Integrated, Software-Defined Pulse Modulator and Laser System for Small Satellite Optical Communication

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PSSL

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Overview

Motivation

Pulsed optical communication systems have different characteristics compared to CW systems:

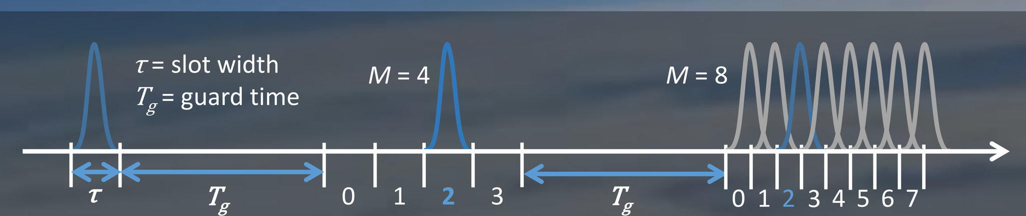
- Lower power consumption
- Lower data throughput
- Higher range with non-linear detection
- Can provide ranging with time of flight, can pass through some clouds

Applications:
Ranging, Time-of-Flight experiment, LIDAR, Optical communications

Miniature Optical Communication Transceiver

- Size, Weight and Power within 0.5 U, ~10 W, 2 kg
- Data throughput is expected to be between 10 Mb.s^{-1} to 100 Mb.s^{-1}

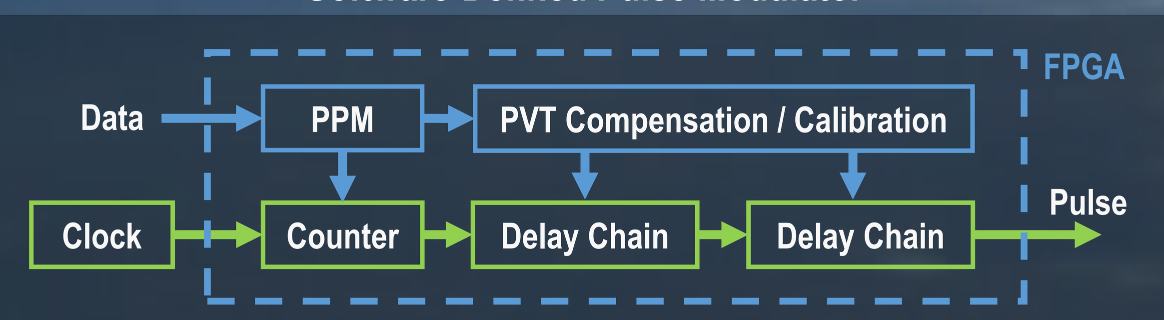
Pulse Position Modulation



Time is cut in slots. Data is encoded in the time between pulses: the symbol sent is the one with a pulse. Achievable slot size depends on timing accuracy. A guard time is inserted to mask dead time in electronics and laser systems.

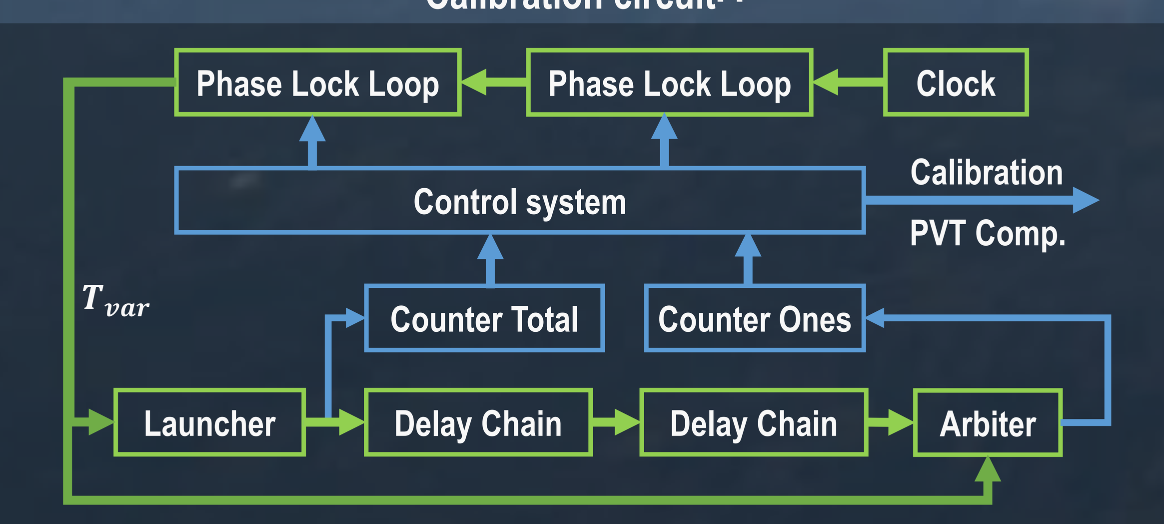
$$D_{M-PPM} = \frac{data\ per\ pulse}{time\ per\ pulse} = \frac{\mathrm{Log}_2\, M}{M\tau + T_g}$$

