High Speed Optical Communication

Status and Prospects

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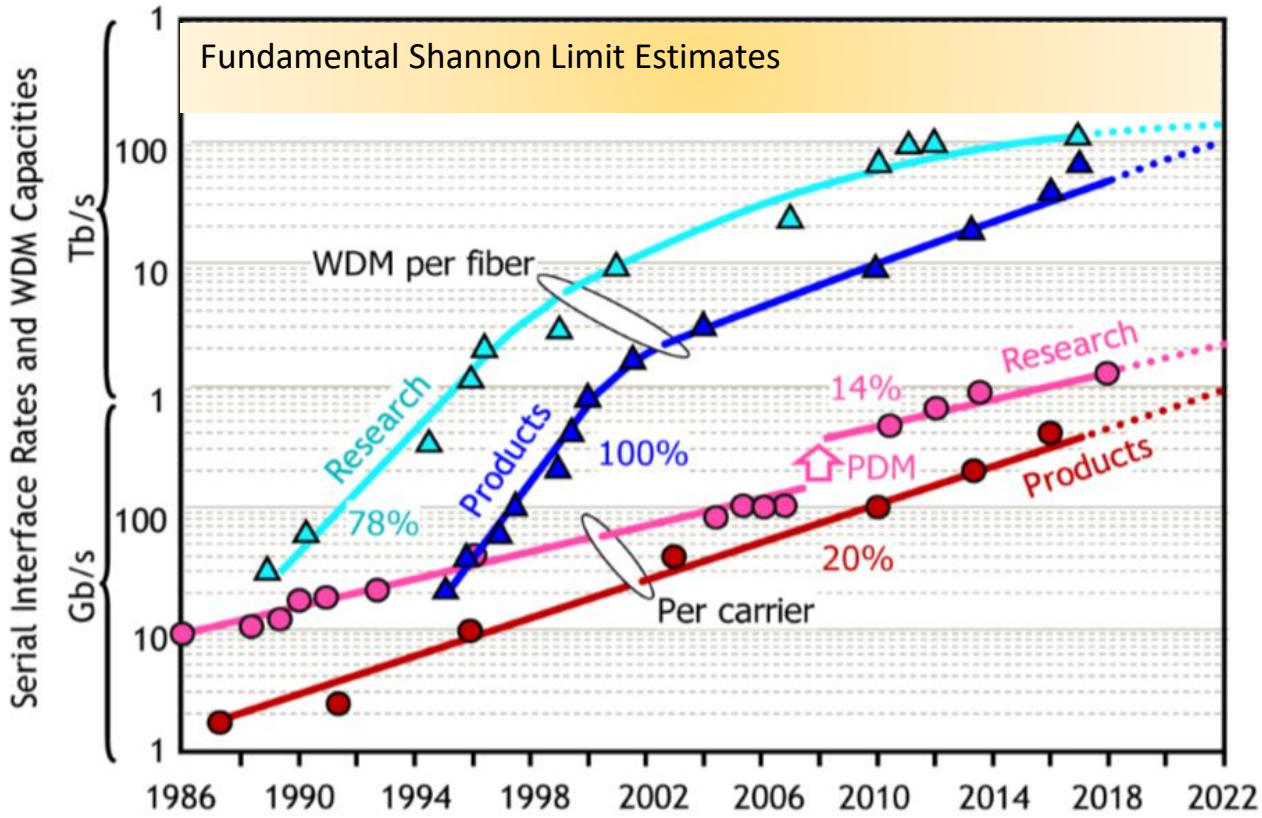
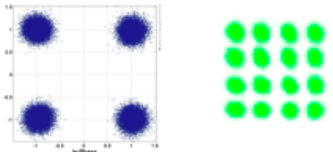
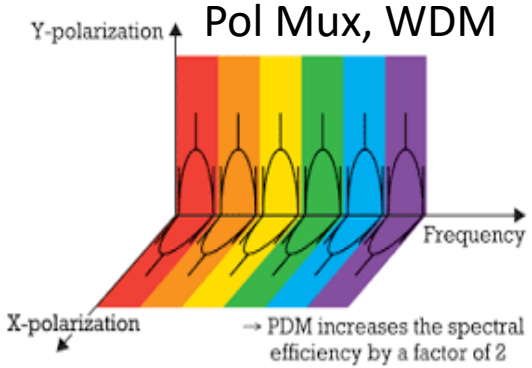
High-speed Optical Communication - Trends



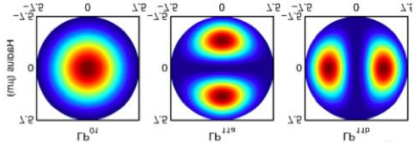
m-QAM

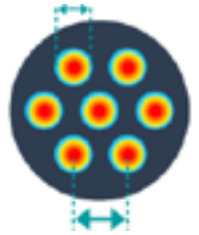


Pol Mux, WDM



Space/Mode Div Mux



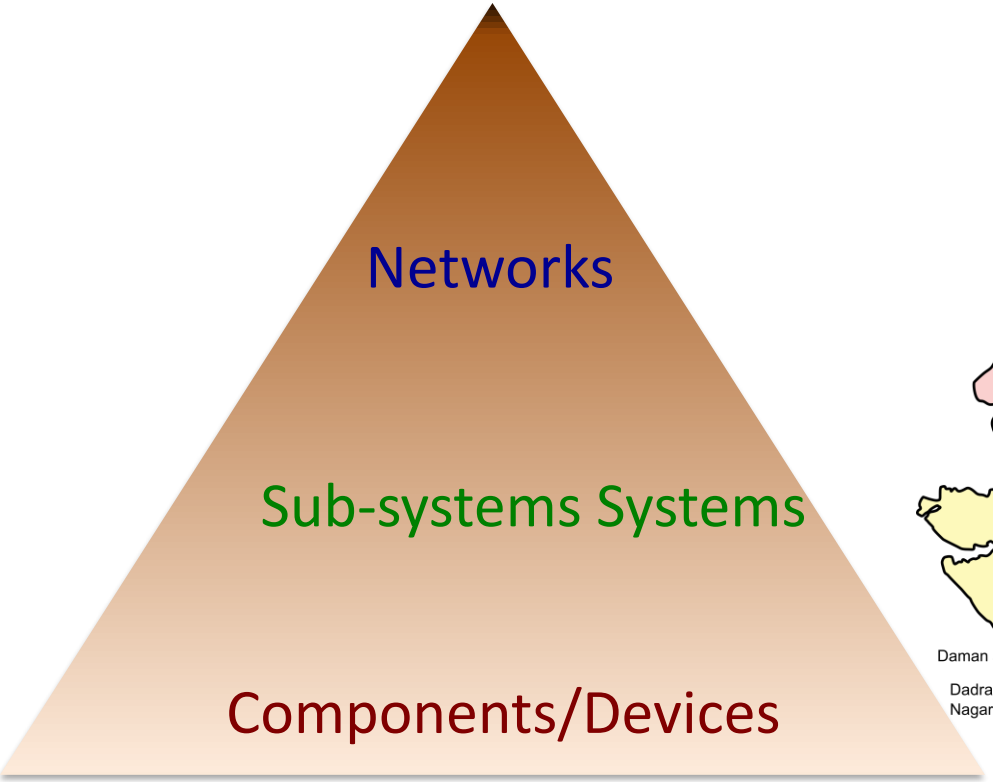


Largest demand for capacity in

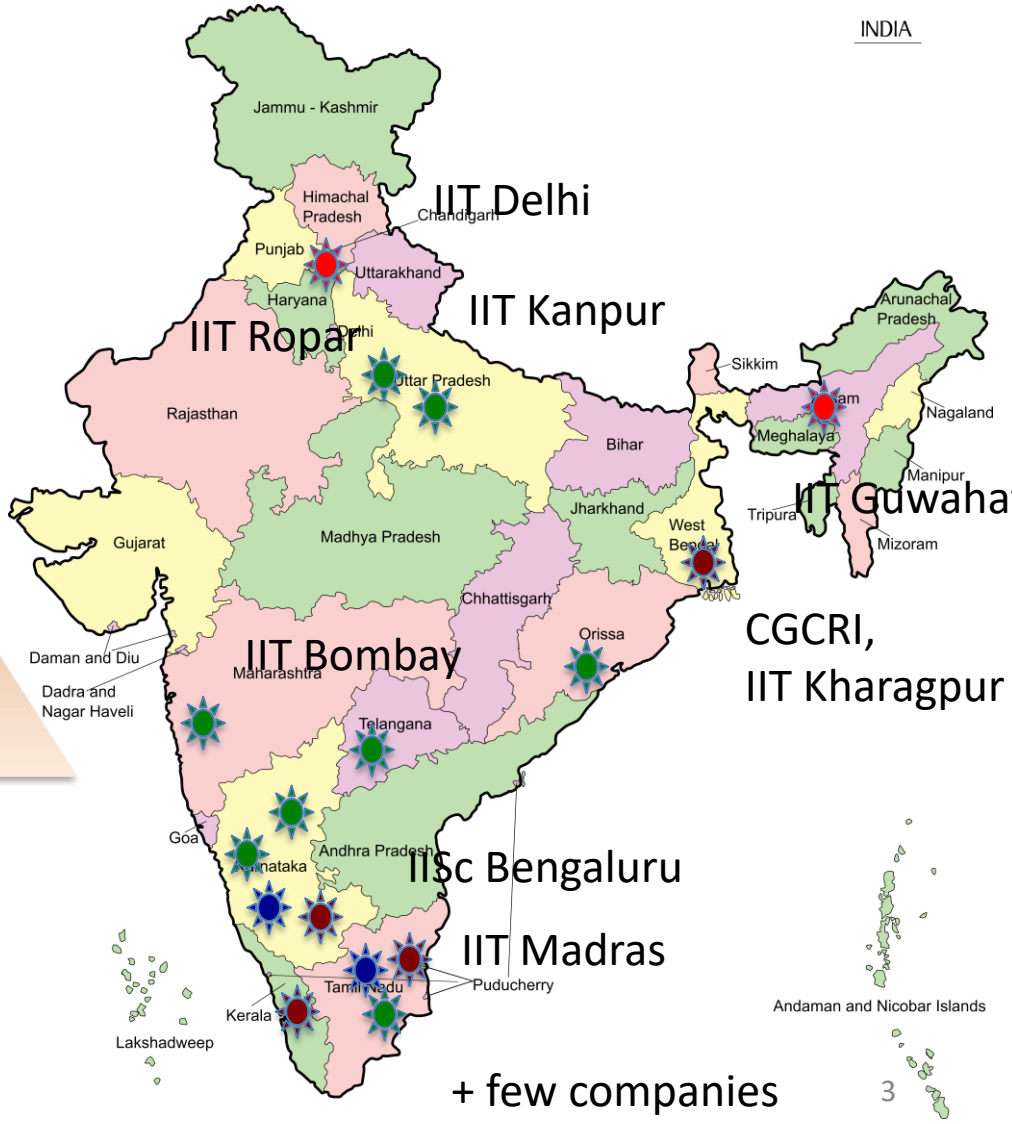
- Data center networks
- Fronthaul and backhaul for advanced wireless systems

