SGSLR Receiver Validation and Pulse Width Amplitude Correction
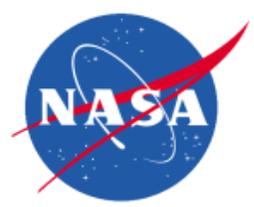
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3 – Hexagon US Federal (Sigma Space Corporation)

Abstract

SGSLR has a receiver system using a detector/timer package not previously used for satellite laser ranging. Using an array of silicon photomultipliers and a flight proven event timer designed by Sigma Space, it promises to deliver spatial information to allow bias correction in a robust, economical package. In order to validate its efficacy in millimeter-level ranging, tests were conducted measuring the long term stability of the receiver and its sensitivity to signal amplitude variation. The receiver was tested directly against the conventional SLR MCP technology.

Although SGSLR will operate in single photon mode to control for signal amplitude, there will still be some amplitude variation from pulse to pulse. By recording signal threshold crossing in both directions, it is possible to estimate the width of a given pulse signal and infer pulse amplitude. Using this information, a correction factor can be applied without additional hardware.

This paper details the validation of the SGSLR receiver with some test results, as well as pulse width processing techniques that allow millimeter stability.

SGSLR Receiver Overview

- Provide Closed Loop Tracking
  - 7x7 pixelated detector array
  - 4 pixels in corners unused
  - Count # of events in each pixel to determine satellite location
  - Signal location used to correct angular position to maximize return signal strength

- Make Precise, High Resolution Timing Measurements
  - Start Events: Single measurement per shot
  - Stop Events: Multi-stop, low dead-time
  - Ancillary Events (e.g., 1 PPS)

- Selection based on proven heritage hardware from aircraft and space-flight designs
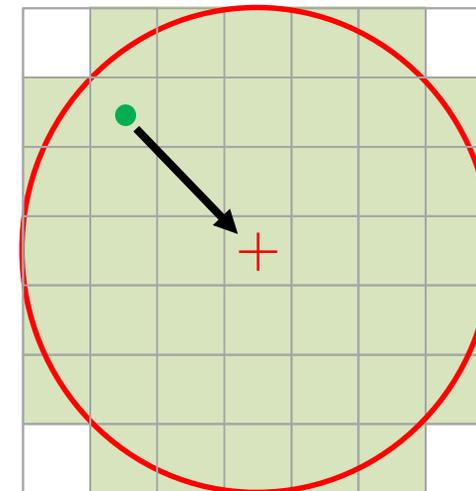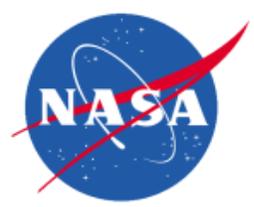
Sigma Space Receiver (SSRx)
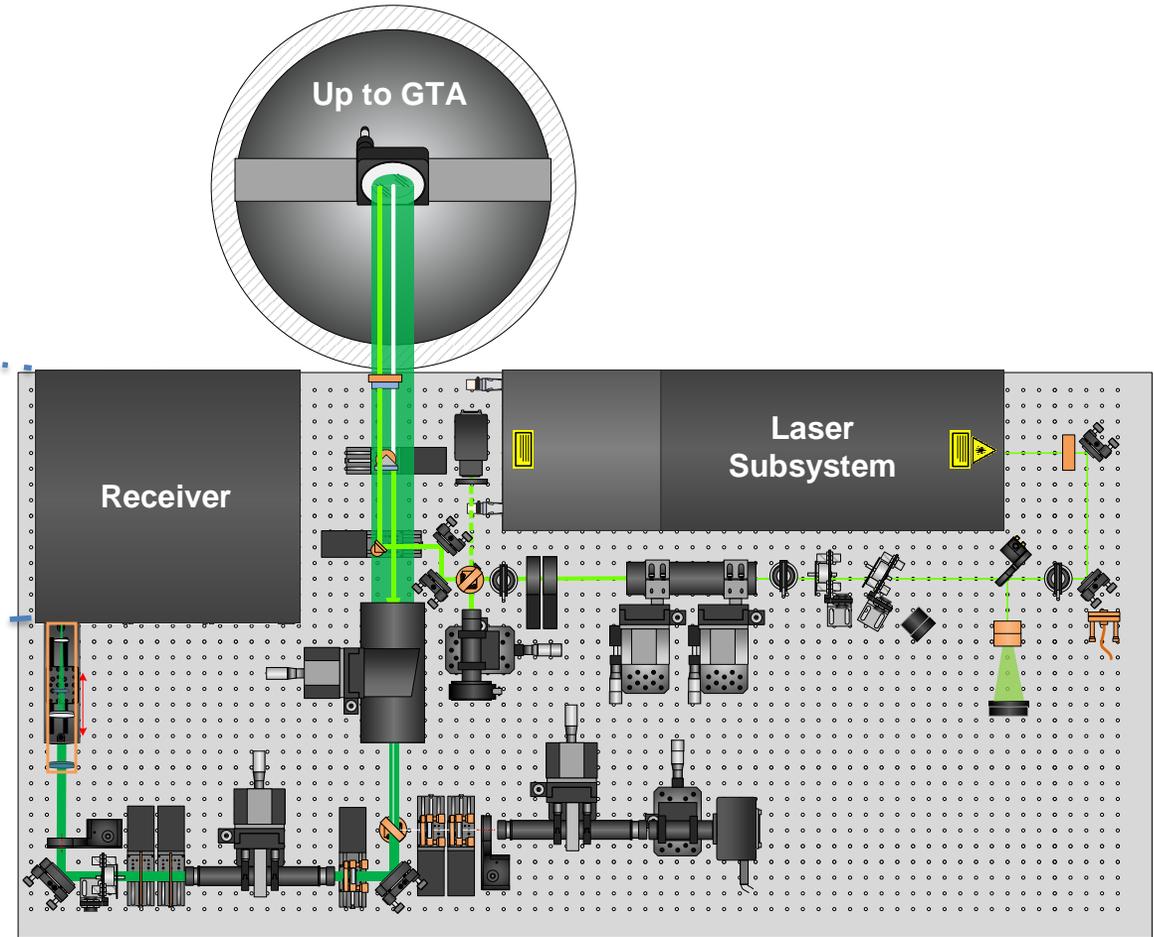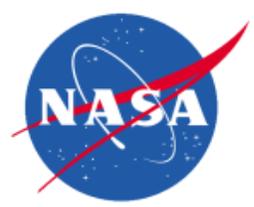
Sigma Space Receiver (SSRx)