Software-Defined Pulse Modulator



The modulator is fully implemented within the FPGA. The only external component is the clock. Since it is based on timestamps, not slots, the modulation is flexible.

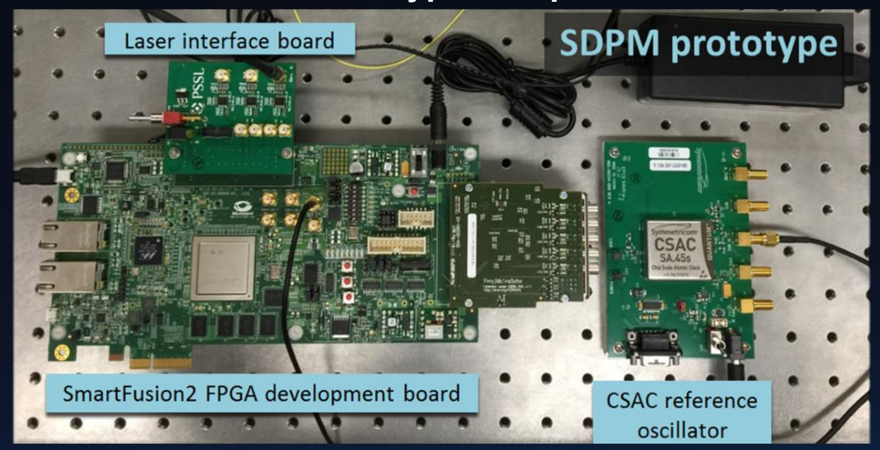
Calibration circuit[1]



A pair of phase lock loops, commanded by a control system, generates a clock signal of period T_{var}. When T_{var} is equal to the delay under test, the arbiter returns a high bit half of the time. The control system adjusts T_{var} to maintain a ratio of Ones/Total of 50%, and records the value of T_{var} over time.

