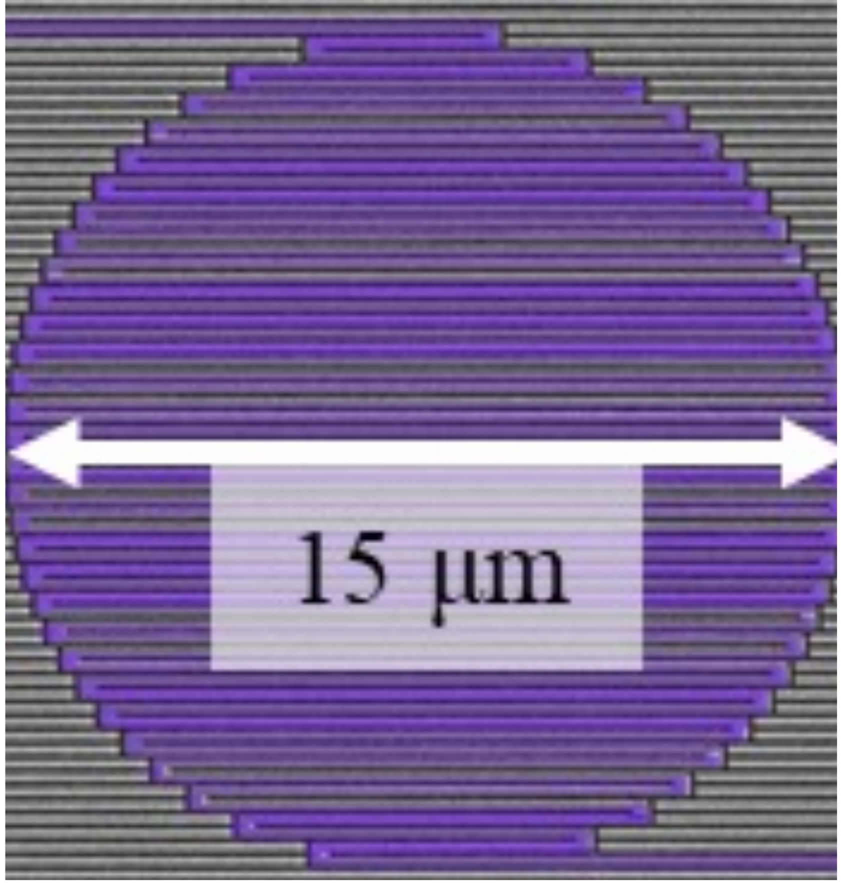

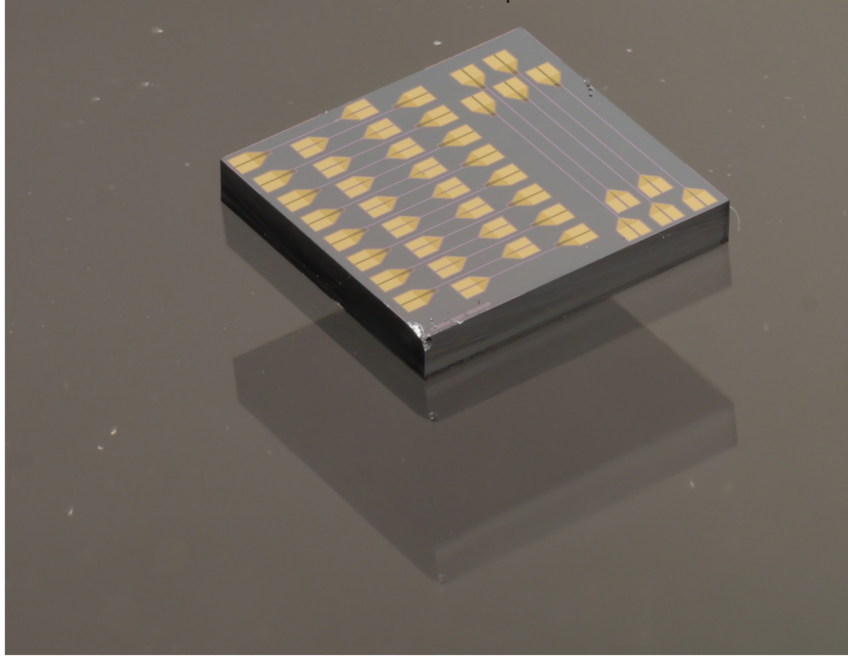

A New Method for Measuring Splice Loss
(in single photon detector efficiency measurements)

Sonia Buckley, NIST Boulder CO, USA
CORM Nov 2023

Outline

National Institute of Standards and Technology
U.S. Department of Commerce

- Motivation
- Introduction to single photon detectors
- Single photon detector calibration
- Measurement and comparison of splice loss for calibrations
- Conclusions and future work

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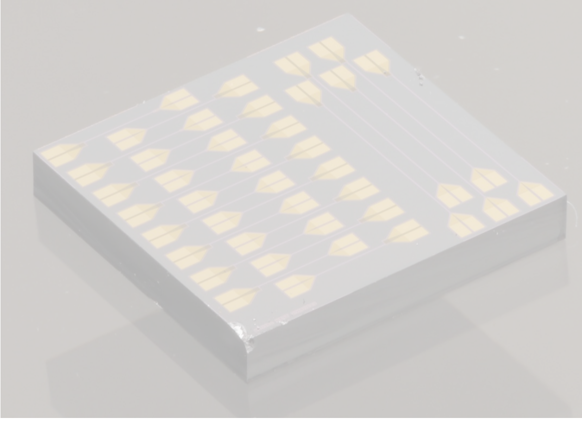
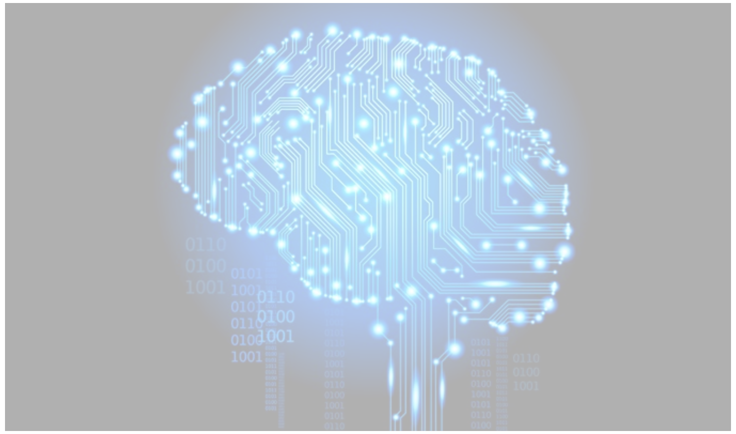
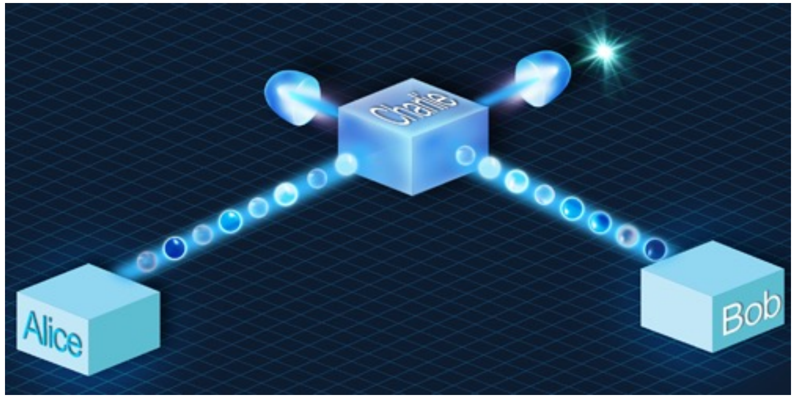
Metrology to support new industries



