Optical Communications

Marla Dowell and Paul Hale

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

CTL Communications Technology Laboratory

CTL Mission

To promote the development and deployment of advanced communications technologies through dissemination of high-quality measurements, data, and research supporting U.S. innovation, industrial competitiveness, and public safety.

CTL Priority Areas: Wireless focus

NIST

Collaborative research organization with research activities spanning organizational boundaries in support of CTL priority areas

1 Public Safety Communications

To support standards research, development, test, and evaluation for first responder communications.

Champion: Dereck Orr

2 Trusted Spectrum Testing

To improve spectrum-sharing agreements, and inform future spectrum policy and regulations through independent validated testing.

Champion: Melissa Midzor

3 Next Generation Wireless

To advance the measurement science infrastructure for next generation wireless communication systems, e.g., mmWave radio channels.

Champion: Nada Golmie

4 Fundamental Metrology for Communications

To advance the measurement science infrastructure for next generation wireless communication systems, e.g., mmWave radio channels.

Champion: Paul Hale

NIST Addresses National R&D Priorities

NIST

Security

Cybersecurity and Privacy · NCCoE · Forensics · Body Armor & Materials · Public Safety Communications · AI · Autonomous Systems · Microelectronics

AI, Quantum &Computing

Cybersecurity and Privacy · Quantum Science · Quantum Computing · JILA · JQI · QuICS · nCOR
Metho

Connectivity & Autonomy

Advanced Communications · Networks & Scientific Data Systems · 5G · Wireless

Manufacturing

Advanced Manufacturing & Material Measurements · Machine Learning · Materials
otics ·
ing

Communications is an enabling technology

CTL supports several National R&D Priorities through wireless programs

Space

Advanced Manufacturing · Materials Development and Measurements · Aerospace Manufacturing · Sensors for Space Measurements

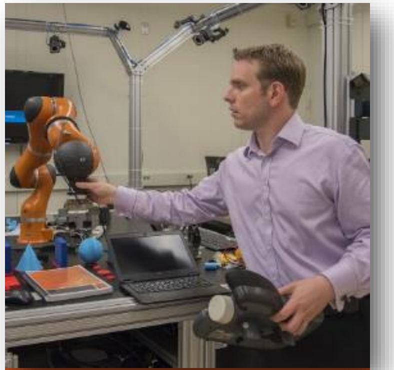
En

Smart Grid · Net-Zero Energy House · Energy Efficiency · Fuels · Sustainability

Health and Bioscience ·IBBR Diagnostic Standards ·JIMB · Biomanufacturing Process and Development Standards · Health IT · Medical Imaging

Water · GPS Technology · Measurements for Aquafarming · MRI of living plant roots

Programmatic Priorities



Advanced Manufacturing

Cybersecurity

Disaster Resilience

© Matt DeLorme

Engineering Biology

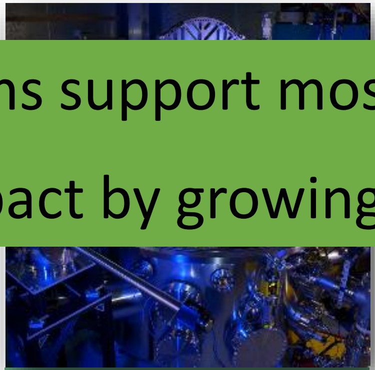
Internet of Things

CTL programs support most of these priorities

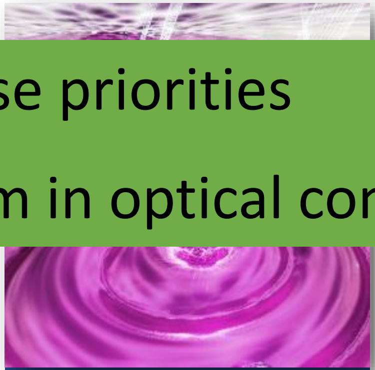
Opportunities to expand impact by growing program in optical communications

