# Time-To-Digital Converter vs. Analog-To-Digital Converter and Matched Filter Performance in Nanosatellite Optical Receivers

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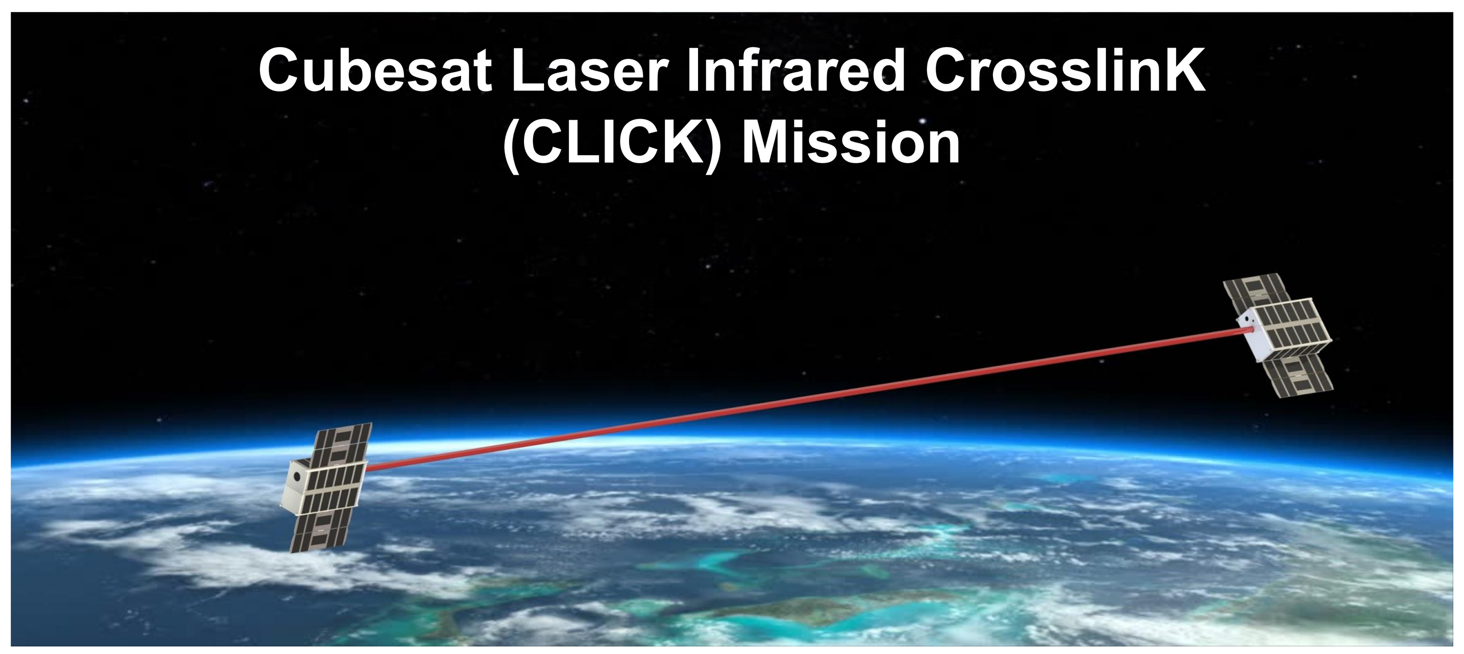
## Introduction




| CLICK Payload Facts | |
|---|---|
| Transmitter Architecture | MOPA, EDFA, MEMS FSM |
| Receiver Architecture | TDC, ADC |
| Beamwidth | 0.71 urad (FWHM) |
| Data Rate | > 20 Mbps @ BER $10^{-4}$, Full Duplex |
| Communication Range | 25 - 580 km |
| Range Resolution | < 50 cm |
| Power | 0.2 W Optical Power, 15 W Avg, 35 W Peak Consumed Power |
| Mass, Volume | < 3 kg, < 2U |

**CLICK Mission Communications Objective:**
Full duplex laser crosslinks at 20 Mbps with a BER of $10^{-4}$ at ranges from 25 km to 580 km.