Integrated photonics



Hardware for AI



Quantum technologies

New quantum industries

National Institute of Standards and Technology
U.S. Department of Commerce

QED·C

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QED-C members

* denotes founding member

Corporate

Accenture	Aegiq	Algorithmiq	Aliro Technologies*
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Anametric*	AOSense*	Aperio Global*	AT&T*
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*Mention of specific companies does not imply endorsement by NIST

Examples of quantum systems

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- Quantum cryptography
- Quantum sensing
- Quantum computing
- Quantum networks

High efficiency is very important for quantum applications

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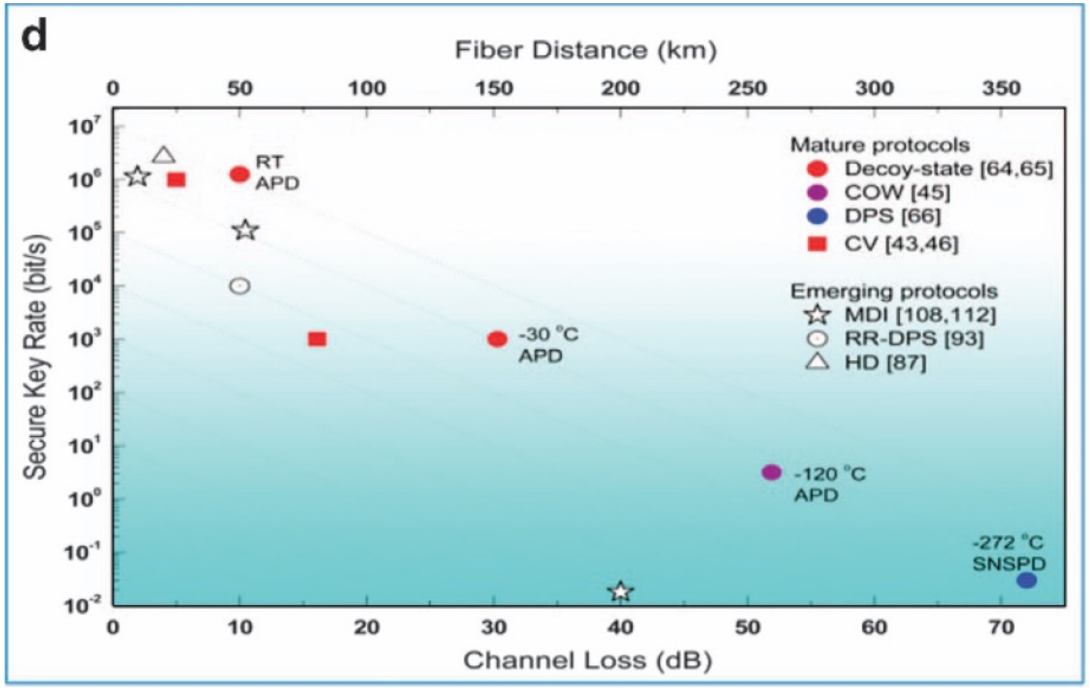
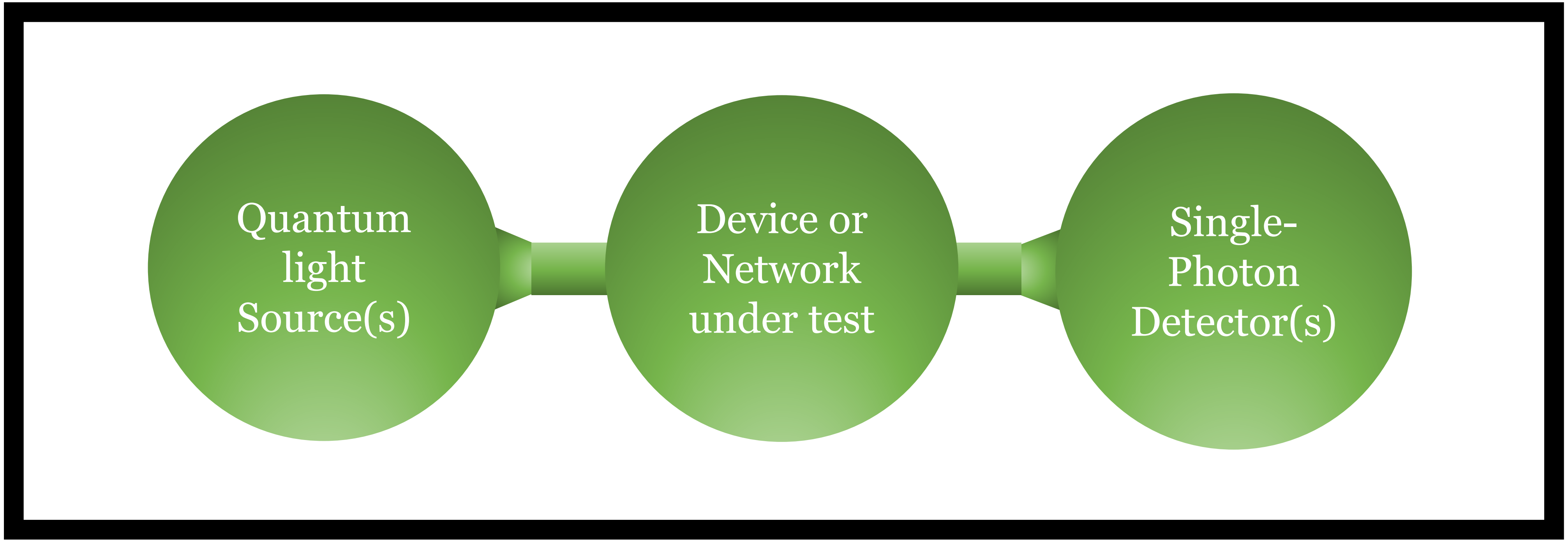


Quantum key distribution

Practical challenges in quantum key distribution, Diamanti et al., [*npj Quantum Information*] **2**, 16025 (2016)

Basic components of quantum systems



Need for standards and metrology

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Single photon detectors and sources

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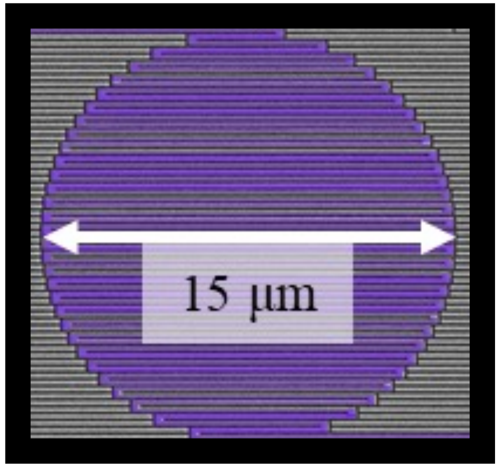
U.S. Department of Commerce