P. J. Winzer and D. T. Neilson, A. Chraplyvy "Fiber Optic Transmission and Networking : the previous 20 and the next 20 years", Opt. Exp., 2018

High Speed Optical Communication : Critical Work Elements



- Fundamental research
- Modeling and Simulation
- Experimental Realizations
- Industry- Production



High-speed communication @ IITM

Dec 2016 — High Speed Test Bed Installation

Dec 2017 — Simultaneous 256G & 10G Transmission over 25 km SMF

Oct 2018 — 400G Nyquist-WDM Superchannel, India's First 6-mode SDM Test

Sept 2019 — First successful 84G 2 mode transmission

Dec 2019 — Tbps CO-OFDM Superchannel*, TDM-SDM Transmission

March 2020 — 1.024 Tbps (SE: 7.11 b/s/Hz) Transmission

SDM : Space division Multiplexing

DAC: 65 GS/s, ADC: 80 GS/s
Coherent Tx, Pol and phase diverse Coh Rx (40 GHz)

Microwave Photonics with high-speed systems

- Radio over fiber : Analog front haul for advanced wireless systems
- Development of Photonic Analog to Digital Converter
- Integrated Optic RF Photonic Filter
- RF generation and distribution
- Optical control of phased array antennas

Photonic ADC

The Team @ IITM


David Koilpillai

Adaptive Sig Proc


Srikrishna B

Sig Proc, Information Th.


R Ganti

Wireless Systems

Signal Processing & Wireless Systems

Photonic Devices

RF & Electromagnetics

Broadband Optical Communication Systems

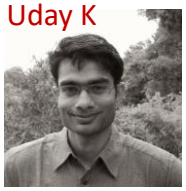
Fiber Optic Systems


Bijoy Das

Silicon Photonics


Shanti B

Diffractive Optics
Structured Light


Uday K

Comp. EM


S Christopher

Radar Systems


Hari R

RF & Optical Comm


Deepa V

Optical Signal Proc., Opt Comm


Anil P

Quantum Comm.


Balaji S

Fiber Systems
Structured Light

Strengths :

Combination of strengths in RF, Signal processing and Photonics

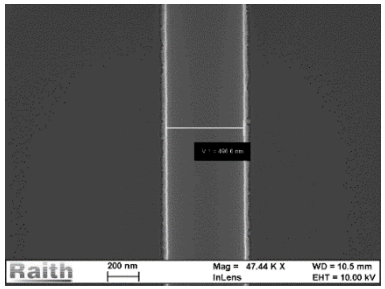
Vertical integration from devices to systems

Silicon Photonics Research at IIT Madras (Since 2006)

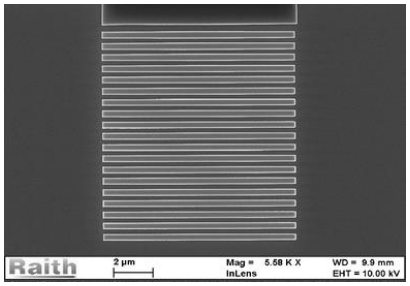
In-house silicon photonics technology

EBL System

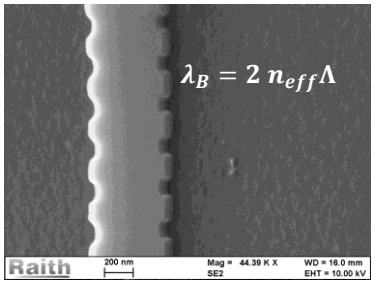
PhW Waveguide (SEM)



Grating Coupler ***(SEM)***

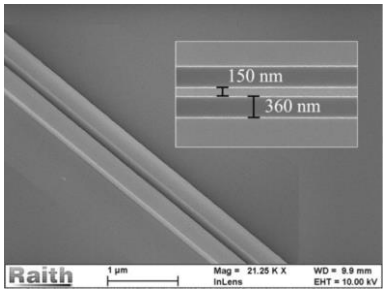


DBR Filter (SEM)

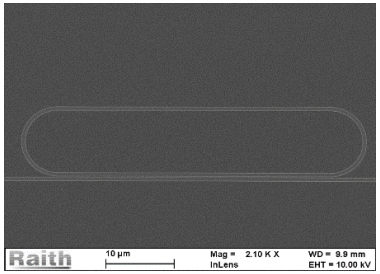


ICPRIE System

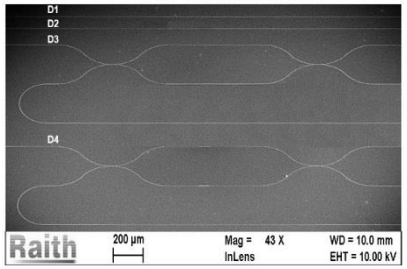
Directional Coupler (SEM)



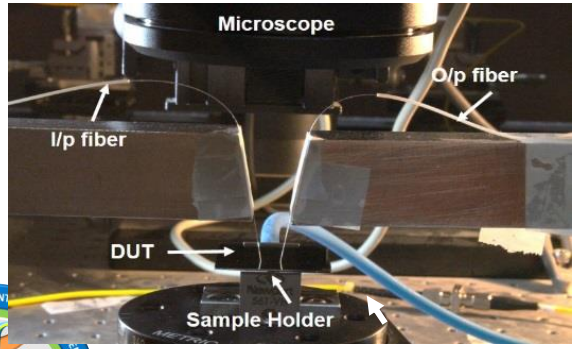
Microring Resonator (SEM)



Add-drop Filter (SEM)



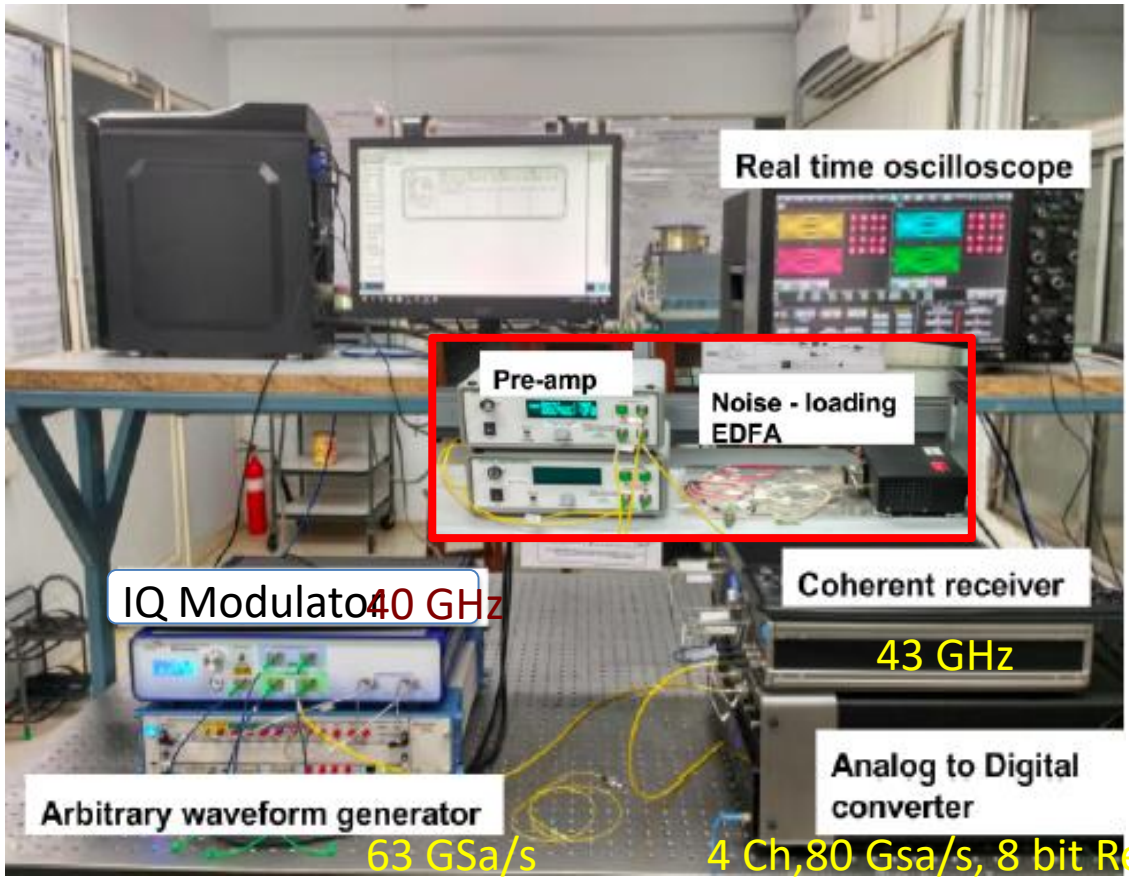
Fiber-Optic Probe Station



On-going Projects

- ❑ PN/PIN waveguides (electro-optic modulators)
- ❑ Integrated optical microheaters (thermo-optic switches)
- ❑ Sub-wavelength grating waveguide filters (add-drop multiplexer)
- ❑ Integrated quantum photonic devices (design and demonstration)