Event Timer: Sigma Space Photon Counting Electronics
- Used in ICESat-2 ATLAS instrument
- Specifically designed for multi-pixel array timing
- Used for altimetry, but our SLR requirements are more exacting

Photon Detection: Array of Silicon Photomultipliers
- Array configuration provides spatial information
- Allows operation in single photon mode
- Much more robust than conventional PMT
- <u>MUCH</u> more economical
- Noisier than our old PMT friend but…
 - Maybe we can deal with it? Lets find out!
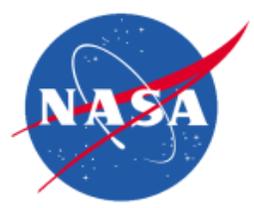
SSRx Testing

We needed to validate these technologies for SLR performance with an eye on the GGOS goal:

*For the ITRF to accurately quantify long-term sea level change, the ITRF must be both **accurate and accessible at the 1-millimeter level**, with a **stability of 0.1 millimeters per year**.*

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- Will the receiver be stable enough between ground calibrations (taken at 1 hour intervals)?
- How does our receiver react to a misbehaving laser (transmit amplitude variations)?
- How does our receiver react to return rate variation?
- How sensitive is our receiver to temperature fluctuations?
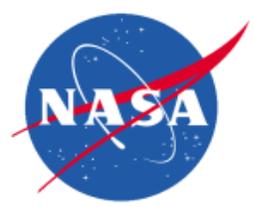
SSRx Testing

Subset of Success Criteria for our testing:

- Single shot standard deviation from the ground target(s) similar to or better than NGSLR's (< 4 cm).

- Mean ground calibration data normal point precision similar to or better than NGSLR's within 120 seconds (< 0.5 mm).

- Standard Deviation of ground calibration normal point data < 1.5 mm over 1 hour.

Let's compare the SSRx side-by-side with a conventional PMT-Constant Fraction Discriminator setup, to see how it holds up.

Lessons Learned: Constructing a good test setup is hard. Constructing a test setup to measure at the millimeter level while isolating the test subject is really really hard.