Photomultiplier Tube

PMT

Single-Photon Avalanche Detector

SPAD



Superconducting Nanowire Single Photon Detector

SNSPD

Transition Edge Sensor

TES

Different flavors of single photon detectors for different applications

Single photon detectors and sources

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Photomultiplier Tube

PMT

Single-Photon Avalanche Detector

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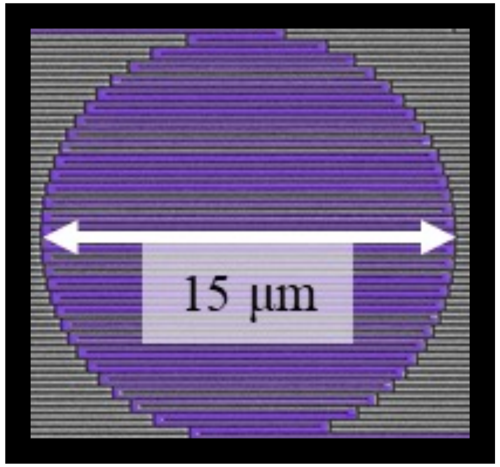


Superconducting Nanowire Single Photon Detector

SNSPD

Transition Edge Sensor

TES

Initial focus: SPAD and SNSPD

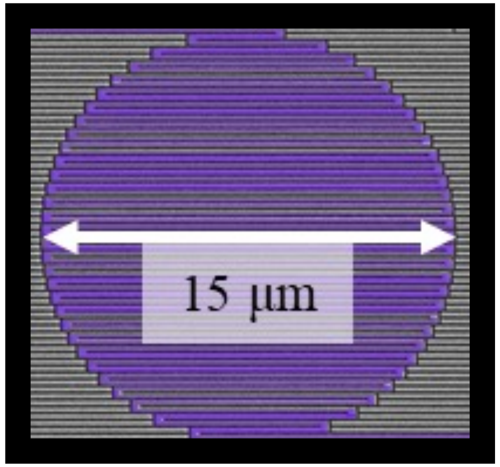
Single photon detectors and sources

Photomultiplier Tube

PMT

Single-Photon Avalanche Detector

SPAD



Superconducting Nanowire Single Photon Detector

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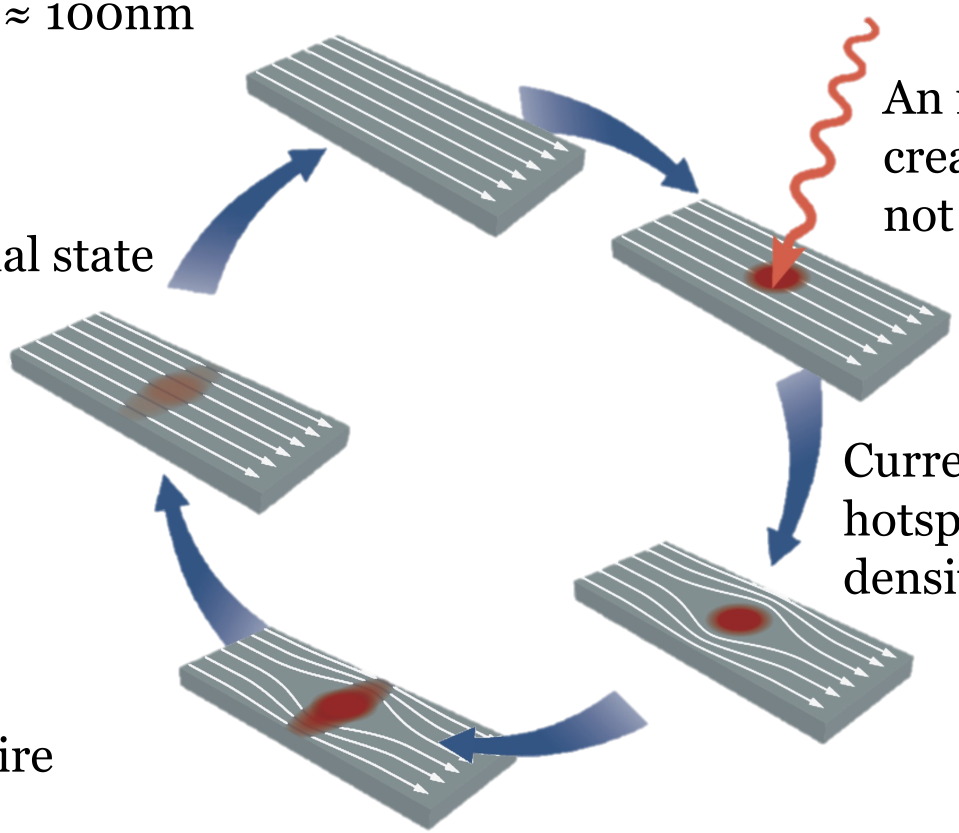
Different flavors of single photon detectors for different applications

Superconducting nanowire single photon detectors



A superconducting nanowire
Width ≈ 100nm

An incoming photon creates a hotspot that is not superconducting

Current diverts around the hotspot, increasing current density elsewhere

The critical current density is exceeded, turning the whole wire width normal

The hotspot cools off, resetting to the original state

Gol'tsman et al. "Picosecond superconducting single-photon optical detector." APL 79 (6), 2001.

Superconducting nanowire single photon detectors

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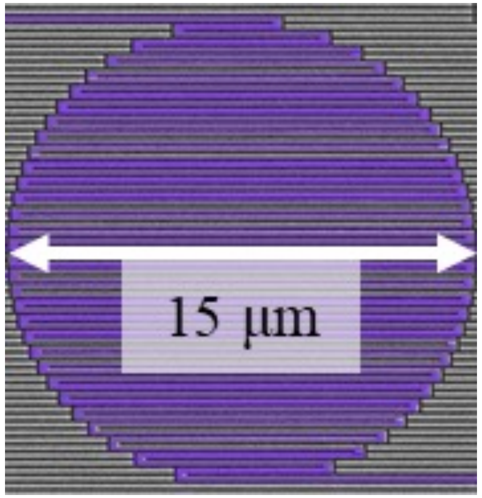
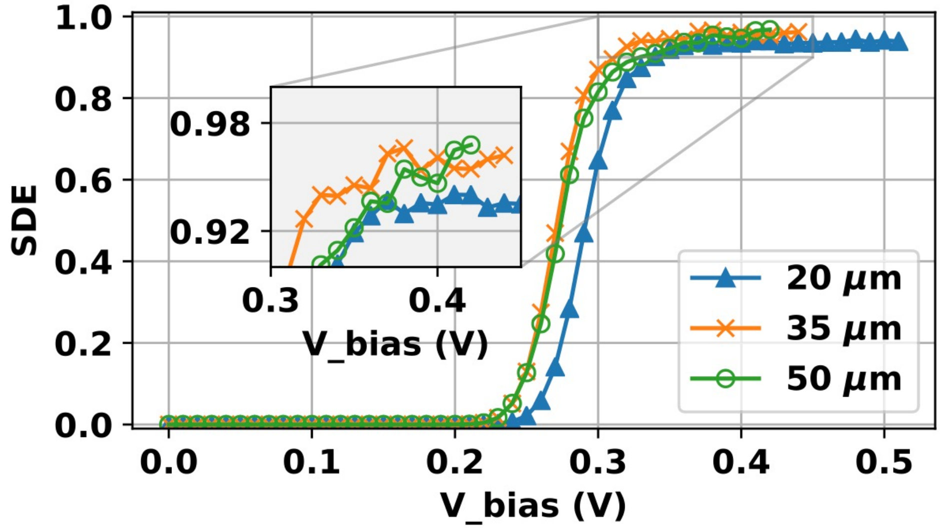
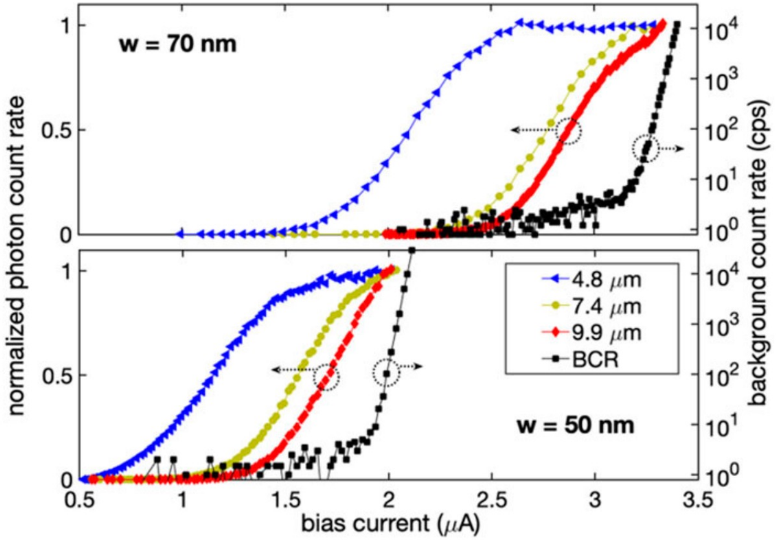