High speed optical communication @Indian Institute of Technology Madras



Long haul Systems

- 100 Gbps with PM QPSK
- 200 Gbps with PM16QAM
- 400, 526 GBps with Nyquist WDM
- MDM with Few mode Fibers

Access Networks

- OFDM for PON
- Analog IFoF for front-hauling in wireless systems

Underwater communication

Optical Signal Processing

- Wavelength conversion
- Phase quantization
- Logic gates
- Clock recovery

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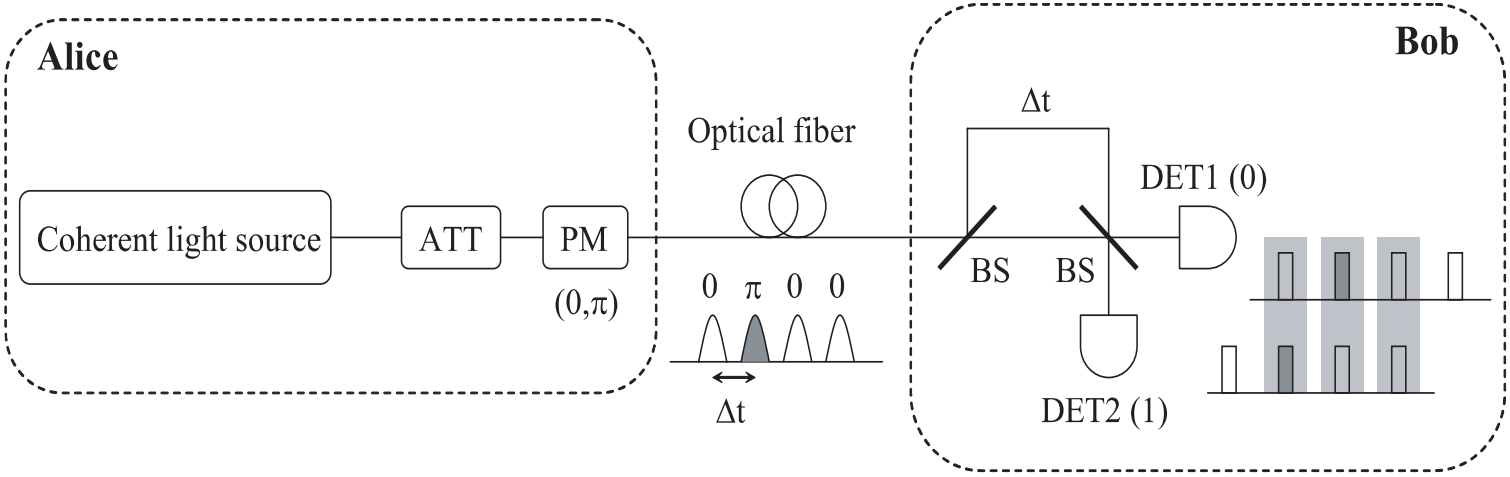
Differential Phase Shift QKD

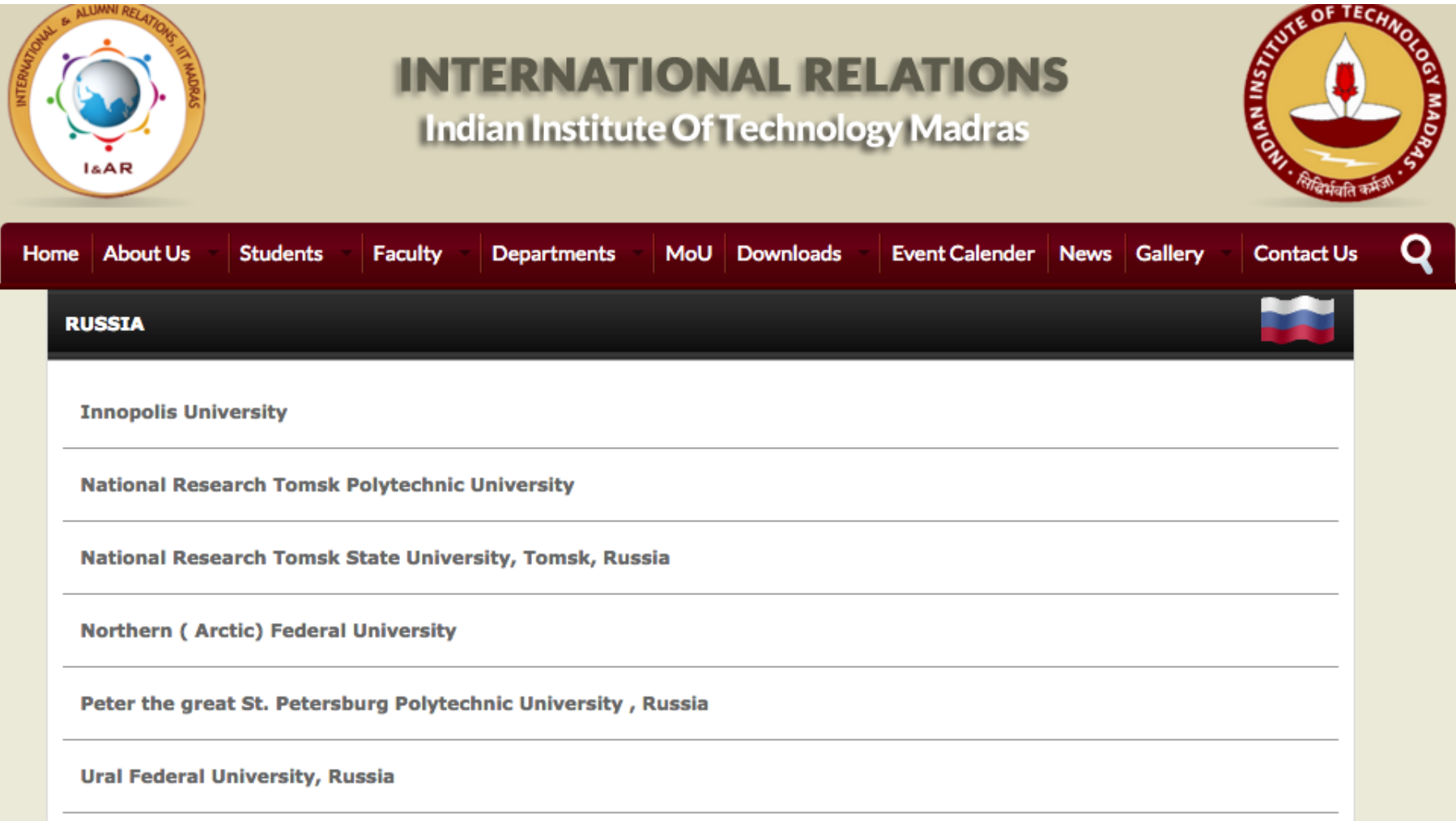


- Information is distributed over several coherent optical states
- Alice sets phase (0,π), Bob will detect either in DET1 or DET2.
- Bob publicly announces the time intervals when he makes a detection
- Alice retains bits from those time intervals as key bits

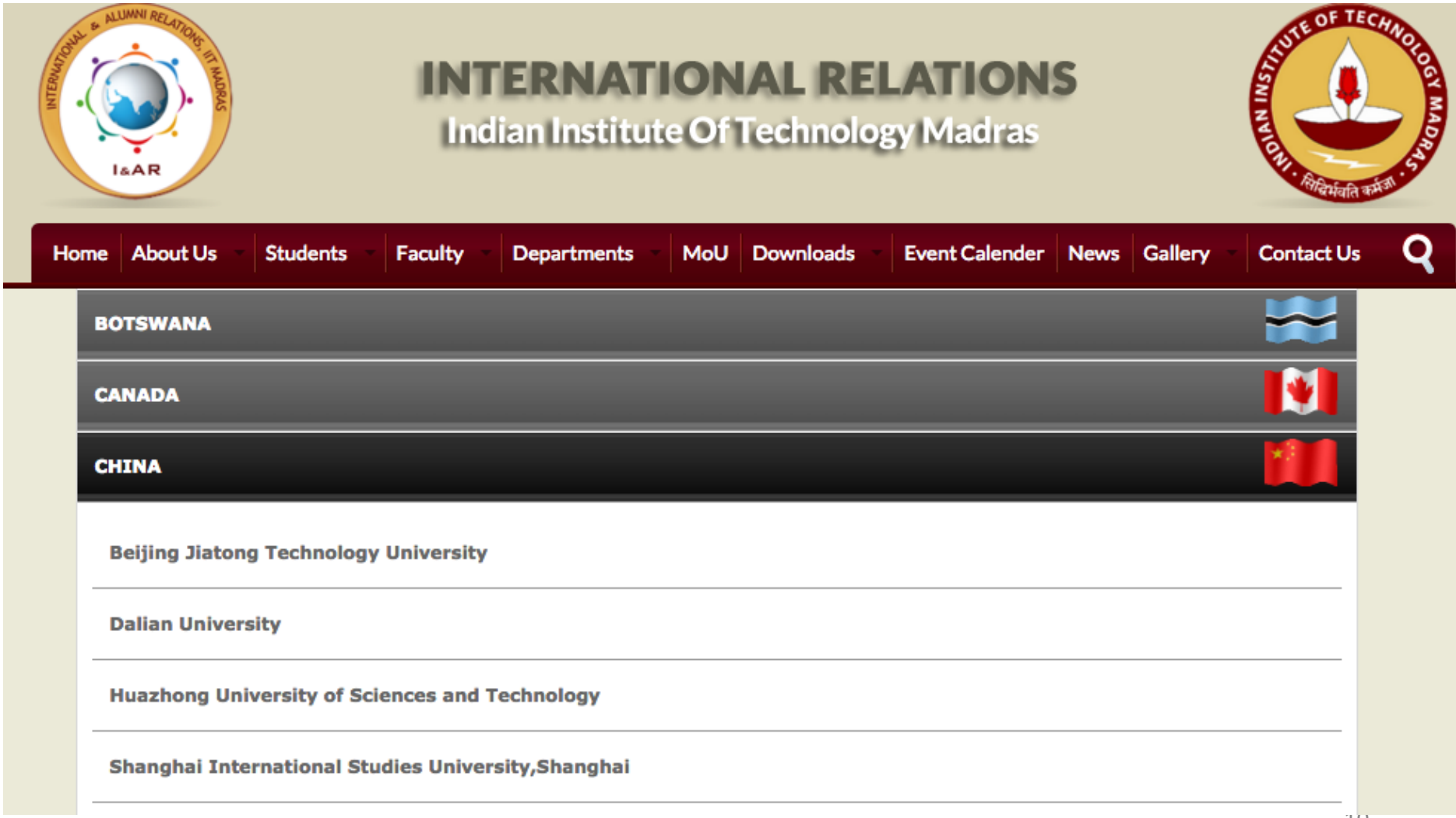
Inoue et al, "Differential phase shift QKD, Phys. Rev. Lett., **89**, 2002.
Diamenti E, Security and Implementation of DPS-QKD, PhD thesis, Stanford Univ., 2006