Testing Layout

Dual Detector Testing:
- MCP with CFD and Guidetech GT668PCIe
- SSRx detector/timer package
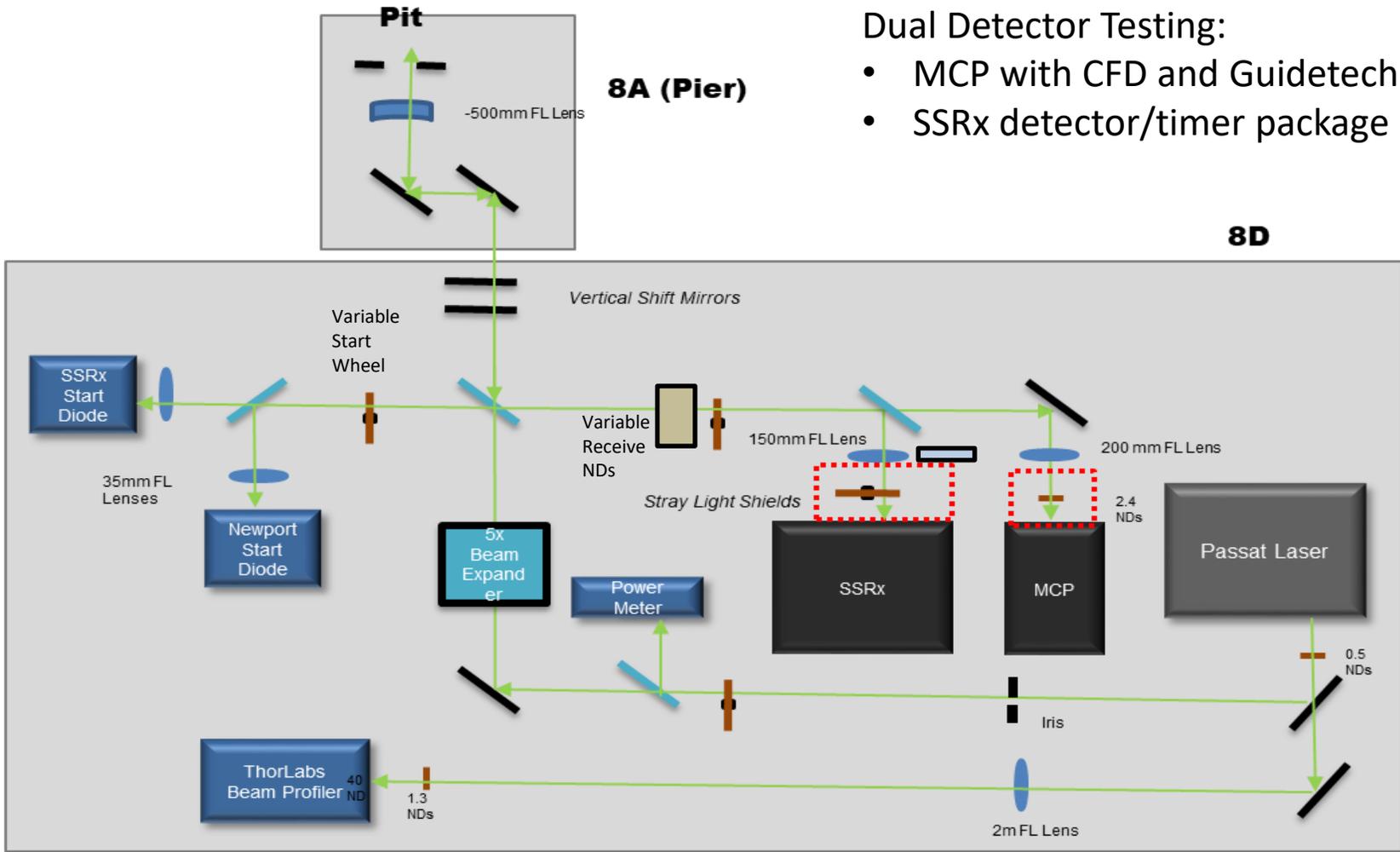
Pulse Amplitude Correction

◆ For the PMT setup, the constant fraction discriminator corrects for range walk due to pulse amplitude variation

◆ Although we are in single photon mode, variations in return rate cause us to have a variable amount of double or triple photon returns

◆ For the SSRx to use this technology, each pixel would need its own CFD or equivalent electronic tunable circuit (45+ CFDs)

◆ Is there another way?

Pulse Amplitude Correction

Answer: YES

- ◆ Instead of measuring pulse amplitude directly, we can measure pulse width and approximate pulse amplitude very closely

- ◆ Can be done with **no extra circuitry**, simply tag both rise and fall of photon detection pulse

- ◆ Tested with various return rates and results are very promising, allowing for higher return rate scenarios

For a more in depth look at the pulse correction technique and its application, please see the poster

"SGSLR Receiver Detector Pulse Width Calibration Technique"
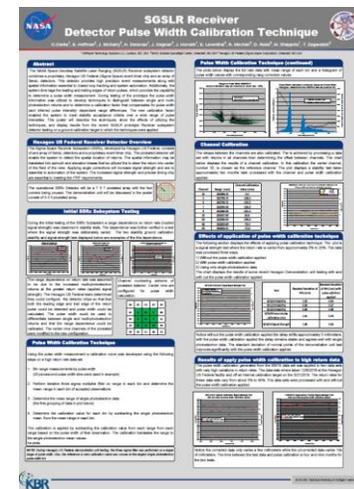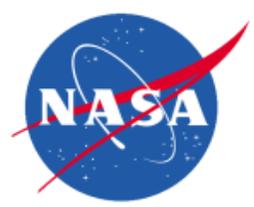
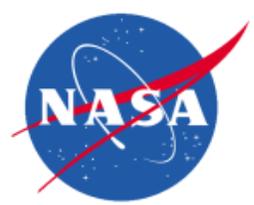# Test Results – Stability over an Hour