> 98% total system detector efficiency at 1550 nm

"Superconducting nanowire single-photon detectors with 98% system detection efficiency at 1550 nm", Optica, Reddy et al. 2020



Single photon detection from the UV to 10 micron

"Single-photon detection in the mid-infrared up to 10 μm wavelength using tungsten silicide superconducting nanowire detectors", APL Photonics, Verma et al., 2021

High efficiency detectors over a broad wavelength range

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How to calibrate a single photon detector

NIST
National Institute of Standards and Technology
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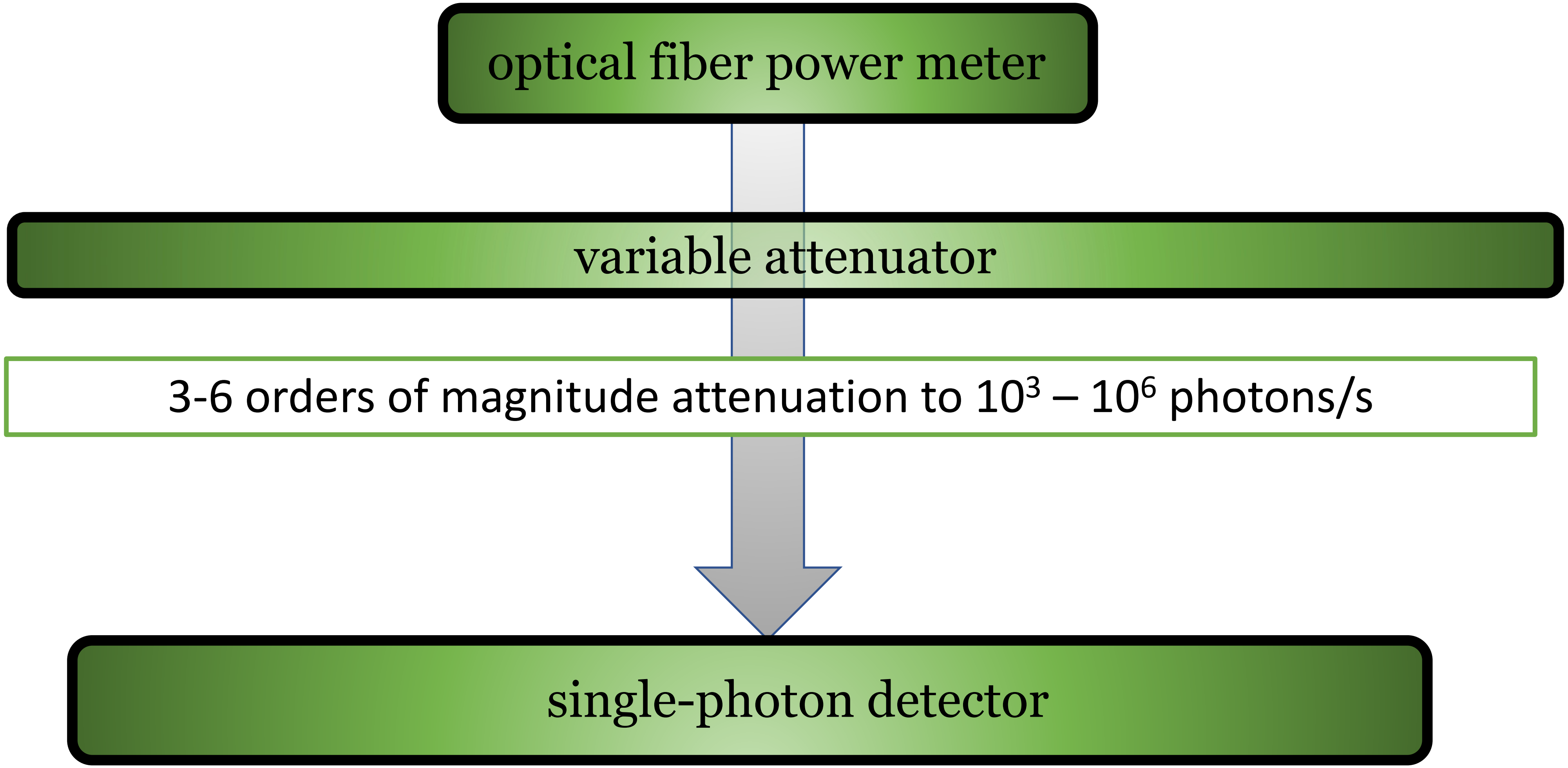


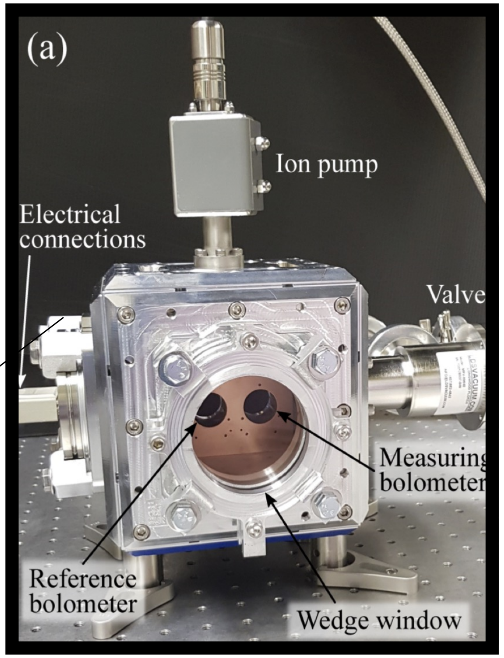
How to calibrate a single photon detector

POWR @ NIST Gaithersburg

1 in 10^5 at 1 mW

The calibration of optical power meters is traceable to a primary standard radiometer

