigating chaotic masking
  - Interfacing with FSO optics
  - Integrating with LCRD and other NASA missions




THANK YOU