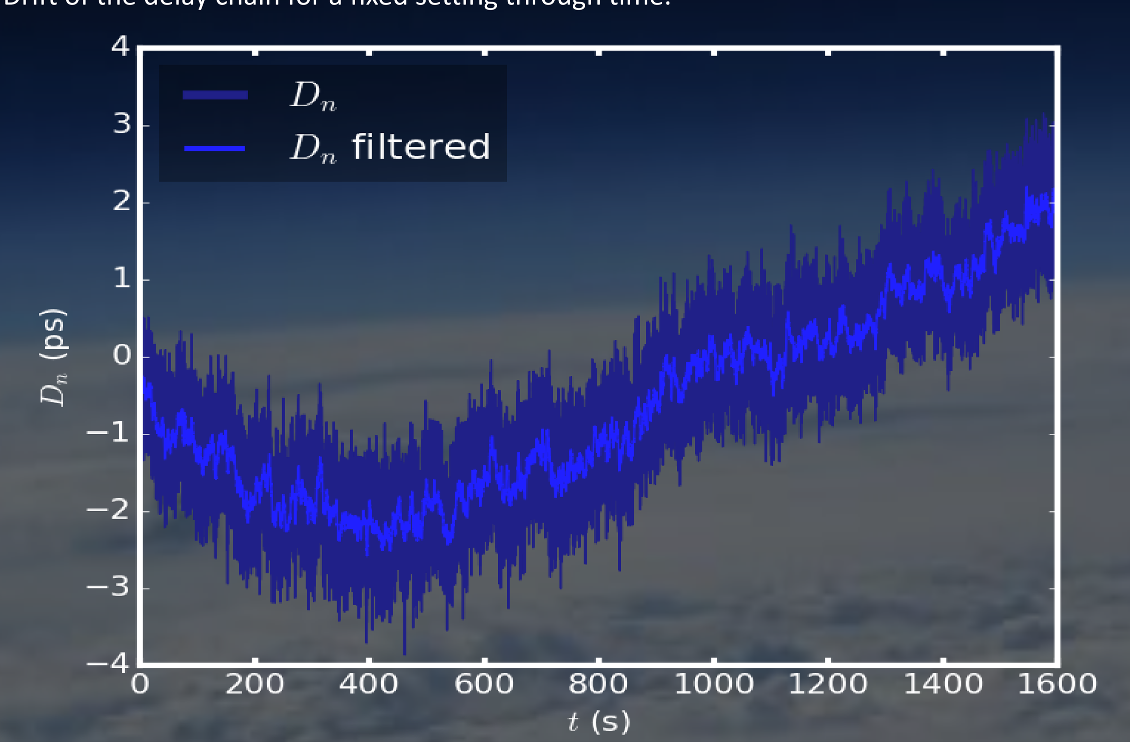
Software-Defined Pulse Modulator

Prototype Setup



Delay Chain Calibration and Tracking[2]

Drift of the delay chain for a fixed setting through time.