PaRROT @ NIST Boulder



Traceable measurements to 1 in 10^3 at 1 mW

optical fiber power meter

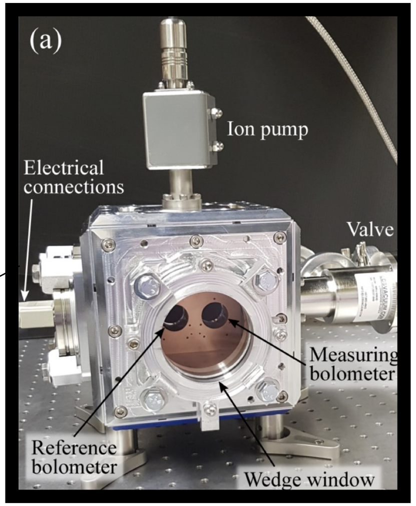
How to calibrate a single photon detector

POWR @ NIST Gaithersburg

1 in 10^5 at 1 mW

The calibration of optical power meters is traceable to a primary standard radiometer

PaRROT @ NIST Boulder



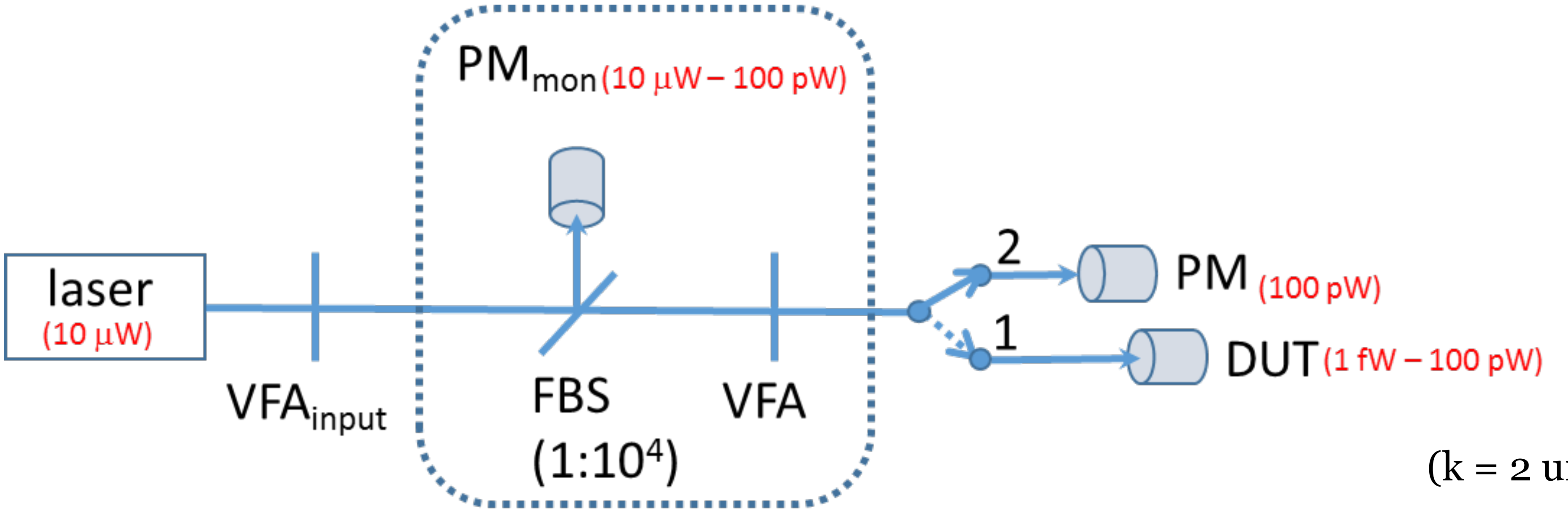
Traceable measurements to 1 in 10^3 at

spectral responsivity — All wavelengths of interest need to be calibrated

optical fiber power meter — Calibrated at 100 uW

power meter nonlinearity — Down to 150 pW

Beamsplitter method



(k = 2 uncertainty)

T. Gerrits et al., Metrologia **57**, 015002 (2020)

Calibration is based on accurate knowledge of monitor-to-output ratio

Beamsplitter method

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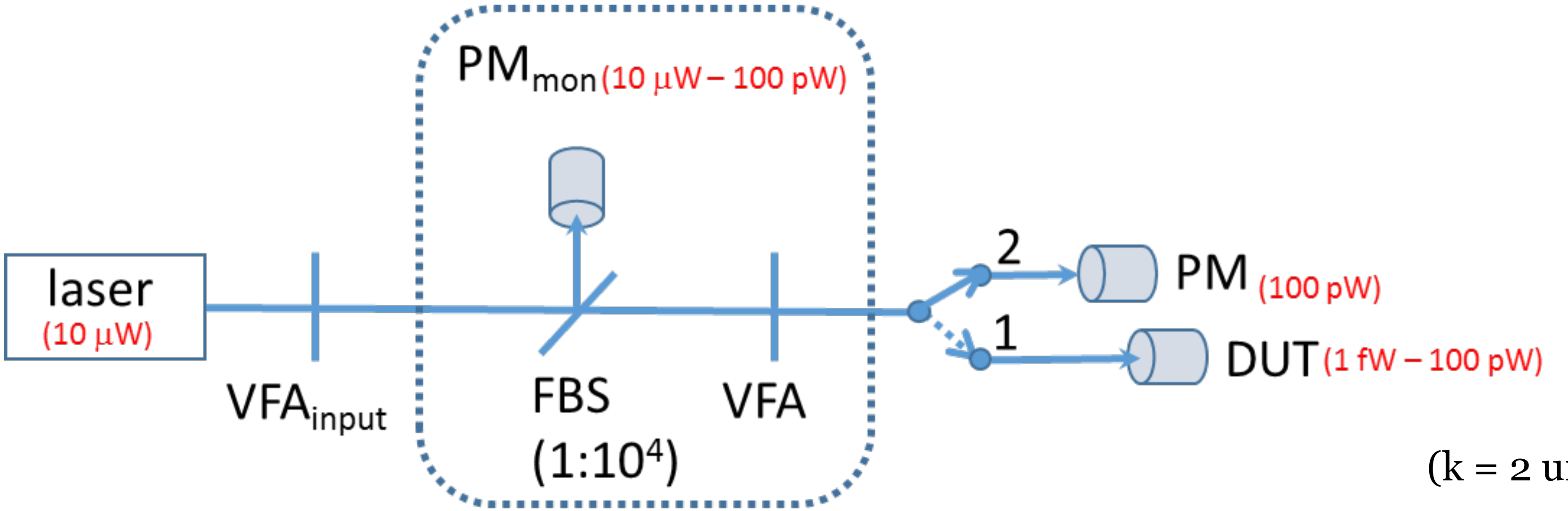

(k = 2 uncertainty)

T. Gerrits et al., Metrologia **57**, 015002 (2020)

0.7% uncertainty at 1533.6 nm for fiber coupled
1.8 % uncertainty at 851.7 nm for free space