Documentary Standards

Technology Transfer



Measurement Dissemination



Quantum Science

Artificial Intelligence

Timeline: NIST Optical Communications

Late 1970's: disagreements between optical fiber manufacturers created impediment to market development

1976 – 2003: NIST Optical Fiber Metrology Program

- Optical Fiber Power
- Optical Fiber properties, *e.g.,* polarization mode dispersion, attenuation, bandwidth, mode profile, fiber cladding diameter
- Wavelength

2003: NIST scales back optical communications program; retains networks efforts

2014: NIST creates CTL with focus on Wireless Communications to address spectrum sharing and next generation wireless needs

JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 26, NO. 9, MAY 1, 2008 1119

Optical Fiber Metrology

Gordon W. Day, *Fellow, IEEE, Fellow, OSA*, and Douglas L. Franzen, *Life Fellow, IEEE, Fellow, OSA*

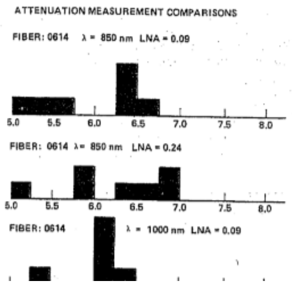
Invited Paper

Abstract—The development of metrology to support the optical fiber communications industry is an excellent case study of how stakeholders—fiber manufacturers, their customers, standards-developing organizations, and (in the U.S.) the Federal Government—worked together to develop product specification standards that facilitated the growth of an industry. This paper reviews some of that history, primarily from the perspective of the National Institute of Standards and Technology, which worked with the industry to provide independent research and neutral coordination of many industry studies and measurement comparisons.

Index Terms—Instrumentation, measurements, multimode fiber, optical fiber metrology, single-mode fiber, standards.

I. Introduction

FROM the 1966 publication of an analysis conc optical fiber could be a viable communicatio [1], through the key experimental achievements [2] liest systems carrying commercial telephone calls in attention seems to have been given to how an optical be accurately specified and characterized. The dif fiber metrology that would emerge and complicate for fiber as a large volume commodity seem to have erally unanticipated or underestimated.



NIST Optoelectronic Measurements for Fiber Optic Applications

K.B. Rochford, P.D. Hale, and N.R. Newbury
Optoelectronics Division, National Institute of Standards and Technology, Boulder, Colorado, 80305
rochford@boulder.nist.gov

Abstract: We describe current measurement capabilities as well as research focused on two areas: improving temporal and frequency response characterization of detectors and instrumentation using electro-optic sampling, and improving wavelength metrology using frequency combs.

OCIS codes: (120.3940) Metrology; (120.4800) Optical standards and testing; (040.0040) Detectors