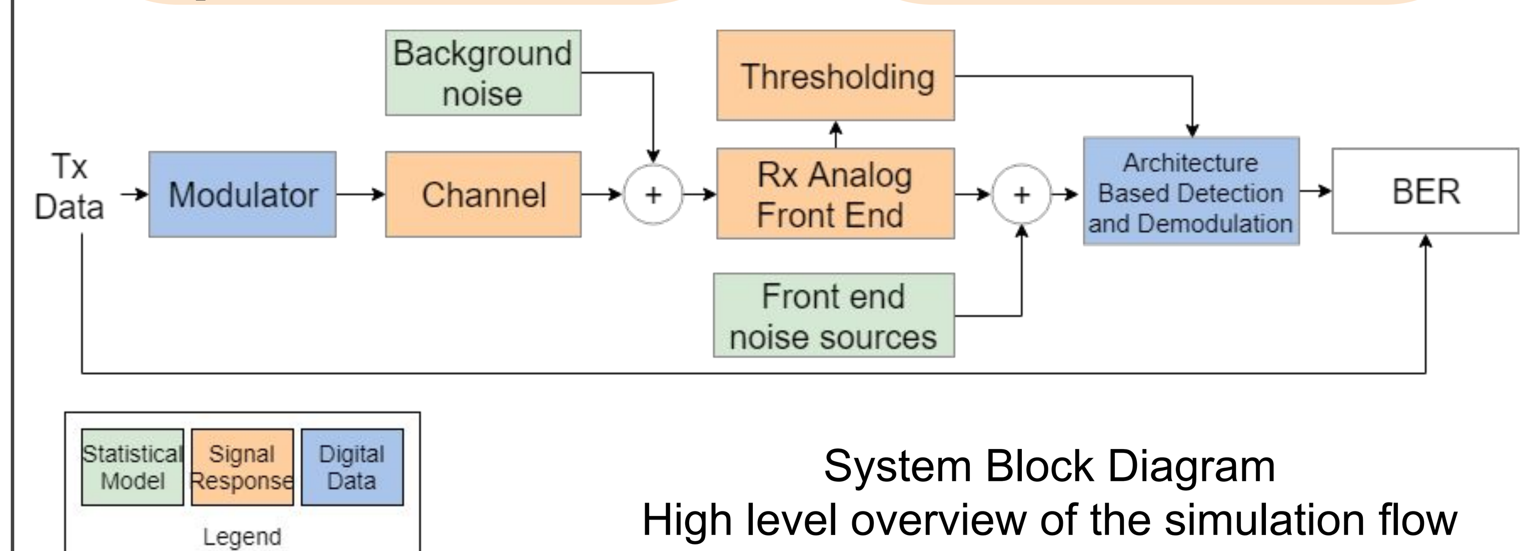
## Motivation

- Matched Filters (MF) are well understood, frequently used in communication receivers, and exhibit the theoretical best performance [1].
- Time-to-Digital Converters (TDCs) are frequently used in applications that require precision event timing, such as ranging. The Deep Space Optical Communication (DSOC) Ground Laser Terminal plans to use TDCs with SNSPD technology [2].
- TDC performance in communication systems unknown. This work estimates the performance of a TDC in communication applications by developing a high-fidelity model for simulation to understand scenarios and environments best suited for each architecture

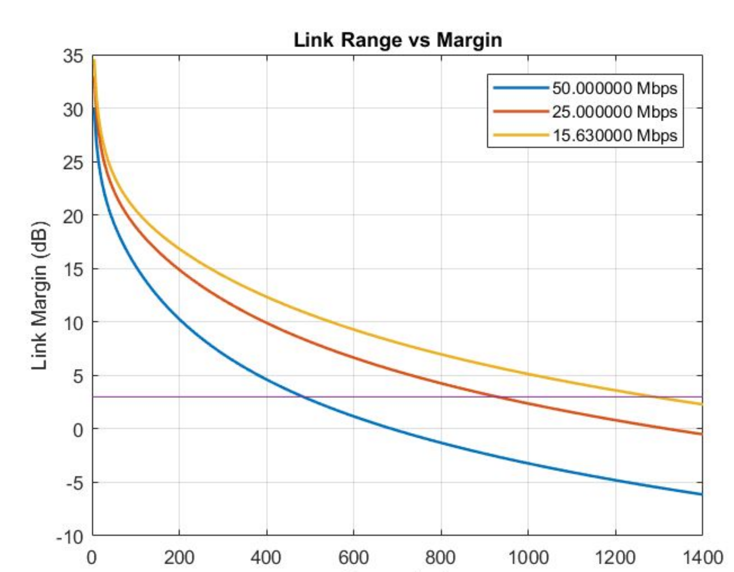
## Approach and Methodology

**ADC + MF**
- Well understood for communications,
- Reconfigurable for other applications
- Limited by sampling frequency
- Power scales with inverse of pulse duration
- Requires intensive post processing, high data volume output