09/04/2019 11:32 One Hour Ground Target Stability Test
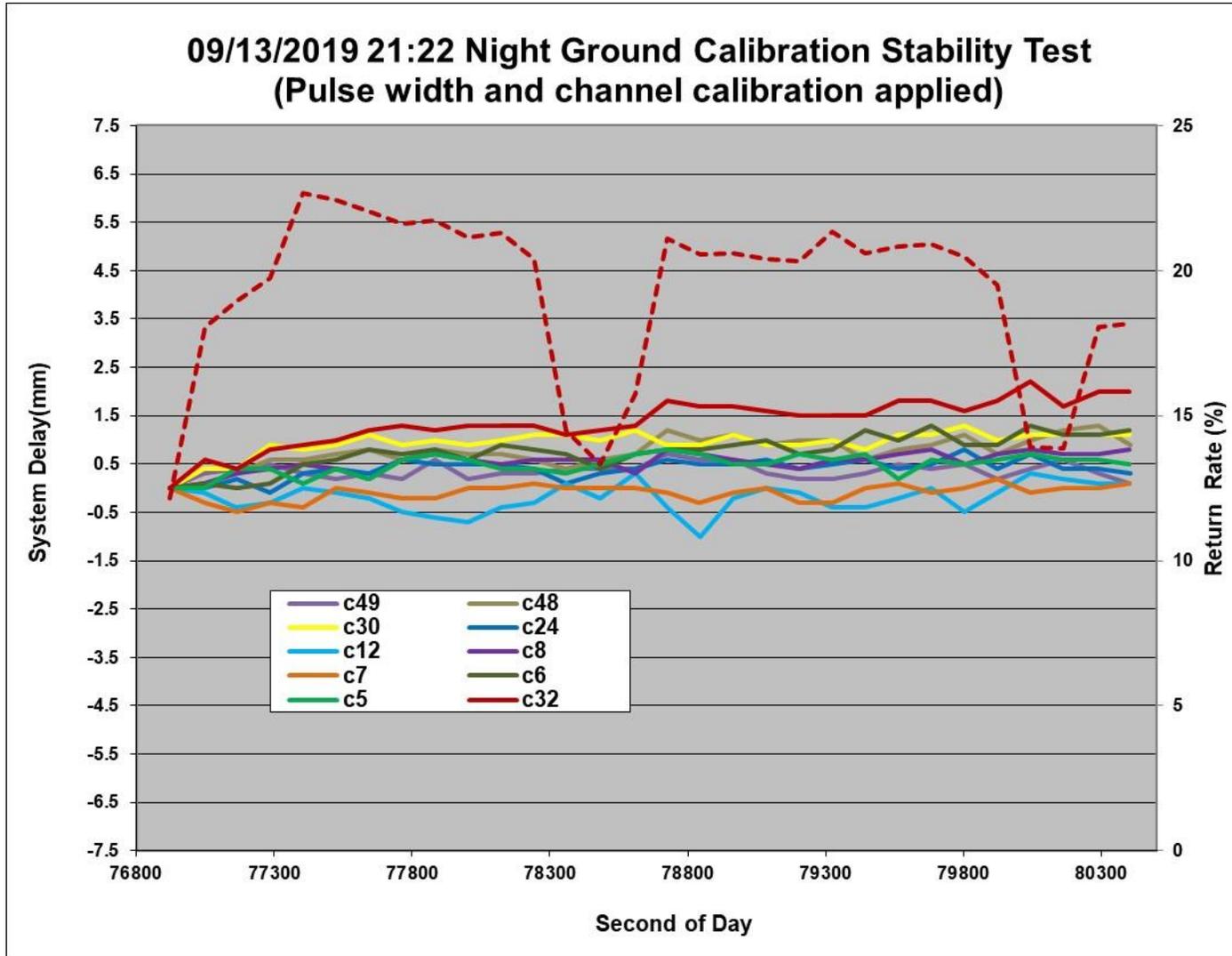SSRx and MCP