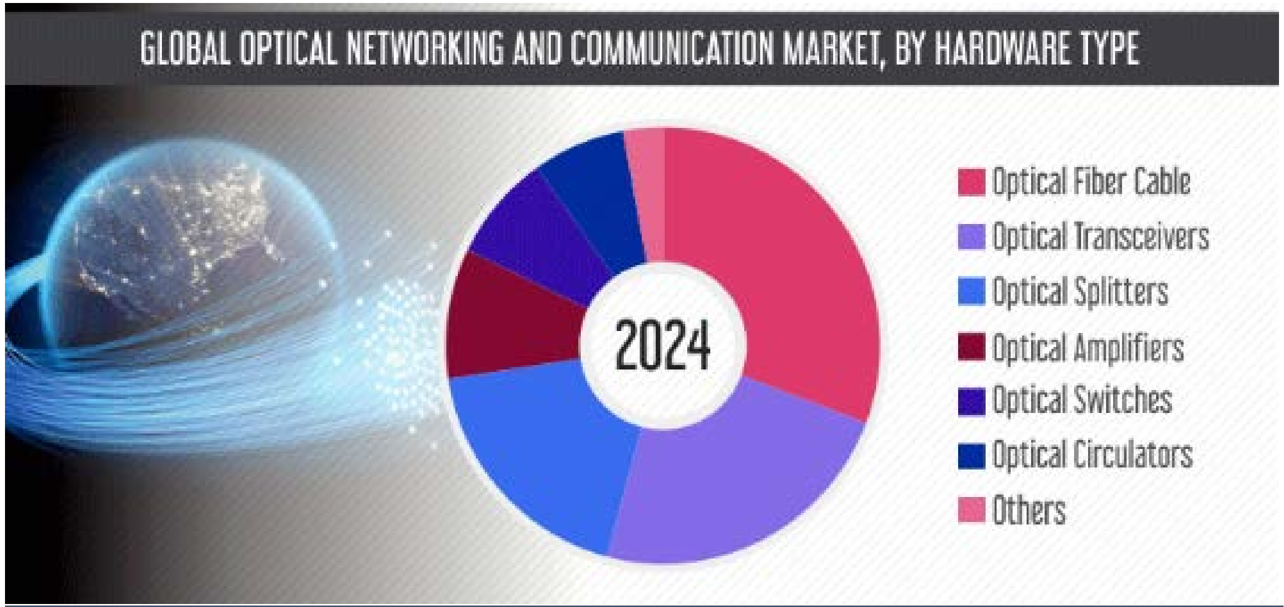
1. Introduction

The National Institute of Standards and Technology (NIST) has the responsibility "to develop, maintain and retain custody of the national standards of measurement, and to provide the means and methods for making measurements consistent with those standards; and to assure the compatibility of United States national measurement standards with those of other nations." This responsibility is twofold: to ensure that U.S. national standards are accurate realizations of the SI units, and to transfer the values of those standards to the U.S. measurement system through calibrations and other types of measurement services. This invokes the concept of traceability, which is the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons, all having stated uncertainties.

NIST researchers have contributed to the improvement of measurements for optical fiber applications since 1976, when the organization was known as the National Bureau of Standards. Early work concentrated on optical fiber properties such as attenuation and fiber diameter, basic properties that affect the loss budget of optical fiber links. With the advent of optical amplifiers, optical losses can be overcome, and parameters that limit transmission capacity and fidelity in optical fiber communications become limiting factors. In this paper we discuss our current measurements that provide traceable optical fiber measurements, and describe two research efforts intended to meet emerging and future needs.

Why NIST? Why Now?

- Application Drivers
  - high-bandwidth network
  - internet of things (IoT)
  - machine-to-machine (M2M) communication technologies.
- End Users want interchangeable hardware
- Manufacturers want well-defined metrics
- 5G expected to have massive impact on optical fiber backhaul



Global Market 2018: $25.9B → 2024: $40.3B

P&S Intelligence (February 2019)