Anil Prabhakar, anil@ee.iitm.ac.in

MoUs with BRICS countries



MoUs with BRICS countries



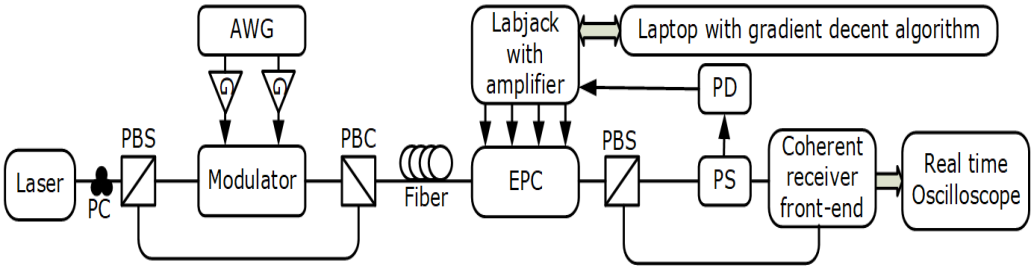
Moving on to some other institutes …

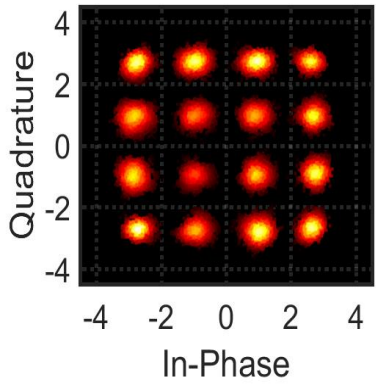
(only representative)

Circuits and Architectures for Low Power Data Center Interconnects

Shalabh Gupta, IIT Bombay

Self-Homodyne 16-QAM Architecture for Optical Low-Power Data Center Interconnects



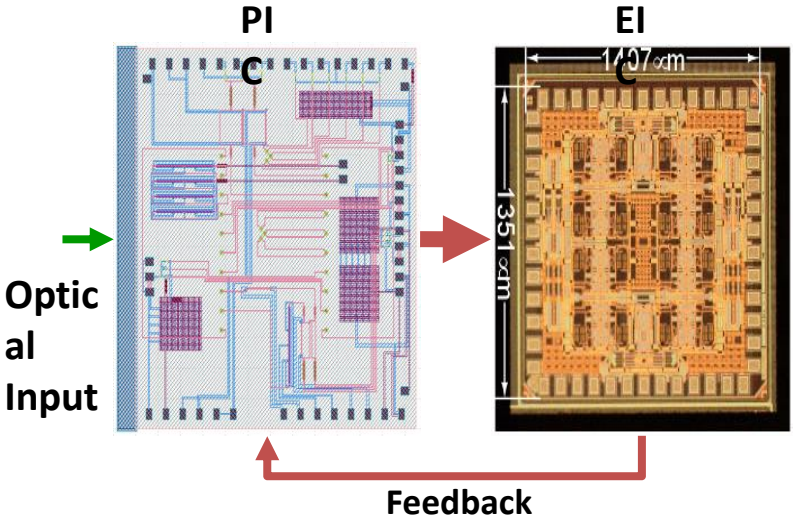


IEEE OI 2019
Indian & US patents pending

200 Gbps SH-16QAM link is an easy replacement for PAM-4 100Gbps links with 50 Gbaud electronics

Equalized 16-QAM received signal (System tested up to 132 Gbps)

Analog Processing Electronics ICs and Silicon Photonic ICs for Low Power Coherent Optical Links

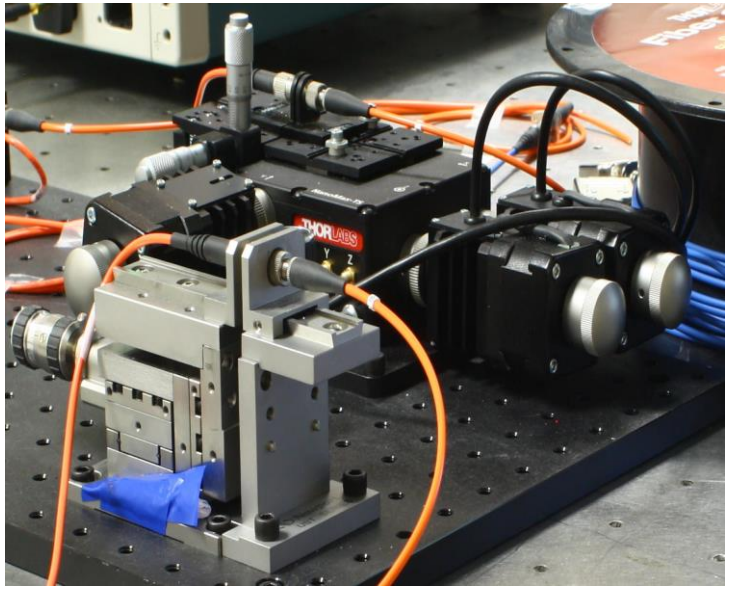


Analog Processing ICs have been demonstrated upto 50Gbps data rates. Electronic and Photonic IC integration in progress

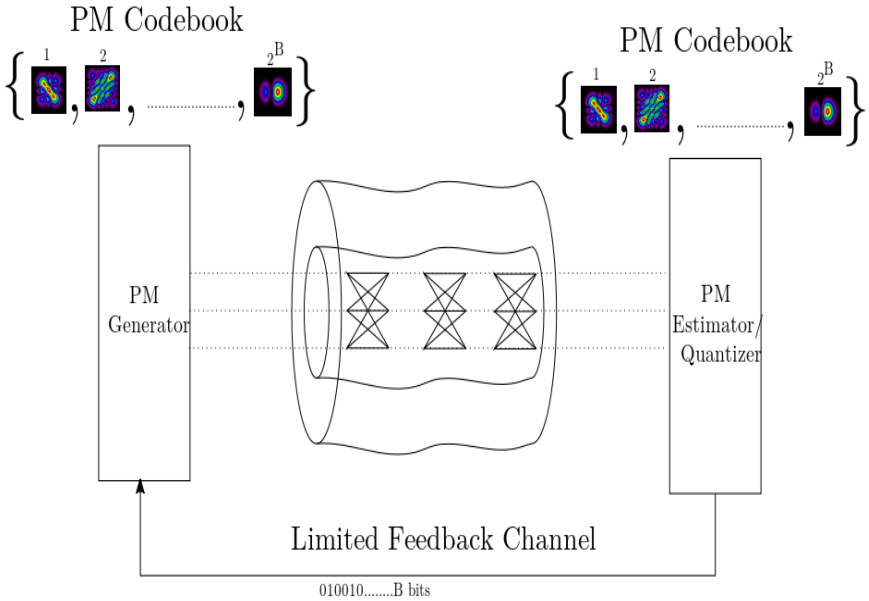
Key demonstrations at OFC 2017, 2019
Indian & US patents pending

Mode-Division Multiplexing with offset coupling
Kumar Appaiah, IIT Bombay

- Key ideas: enhancement of fiber capacity with offset coupling and feedback
- Potentially leads to higher throughput in short and medium-haul links
- Initial results: solution can lead to reduced energy-per-bit, esp. In FTTH and data centre links, experimental evaluation underway



Offset coupling at transmitter/receiver



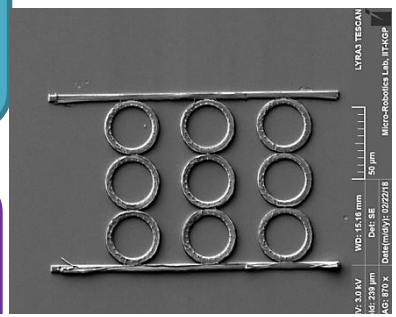
Feedback of coupling information for simpler receivers

Optical Communication: Current research activities at IIT Kharagpur (SK Varshney, Dept of E&ECE)

Quantum Communication — Fiber based as well free space

Optical Wireless (LiFi, Underwater)

Few-mode fiber components for high speed access network — Mode division MuX and Demux



Microring resonators based devices for on-chip optical communication

Integrated WDM source (Frequency comb)

PHYSICAL REVIEW A **99**, 033848 (2019)

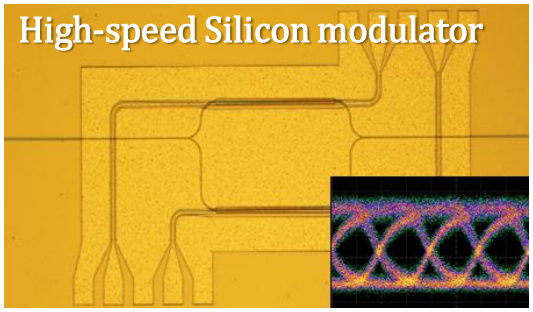
Free-carrier-driven Kerr frequency comb in optical microcavities: Steady state, bistability, self-pulsation, and modulation instability