Ground Calibration Comparison
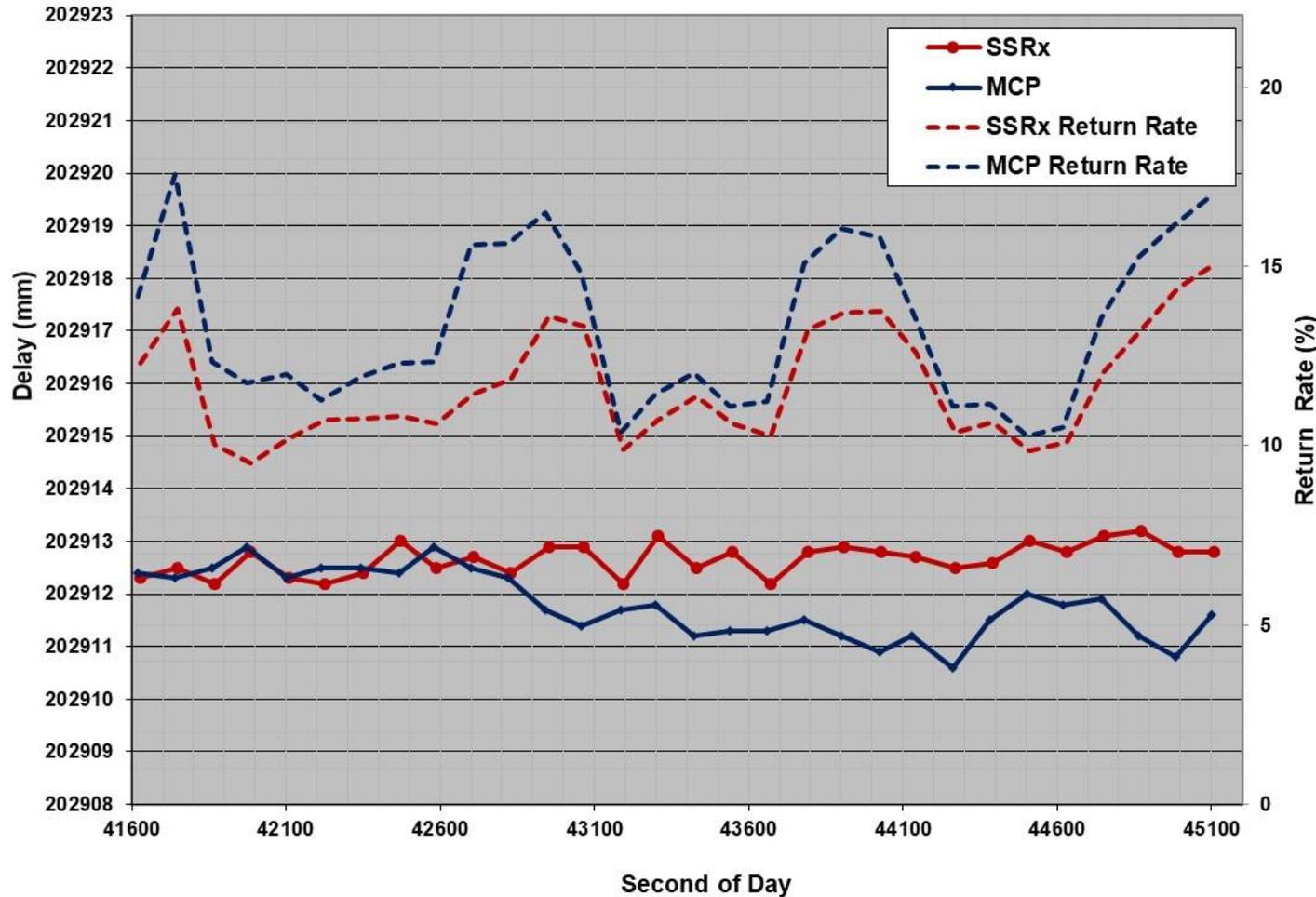
MCP STDDEV = 0.51 mm
SSRX STDEV = 0.29 mm