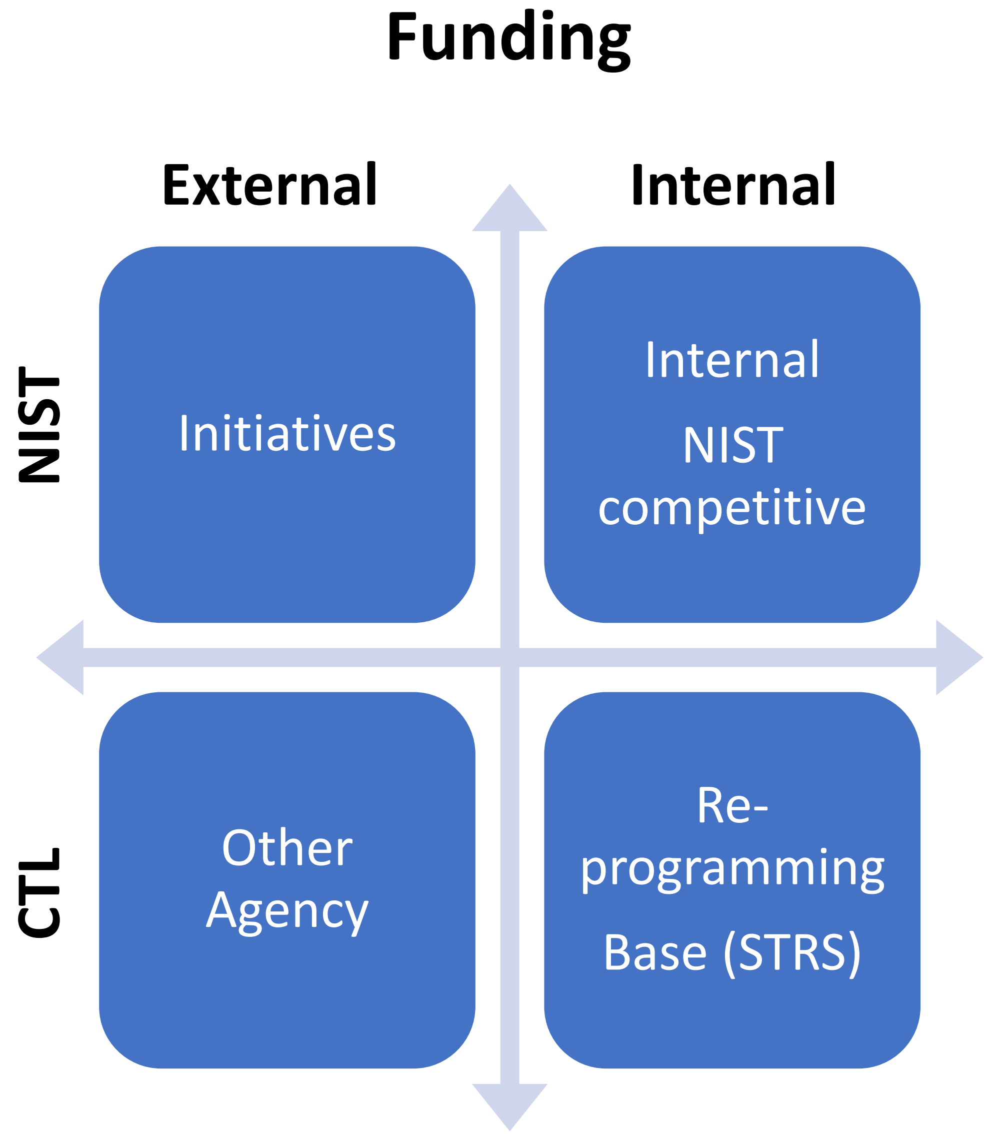
Growing CTL optical communications program

Two pronged approach:

Internal: Leverage NIST competitive programs to partner with other NIST Labs on NIST Priorities with optical communications focus

External: Seek out external partners with optical comms expertise

- Invited speakers
- Attend conferences
- Hold NIST workshop



Internal: CTL Innovations in Measurement Science

NIST

Programmable Waveform Synthesizers with Quantum-based Accuracy

Quantum-synthesized waveforms from DC to 300 GHz

DC to 1 THz Large-Amplitude Optoelectronic Multitone Electrical-Signal Synthesizer

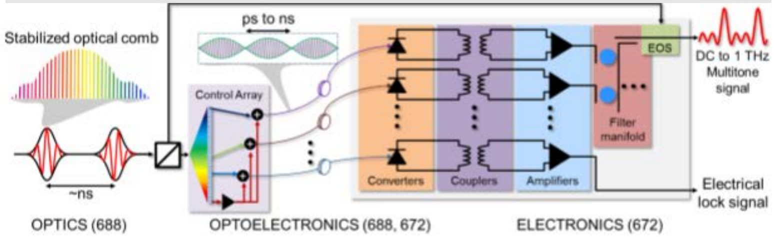
Enabling precise tests on modern electronics operating > 40 GHz

Establishing the S&T of networks for superconducting quantum computing

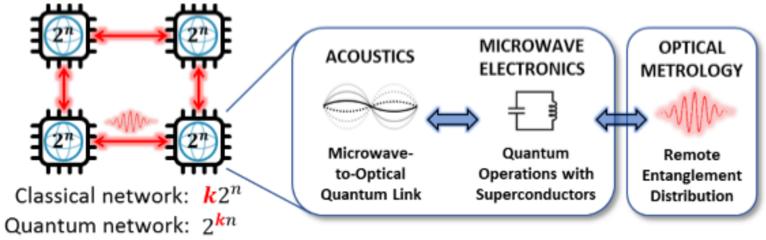
World's first small-scale quantum network for standards development