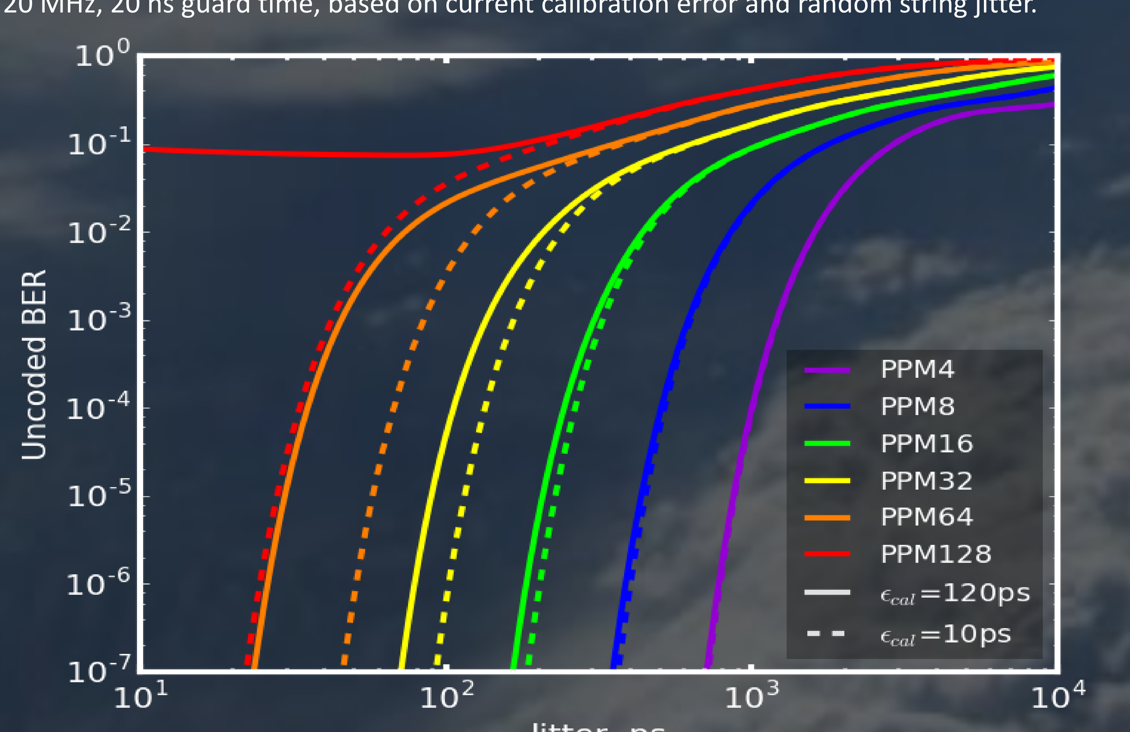


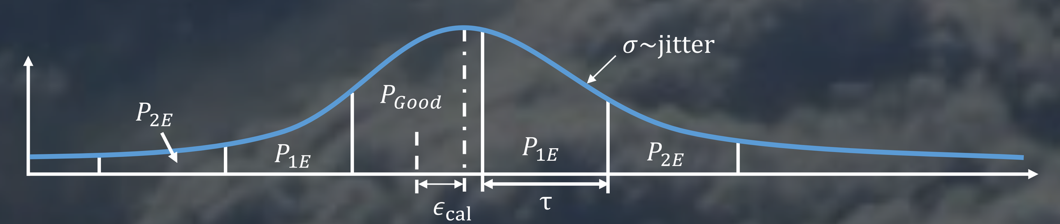
Delay calibration and tracking demonstrated.
Bias and noise < 2 ps

The delay measurement circuit is used both for initial calibration of delay chains and for compensation of delay variation due to process, radiation, voltage, temperature (PVT). The circuit records 60 samples each second. PVT Variations as fast as 1 Hz can be measured.

Bit Error Rate

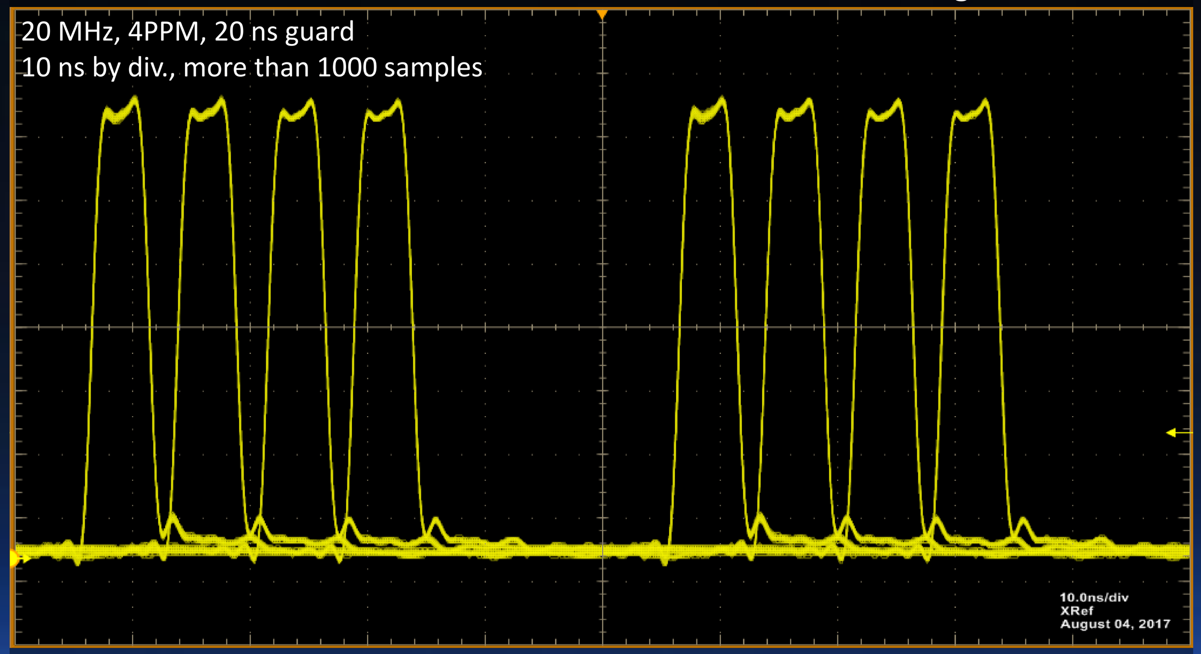
20 MHz, 20 ns guard time, based on current calibration error and random string jitter.





Calibration errors ϵ_{cal} = 120 ps are achieved. The objective is ϵ_{cal} = 10 ps.