For 2 minute normal points, this dataset showed 0.29 mm standard deviation between the normal points over an hour after pulse width correction!
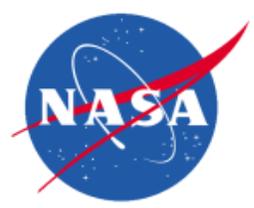
This is not cherry-picked, most datasets were under 0.5 mm for this statistic.
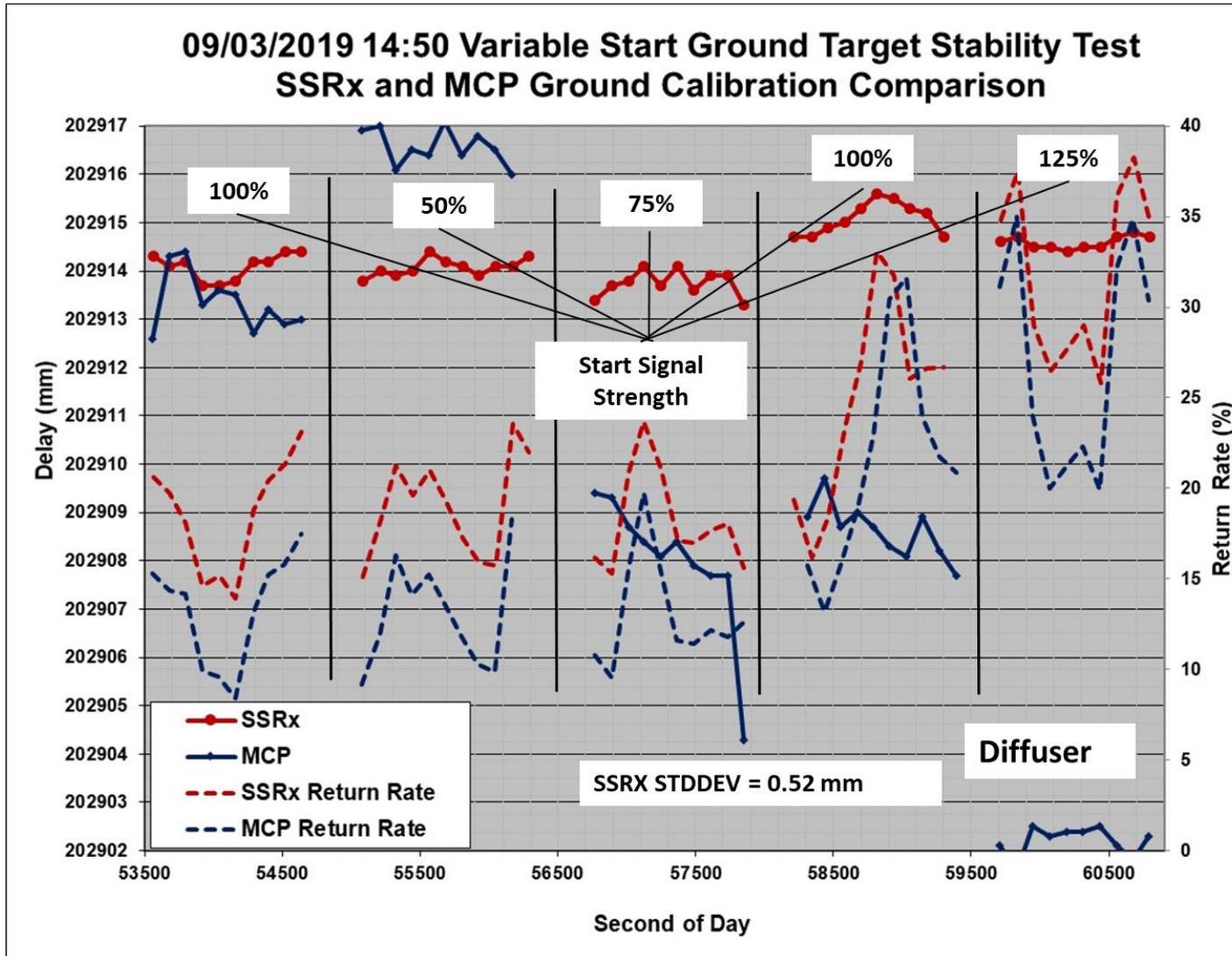
09/13/2019 21:22 Night Ground Calibration Stability Test
(Pulse width and channel calibration applied)