Calibration is based on accurate knowledge of monitor-to-output ratio

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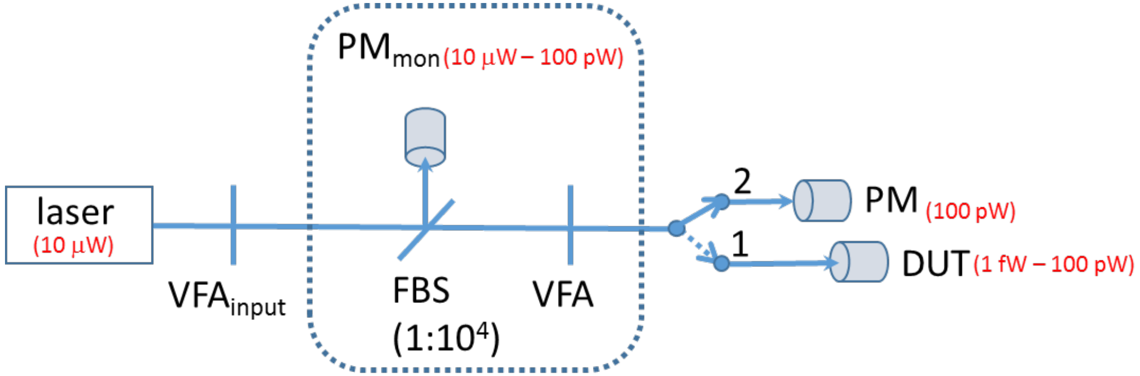
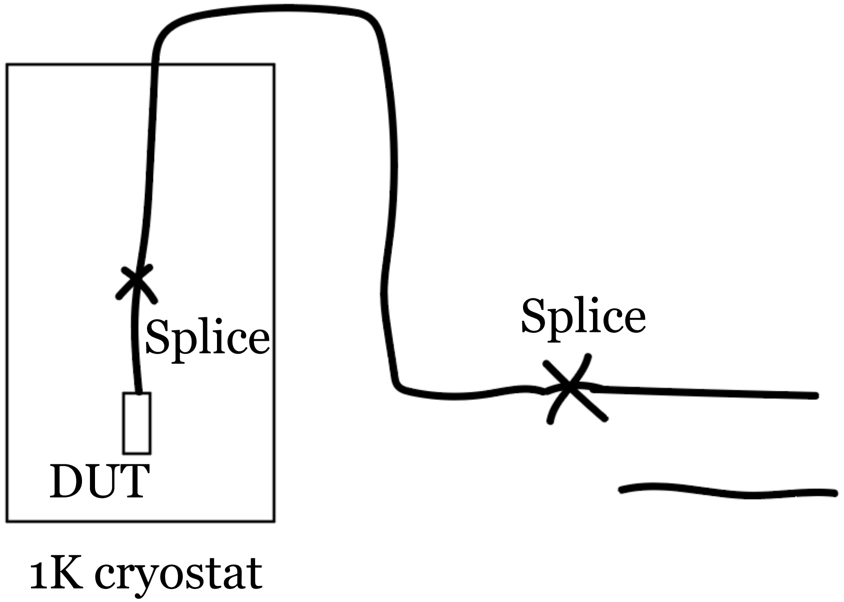
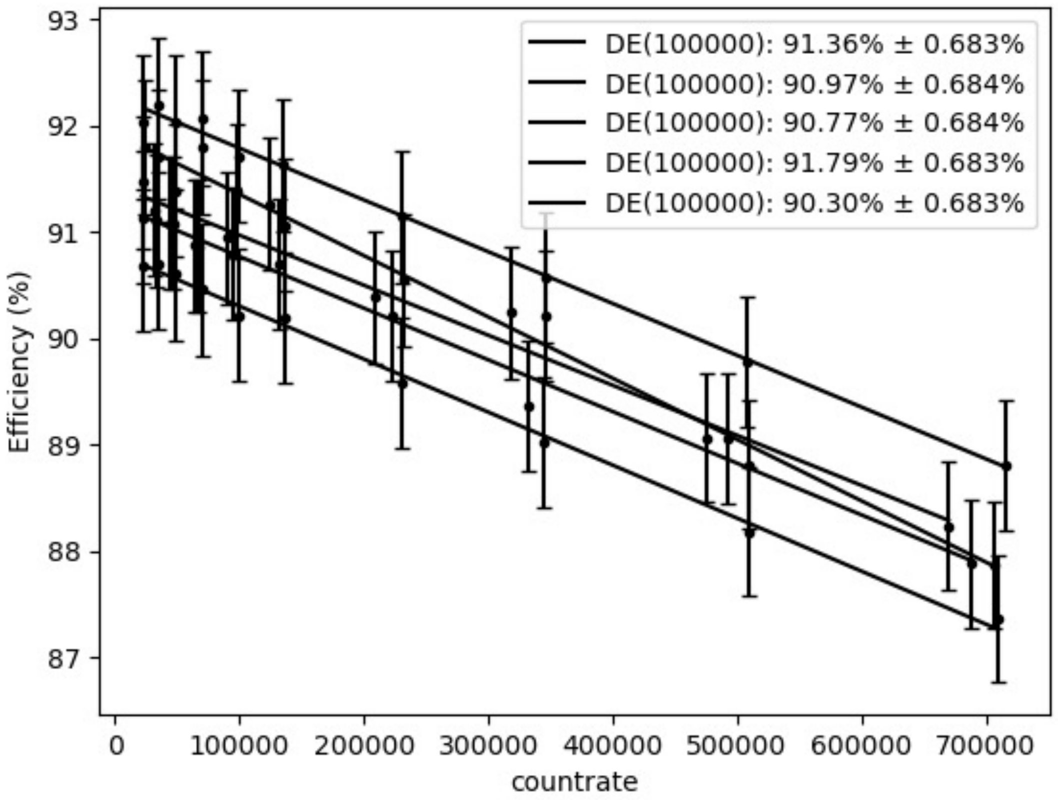
Quantifying uncertainty and loss due to splices

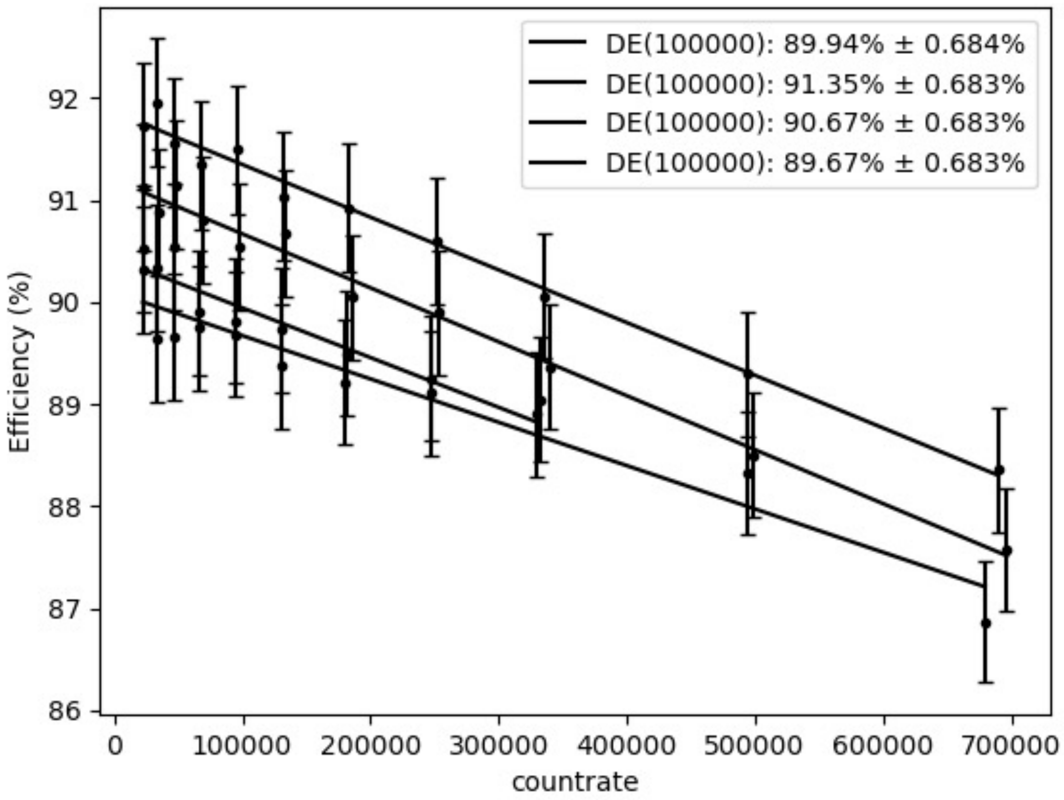




- The difference between the splices and the loss due to the splice to the DUT are unknown.
- How can these be measured?