**TDC**
- Well understood for ranging, provides cm level resolution
- Pulse duration can be decoupled from slot duration
- Power scales with pulse repetition rate
- Requires minimal post processing, low data volume output



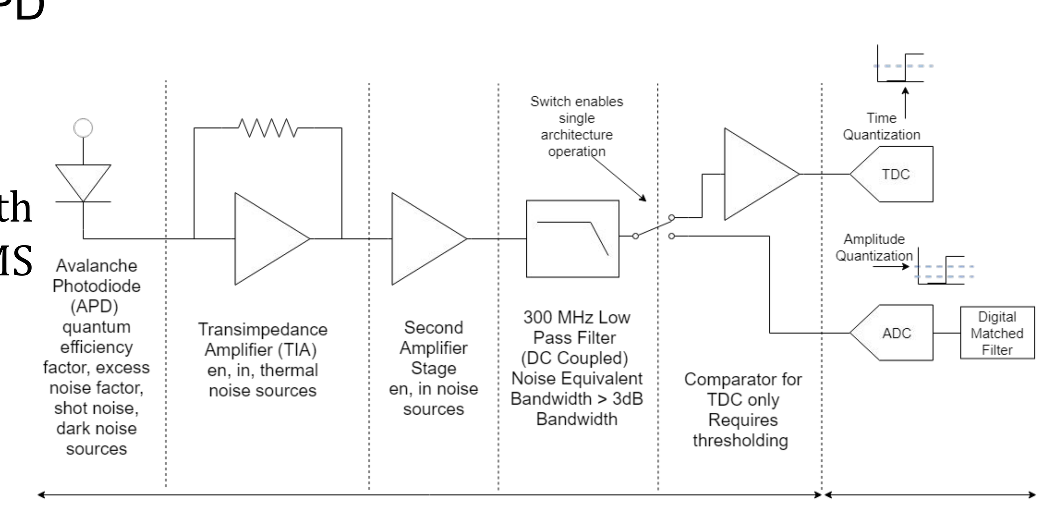

System Block Diagram
High level overview of the simulation flow




Link Budget Analysis. Used to determine received power levels at the APD

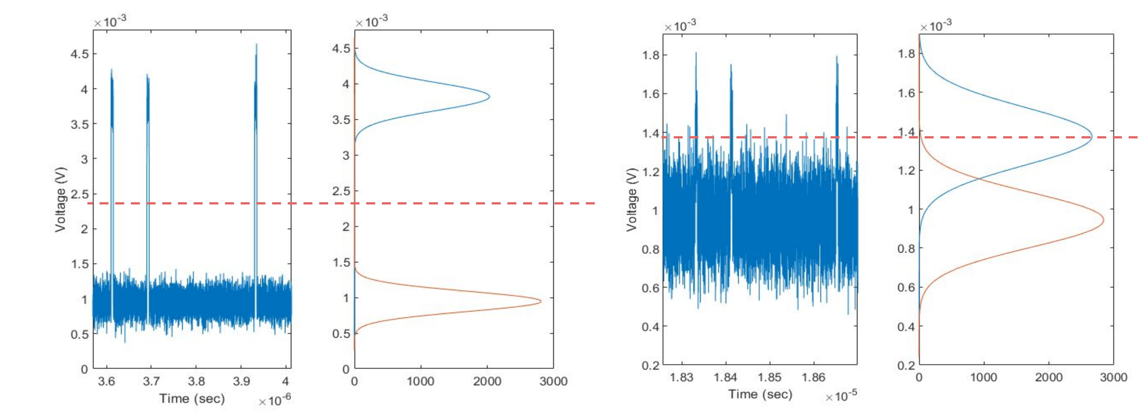
1. Determine signal power at the receiver APD with link budget analysis
2. Apply noise from electronics, detector, and background
3. Find the optimal threshold (statistics based) and on-orbit threshold (proportional to received power) for comparator preceding TDC
4. Timestamp edges from comparator output, demodulate, compare to transmitted data