Channels stay within 1.5 mm of each other over 1 hour

09/03/2019 14:50 Variable Start Ground Target Stability Test
SSRx and MCP Ground Calibration Comparison

Takeaway – Variations in laser energy from 50-125% of a given reasonable value can be accepted

09/17/2019 13:56 Variable Receive Ground Target Stability Test SSRx and MCP Ground Calibration Comparison

SSRx STDDEV = 0.41 mm

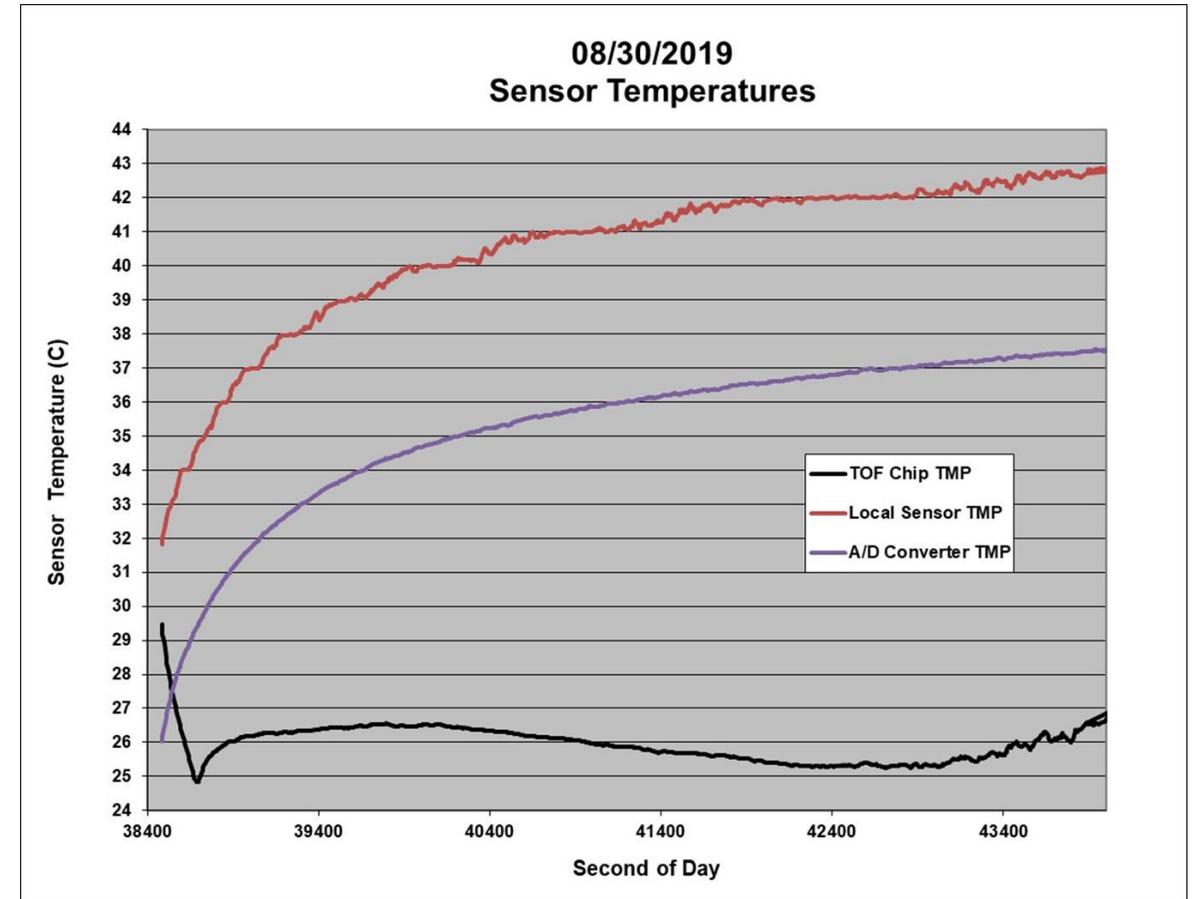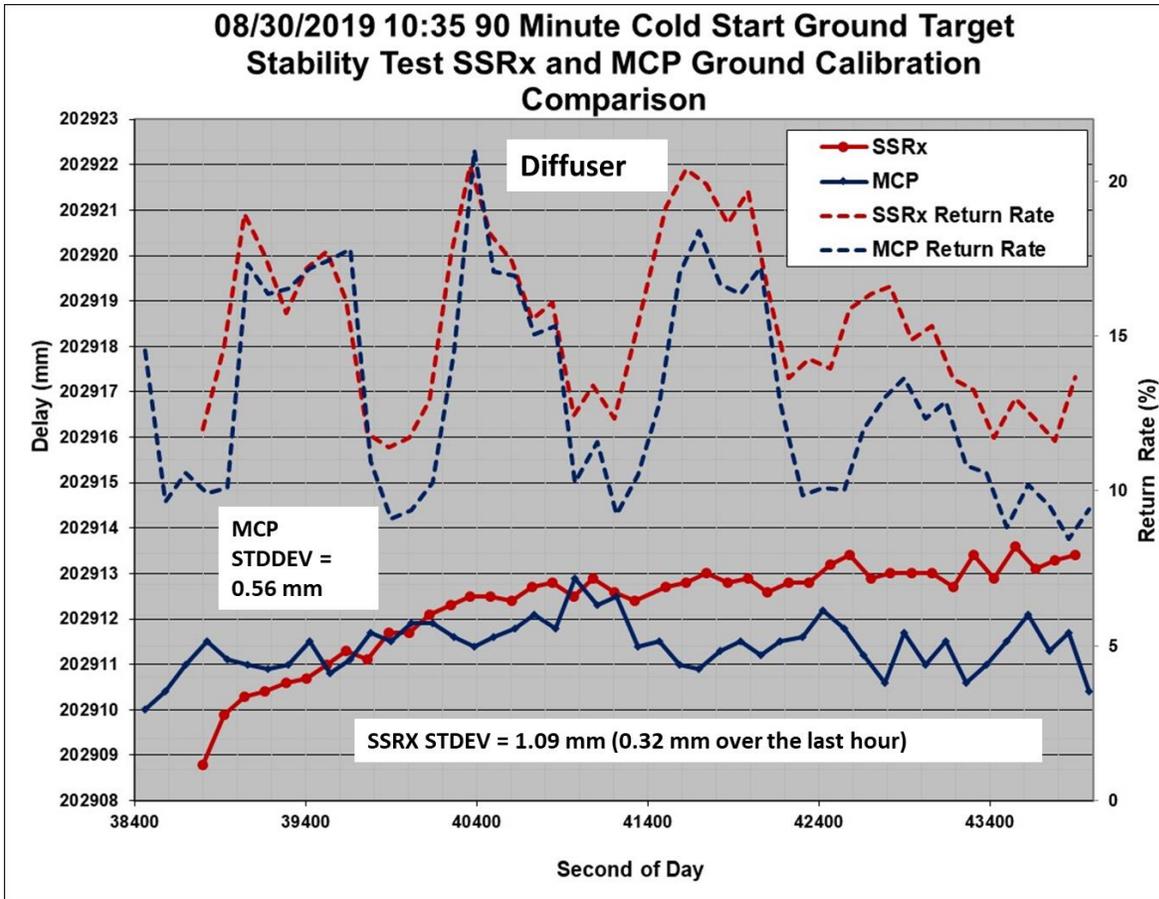MCP STDDEV = 2.33 mm