Effects of splice loss on measurements





Each line represents a different splice – variation is worse than the rest of the uncertainties!

Splicing statistics

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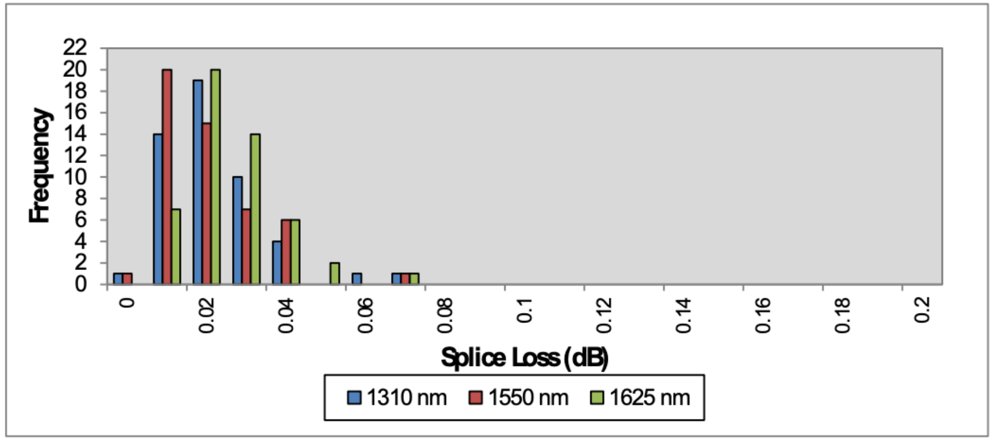
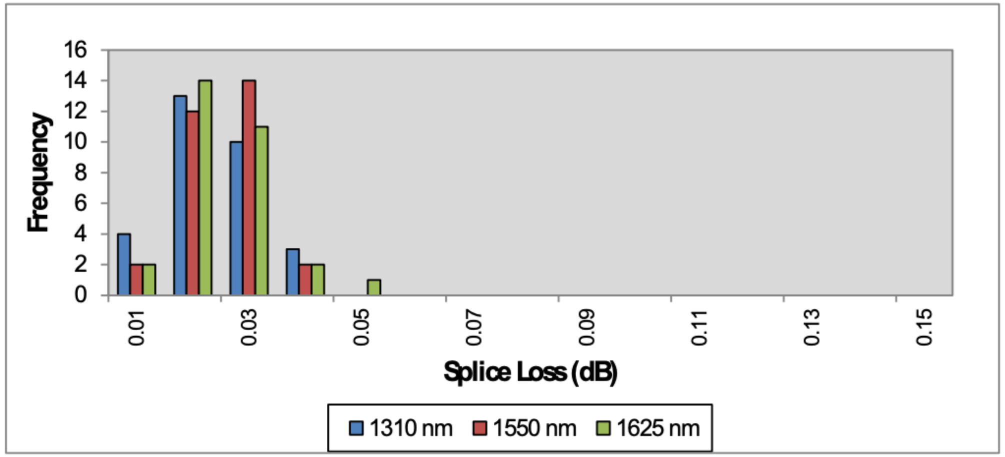
Splicing Corning® SMF-28® Ultra optical fiber to Corning® SMF-28® Ultra optical fiber



Splicing Corning® SMF-28® Ultra optical fiber to Corning® SMF-28e+® optical fiber



Corning Application Note, October 2017

- Getting losses this low depends on your splicing equipment being well optimized and in good working order.
- Even then, losses can vary up to 1%.
- Distribution of losses depends on fibers being spliced.

Integrating sphere and photodiode

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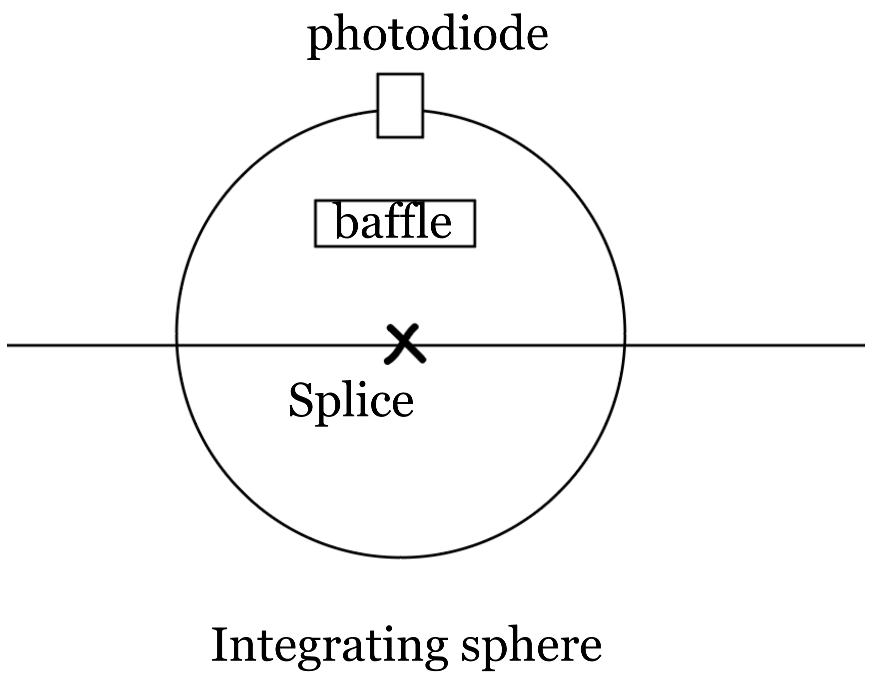