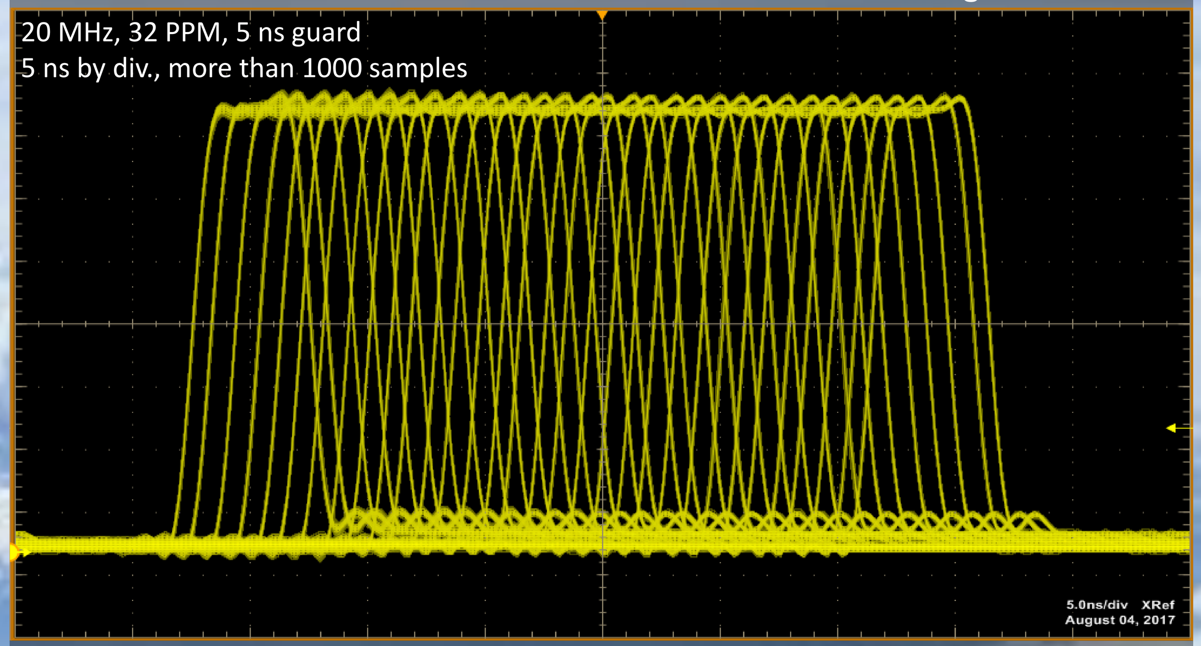
4 PPM Demonstration, Stacked Random Strings



4 possible symbols at 20 MHz → 40 Mb.s^{-1}

5 ns pulses are emitted in 5 ns time slots, equivalent slot clock of 200 MHz.

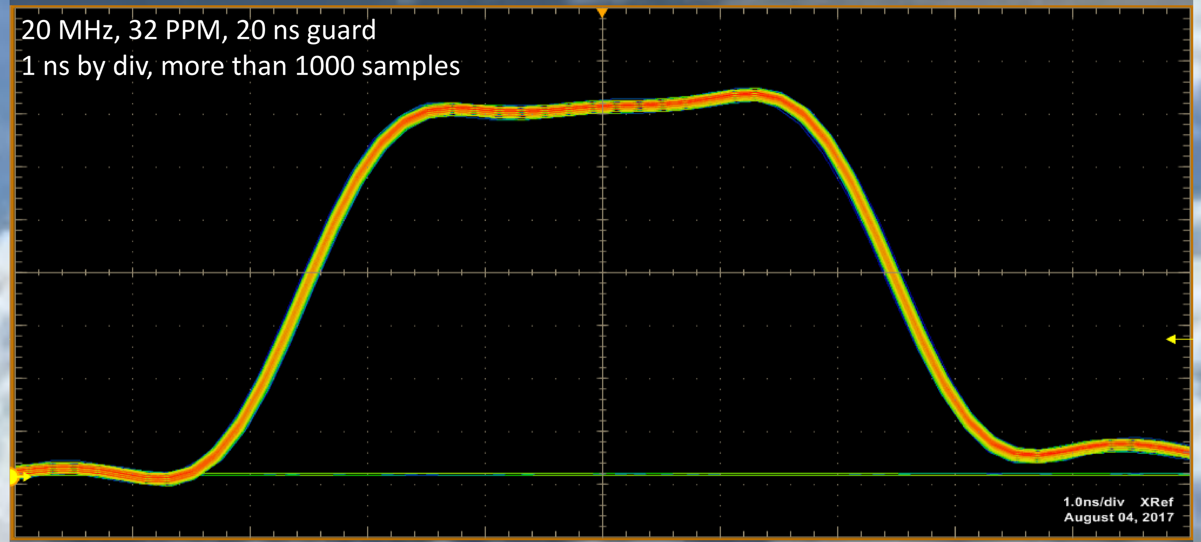
32 PPM Demonstration, Stacked Random Strings