Diffuser
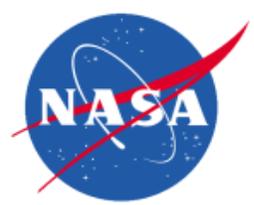
Legend:
- SSRx
- MCP
- SSRx Return Rate
- MCP Return Rate
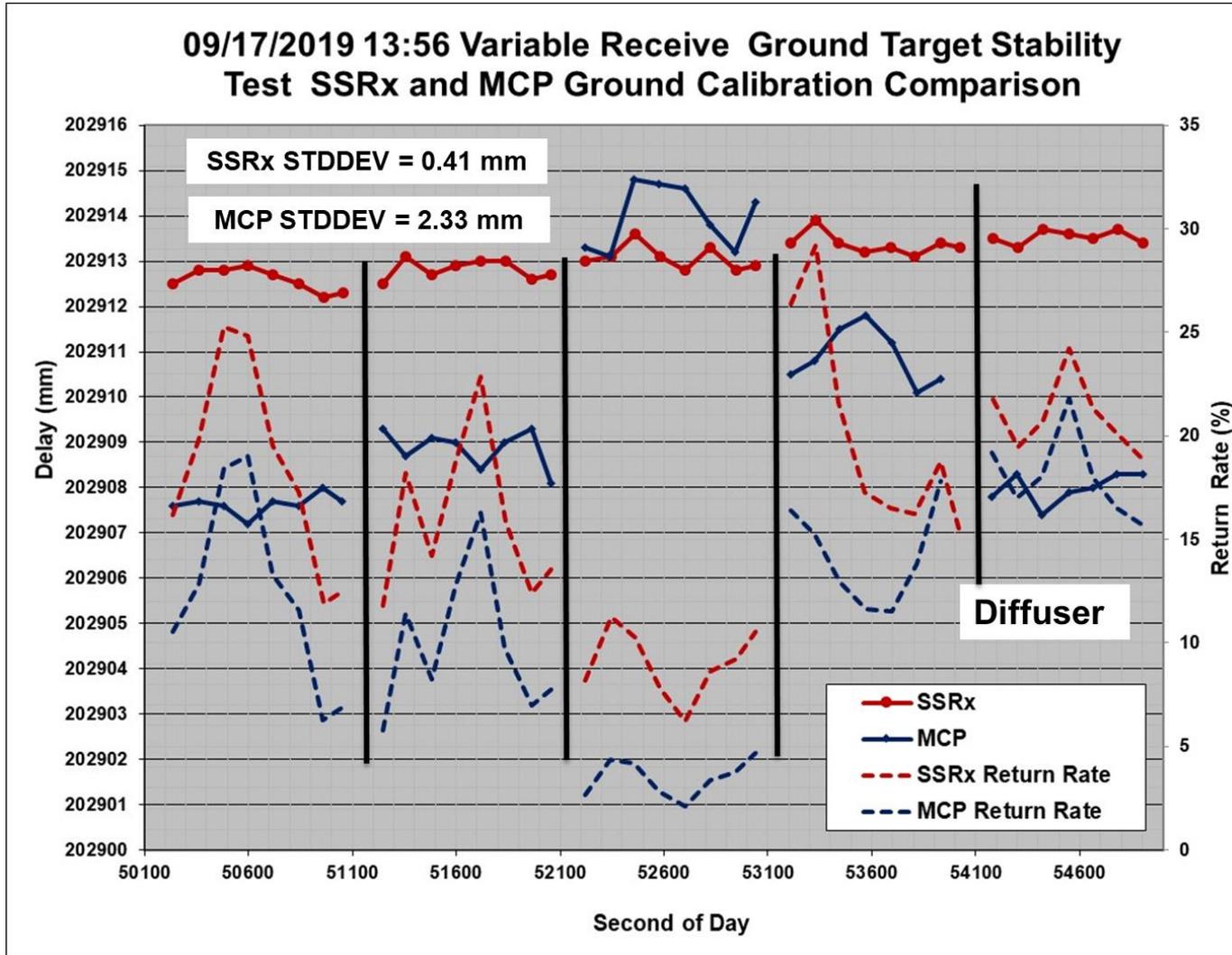
Return rates from 5% to 30% (and beyond) are acceptable
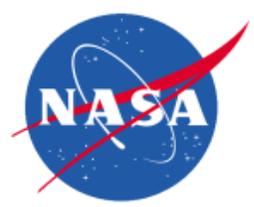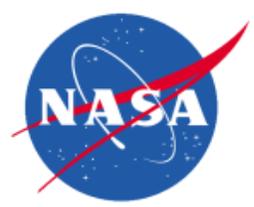
Strong temperature correlation suggests a warm-up of 15 minutes or possible additional correction factor

Conclusion

- ◆ SGSLR's proposed receiver survived its round of testing intact

- ◆ Both the SiPM array and developed Sigma Space timer technology meets and/or exceeds its requirements and compares very favorably to conventional SLR detector technology

- ◆ Pulse Width correction works very well to remove range walk due to pulse amplitude variation, eliminating our needs for constant fraction discriminators

- ◆ Much respect for test engineers