Integrating sphere and photodiode

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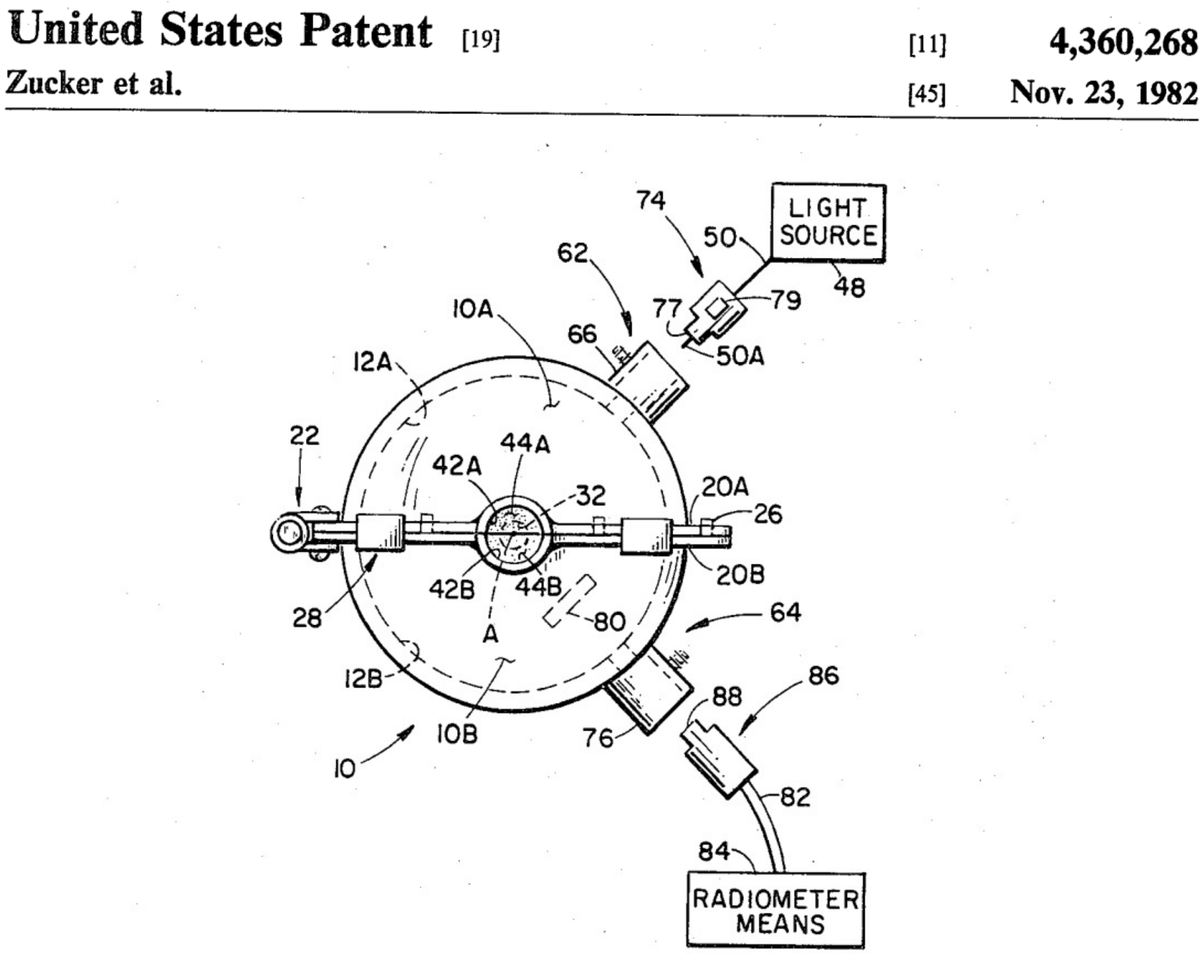

Correlation between loss and reading

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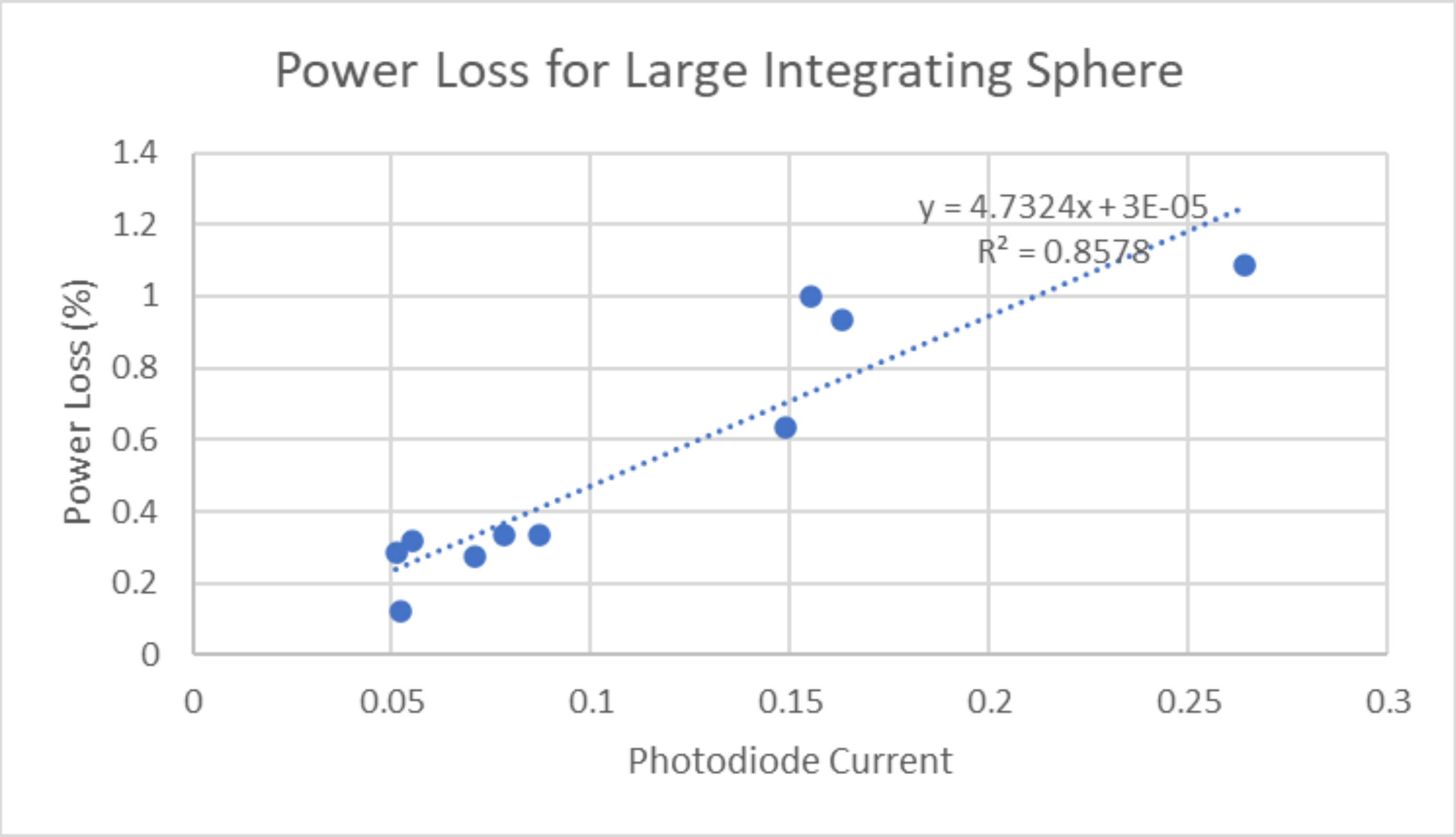

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Conclusions and future work

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- The technique is already useful for evaluating whether a particular splice is “good”
- Add a low-cost photodiode readout circuit and fabricate multiple copies for use in the labs at NIST.
- Can the device be used in a quantitative way to lower the uncertainty?

Acknowledgements

National Institute of Standards and Technology
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Nima Nader
Dileep V. Reddy
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Krister Shalm
Marty Stevens
Eric Stanton
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