R. Haldar,[1,*] A. Roy,[1,2] P. Mondal,[3] V. Mishra,[3] and S. K. Varshney[1]
[1]*Department of Electronics and Electrical Communication Engineering, IIT Kharagpur-721302, West Bengal, India*
[2]*Electrical Engineering Department, California Institute of Technology, 1200 East California Boulevard, Pasadena, California 91125, USA*
[3]*Department of Physics, IIT Kharagpur-721302, West Bengal, India*

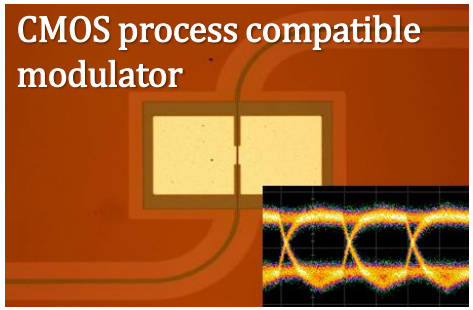
(Received 16 January 2019; published 25 March 2019)

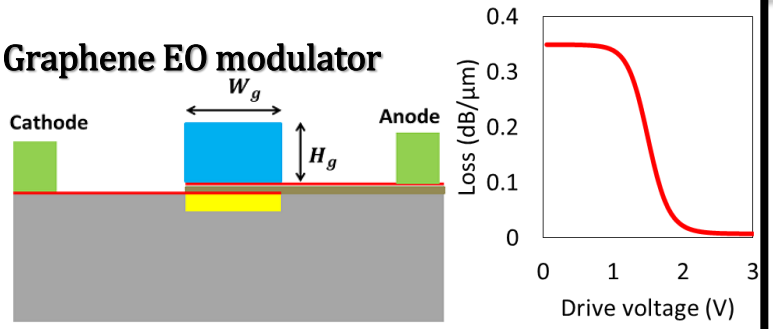
Silicon Photonics: Bringing optical communication into the chip (K Debnath, E&ECE Dept., IIT Kharagpur)

Electro-optic Modulators



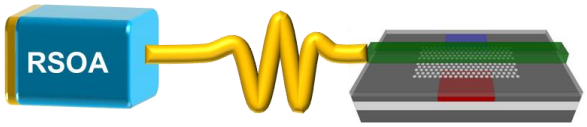
Photonics Research 6, 373-379 (2018)

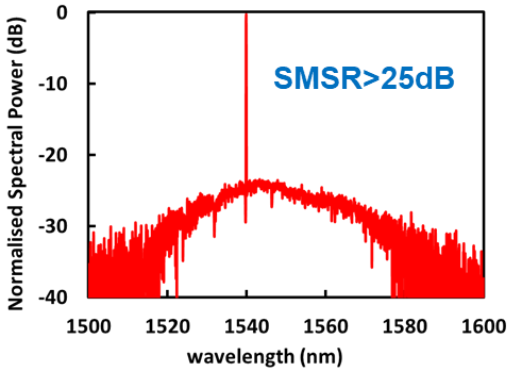




OSA Continuum 2, 1273-1284 (2019)

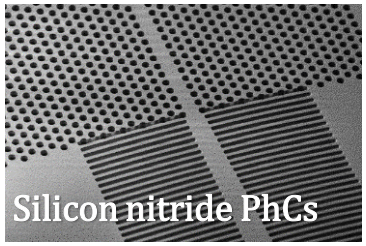
Light sources

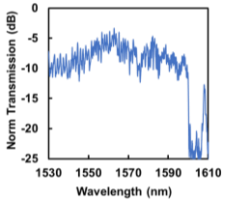




Optics letters 41, 894-897 (2016)

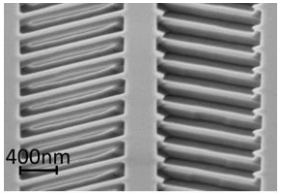
Passive components





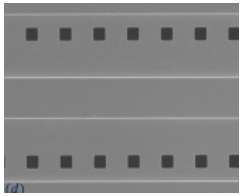
Optics express 25, 3214-3221 (2017)

Silicon Fin waveguides



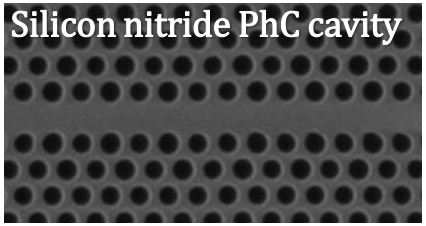
Optics express 26, 33180-33191 (2018)

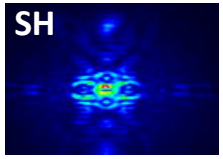
Ge waveguide

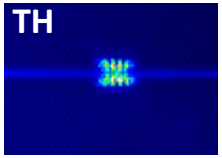


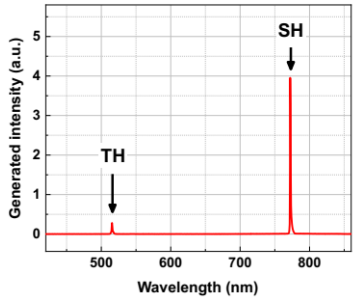
Optics letters 43, 5997-6000 (2018)

On-chip nonlinear photonics









Applied Physics Letters (2019)

SILICON PHOTONICS @ IIT GUWAHATI

- Active and passive devices for C-band optical communication
  - Low cost, low power, and high efficiency
- Group IV modulators – enhanced modulation

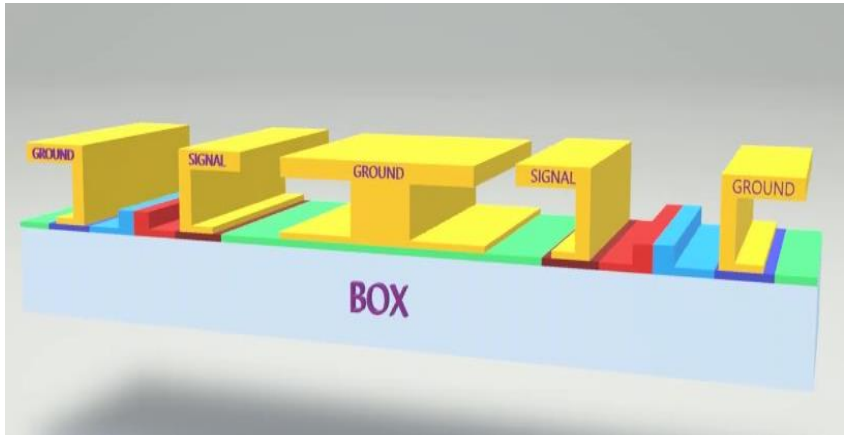
SiGe phase shifters*

- High speed PN diodes
- < 1 V.cm modulation efficiency @ -5 V
- < 2 dB insertion loss

Mach-Zehnder modulators*

- G-S-G-S-G traveling wave design
- Operating voltage: < 5 V_{pp}
- 3 dB bandwidth: > 70 GHz
- Speed: > 100 Gbps over single channel with NRZ-OOK modulation
- BER < HD-FEC threshold
- Energy-per-bit: < 1pJ

* Simulation results



Advantage over current silicon optical modulators

- Higher speed
- Lower energy-per-bit
- Greater fiber transmission length
- Higher received power tolerance
- Higher fiber dispersion tolerance

SILICON PHOTONICS @ IIT GUWAHATI

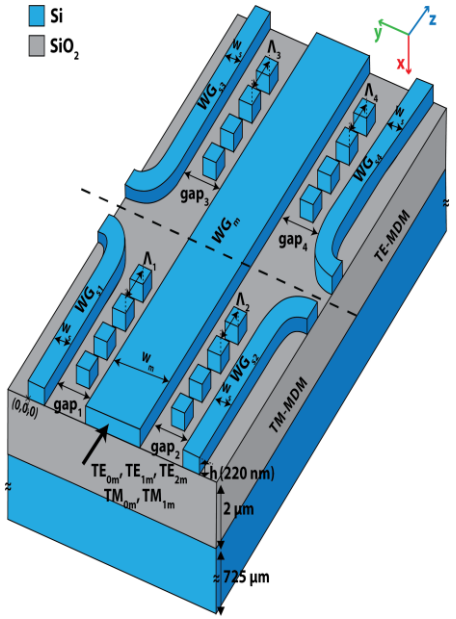
- Hybrid (de)multiplexers for enhanced channel capacity @1550 nm

TE Mode-Division Multiplexer*

- Simulation: 2D FDTD
- 3 mode channels
- Insertion loss > -1.27 dB
- Return loss < -8.65 dB
- Crosstalk < -15.31 dB

TM Mode-Division Multiplexer*

- Simulation: 2D FDTD
- 3 mode channels
- Insertion loss > -2.01 dB
- Return loss < -9.17 dB
- Crosstalk < -8.05 dB



Hybrid Mode and Polarization Division Multiplexer*

- Simulation: 2.5D FDTD
- 5 mode channels (3 TE and 2 TM)
- Insertion loss > -0.76 dB
- Return loss < -11.23 dB
- Crosstalk < -12.42 dB