32 possible symbols at 20 MHz → 100 Mb.s^{-1}

5 ns pulses are emitted in 930 ps time slots, equivalent slot clock of >1 GHz

Noise with Random Strings



Random Jitter + Symbol-to-Symbol crosstalk:
200 ps max, ~70 ps standard deviation

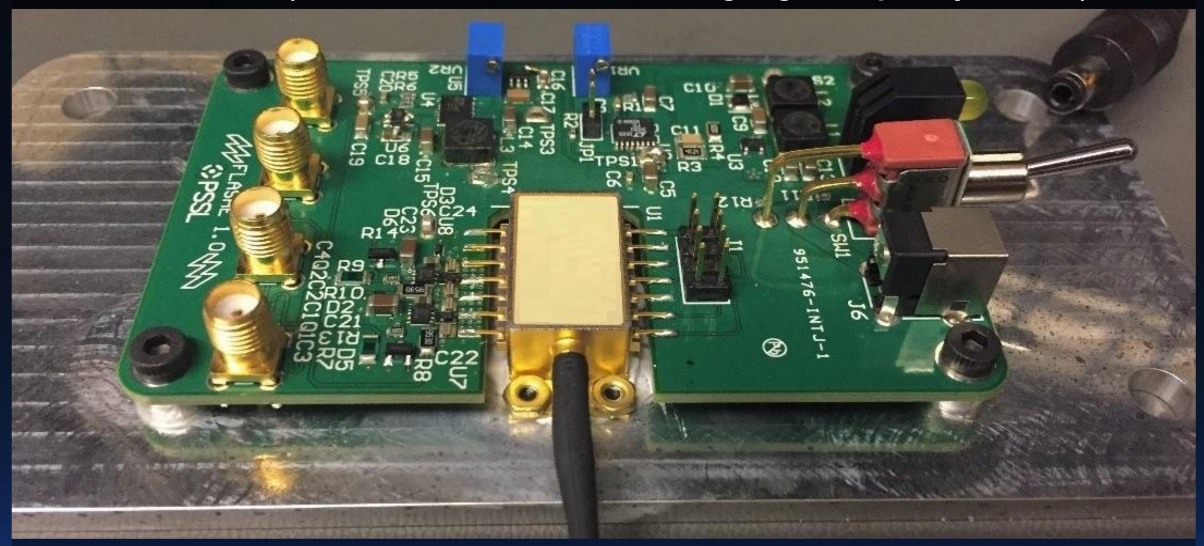
The order of modulation is limited by calibration. Slot sizes down to 300 ps could be achieved with a high precision receiving channel, enabling 32 or even 64-PPM.

Future Mission

CLICK (Cubesat Laser-com Infrared Cross linK) is a mission combining a UF PSSL modulator with an optical system provided by MIT StarLab. Its goal is to establish a laser communication cross-link in orbit and demonstrate ranging capabilities.