All of these programs rely on core competencies in optoelectronics and optical metrology

design for high-bandwidth, low-latency applications from telecommunications to robotics



superconducting qubits and communications

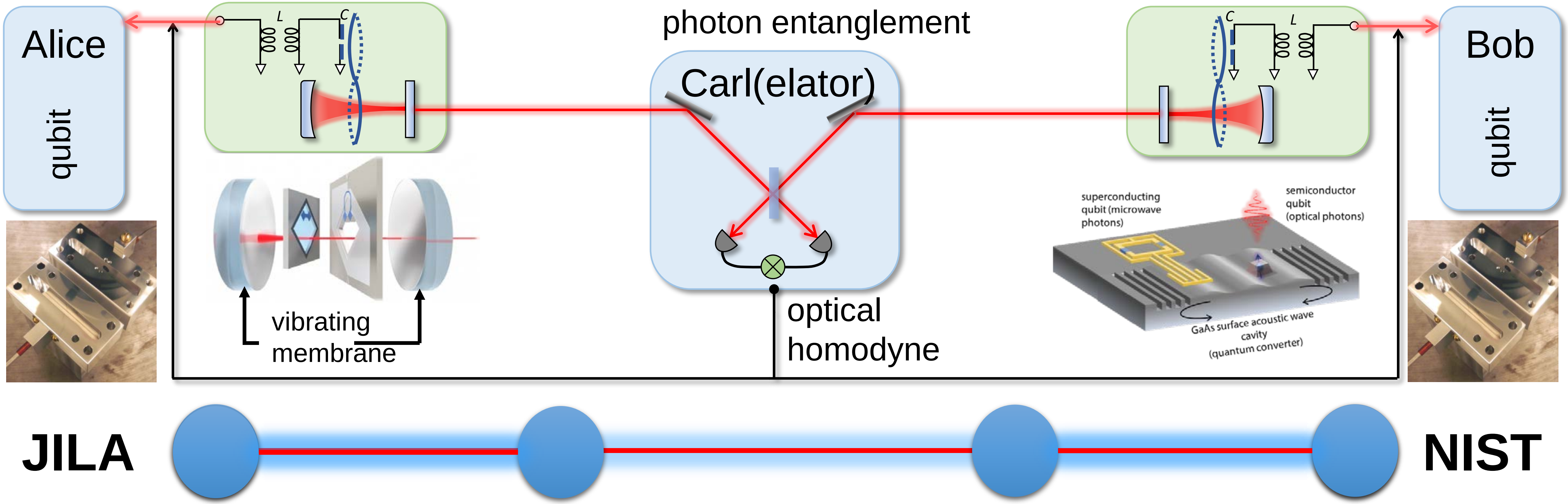


Start: FY16
$6.7M over 5 years
Collaborators: NIST PML

Start: FY18
$6.5M over 5 years
Collaborators: NIST PML

Start: FY19
$6 M over 5 years
Collaborators: NIST PML and ITL

Quantum Networking



Primary Activities

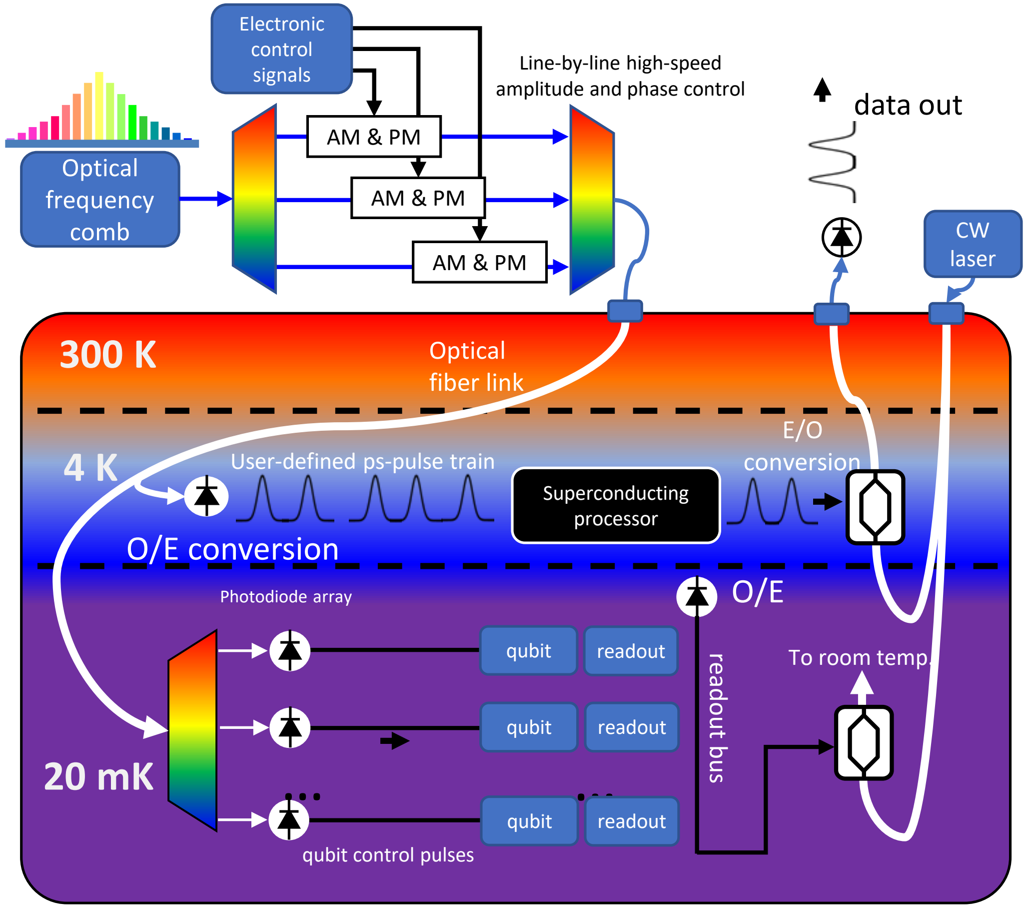
- Transduction
- Quantum correlation
- Quantum Networks

Goals

- First link in a quantum network of superconducting qubits
- Expandable test-bed and technology pathfinder network
- “Plug and play” networking for disparate qubit technology

Proposed NIST Internal Quantum Activities

- Low-Loss Microwave Materials for QIS (CTL)
- Using Rydberg-Atoms for Quantum SI Traceable RF-Power Measurements and Calibrations (CTL)
- Rydberg Atom Coherent Receiver from 1 GHz to 1THz (CTL)
- Broadband and phase coherent photonic systems for large-scale superconducting circuit control and readout (CTL, PML)
- Rydberg Laser (RASER) (CTL, PML)
- High-Bandwidth Cryogenic Optical Data Link for Quantum Metrology and Qubit Control (CTL, PML)
- Measurement Science for microwave components in cryogenics systems in support of QIS (CTL, PML)
- Quantum Network Testbed Infrastructure (CTL, ITL, PML)
- Rydberg Atoms and Molecules for Enabling Technologies and Applications (CTL, PML)
- FY20 IMS proposal: Calibrations for the First Million-Qubit Computer (CTL, MML, PML)



Cryogenic Microwave Metrology for Qubits

These programs rely on core competencies in optoelectronics and optical metrology

Workshop: Machine Learning For Optical Communication Systems

NIST

Objective: Identify and develop applications of AI and ML in the context of accelerating the use of software-based networking in optical systems for improved performance and scalability.

Paths to realizing reference training data sets for ML in optical communications systems including needs for new or different metrology will be examined.