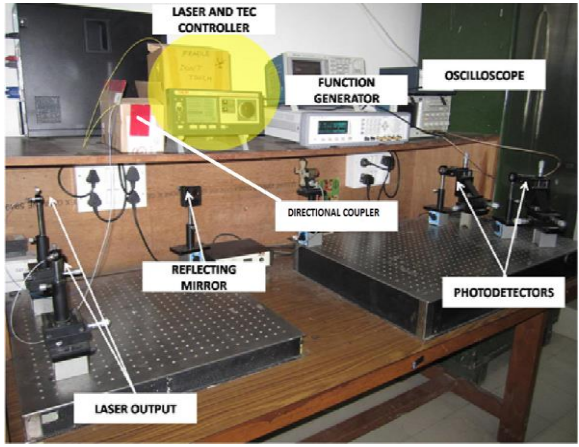
*

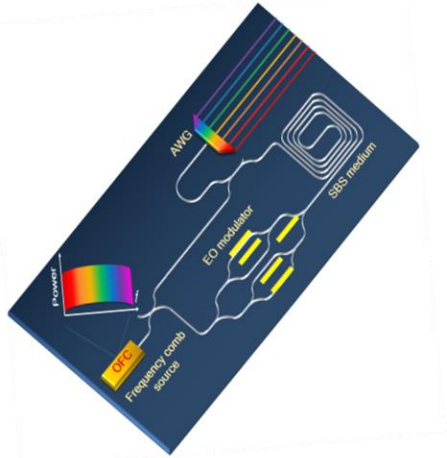
Photonics Research Group

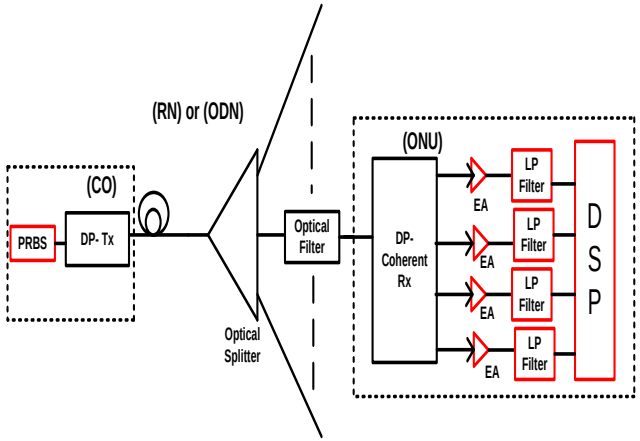
- Website: https://iitg.ac.in/sonkar/index.html
- Faculty: Dr. Ramesh Kumar Sonkar
- Group publications: https://iitg.ac.in/sonkar/PRG%20IITG%20-Publications-.htm

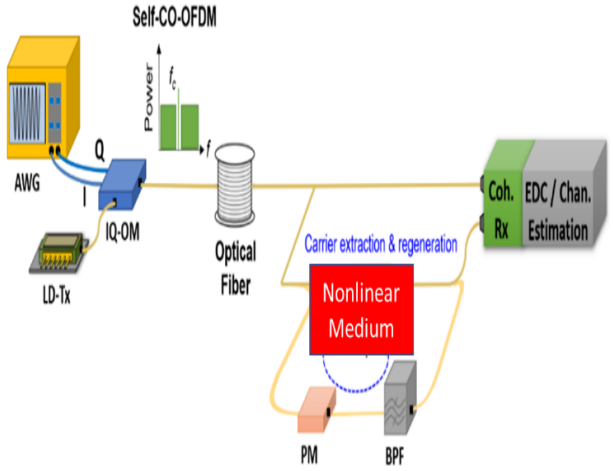
Optical Communications @IITD

- Faculty: A. Choudhary, A. Dixit, J. Ghosh, V. Venkataraman
- Visible Light communications
- Free space optical communications (a)
- ML for Nonlinearity compensation
- Self coherent optical communications (b)
- Single-photon sources and QKD
- Optical Access Networks (c)
- Integrated Optical Source development (d)



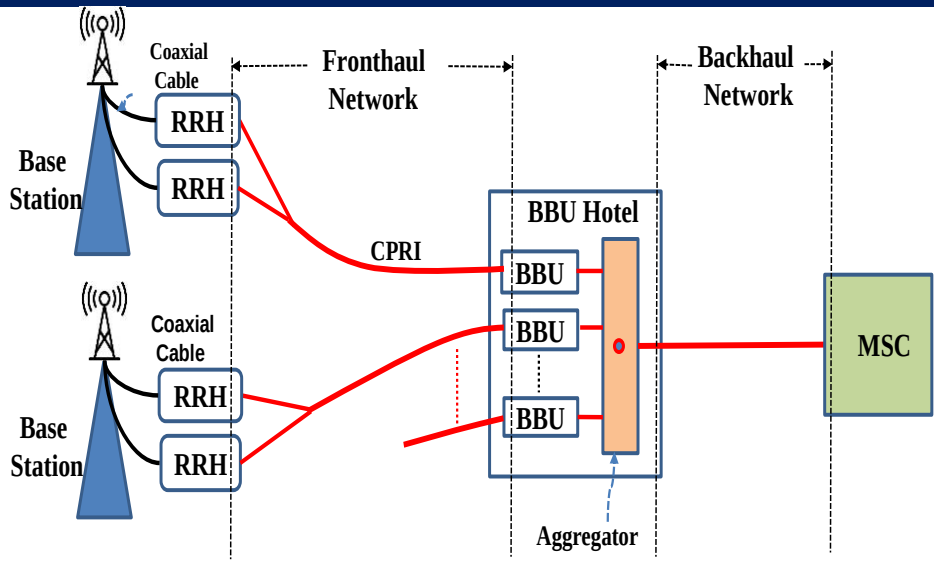


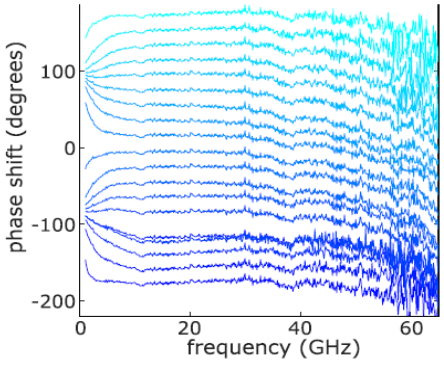


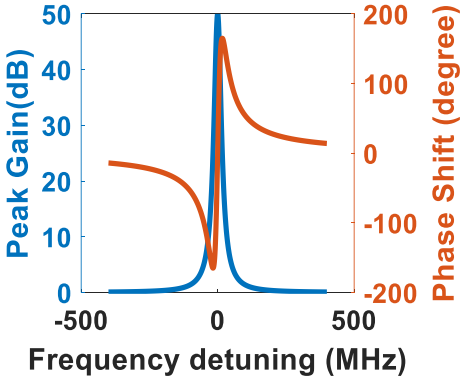


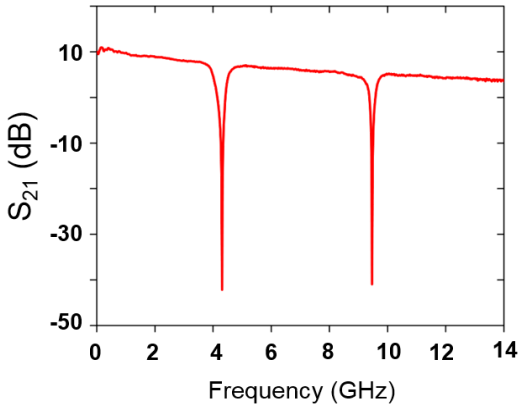
Microwave Photonics @IITD

- Faculty involved: A. Choudhary & A. Dixit
- Radio over fiber for high data rates (a)
- RF signal generation
- Microwave photonic filters (b)
- Brillouin microwave processors (c)
- Photonics Radar
- Phase shifters to 60 GHz (d)









Activities on High Speed Optical Communication @ IIT Patna (Dr Sumanta Gupta & Group)

- Medium and Short Reach Fiber Optic Communication Systems
  - DSP & ML enabled Polarization multiplexed WDM transmission
  - SMF and MMF based link using novel modulation, multiplexing, and reception
  - Characterization using test-bed
- Free Space WDM Optical Communication
  - Gbps rate transmission over C-band with offline DSP at Rx
  - Test-bed for turbulent multiplexed channel
- Underwater Wireless Optical Communication
  - Mbps rate transmitter receiver prototype development
  - Modeling and characterization of underwater channel
  - For AUV and underwater divers
- Si Photonics Device Modeling and Simulation
  - Low power & high speed modulator and switch
  - Strain engineering in passive devices
- *Other Activity: Optical Fiber Based DAS for Intrusion Detection*

Mahindra University Hyderabad Ecole Centrale School of Engineering

Indian Institute of Technology Delhi Physics Department

Optical Engineering 58(3), 037102 (March 2019)

Design of a silicon-on-calcium-fluoride-based ultracompact and highly efficient polarization splitter for the midinfrared

Babita Kumari,[a] Ravendra K. Varshney,[a,*] and Bishnu P. Pal[b]
[a]Indian Institute of Technology Delhi, Physics Department, New Delhi, India
[b]School of Natural Sciences, Mahindra Ecole Centrale, Hyderabad, India

Optik - International Journal for Light and Electron Optics 180 (2019) 71–83

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Design of a promising silicon slot waveguide-based ultra-short low loss efficient polarization rotator for the mid-IR

Babita Kumari[a], R.K. Varshney[a,*], Bishnu P. Pal[b]

[a] Physics Department, Indian Institute of Technology Delhi, New Delhi, 110016, India
[b] School of Natural Sciences, Mahindra École Centrale, Hyderabad, 500043, India

Contents lists available at ScienceDirect

Sensors and Actuators B: Chemical

journal homepage: www.elsevier.com/locate/snb

Research paper

Design of chip scale silicon rib slot waveguide for sub-ppm detection of N_2O gas at mid-IR band

Sensors and Actuators B 236 (2016) 759–764

Contents lists available at ScienceDirect

Sensors and Actuators B: Chemical

journal homepage: www.elsevier.com/locate/snb

Silicon-on-nitride slot waveguide: A promising platform as mid-IR trace gas sensor

Babita Kumari[a], Ajanta Barh[a,1], R.K. Varshney[a,*], B.P. Pal[b]

[a] Physics Department, Indian Institute of Technology Delhi, New Delhi 110016, India
[b] School of Natural Sciences, Mahindra École Centrale, Hyderabad 500043, India

Research Article Vol. 1, No. 4 | 15 Dec 2018 | OSA CONTINUUM 1158

OSA CONTINUUM

Design of a silicon-on-calcium-fluoride-based compact and efficient polarization rotator for the mid-IR