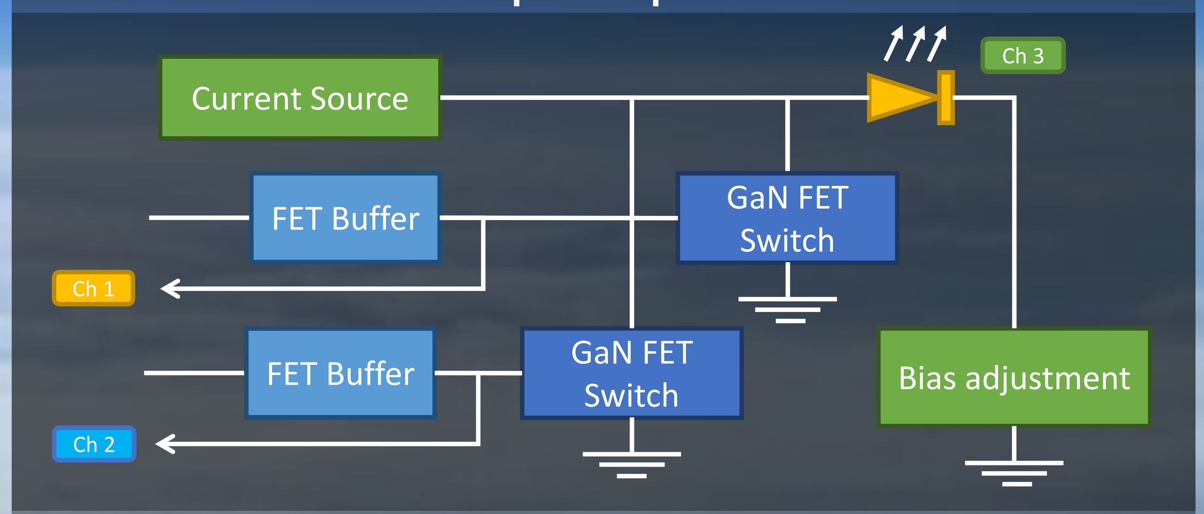
Seed Laser Driver

FLASHE (Fast Laser Advanced Switching High-Frequency Emitter)



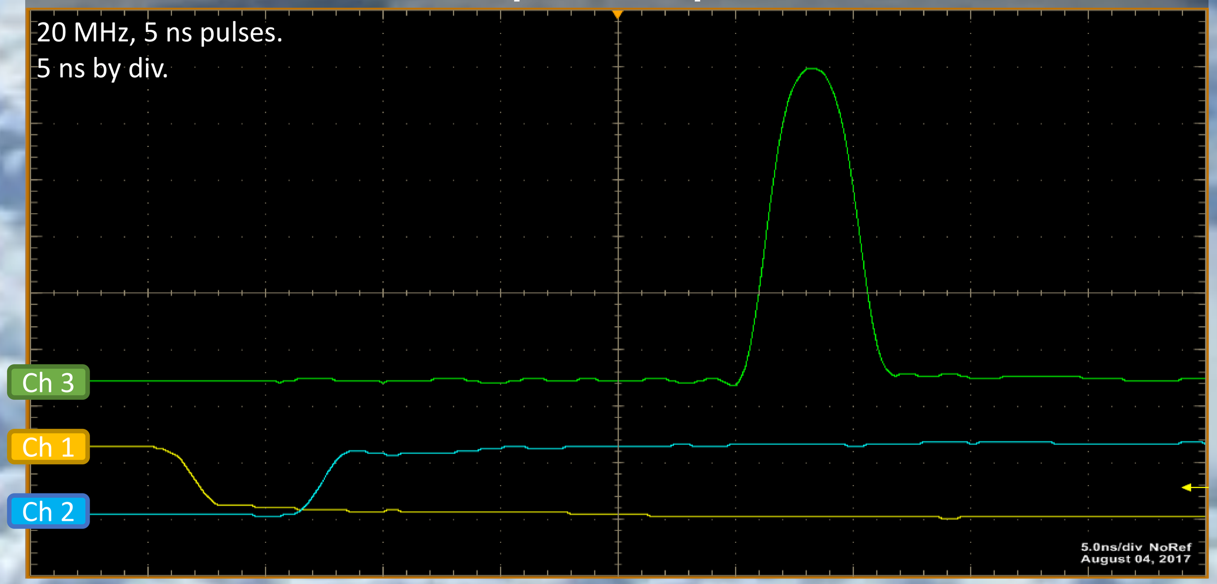
~100s ps laser diodes pulse driver, designed for low jitter, low symbol-to-symbol crosstalk, max extinction ratio, capable of gain-switching. 20 ns guard time.

Principle of operation



Current from the anode source can be shorted to ground or forced through laser. >300 mA pulses shorter than 1 ns demonstrated. Fine pulse width control.

Optical Output



Acknowledgements

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References

[1] Serra, P., Barnwell, N., Ritz, T., Conklin, J. 2016. "Deep Space Laser Communication Transmitter and High Precision Timing System for Small Satellites," *Proceedings of the AIAA/USU Conference on Small Satellites*, Technical Session VII: Communications, SSC16-VII-1. http://digitalcommons.usu.edu/smallsat/2016/TS7Communication/1/.
[2] Serra, P., Conklin J. 2017 "On-Chip System for Fast, High Range, High Precision Measurements of Delays", *IEEE Trans. Instr. Meas.*, Under review.

Photo Credit: University of Florida team high altitude balloon flight photo at the S.H.O.T. workshop hosted by UC Boulder