Outcomes: White paper for a plan and path to develop and disseminate reference data sets for ML training and applications

Working group to further develop these ideas.

Program Committee: NIST, University of Arizona, Nokia
NIST Chair: Josh Gordon

WORKSHOP

August 02, 2019

NIST, 325 Broadway, Boulder, CO 80305

Register Now

Registration fee is $139 and includes continental breakfast, lunch and pm break. All visitors to the NIST campus must be pre-registered. There is no onsite registration for meetings held at NIST.

https://www.nist.gov/news-events/events/2019/08/machine-learning-optical-communication-systems

DISCUSSION

Working with NIST

NIST Communication Technology Laboratory	NIST
Informal collaborations: visiting scientists, sabbaticals, joint peer-reviewed papers, Cooperative Research and Development Agreements (CRADAs): formal partnership to facilitate work with U.S. companies, academia, and other organizations on joint projects. Use of Designated Facilities: NIST has several unique and valuable laboratory facilities available for use by U.S. organizations for both proprietary and non-proprietary research. Access to these designated facilities is generally provided on a first-come, first-served cost-reimbursable basis. marla.dowell@nist.gov (303) 497-7455	Manufacturing Extension Partnership: nationwide network of resources for manufacturing and business expertise for U.S. companies Colorado Association for Manufacturing and Technology: http://newcamt.camt.com/

TECHNOLOGY PARTNERSHIPS OFFICE

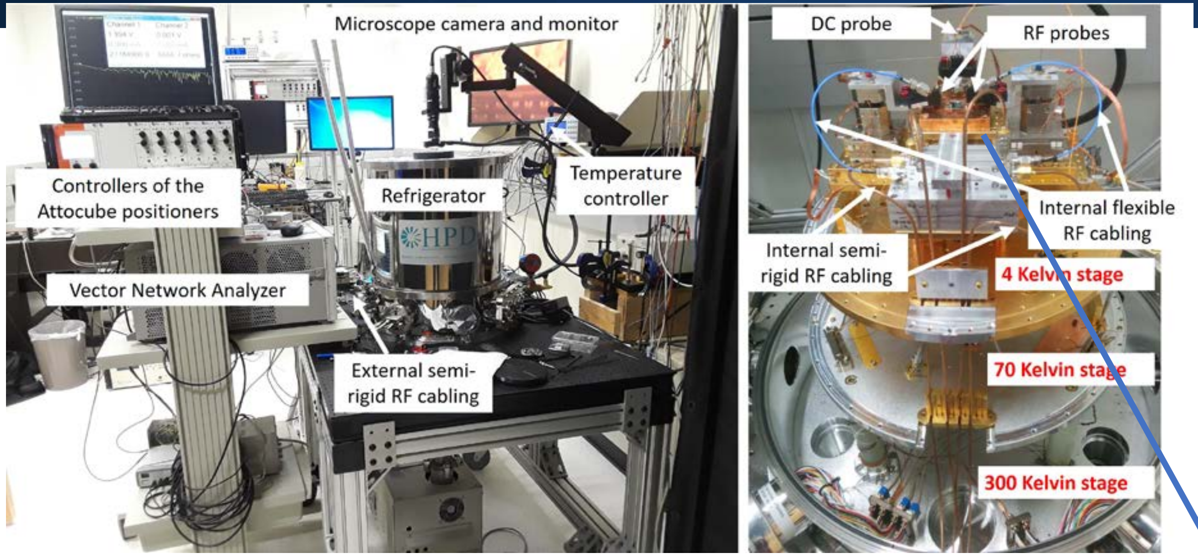
301-975-2573
tpo@nist.gov

General inquiries about patents, licensing, and NIST Small Business Innovation Research Program

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

CTL Communications Technology Laboratory

Cryogenic Network Analysis



CTL Goals

Develop traceable microwave measurement strategies to support the RF JAWS design

1) Development of cryogenic calibration kits
2) Modelling and characterization of passive and active superconducting circuits
3) <u>De-embedding of quantum RF waveform standards to room temperature</u>