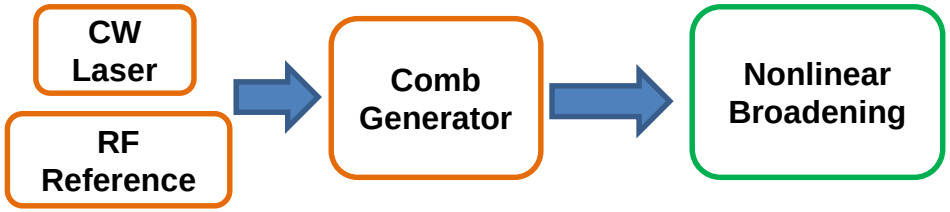
BABITA KUMARI,[1] R. K. VARSHNEY,[1,*] AND B. P. PAL[2]

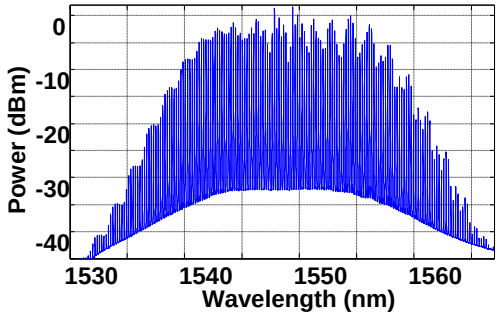
[1]Physics Department, Indian Institute of Technology Delhi, New Delhi-110016, India
[2]School of Natural Sciences, Mahindra École Centrale, Hyderabad-500043, India
*ravi@physics.iitd.ac.in

High Power, High Repetition Rate Optical Frequency Combs @ IISc Bangalore

Goal: High Power, high repetition rate optical frequency combs for applications in metrology and optical communications.

Step 1: Directly modulated combs with tunable frequency and repetition rate (10-40GHz)

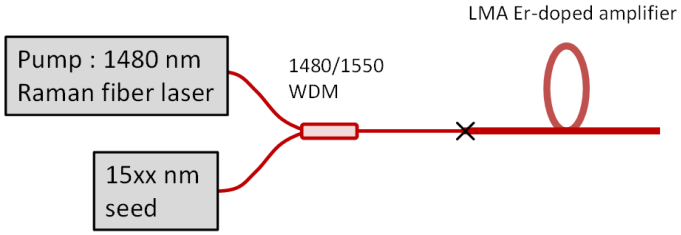


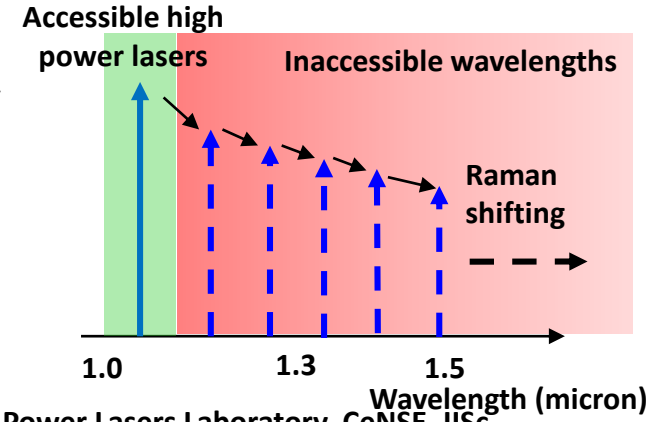


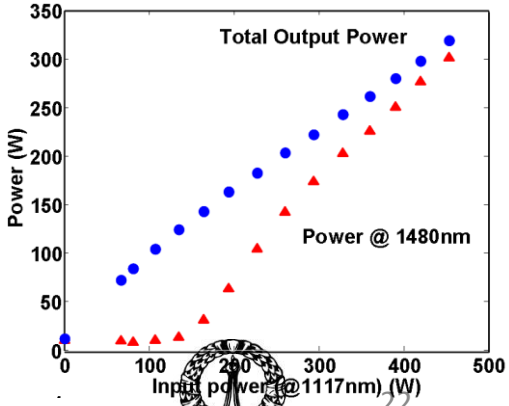
Over 100 lines at 25GHz demonstrated

Step 2: Amplification of frequency combs using very low nonlinearity Raman Laser pumped fiber amplifiers