TDC simulator performance and behavior baselined with specifications from AMS GPX2
- Timing jitter: 45ps
- Timing resolution: 1ps
- Operating in LVDS, pulse width detection mode




Receiver Front End Model
Illustrates noise sources and signal chain

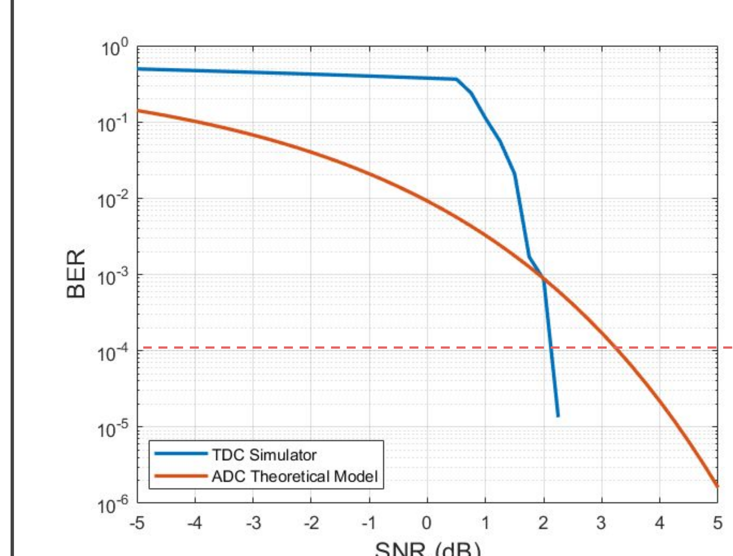
Thresholding required for comparator preceding TDC to detect edges of pulses




Ideal Thresholding On-Orbit Thresholding

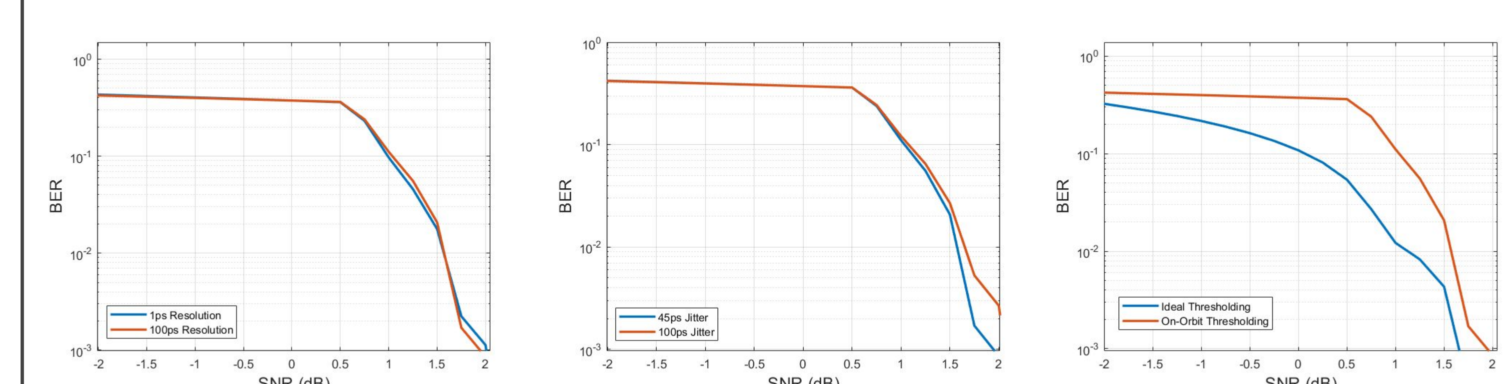
## Results

Simulation run with $10^5$ instances with 10 pulses per instance for adequate sample space. Theoretical model of ADC is well known and used for this analysis




ADC has higher performance in low SNR scenarios, but performance expected to converge around SNR of 2dB.

TDC performance better than ADC is result of finite samples in simulation. Not expected in implementation




Sensitivity Analysis with timing resolution (left), jitter (middle), and ideal vs received power thresholding (right). System is most sensitive to thresholding

## Future Work

System expected performance predicted to match at ranges of interest. Model and results will be verified with CLICK flat-sat testing scheduled for completion in Fall 2018.


Citations
[1] Proakis et. al, *Communication Systems Engineering*, Wiley, 2002
[2] Biswas et al., "Deep Space Optical Communication", SPIE LASE, 2018



Acknowledgements
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