Over 300W Raman laser pumps, 100W class EDFAs developed

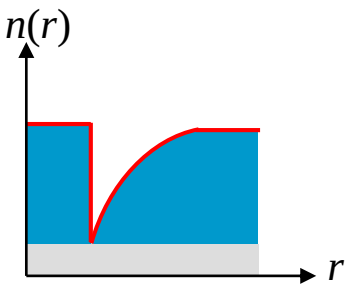




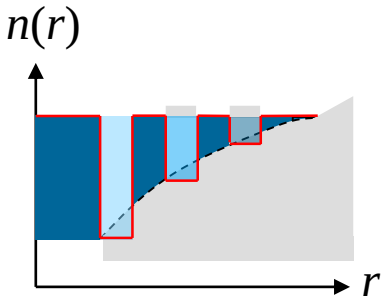


OPTICAL FIBERS FOR HIGH DATA RATE COMMUNICATION AND HIGH POWER FIBER LASERS

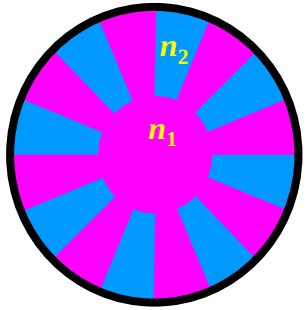
GI clad LMA Fiber



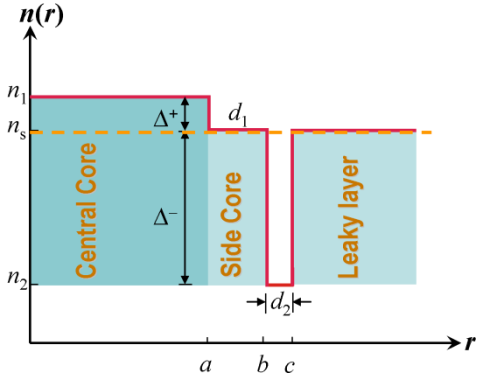
Multilayer clad LMA Fiber



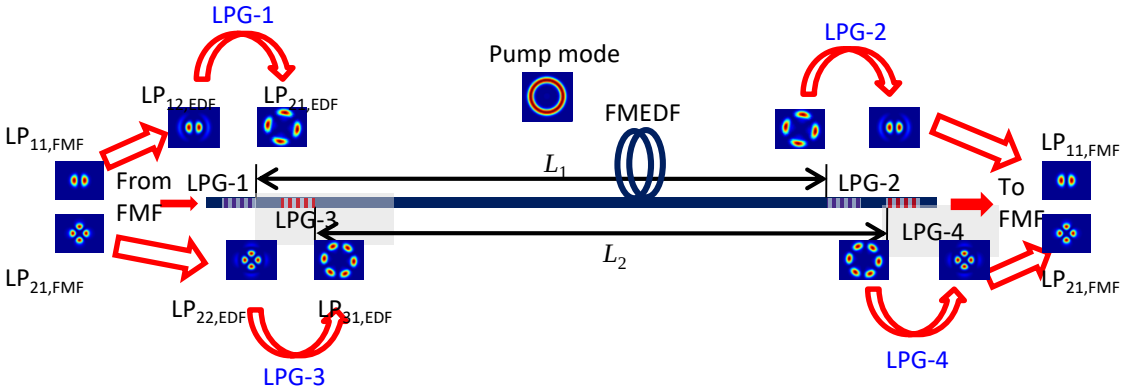
Segmented Cladding Fiber



Dual-shape core LMA Fiber

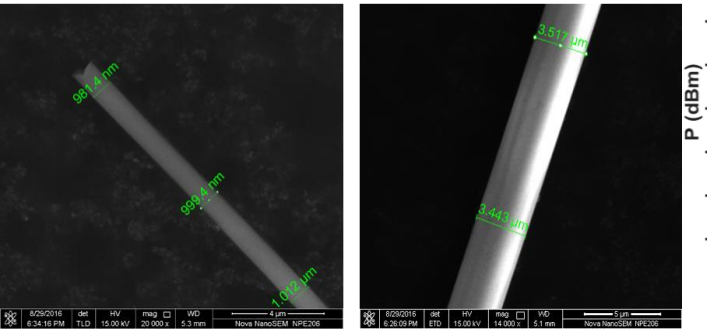


FMEDFA for SDM Communication System

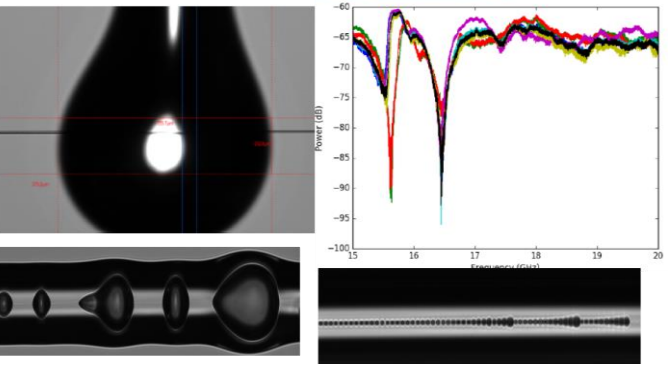


Microwave Photonics @ Indian Institute of Science Education & Research, Kerala

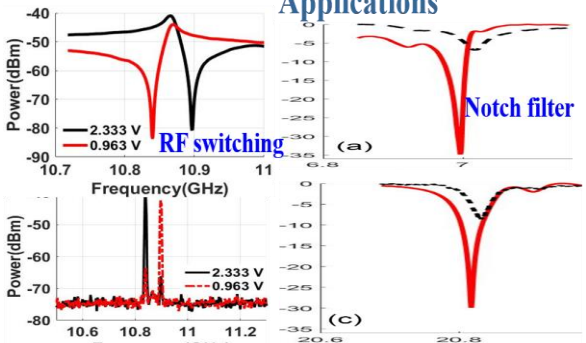
NLO in Nanostructures



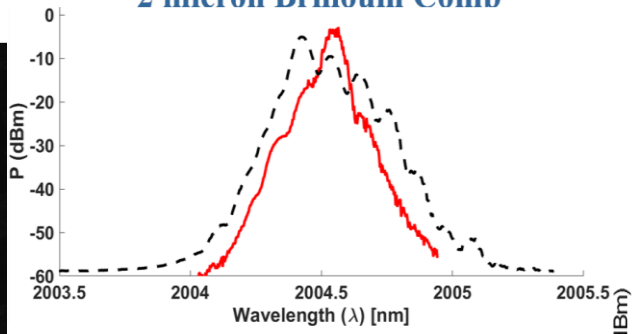
NLO in Microresonators



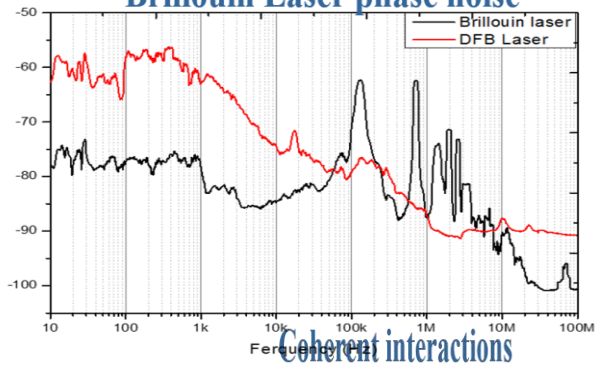
Applications



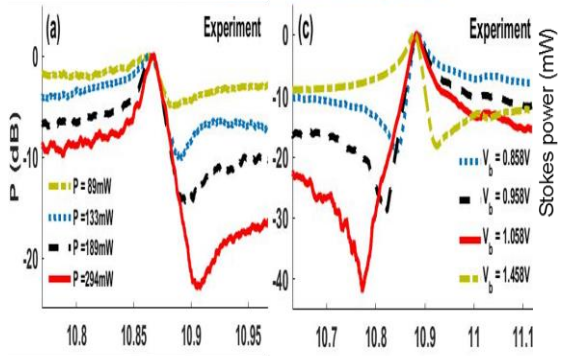
2 micron Brillouin Comb



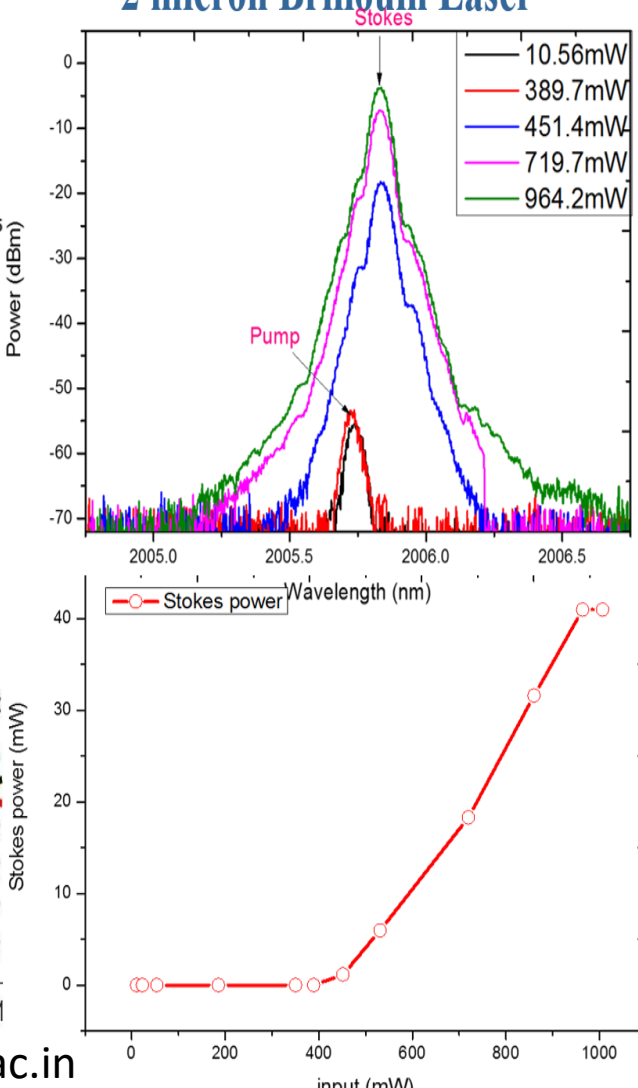
Brillouin Laser phase noise



Coherent interactions



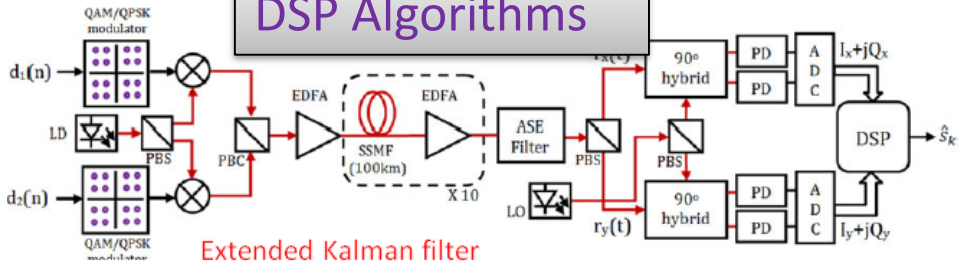
2 micron Brillouin Laser



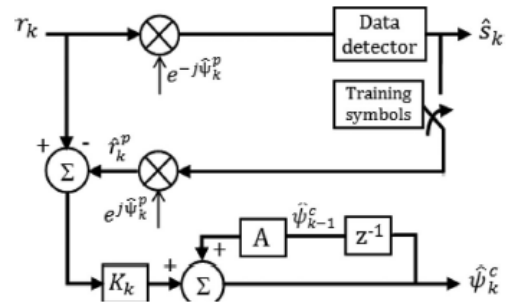
Ravi Pant : rpant@iisertvm.ac.in

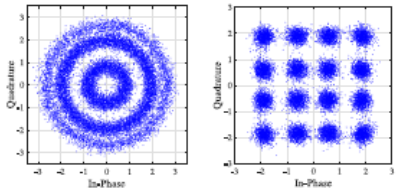
Optical Communications @ IIT Kanpur

DSP Algorithms

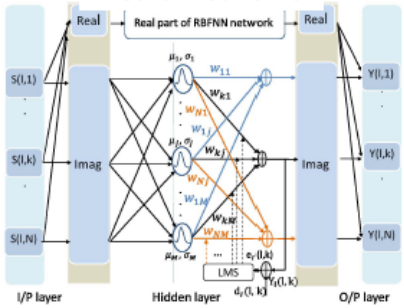


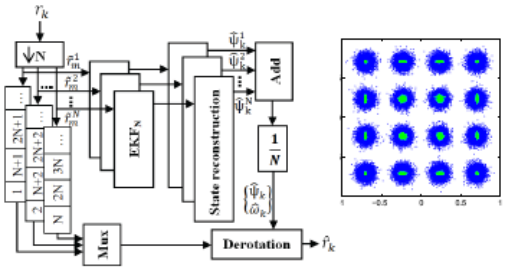
Extended Kalman filter





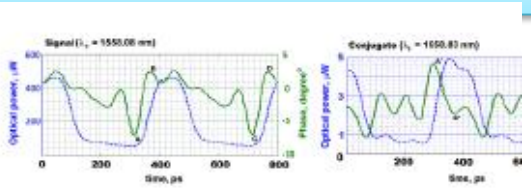
Neural networks

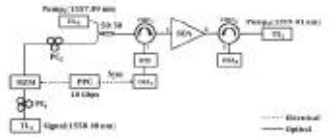




Parallelized EKF bank

Optical Signal Processing

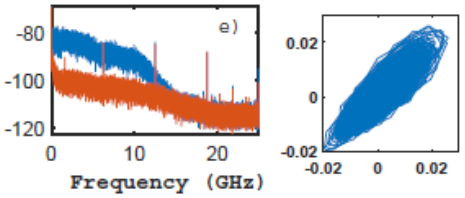


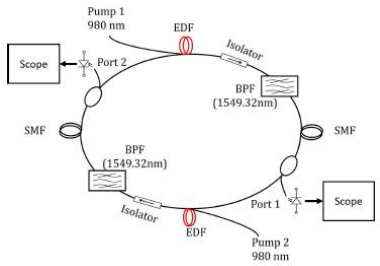


Wideband Optical Chaos

25 GHz bandwidth chaos in EDFRLs

High-speed random number generation





Optical Fiber Modeling

Macro and Micro-bend theory

Bend-insensitive fibers for FTTH

Pradeep Kumar K, pradeepk@iitk.ac.in

Representative Examples of Photonics Industry

Industry :

NEST Photonics

Devices/Components/Subsystems

Optiwave Photonics

(Erbium doped fiber amplifiers)

Fiber Optika (Educational Kits for communication)

Preston Engineering (Components) and so on..

Lightmotif Hyderabad

- Focus:
  - Microwave Photonics
  - RF to optical conversion
- Products:
  - Radio over fiber links up to 6GHz
  - Fiber optic transmitters, receivers and signal distribution for Radars
  - Submarine tethered communication links

Enabling the Indian Army to communicate across the no network zones of Ladakh and Kashmir.

Prospects

- Digital Signal Processing algorithms for high-speed communication systems
- Optical Signal Processing – Phase conjugation, phase sensitive amplification, wavelength conversion for improving the efficiency of high speed communication systems (both long haul and short reach)
- Analog/hybrid communication for bandwidth efficient fronthaul for advanced wireless networks
- Devices, subsystems and systems for photonic Radars.

Prospects- shared facilities

- Packaging facility for Photonic Integrated Circuits
  - Lasers, VCSELs
  - Transponders
  - Other network components

- Sharing fabrication facilities
- Real-time test beds for high speed communication > 10 Tbps
- Real time test beds for Advanced Wireless Fronthauling